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# Notes on Irrigation Engineering

Sumit Paudel (NEC)

**This Note is for Exam Preparation Only. For More Concept and Knowledge, Prefer Other Books as Well as Other Research Papers.**

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Sumit paudel, NEC, 017-022

Irrigation Engineering:-

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Course Contents:-

1. Introduction
2. Soil moisture and crop relation
3. Method of Irrigation
4. Canal Design
5. Hydraulic structures in surface Gravity Irrigation System
6. Hill Irrigation
7. River Control & Drainage
8. Planning & Design of Groundwater Irrigation schemes.
9. Planning & Management of Irrigation System.

Course Objectives:-

a) Design surface and groundwater irrigation system
b) Operate & manange irrigation system
c) Design infrastructure needs for acquisition, conveyance, distribut and control for regulated flow of water from the source to the farmers fields.
d) Design removal of excess water to maintain condition for crop production.

Chapter-1

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## Introduction:-

→ Irrigation is the science of applying water artificially to the land in accordance with the crop water requirements through the crop period to full fledged nourishment of the crop.

→ The basic objective of irrigation is to supplement water to the land so as to obtain an optimum crop yields.

### ※ Necessity of Irrigation:-

→ Basic source of food, cloth & shelter are the plants, to grow plants, water is essential & plant cannot grow properly if there is water stress during its cropping season.

→ The necessity of irrigation is summerized below.

(a) Inadequate rainfall:-
When the seasonal rainfall is less than the minimum requirement for the satisfactory growth of crop.

(b) Uneven distribution of rainfall:-
When the rainfall is not evenly distributed during the crop period through cultivated area.

(c) Improvement of prennial Crops yield:-
Some crops require throughout the major parts of the year but the rainfall fulfills the demand during the rainy season only & remaining part of the year, irrigation is necessary.

(d) Development of agriculture in the desert areas:-
→ In the desert area, where the rainfalls very scanty, irrigation is required for development of agriculture.

(e) Insurance of drought:-
→ Irrigation may not required during the normal rainfall condition & can be necessary during drought.



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### * Resources of Irrigation:-

- Rainfall
- Surface
- Subsurface

### ※ Types of Irrigation System:-

(a) Gravity flow / Surface water flow irrigation:-
→ In this system, no irrigation pump is involved. Here, water is distributed across the land by gravity.

(b) Tank or reservoir Irrigation:-
→ Tank or reservoir are used for preserving the local rainfall & water from streams & rivers for later use in irrigation.

(c) Lift irrigation or underground Irrigation:-
→ The water is lifted to the delivery chamber from underground source. The delivery chamber is located at the topmost point of the commanded area. Then, water is supplied to agricultural land from delivery chamber by gravity flow.

### * Function / Advantages of Irrigation System:-

(a) Yield of Crops:- In the period of low rainfall or drought, the yield of crop may be increased by irrigation system.

(b) Protection from famine:- The food production of a country can be improved by ensuring the growth of crops by availing the irrigation facilities. This helps a country to prevent famine situation.

(c) Improvement in cash-crops:- Irrigation helps to improve the cultivation of cash crops like vegetables, fruits, tobacco etc.

(d) Prosperity of farmers:- When the supply of irrigation water is assured, the farmers can grow more than two crops in a year

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on the same land. Thus, the farmers may earn money and improve their living standards.

(e) Hydroelectric Power Generation:- In some river valley projects, multipurpose reservoirs are formed by constructing high dams where hydroelectric power may be generated along with the irrigation system.

(f) Water Supply:- The irrigation canal may be the source of water supply for domestic & industrial purposes.

## * Disadvantage of Irrigation:-

1) Increase pollution:-
Ground water contamination by nitrate from urea through seepage of irrigation wells, tubewells etc. causes disease anemia. Pesticide, Insecticides cause environment pollution. water resources contamination.

2) Water logging:-
Due to over irrigation, the water is logged for long time, due to poor aeration in root zone, reduce the crop yield.

3) Outbreak of waterborne diseases:-
When continuous water is supplied in agricultural land, due to colder & damper climate, it will be the place for shelter for breeding of mosquitoes & bacteria.

4) High Investment:-
Procuring & supplying irrigation is complex & expensive in itself.

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## * Status of Irrigation development of Nepal:-

→ The development of irrigation has long history in Nepal. Records (Annals) shows that irrigated agriculture was practiced in Nepal as early as during the era of Gautam Buddha.

→ The history of irrigation development in Nepal can be divided into four phases.

(i) Primary phase / Period Prior to planned development (Before 1956)
(ii) Infrastructure development phase (1957-1970)
(iii) Intensive Development phase (1971-1985)
(iv) Integrated Development phase (1986-Date)

### (a) Primary phase to planned development (Before 1956)

→ Raj kulos during Lichivi and Malla dynasty, chandra Canal System in 1928 (British help), Tuddha canal in sarlahi district, Jagadishpur irrigation System in kapilvastu, Pardi irrigation System in pokhara

→ Within this period, covered 6228 ha.

### (b) Infrastructure Development phase:- (1957-1970)

→ 1st, 2nd and 3rd five year plan
→ State → India, USA
→ Tika Bhairav, Mahadev khola, Sudhanlkantha irrigation system in kathmandu valley, Vijaypur irrigation system in pokhara valley, khageri (chitwan), Tinau (Rupendehi) etc
→ Koshi & Gandak canals.

### (c) Intensive Development phase (1971-1985)

→ During 4th, 5th & 6th five year plan
→ Multilateral donor agencies like world bank & ADB came forward.
→ Development of kankai & Mahakali-I, irrigation projects, initiation of command area development in Narayani Zone irrigation System.
→ Covered - 10,000 ha
→ Lumbini Groundwater, Marchawar lift & hill irrigation project

DOI ⇒ Department of Irrigation
DTW ⇒ Deep Tube Well

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(d) Integrated Development Phase:- (1986 - Date)
→ From 7th plan onward
→ Bagmati, Babai, Mahakali II, Sikta irrigation projects
→ More importance on farmer's participation in canal rehabilitation
→ Cummnity management Irrigation Project.

In Overall,
Total agriculture land - 2,641,742 ha
Irrigable land - 1,765,840 ha
Land with irrigation fascilitres - 1,227,354 ha
Year round irrigation is available only in 745445 ha (60% of irrigated area)
Farmers Managed Irrigation Systems (FMIS) - 621663 ha (about 51% of total irrigated area.

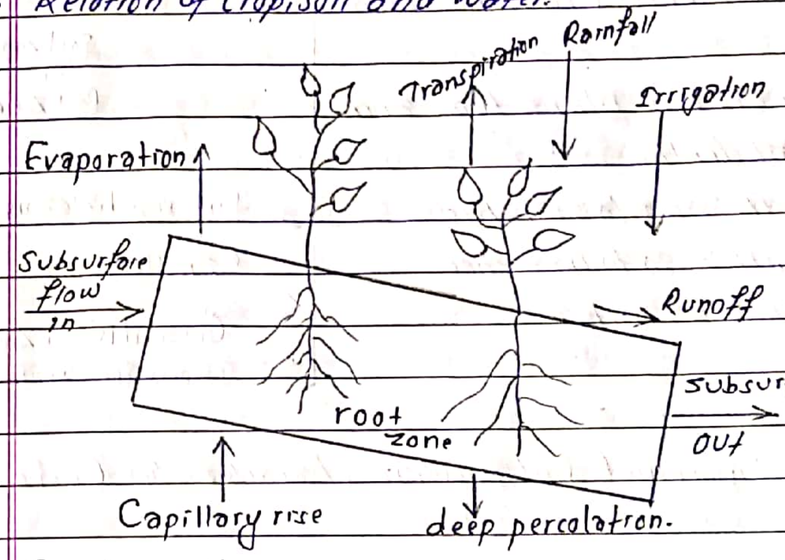
* Irrigation Projects
(i) Bagmati Irrigation project → Rautahat
(ii) Ranijamara " " → Kailali
(iii) Praganna " " → Dang
(iv) Tilawe " " → Parsa
(v) Marchabar " " → Rupendehi
vi) Manushmara " " → Rautahat
vii) Rajapur " " → Bardiya
viii) Sikta " " → Banke
(ix) Chardo Canal " " → Saptari
(x) Jamuna " " → Bara
(xi) Juddha Canal → Sarlahi

Chapter - 2, Soil Moisture & Crop Relation

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→ Soil is main base to supports the crops & supply the minerals & water essential for crop growth through root of the plant.
→ Soil type and its characteristics to hold water is important for application of irrigation efficiently.

* Relation of Crop, soil and Water:-




3 types of relation in effective irriga
→ Soil-water Relati
→ Soil-Plant Relati
→ plant-Water Relat

Photosynthesis →
$6CO_2 + 6H_2O \rightarrow 6O_2 + C_6H_{12}O_6$
(starch/carbohydrate)

* Suitability of soil for agriculture Practices:-
→ Effective soil depth
→ Water holding Capacity
→ Soil structure
→ Non-capillary porosity
→ Soil consistence
→ Soil permeability & hydraulic conductivity.
→ Topography
→ Texture
→ Salinity (Soluble Salt content)
→ Amount of exchangeable sodium
→ Soil reaction (pH)

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## * Soil moisture/ Crop water requirement:-

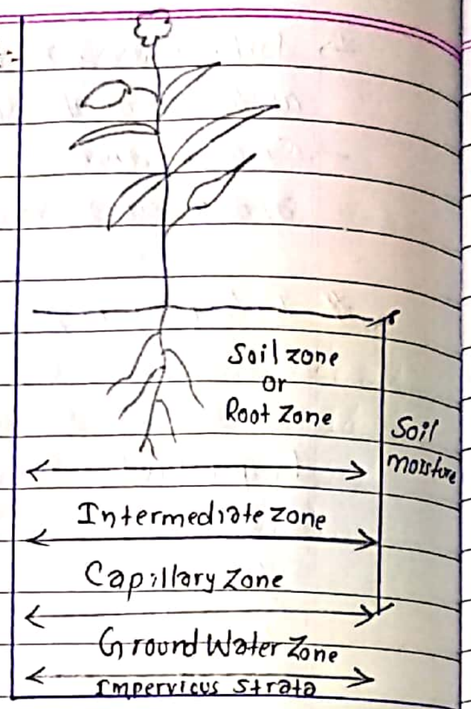
## * Soil zone/ Root zone/ Soil Depth:-

→ Over the rock or earth's crust in which the roots of the vegetation or plant penetrates.

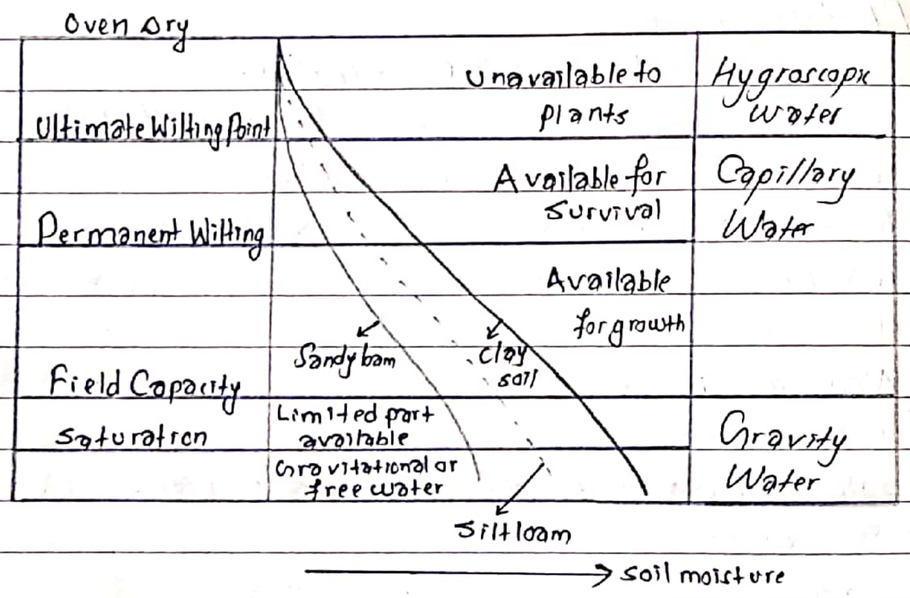
→ The plant takes water & minerals from root zone.

→ Soil zone depends on plant type and available soil depth.

- Shallow depth :- 10 to 20 inches
- Moderate depth :- 20 to 40 inches
- Deep depth > 40 inches




## * Types of Soil moisture & Soil moisture characteristics Curve:-




→ Soil Moisture Content = $\frac{\text{Weight of water stored in certain volume of soil}}{\text{Dry weight of soil in the same soil volume.}}$

→ Gravity Water:- The water that flows downwards under the action of gravity.

→ Field Capacity:- The water content of a soil after free gravity drainage has taken place for a sufficient period (2 to 5 days) The field capacity is the quantity of water which any soil can retain indefinitely against ~~water~~ gravity.

→ Gravitational Water:- Water is rapidly drained from the soil profile by the force of gravity. The term rapid is relative & in soil-water studies normally refers to periods of 24 to 48 hours.

→ Capillary Water:- The water remaining after rapid drainage by gravity that can require force greater than gravity such as those exerted by plant roots may remove this water.

→ Hygroscopic Water:- The water that is forces generally found in nature due to adheres to soil particles. It cannot be taken from soil particles by plant roots. Hygroscopic water can be removed by oven drying a soil sample in laboratory.

## * Soil Moisture Irrigation Relationship:-

→ Consider the effective depth of root zone of the plant is 'd' & 'F' is the field capacity.

Then, according to defn of field capacity,

$F = \frac{\text{Weight of water ~~required~~ retained in certain volum of soil}}{\text{Weight of dry soil of same volume.}}$

For unit area of soil,

Weight of dry soil = $\gamma_d \times d$

Weight of water retained = $F * \text{Weight of dry soil}$

$= F * \gamma_d * d$

Volume of water retained = $\frac{F * \gamma_d * d}{\gamma_w}$

Depth of water retained per unit area ($d_w$) = $\frac{F * \gamma_d \times d}{\gamma_w}$

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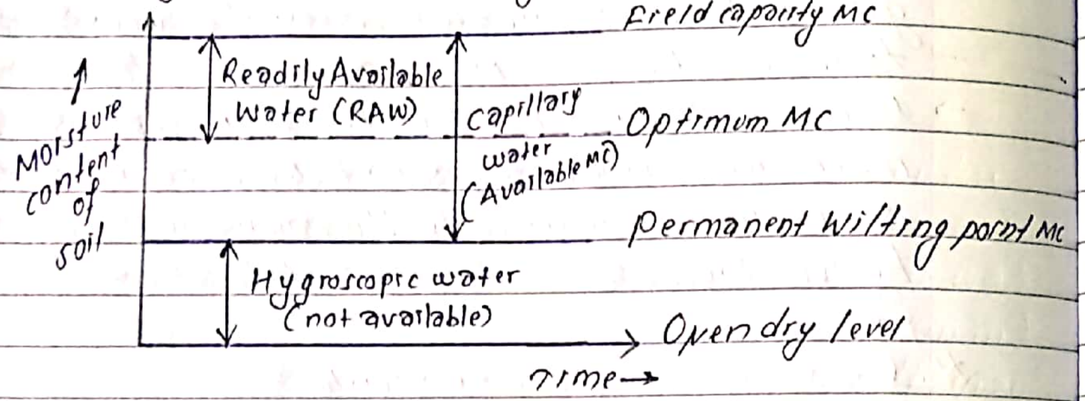
As moisture content of soil is not below the OMC.

$$\text{Depth of moisture content} = \frac{\gamma_d}{\gamma_w} * d * (F - OMC)$$

$$\text{Irrigation Interval} = \frac{\text{Moisture depth}}{ET}$$

## * Optimum Moisture Content:-

→ The optimum level up to which the soil moisture may be allowed to be depleted in the root zone without fail in crop yields has to be worked out with experimentation. The optimum soil water range is also called readily available water (RAW).




## ※ Types of Soil moisture:-

- Permanent wilting point → The water content at which the plant can no longer extract sufficient water for its growth & wilts up.
- Available Moisture Content → Difference of water content of soil between the field capacity & permanent wilting point.
- Readily available Moisture → It is the portion of the available moisture which is most easily extracted by the plant. i.e 75 to 80% of available moisture.
- Soil moisture Deficiency → The water required to bring the soil moisture content of the given soil to its field capacity. It is also called as field moisture deficiency.

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## ※ Crop-Water Requirements:-

→ It is the total quantity of water required to grow crop from time of its ~~shown~~ sown to its harvest.
→ The crop water requirements includes both evaporation from the soil surface & evaporation from plant body.
→ As per FAO (Food & Agriculture Organization of UN) → The depth of water needed to meet the water loss through evapotranspiration of a disease free crop growing in large fields under non-restrictive soil conditions including soil water, fertility & achieving full production potential under the given growing enviroment
→ The crop-water requirement is also known as consumptive use.
→ The crop water requirement rate is varying at different stages of the crops (Seedling/sowing, transplanting, growing, flowering & harvesting) due to different rate of transpiration through the plant body.

## ※ Factors affecting ~~water~~ crop water requirements:-

(a) Crop type:-

→ Different types of crop has different types of plant cells, leaf, stomata & different stages of development with different time intervals affecting evapo-transpiration.

(b) Climate:-

→ Temperature, sunshine hours/Radiation, Relative Humidity, wind speed
→ Evaporation is directly proportional to the temp$^n$, RH & windspeed of crops under which it was grown. The transpiration is dependent on the sunshine hours & radiation

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## Duty of water (D)

→ It is the capacity to irrigate land. Duty (D) is defined as the area of land which can be irrigated if one cumec ($m^3$/sec) of water was applied to the land continuously for the entire base period of the crop & it is expressed in hectares/cumecs.

## Base Period (B):-

→ The base period is the period between first watering & the last watering. The base period is slightly different from crop period, which is the period between time of sowing & time of harvesting the crop.

## Delta (Δ):-

→ It is the water depth required for crop during the entire base period. If the entire quantity of applied water were spread uniformly on the land surface, the depth of water would have been equal to delta. Thus, the delta (in 'm') of any crop can be determined by dividing the total quantity of water (in ha-m), required by the crop by area of land (in ha),

$$\text{Delta } (\Delta) = \frac{\text{Total quantity of water (ha-m)}}{\text{Total area of land (ha)}}$$

## Relation between duty, base period and delta:-

→ Considering the area of land of D-hectares & if duty is expressed in hal cumecs, the total quantity of water used in the base period 'B' days is equal to that obtained by a continuous flow of 1 cumecs for 'B' days.

Quantity of water $= 1 * B * 24 * 60 * 60\ m^3$ ---- (a)

If $\Delta$ is the total depth of water in meters supplied to the land of D-hectares, the quantity of water is also given by,

Quantity of water $= \Delta \times D \times 10^4\ m^3$ ------ (b)

Equating eqn (a) and eqn (b)

$$1 * B * 24 * 60 * 60 = \Delta * D \times 10^4$$

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

Where, D = in hal cumec
B = in days.

## Commanded area of irrigation System:-

→ The area covered by irrigation boundary of a project which can be irrigated.

→ Gross Commanded Area (GCA):-

The whole area enclosed between an imaginary boundary lines which can be included in an irrigation project for supplying water to agricultural land by the network of canals is known as gross commanded area (GCA). It includes both the cultivable & uncultivable areas.

Gross Command Area = Cultivable Command Area + Uncultivable Command Area

→ Cultivated / Cultivable Commanded Area (CCA)

Cultivated area is the cultivated part of GCA & includes all the lands of GCA on which cultivation is possible.

→ Uncultivated Commanded area:-

The area where the agriculture cannot be done & crops cannot be grown is known as uncultivated area. The marshy lands, lakes, ponds, forests, villages etc are considered as uncultivated

## Some Important Terminologies:-

→ Intensity of Irrigation:-

It is defined as the ratio of cultivated land for a particular crop to the total C.C.A. It is expressed as a % of C.C.A.

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※ Number of Watering:-
→ The total depth of water required by a crop is not applied at one time but it is supplied over the base period by stages depending upon requirements, these numbers of stages are known as Number of Watering.

※ Paleo:-
→ The initial watering which is done on the land to provide moisture to the soil just before sowing any crop is known as paleo or paleva.

※ Kor Watering:-
→ The first watering which is done when the crop has grown to about three centimeters is called kor watering.

※ Some Efficiencies:-
(a) Irrigation Efficiency:- The ratio of the amount of water available (output) to the amount of water supplied (input) is known as irrigation efficiency.

(b) Water Conveyance Efficiency($\eta_c$):- It is the ratio of the amount of water applied, to the land to the amount of water supplied from the reservoir.

(c) Water Application Efficiency ($\eta_a$) → It is the ratio of water stored in root zone of plants to the water applied to the land.

(d) Water Use Efficiency ($\eta_u$) → It is the ratio of amount of water used to the amount of water applied.

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(e) Consumptive Use Efficiency ($\eta_{cu}$) ⇒ It is the ratio of consumptive use of water to the amount of water depleted from the root zone.

※ Principal Crops & their Seasons:-
→ Principal Crops
Rice, Wheat, maize, potato, Grains (Maggi, peas, grams, beans etc), vegetables, sugarcane and other cash crops like jute, tea and coffee etc.

→ Crop Season:-
The period during which some particular types of crops can b grown every year on the same land is known as crop season.

(1) kharif Season:-
→ This season ranges from June to October
→ The crops are sown in the very beginning of monsoon and harvested at the end of autumn.
→ The major kharif crops are Rice, Millet, Maize, Jute & Groundnut

(2) Rabi Season:-
→ This season ranges from october to march.
→ The crops are sown in the beginning of winter and harvested at the end of spring.
→ The major rabi crops are wheat, gram, mustard, Rapeseed, Linseed, pulses, onion etc.

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**Q1** The field Capacity of soil is 70%, permanent wilting point is 25%, effective root depth is 120cm, evapotranspiration of crop is 10 mm/day, density of soil is $1.2 gm/cm^3$. Calculate the irrigation interval if the readily available moisture is 80% of available soil moisture Capacity.

→ Field Capacity (FC) = 70%

Permanent wilting point (PWP) = 25%

Density of soil = $1.2 gm/cm^3$

Effective root depth (d) = 120 cm

ET crop = 10 mm/day

Now, Available Moisture Capacity (AMC) = FC − PWP = 70 − 25 = 45%

Readily available moisture (RAM) = OMC = 0.8 × 45% = 36%

Depth of water available for consumptive use,

$$d_w = \frac{\gamma_d}{\gamma_w} \times d \times RAM\ (OMC)$$

$$\Rightarrow d_w = \frac{1.2}{1} * 120 \times 0.36 = 51.84 cm$$

$$\text{Irrigation Interval} = 51.84 * \frac{10}{10} = 51.84 \text{ days.}$$

**Q2** What quantity of water you will supply to a soil in order to ensure sufficient irrigation of the given crop if field Capacity of soil is 30%, PWP = 10%, density of soil = $1.25 gm/cm^3$, effective depth of root zone = 60cm, daily consumptive use of water for the given crop = 12.5mm. Assume RAM is 80% of AMC. Also find the frequency of irrigation.

→ Given

Field Capacity (FC) = 30%

Permanent wilting point (PWP) = 10%

Density of soil ($\gamma_d$) = $1.25 gm/cm^3$

Effective root zone (d) = 60cm

Consumptive use of water (ET crop) = 12.5mm

Now, Available moisture Content (AMC) = FC − PWP = 30 − 10 = 20%

Readily Available Moisture (RAM) = 0.8 × 20 = 16%

Available Water depth for consumptive use, $d_w = \frac{\gamma_d \times d}{\gamma_w} \times RAM$

$$d_w = \frac{1.25 \times 60}{1} \times 16 = 12 cm$$

Hence, Irrigation frequency = $\frac{12 \times 10}{12.5} = 9.6$ days

**Q3** Determine the field capacity of the soil with following data, root zone depth = 3m, existing water content = 7.5%, dry density of soil = $1.5 gm/cm^3$, water applied to the soil = $650 m^3$, water loses due to evaporation = 15% and area of plot = $1000 m^2$

→ Here,

Field Capacity (FC) = ?

Root Zone depth (d) = 3m

Existing water content = 7.5%

Dry density of soil = $1.5 gm/cm^3$

Water applied to soil = $650 m^3$

Water losses due to evaporation = 15%

Area of plot = $1000 m^2$

Now, volume of water consumed by plants = (100 − 15)% × 650 = 552.5 $m^3$

Eqvt reqd water depth (dw) = $\frac{552.5}{1000} = 0.5525 = 55.25 cm$

But, Equivalent water depth, $d_w = \frac{\gamma_d}{\gamma_w} \times d \times (FC - AMC)$

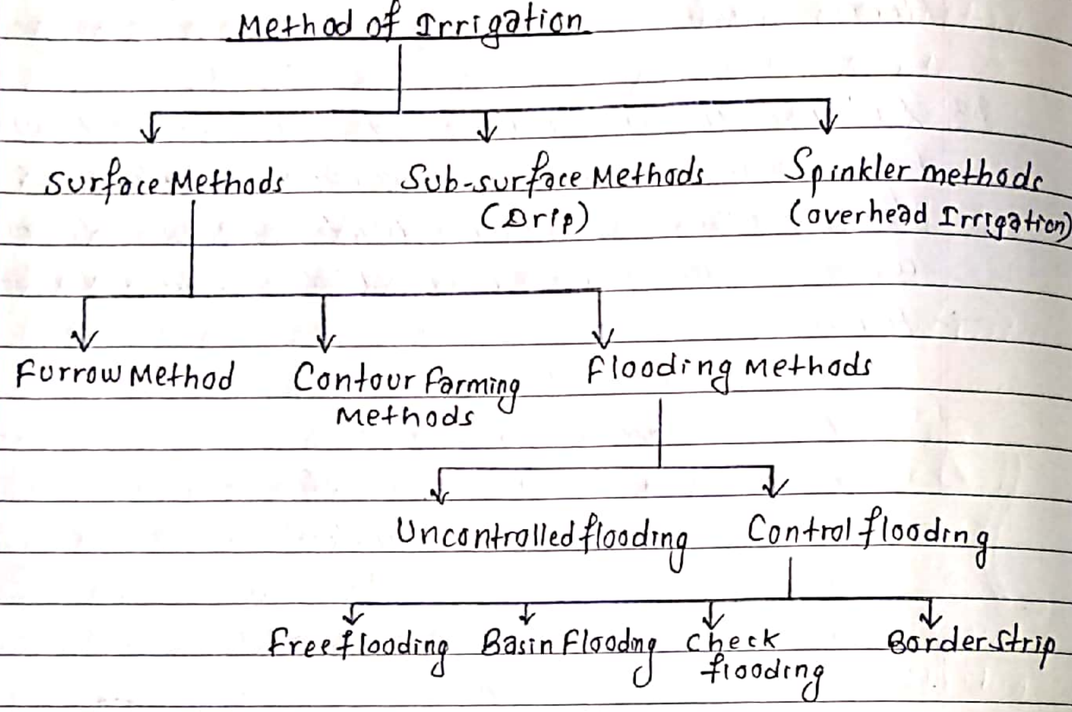
$$\Rightarrow 55.25 = \frac{1.5}{1} \times 300 \times (FC - 7.5\%)$$

$$\Rightarrow FC = 19.7\%$$

# Chapter-3. Method of Irrigation

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→ After obtaining irrigation water from the sources by using any techniques like diversion from river or reservoir or pumped from the ground sources, then it can be distributed to the agricultural field. Such a different distributron method is called method of irrigation.




## ☆ Surface Irrigatron:-

→ In surface irrigation method, the water is directly applied to the surface of the land.

→ Surface irrigation is also called as gravity irrigatron. When the water flow under the gravity & irrigatron water sources must be at higher elevation than the field to be irrigated.

→ Surface irrigation in which water is pumped up from the lower elevation to the upper elevation & called as surface lift irrigation.



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## * Sub-Surface Irrigation:-

→ It is termed as sub-surface irrigation because in this type of irrigation water doesnot wet the soil surface. The underground water nourishes the plant root by capillarity. It may be classified as

• Natural Sub-surface Irrigation:-
When underground irrigation is achieved simply by natural processes without any additional extra efforts it is called natural sub-surface irrigation.

• Artificial Sub-surface Irrigation:-
When a system of open jointed drain is artificially laid below the soil, so as to supply water to crops by capillary then it is called artificial subsurface irrigation.

## * Free Flooding:-

→ In this method, the field is divided into small plots which are practically level. Water enter the field at its higher end flows toward the lower end. It is stopped a little before it actually reaches the lower end.

→ Generally used in inundation irrigation system, where steep land is available.

→ Used for close crop. Eg: Rice

→ Large quanity of water wasted.

→ This method involves less labor because no land preparation is done in the form of leaves, field ditches, grading etc.

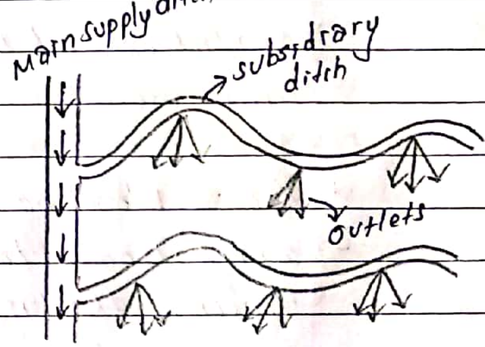



Fig: Free Flooding

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## * Border Flooding Irrigation:-

→ In this method, the field is divided into number of long parallel strip called boarder, which are separated by ~~long~~ low ridges.
→ Land divided into strip 10M to 20M wide & 100m to 400m long.
→ Used for closed growing crop. Eg: Wheat, fodder etc.

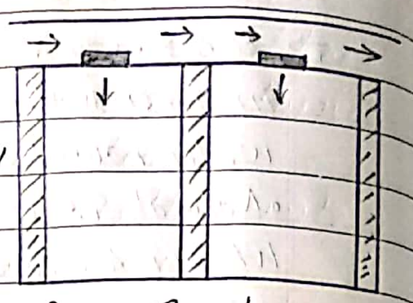


Figure:- Boarder Flooding

## * Check flooding:-

→ In this method, the field is divided into a relatively level plots surrounded by checks or levees.
→ Levees are generally constructed along the contours of vertical interval (5-10) cm.
→ This result in more even spread of water & avoid wastage. However, it requires constant attendance & work during irrigation.
→ Suitable for both permeable & impermeable soil.

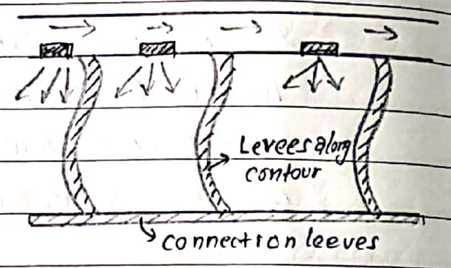
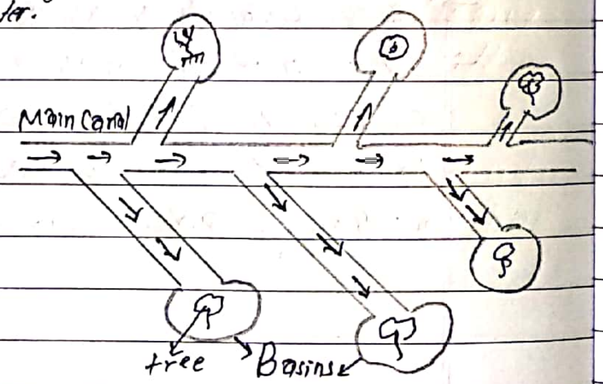



Fig:- Check flooding

## * Basin Flooding:-

→ Irrigation of land surrounding it with embankments to form basin & flooding it with water.
→ Specially for orchard trees.




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## * Sprinkler Irrigation:-

→ In this method, water is applied in the form of spray as ordinary rain.
→ Also called overhead irrigation
→ Used for flowers, coffee, tea etc.
→ Not used for crop like rice, jute etc.
→ The sprinkler method of irrigation is more useful under the following conditions.
(a) Land unsuitable/uneconomical for levelling.
(b) Soils too porous, highly erodible or relatively impervious so, that it is difficult to irrigate them by other method.
(c) Rate of flow available is too low to distribute water by surface irrigation.
(d) Where frequent light application of irrigations are needed.

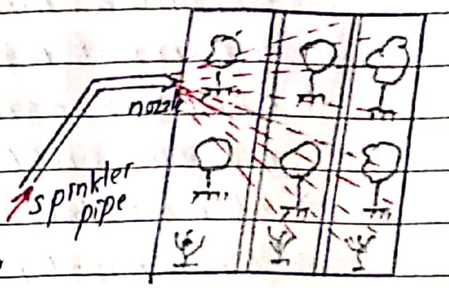



Fig:- Sprinkler Irrigation

## * Advantage of Sprinkler over Surface Irrigation

→ Elimination of channels for conveyance, their maintenance & losses in conveyance.
→ Elimination of land for making ridges & furrows, borders etc.
→ Closer control of water application convenient for giving light & frequent irrigation & higher application efficiency.

## * Limitation of Sprinkler Irrigation:-

→ Uneven water distribution in windy area
→ High evaporation losses under high temperature.
→ Investment & operation cost is relatively high compared to surface irrigation.

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## * Drip Irrigation:-

→ Drip Irrigation is a method of crop irrigation that involves a controlled delivery of water to plants through system of pipes, valves, tubing & emitters.
→ The water is delivered from a source directly to root zone of individual plants or to the surface of soil.
→ This method is suitable where scarcity of water happens.
→ Drip nozzles are the small orifice made on the pipe network burried under the surface providing water to the root zone of the plants & crops.

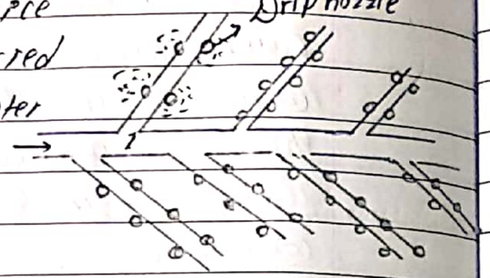



Fig:- Drip Irrigation

### ⇒ Advantages:-

(a) It has very high water application efficiency (>90%)
(b) The evaporation losses from the land surface are quite low.
(c) The deep percolation losses are entirely eliminated.
(d) It is quite suitable for small trees & widely spaced plants.

### ⇒ Disadvantages:-

(a) It is expensive method
(b) There are maintenance problem because of clogging of small pipe & opening of emitter by clay & silt particles.
(c) It is not suitable for closely spaced crop such as wheat.
(d) Because only a part of soil is wetted, root growth is sometime inhibited.

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## * Furrow Irrigation method:-

→ In this method, furrows are developed between the crop rows in the planting & cultivating processes.
→ The size & shape of furrow depends upon the spacing betn the crop rows & the type of crops grown.
→ The water is applied to the furrows & due to percolation, water reaches to the root of plants.
→ In this method, water is not applied to the entire surface area of land & hence evaporation loss are less.
→ Used for crops like tomato, tobacco, potatoes, Cauliflowers etc.

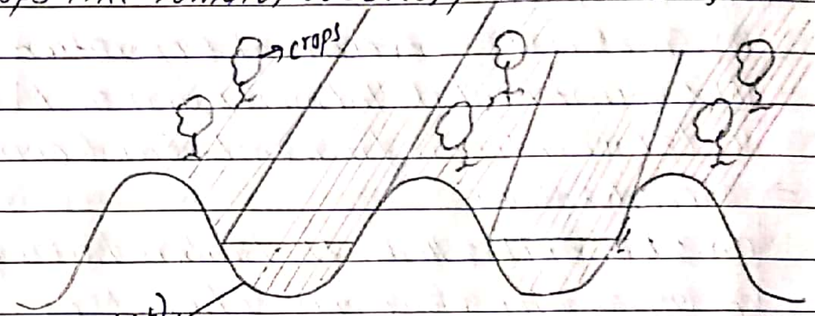



Fig:- Furrow Irrigation.

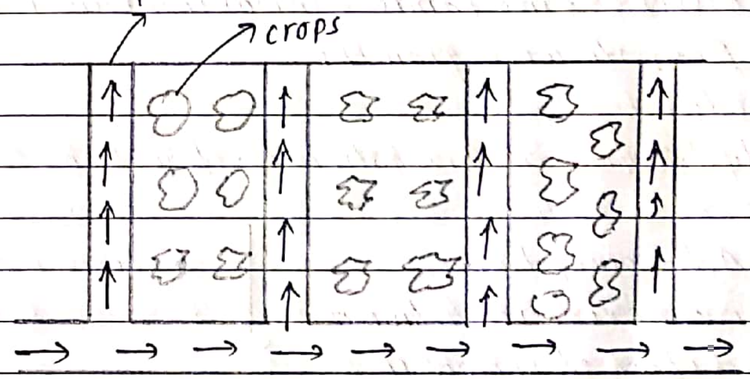



Fig:- plan of furrow irrigation.

→ In this method, less evaporation takes place since $(1/2)^{th}$ to $(2/5)^{th}$, land surface is wetted by water.

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## ✻ Factors affecting the selection of Irrigation Methods:-

- Natural condition (Topography, source of water & adequacy)
- Type of crop
- Type of technology
- Previous experience with irrigation
- Required labour inputs
- Costs & benefits

## ✻ Advantage & Disadvantage of surface Irrigation

⇒ Advantages

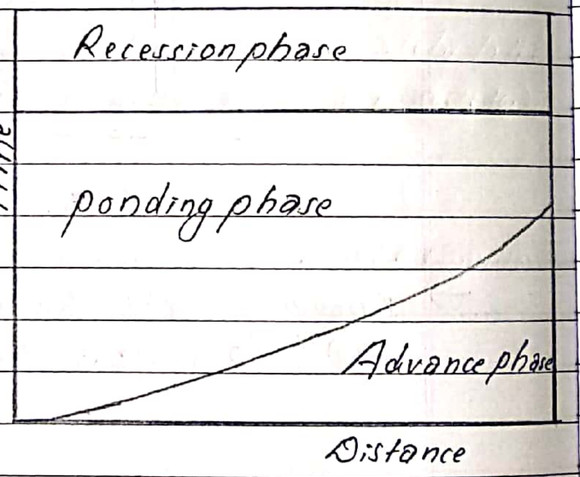
(a) Small cost of investment & operation
(b) Doesnot need skilled man power and common in farmers level.
(c) Labour intensive for maintenance & operation

⇒ Disadvantages

(a) It is applicable for the locations having abundant water
(b) Irrigation efficiency is low.
(c) Need level or graded land.
(d) losses of some lands for making ridges, furrow & borders.
(e) Promote weed growths.

## ✻ Hydraulics of Irrigation Distribution:-

(a) Advance phase:-
The time interval between the start of irrigation & arrival of the advancing (wetting) front at the lower end of the field.




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(b) Ponding (wettingstorage or continuing) phase:-
→ The irrigation time extending between the end of advance and inflow cutt off. The term wetting phase is usually used fo furrow and border where tail water runoff can occur whereas ponding is the preferred term for basin irrigation.

(c) Depletion (Vertical Recession) phase:-
→ It is the time interval between supply cut off and the time that water dries up at the inlet boundary.

(d) Recession (horizontal recession) phase:-
→ The time required the water to recede from all points in the channel starting from the end of the depletion phase. The time difference at each measuring station between cumulative time for advance & recession is the opportunity tim

Sumit Paudel (NEC)

Chapter-4, Canal Design

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* Components of surface Gravity Irrigation System.

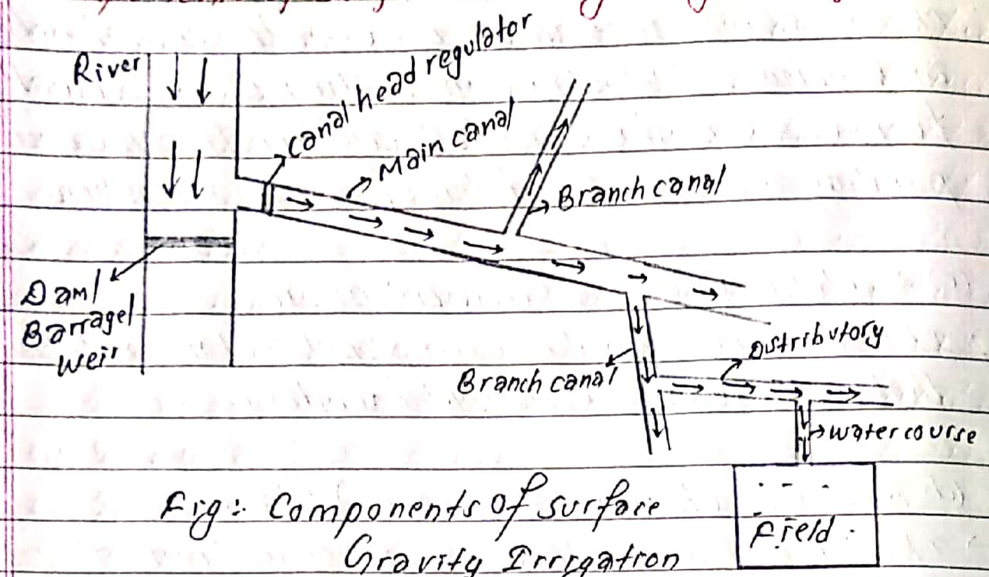



Fig:- Components of surface Gravity Irrigation System.

→ The components of surface gravity irrigation system
(i) Dam/Barrage/Weir
(ii) Canal Head Regulator
(iii) Main Canal
(iv) Branch Canal
(v) Distributory Canal
(vi) Minorcanal
(vii) Water Course

* HeadWorks:-
→ Hydraulic structures which supplies water to the off taking canal is called as head work.
→ The structures made to control desired water flow safely to the desired direction of the water source (rivers, lakes, reservoirs etc) is known as headworks.
→ It server the following purposes:
(a) It raises the water level in the river so that the command area can be increased.
(b) It regulates the intake of water into canal.
(c) It controls the silt entry into the canal.
(d) It reduces fluctuations in the level of supply in river.
→ The headworks should safely dispose excess flood water at downstream.
→ Dam/Barrage/Weir are the major structures in head works to store water in reservoir/to create small pond/to raise water level.
⇒ Types of Headworks:-
(a) Storage Headwork:-
When dam is constructed across a river to form a storage reservoir. It is known as storage headwork. It stores water during the period of excess supplies in the river and releases it when demand overtakes the available supplies.

(b) Diversion Headwork:-
→ When a weir or barrage is constructed across a river to raise the water level & to divert the water to the canal, then it is known as diversion headwork.
→ Diversion headwork are common for irrigation projects.
→ Diversion headworks may be temporary or permanent types.
• Temporary → Spurs or bunds are those which are temporary and are constructed every year after floods. (more common in Farmer Managed Small Irrigation System)
• Permanent → Weirs or Barrage are constructed & made up of concrete for large irrigation project (Barrage in Bagmati, Sikta irrigation project & weir in kankai Irrigation project)

* Weirs:-
→ The weir is a solid obstruction put across the river to raise its water level & divert the water into canal.
→ If weir stores water for tiding over small period of short supplies, it is called as storage weir. The main difference between weir and dam is only in height & duration for which the supply is stored. A dam stores the supply for a comparatively longer duration.

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## * Barrage:-

→ The function of barrage is similar to that of weir; the heading up of water is affected by the gates alone. No solid obstruction is put across the river. The crest level in the barrage is kept at low level. During the floods, the gates are raised to clear off the high flood level, enabling the high flood to pass downstream to max afflux. When the flood recedes, the gates are lowered & flow is obstructed, thus raising the water level to upstream of the barrage. Due to this, there is less silting and better control over the levels. However, barrage are much more costly than weirs.

## * Difference between Weir and Barrage:-

| Weir | Barrage |
|---|---|
| (1) It is cheaper because of simple construction. | (1) It is relatively costly due to complicated structure construction. |
| (2) A weir has high crest level | (2) It is with lower crest level |
| (3) It provides more afflux. | (3) It provides less afflux |
| (4) It doesnot have control all over the river water. | (4) It provides effective control over the entire river flow. |
| (5) It causes more silting on up-stream. | (5) It provides less silting on upstream bed. |
| (6) Over the weir, bridge cannot be constructed. | (6) Bridge for transportation purpose can be constructed. |
| (7) Crest shutter is difficult to operate i.e. more time and labour is required. | (7) Gates are convenient to operate. |

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## * Classification of Canals:-

→ Canal is an artificial structure made to convey water from its source to desired place. Generally, the section of canal is trapezoidal for large canal. Canal should be of sufficient capacity to pass the design discharge. Loss of water should be minimum as far as possible. Silting & scouring in canal bed should be avoided. Canal length should be minimum.

⇒ Classification of Canals according to function

(a) Irrigation Canal → Carries water directly to agricultural fields.
(b) Navigation Canal → Utilize for navigation besides doing irrigation.
(c) Power Canal → Utilize for power generation
(d) Link Canal → Canal used for diverting water from one canal to another due to insufficient water.
(e) Feeder Canal → Canal constructed to supply water to other canal.

⇒ Classification of canals based on discharge

(a) Main canal (primary canal) → $Q > 10\ m^3/sec$
(b) Branch Canal (Secondary Canal) → $Q > 5\ m^3/sec$
(c) Distributary Canal (Tertiary Canal) → $0.25\ m^3/s < Q < 3\ m^3/sec$
  - Major distributary ($0.25 - 3\ m^3/sec$)
  - Minor distributary ($< 0.25\ m^3/sec$)
(d) Field Canal (Water Courses) → Outlet of Distributary Canal to field.

⇒ Classification on the basis of nature of Source:-

(a) Permanent Canal:-
The canal which get water throughout the year is called permanent canal. Made up of earth, stone masonry or concrete. Regulating gates are provided to control flow.
(b) Inundation Canal:-
They draw their supplies from river when there is a high stage

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in the river. They are not provided with any headworks for diversion of river water to canal.

## ※ Alignment of Canals:-

→ Canal has to be aligned in such a way that it covers the entire proposed command area with shortest possible length & minimum cross drainage works.

→ A shorter length of canal ensures less loss of head due to friction, small loss of discharge due to seepage and evaporation thus making additional field can be brought under irrigated cultivation.

→ According to alignment, canal can be classified as,

(i) Ridge canal or watershed canal
(ii) Contour canal
(iii) Sideslope canal

### (i) Ridge Canal or Watershed Canal:-

Canal has to be designed in such a way that most of its length is aligned along the ridge line of watershed. It can command areas on both banks and a large area can be brought under cultivation. No drainage can intersect at the ridge hence no cross drainage structures are required. Most appropriate for irrigation in Terai or plain Terrain.

### (ii) Contour Canal:-

→ A canal aligned parallel to contour except for the necessary longitudinal slope is called contour canal. Such type of canal is constructed in hilly areas. It is economical than ridge canal when ridge is very higher than river flows.

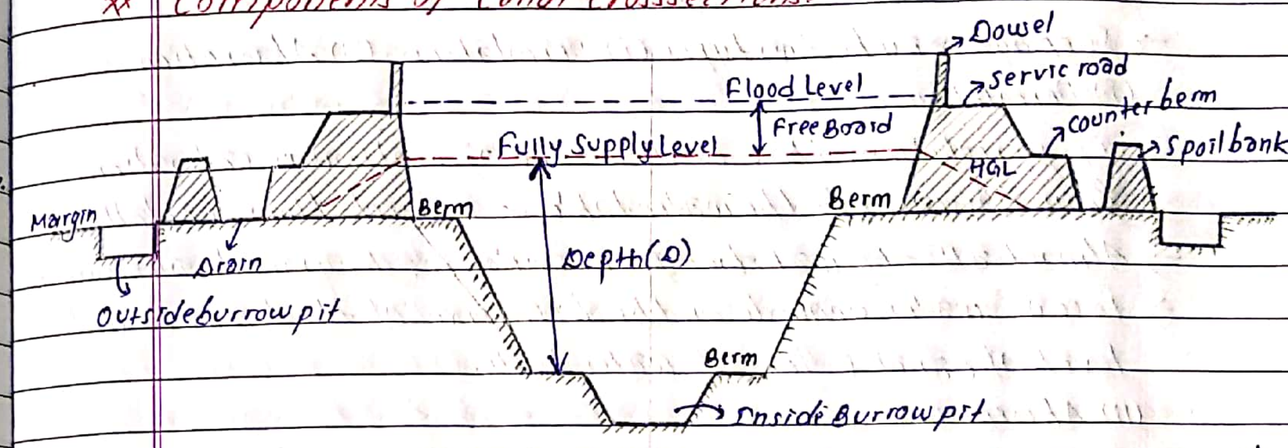
→ It irrigates only one side of canal so serves small area.

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### (iii) Side Slope Canal:-

It is the canal aligned roughly at right angle to contours. Such a canal is roughly parallel to the natural drainage & hence does not intercept cross drainage. Such canal can irrigate on both sides but they have steep bed slopes.

## ※ Components of Canal Crossections:-




(a) Side slopes:- The side slope of ~~channel~~ canal depend upon nature of soil. For loam soil, In cutting slopes 1:1 & in filling 1.5:1.
For Sandy soil, In cutting slope is 1.5:1 & in filling 2:1.

(b) Berm:- Berm is the horizontal distance left at ground level bet^n toe of bank & top edge of cutting. provide additional strength to the bank & also provided for future widening of channel.

(c) Free Board:- Free board is defined as the vertical distance betwee designed full supply level in the canal & top level of canal bank.

(d) Banks:-

(e) Inspection Road – For inspection, repair & maintenance

(f) Dowel:- For safety purpose

(g) Burrow pits:- inside to flow water in less amount & outside for drainage.

(h) Spoil bank:- Extra earth is usually deposited in the form of spoil bank

(i) Canal width:- Total width of Canal. (j) Counter Berm

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## * Canal Seepage & evaporation & Other losses:-

(a) Evaporation loss:-

→ The water loss by evaporation is generally very small, as compared to water lost by seepage.

→ Evaporation loss are generally 2-3% of total loss (Maximum 7% in summer)

(b) Seepage loss:-

→ Seepage may be two types (i) percolation (ii) Absorption

(i) Percolation:-

⇒ In percolation, there exists a zone of continuous saturation from the canal to the water table & a direct flow is established.

⇒ Almost all the water lost from canal reaches ground water reservoir.

⇒ Loss of water depends on the difference of the top water surface level of canal & level of water table.

(ii) Absorption:-

⇒ In absorption, a small saturated soil zone exists round the canal section & is surrounded by zone of decreasing saturation.

⇒ A certain zone just above the water table is saturated by capillarity. Thus, there exists an unsaturated soil zone between the two saturated zones.

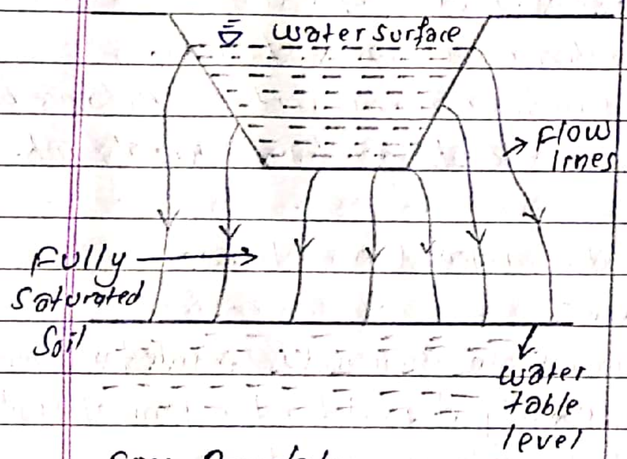



Fig: Percolation

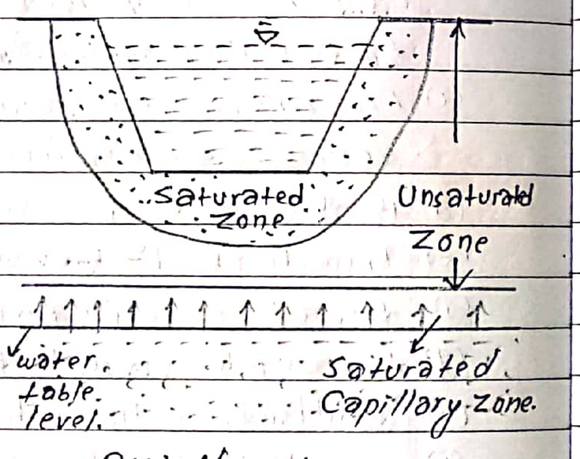



Fig: Absorption

## * Types of Canal on the basis of lining:-

(a) Unlined Canal:-

→ Beds and banks made up of natural soil

→ water velocities higher than 0.7 m/s are not tolerable.

→ High Seepage & Conveyance water loss

→ Profuse growth of adequate weeds retards the flow.

(b) Lined Canal:-

→ Lining of impervious material on its bed and banks to prevent the seepage of water.

→ Different types of lining used. Ex:- Concrete, brick or burnt clay tile, boulder etc.

## * Types of Canal on the basis of cutfill

(a) Fully cutting:- Canal prepared by fully cutting the ground.

(b) Fully filling:- Canal constructed above ground without excavating the ground. (Fully embankment)

(c) Partially filling & partially Cutting:- Canal constructed by both filling & cutting. (Economic)

(Earth cutting ≈ Earth filling)

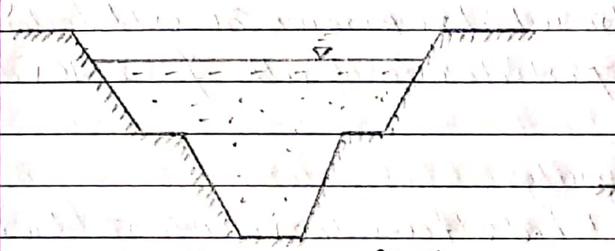


Fig: Fully cutting Canal

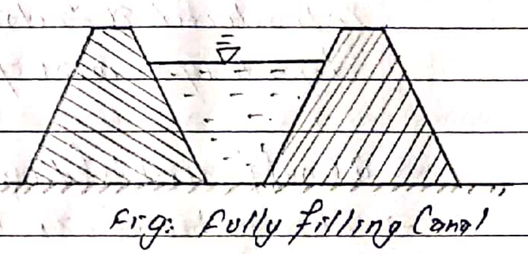


Fig: Fully filling Canal

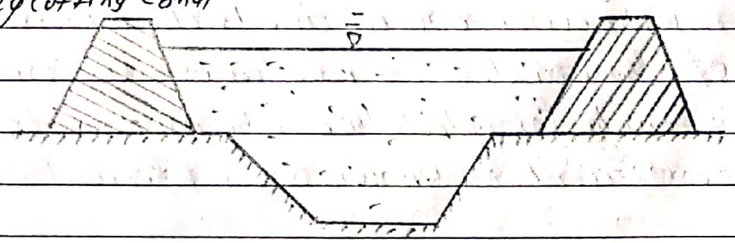


Fig: Partially cutting, partially filling

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* Important terms related to Canal Design:-

1) Alluvial Soil:-

→ The soil which is formed by the continuous deposition of silt is known as alluvial soil. The river carries heavy charge of silt in rainy season. When the river overflows its banks during the flood, the silt particles get deposited on adjoining areas. This type of soil is found in deltaic region of river. This soil is permeable, soft & very fertile. The river passing through this type of soil has tendency to change its course.

2) Non-Alluvial Soil:-

→ The soil which is formed by the disintegration of rocks is known as non-alluvial soil. It is found in mountainous region of river. The soil is hard & impermeable in nature. This is not fertile. The river passing through this type of soil has no tendency to change its course.

3) Silt factor (f)

→ During the investigation works in various canals in alluvial soil, Gerald Lacey established the effect of silt on the determination of discharge & canal section. So, Lacey introduced a factor which is known as silt factor. It depends upon mean particle size of silt. $f = 1.76\sqrt{d_{mm}}$

4) Coefficient of Rugosity:-

→ The roughness of canal bed affects the velocity of flow. The roughness is caused due to the ripples formed on the bed of the canal. So, a coefficient was introduced by R.G Kennedy for calculating the mean velocity of flow. This coefficient is known as coefficient of rugosity ($\eta$).

5) Mean Velocity:-

It is found by observation that the velocity at a depth 0.6D represent the mean velocity, where D is the depth of water in canal.

By chezy's eqn, $V = C\sqrt{RS}$

By Manning's eqn, $V = \frac{1}{n} \times R^{2/3} \times S^{1/2}$

6) Critical Velocity Ratio (C.V.R.)

The ratio of mean velocity 'V' to the critical velocity ($V_c$) is known as C.V.R.

$$CVR\ (m) = \frac{V_{mean}}{V_c}$$

when $m = 1$, there will be no silting & no scouring

$m > 1$, scouring will occur

$m < 1$, silting will occur

7) Critical Velocity

→ When the velocity of flow is such that there is no silting or scouring action in the canal bed, then that velocity is known as critical velocity.

$$V_c = 0.546 * D^{0.64} \quad [D = \text{Depth of water}]$$

8) Regime Channel:-

→ When the character of bed and bank materials of the channel are same as that of the transported materials and when the silt charge & silt grade are constant, then the channel is said to be in its regime & the channel is called regime channel. This ideal condition is not practically possible.

9) Hydraulic Mean Depth:-

→ $R = A/p$

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(10) Fully supply discharge:-
The maximum capacity of the canal for which it is designed, is known as fully supply discharge.

(11) Economic Section:-
→ If a canal section is such that the earth obtained from cutting (excavation) can be fully utilized in forming the banks then that section is known as economical section.
→ Discharge is maximum with minimum cross-section
→ Here, no extra earth is required from borrow pit & no earth is in excess to form the spoil bank. This condition can only arise in case of partial cutting & partial filling.

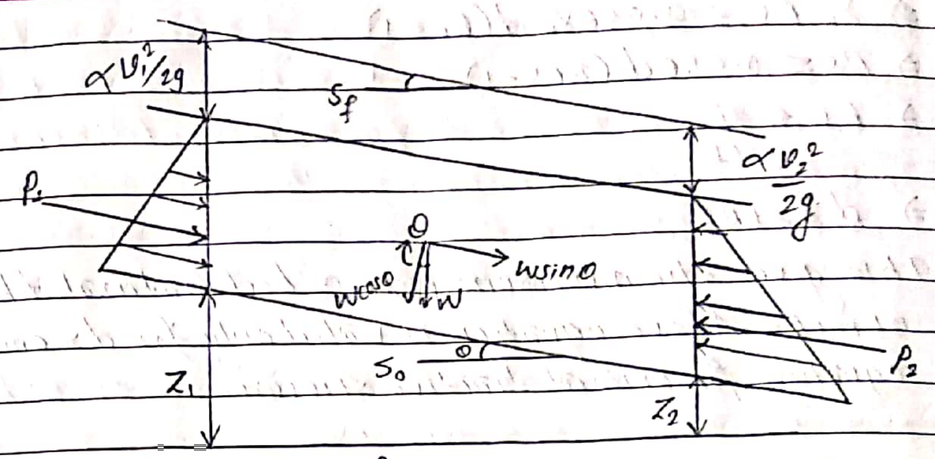
## Tractive Force Approach in Canal Design:-

→ The movement of the sediments at bed is caused by a force exerted on its grains by the flowing water. This force is known as tractive force & is equal to component of the weight of water in the direction of flow. For uniform flow, the mean tractive force per unit area is given by,

$$\tau = \gamma R S$$

Where, $\tau$ = Tractive force per unit area ($kN/m^2$)
$\gamma$ = Unit weight of water
$R$ = Hydraulic Mean depth
$S$ = slope of bed.

→ The critical tractive force ($\tau_c$) is defined as the maximum tractive stress that will not cause movement of the material forming the channel bed on a level surface. When tractive stress exceeds the critical tractive stress, the particles starts moving. The critical tractive stress is a function of the sediment concentration and the average particle size of the bed material in the case of channels in sandy soil.




Calculation of tractive force,
For a channel of length L, cross sectional Area 'A' & slope S.
Volume of water = A×L
Weight of water stored = $\gamma_w \times AL$
Horizontal Component of this force = $\gamma_w \times AL \times \sin\theta$
For small value of $\theta$,

$$S = \sin\theta \approx \tan\theta$$

$\therefore$ Tractive force = $\gamma_w \times AL \times S$
Now, Tractive force per unit area = $\frac{\gamma_w \times AL \times S}{L \times P} = \gamma_w \times R \times S$

This average unit tractive force is called shear stress ($\tau_0$) = $\gamma_w RS$

→ According to shield the critical tractive stress is proportional to the grain diameter & submerged unit weight of the sediment & is given by,

$$\tau_c = 0.056\, \gamma_w d\,(G_s - 1); \text{ for } (d > 6mm)$$

Where, $\tau_c$ = critical shear stress ($kN/m^2$)
$G_s$ = Specific gravity of sediment
$d$ = Diameter of sediment grain (m)

For no movement of bed particles,
Average tractive stress ≤ Critical Tractive stress

$$\tau_0 \leq \tau_c$$

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$\Rightarrow \gamma_w RS \leq 0.056 \gamma_w d(G_s - 1)$

$\Rightarrow RS \leq 0.056 d (2.65 - 1)$

$\Rightarrow RS \leq \frac{d}{11}$

$\Rightarrow d \geq 11RS$

This gives the minimum size of bed material that remains at rest. Above equation is valid only for $d > 6mm$. General equation for critical tractive stress is,

$$\tau_c = 0.155 + \frac{0.409 d^2 (mm)}{\sqrt{1 + 0.177 d^2 (mm)}} \quad \text{[valid for all conditions]}$$

→ The critical tractive stress on a sloping surface is less than that on a level surface. The ratio can be determined from the relation

$$\frac{\tau_s}{\tau_L} = \cos\theta \sqrt{1 - \frac{\tan^2\theta}{\tan^2\phi}} = K$$

Where,

$\tau_s$ = Critical tractive stress on sloping surface

$\tau_L$ = Critical tractive stress on level surface

$\theta$ = Angle of sloping surface

$\phi$ = Angle of Repose

$K$ = Tractive force ratio.

→ The above equation shows that $\tau_s < \tau_L$, which shows that the shear stress required to move a grain on the side slopes is less than the shear stress required to move the grain on canal bed. Morever, on the canal bed, the average value of actual shear stress generated by the flowing water in a canal of given 'R' & 'S' is given by the equation.

$$\tau_0 = \gamma_w RS$$

While on slopes, this value is given by

$$\tau_0 = 0.75 \gamma_w RS$$

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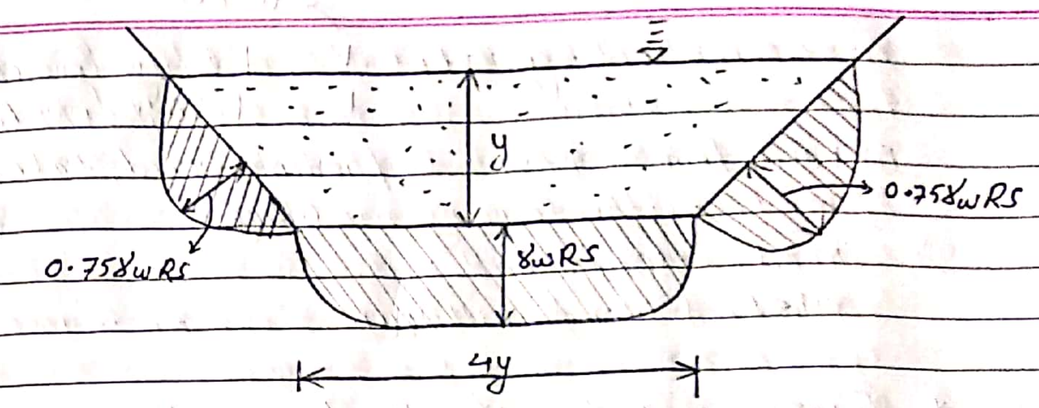



Fig: Shear stress distribution in trapezoidal channel section.

## ※ Silt Theories:-

→ After long research in different canals and different conditions, R.G. kennedy & Gerald Lacey have established some theories for the design of canals which are known as kennedy's theory & Lacey's theory. These two theories are based on the characteristics of sediment load in canal water. The behaviour of the silt is explained by the theory which is known as Silt theory.

### * Kennedy's Theory:-

→ From the experiment & observations of 50 years in 20 sites he conclude the following.

(a) The silt supporting power in a channel cross section was mainly dependent upon the generation of eddies, rising to the surface.

(b) The eddies are generated due to friction of flowing water with channel surface.

→ According to him, the critical velocity ($V_0$) is given as,

$$V_0 = 0.84 m D^{0.64} \text{ (FPS)}$$

$$V_0 = 0.55 m D^{0.64} \text{ (SI)}$$

When, $D$ = Depth of channel

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$m$ = critical velocity ratio = $\frac{V}{V_0}$ = $\frac{\text{Velocity from chezy's formula } (V = C\sqrt{RS})}{\text{Velocity from kennedy's theory}}$

'm' varies from 0.9 to 1.1 & if not mentioned, take $m = 1$.

If $m = 1$, neither scouring nor silting

$m > 1$, scouring will occur.

$m < 1$, silting will occur.

* Design procedure of unlined irrigation canal by kennedy's Silt theory:-

1) Assume depth
2) Calculate Critical Velocity, $V_0 = 0.55\, m D^{0.64}$ (SI unit)
3) Calculate area using eqn of continuity, $A = Q/V_0$
4) Calculate bed width from area
5) Calculate hydraulic radius, $R = A/P$
6) Calculate chezy's coefficient using kutter's Equation

$$C = \frac{23 + \left(\frac{0.00155}{S} + \frac{1}{n}\right)}{1 + \left(23 + \frac{0.00155}{S}\right) \times \frac{n}{\sqrt{R}}}$$

7) Calculate actual velocity of flow using chezy's equation $V = C\sqrt{RS}$ / $V = \frac{1}{n} R^{2/3} S^{1/2}$
8) Calculate critical velocity Ratio (m) = $V/V_0$
9) If $m = 0.9 - 1.1$, then design is ok, otherwise revise the section assuming different depth.

* Design of unlined canal by Lacey's regime theory:-

→ Following are two assumptions in Lacey's Theory:-

(a) Dimensions such as width, depth and slope of a regime channel to carry a given discharge loaded with given silt charge are all fixed by nature.

(b) He also stated that silt is kept in suspension due to the force of vertical eddies. According to him, eddies are generated from bed and sides, both normal to the surface of generation. Hence, the vertical component of eddies generated from sides will also support the silt.

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• Regime Channel:- Lacey defined the regime channel as a stable channel transporting a regime silt charge. A channel will be regime if it flows in incoherent unlimited alluvium of the same character as that of transported and the silt grade as well as silt charge are constant.

→ Condition for regime channel

(a) The channel is flowing in incoherent unlimited alluvium of the same character as that of transported.

(b) Silt grade as well silt charge are constant

(c) Discharge is constant.

→ If all the conditions are fulfilled then the channel is ~~then~~ said to be "true regime". However, it is very rare that all the above three conditions are realized in the field. So, Lacey gave the idea of initial & final regime for actual channels.

→ Initial Regime:- It is the state of the channel which has formed its section only and yet not secured the longitudinal slope. Lacey Silt theory is not applicable to the channels in initial regime

→ Final Regime:- The channel after attaining its section as well as its longitudinal slope is said to be in final regime. Unlined channels will be either in initial regime or in final regime.

→ Permanent Regime:- A channel is said to be in permanent regime when its section is provided with a lining to protect against scouring of the section, thereby imparting the

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permanency to the channel section & longitudinal slope. Lacey regime theory is not applicable to such channels. This case can only exist in lined channels.

→ Incoherent Alluvium:- It is the soil composed of loose granular graded material which can be scoured with the same ease with which it is deposited.

→ Regime Silt charge:- It is the minimum transported load consistent with fully active bed.

## * Design steps:-

→ Lacey's worked on the canal which were at final regime conditions. He gave the following formula to determine the regime section and the bed slope of channels.

Steps

(a) Silt factor, $f = 1.76\sqrt{m}$, m = Mean particle size in mm. Following Relation between 'f' and critical velocity ratio can be used. $f = \left(\frac{v}{v_o}\right)^2$

(b) Velocity of flow, $v = \left(\frac{Qf^2}{140}\right)^{1/6}$

(c) Hydraulic Depth $R = 2.5 \times \frac{v^2}{f}$

(d) Area of flow, $A = \frac{Q}{v}$

(e) Wetted perimeter, $P = 4.75\sqrt{Q}$

(f) Base width & Depth of water, $R = A/P$

(g) Bed slope, $S = 0.0003\left(\frac{f^{5/3}}{Q^{1/6}}\right)$

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## * Options of Canal Lining:-

→ The lined canals are not designed by the use of Lacey's & Kennedy's theory, because the section of the canal is rigid. Manning's equation is used for designing. The design consideration are:-

(a) The section should be economical (x-sectional area should be maximum with minimum wetted perimeter).

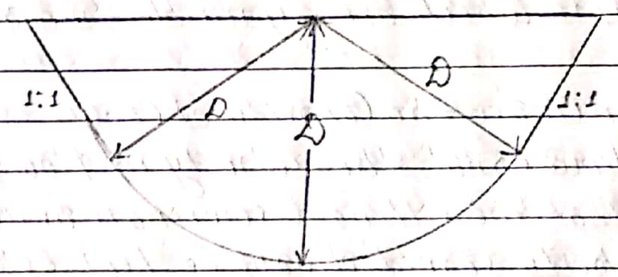
(b) The velocity should be maximum so that x-section area becomes minimum.

(c) The capacity of lined section is not reduced by silting.

→ The following two lined sections are generally adopted.

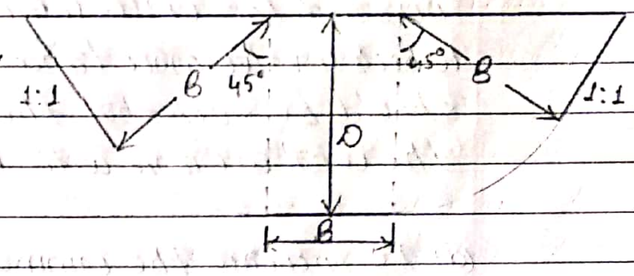
### * Circular Section:

The bed is circular with its centre at the full supply level and radius equal to full supply depth 'D'. The sides are tangential to the curve. However, the side slope is generally taken as 1:1.




### * Trapezoidal Section:

The horizontal bed is joined to the side slope by a curve of radius equal to full supply depth 'D'. The side slope is generally kept as 1:1



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## ✱ Object of Canal Lining:-

(a) To control Seepage:-

The seepage loss is the maximum loss in unlined canals. Due to seepage the duty of canal is much reduced which involves enhancement of storage capacity of reservoir by constructing high dam. Thus, the expenditure of the project is increased. So, to control the seepage loss through the bed and sides of the canal, the lining of canal is necessary.

(b) To prevent Water-logging:-

Along the course of canal, there may be low lying areas on one side or both sides of the canal. Due to the seepage of water through the sides of the canal, these areas may get converted into marshy lands. This water logging makes the land alkaline which is unsuitable for agricultural. This water-logging area may become the breeding place of mosquitos which are responsible for many infectious diseases.

(c) To increase the Capacity of Canal:-

In unlined canal, the velocity of flow should be fixed such that the silting & scouring is avoided. In practice, the velocity should always be kept below 1 m/s. Due to the low velocity, the discharge capacity of canal becomes low. In unlined canal, if the capacity of the canal is to be increased the cross-sectional area has to be increased which involve more land width. So, the lining of the canal should be such that the velocity and the discharge of the canal are more with minimum cross-sectional area.

(d) To increase the command Area:-

→ If the lining is provided in the canals the various losses can be controlled and ultimately the command area of the project may be enhanced.

(e) To protect the canal from the damage by flood:-

→ The unlined canals may be severely damaged by scouring & erosion caused due to high velocity of flood water at the time of heavy rainfall. So, to protect the canals from the damage the lining should be provided.

(f) To control the growth of weeds:-

→ The growth of various types of weeds along the sides of the canals is a common problem. Again, some type of weeds is found to grow along the bed of canals. These weeds reduce the velocity of flow and capacity of canals. So, the unlined canals require excessive maintenance works for clearing the weeds. If lining is provided in the canal, the growth of weeds can be stopped & velocity & the capacity of the canal may be increased.

## ✱ Advantages & Economics of Canal lining:-

Advantages:-

→ It reduces the water logging and hence the bad effects of water logging are eliminated.
→ It reduces the loss of water due to seepage & hence the duty is enhanced.
→ It provides smooth surface and hence the velocity of flow can be increased.
→ Due to the increased velocity, discharge capacity of canal is also increased.
→ Due to increased velocity, the evaporation loss also be reduced.
→ It eliminates the effect of scouring in the canal bed.

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→ The increased velocity eliminates the possibility of silting in the canal bed.
→ It controls the growth of weeds along the canal sides & bed
→ It provides the stable section of canal.
→ It reduces the requirement of land width for the canal, because smaller section of the canal can produce greater discharge.
→ It prevents the sub-soil salt to come in contact with the canal water.
→ It reduces the maintenance cost for the canals.

* Disadvantages:-
→ The initial cost of the canal lining is very high. So, it makes the project very expensive with respect to the output.
→ It involves much difficulty for repairing the damaged section of lining.
→ It takes too much time to complete the project work.
→ It becomes difficult, if the outlets are required to be shifted or new outlets are required to be provided, because the dismantling of the lined section is difficult.

* Selection of type of lining:-
→ The selection of particular type of lining depends on the following factors:-
(a) Imperviousness-
(b) Smoothness-
(c) Durability-
(d) Economy-
(e) Site Condition-
(f) Life of project-
(g) Availability of Construction Material:-

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* Types of Lining:-
(a) Shotcrete lining:-
→ In this system, the cement mortar (1:4) is directly applied on sub-grade by an equipment known as cement gun. The mortar is termed as ~~shot~~ shotcrete & the lining is known as shotcrete lining. (Gunite also).
→ The lining is done in two ways.
(i) By dry mix:- (mixture of cement & moist sand)
(ii) By wet mix:- (mixture of cement, sand & water)
→ This type of lining is very costly and it is not durable. It is suitable for resurfacing the old cement concrete lining.

(b) Asphalt lining:-
→ This lining is prepared by spraying asphalt (bitumen) at very high temperature (about 150°C) on the subgrade to a thickness varies from 3mm to 6mm. The hot asphalt when becomes cold forms a water proof membrane over the subgrade. This membrane is covered with a layer of earth and gravel. The lining is very cheap and can control the seepage of water very effectively but it cannot control the growth of weeds.

(c) Bentonite & Clay lining:-
→ In this lining a mixture of bentonite and clay are mixed thoroughly to form a sticky mass. This mass is spread over the subgrade to form an impervious membrane which is effective in controlling the seepage of water, but it cannot control the growth of weeds. The lining is generally recommended for small ~~shall~~ canals.

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(d) Soil-Cement Lining:-

→ This lining is prepared with a mixture of soil & Cement. The usual quantity of cement is 10% of the weight of dry soil. The soil and cement are thoroughly mixed to get an uniform texture. The mixture is laid on subgrade & it is made thoroughly compact. The lining is efficient to control the seepage of water but it cannot control the growth of weeds. So, this is recommended for small channels only.

* Specific design Consideration for canals in hill irrigation Systems:-

(a) Head Work location:-

Should be in stable zone free from landslide, good bed rock, less scouring, at straight reach as far as possible with sufficient water available. Select the location where sediment load is less (good vegetation, no land slide zones in watershed)

(b) Intake of Canal:-

Should be located to have minimum intrusion of the silt into the canal; the canal off take (head regulator) is to be outer part of the curved portion securing water at low flow and less sediment intrusion at the high flow season.

(c) Simple Diversion Weir:-

It is more applicable than barrage due to steep slope in hills & there will be no space to store water.

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(d) Trash racks & gravel traps:-

They are needed at the headwork site since there are more chances of flowing gravel, boulders & debris with flood water at high river gradient.

(e) Energy Dissipations Structures:-

- They may required at the headwork for controlling the downstream erosion due to high velocity of water in rainy seasons in steep slopes.

(f) Canal Alignment

Mostly contour canals are provided for the main & branch canals which may require more number of cross drainage structures, contour as well as side slope canals are common for distributory and water course or field channels.

(g) Slope generally steep & critical or super critical flow will occur which may erode the canal bank and the bed surface of unlined earthen canal.

(h) Canal falls:-

They are common and can be utilized for power production as byproduct of the irrigation. The canal falls need to be design to have effective energy dissipation at the canal falls with hydraulic jump, vertical drops & stilling pools as per requirement from the prevailing site conditions.

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(Q) Design an irrigation channel to carry 30 cumecs of discharge. The channel is to be laid at a slope of 1 in 5500. The critical velocity ratio for the soil is 1. Use manning's rugosity coefficient as n = 0.0225. channel sideslope is 1H: 2V.

→ Given,

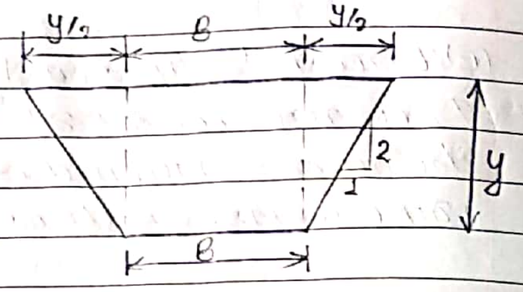
$Q = 30 m^3/sec$

$m = 1$

$n = 0.0225$

Sideslope = 1H: 2V

$S = 1:5500$




By using kennedy's method,

$$v_0 = 0.55 m y^{0.64} = 0.55 \times y^{0.64}$$

$$A = \frac{Q}{v_0} = \frac{30}{v_0}$$

Also, $A = \frac{1}{2}(B + B + y) \times y \Rightarrow 2B + y = \frac{2A}{y} \Rightarrow B = \left(\frac{2A}{y} - y\right) \times \frac{1}{2}$

$$Q = B + 2 \times \sqrt{(y/2)^2 + y^2} = B + 2y \times \sqrt{1^2 + 0.5^2}$$

$$R = A/p$$

$$v = \frac{1}{n} \times R^{2/3} \times S^{1/2} = \frac{1}{0.0225} \times R^{2/3} \times \left(\frac{1}{5500}\right)^{1/2}$$

Iteration table,

| Trial No. | y | $v_0$ | A | B | P | R | v | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.5 | 0.7129 | 42.078 | 27.302 | 30.656 | 1.372 | 0.7401 | $v_0 \neq v$ |
| 2 | 1.75 | 0.7868 | 38.125 | 20.911 | 24.824 | 1.535 | 0.797 | $v_0 \neq v$ |
| 3 | 2 | 0.857 | 35.002 | 16.501 | 20.973 | 1.6689 | 0.8431 | $v_0 \neq v$ |
| 4 | 1.8 | 0.8011 | 37.444 | 19.902 | 23.927 | 1.5649 | 0.8077 | $v_0 \neq v$ |
| 5 | 1.81 | 0.804 | 37.311 | 19.709 | 23.756 | 1.5705 | 0.809 | $v_0 \neq v$ |
| 6 | 1.811 | 0.8043 | 37.298 | 19.689 | 23.739 | 1.5711 | 0.8099 | $v_0 \approx v$ |

Hence, $y = 1.811 m$

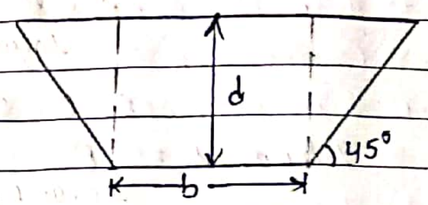
$B = 19.689 m$

Q. Design a suitable canal by Lacey's theory for a design 'Q' of 40 $m^3$/sec & silt factor of unity. What will be the bed width of canal if it were to be designed on the basis of kennedy's method with critical velocity ratio equal to unity & ratio of bed width to depth of flow is same as obtained from Lacey's method.

→ Given,

$Q = 40 m^3/sec.$

silt factor (f) = 1.




$$v = \left(\frac{Qf^2}{140}\right)^{1/6} = 0.811 m/s$$

$$A = \frac{Q}{v} = \frac{40}{0.811} = 49.287 m^2$$

$$P = 4.75\sqrt{Q} = 4.75\sqrt{40} = 30.041 m$$

$$R = 2.5 \times \frac{v^2}{f} = 2.5 \times \frac{0.811^2}{1} = 1.644 m.$$

Assuming trapezoidal channel of slope 1:1,

$$A = \frac{1}{2} \times (b + b + 2d) \times d = d(b + d)$$

$$b = \frac{49.287}{d} - d \quad ---(1)$$

Also, $P = b + 2\sqrt{d^2 + d^2} = b + 2 \times \sqrt{2} \times d$

$$\Rightarrow 30.041 = \frac{49.287}{d} - d + 2\sqrt{2}d \Rightarrow d = 8.593 m, 2.027 m$$

When $d = 8.593 m$, $b = -2.857 m$

$d = 2.027 m$, $b = 22.28 m$

Hence, depth of canal = 2.027 m & width = 22.28 m.

Case II,

Critical velocity ratio (m) = 1

$$B/D = \frac{22.28}{2.027} = 10.991, \quad Q = 40 m^3/sec$$

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$$v_c = 0.55 m D^{0.64} = 0.55 \times 1 \times \left(\frac{B}{10.991}\right)^{0.64}$$

Then, $A = \frac{Q}{v_c} \Rightarrow d(B+d) = \frac{40}{0.55 \times \left(\frac{B}{10.991}\right)^{0.64}}$

$$\Rightarrow \frac{B}{10.991} \times \left(B + \frac{B}{10.991}\right) = \frac{40}{0.55 \times \left(\frac{B}{10.991}\right)^{0.64}}$$

$$\Rightarrow B = 21.755 m$$

Then, $D = \frac{B}{10.991} = \frac{21.755}{10.991} = 1.979 m$

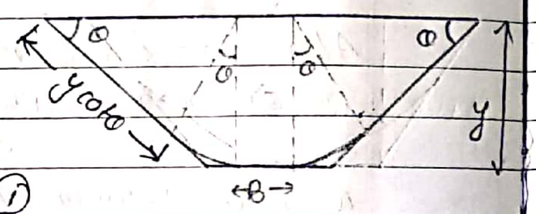
$\therefore B \times D = 21.755 m \times 1.979 m$

Q Design a trapezoidal shaped Concrete line channel to carry a distance of 250 cumecs at a slope of 40 cm/KM. The side slopes of the channel are 1.5:1. The value of 'N' may be taken as 0.017. Assume limiting velocity in the channel as 3 m/sec.

→ Given, $Q = 250$ cumecs

$$S = \frac{40 cm}{1 \times 1000 \times 100 cm} = 0.0004$$

$A = B*y + 2 \times \left(\pi y^2 * \frac{\theta}{2\pi}\right) + 2 * \frac{1}{2} \times y \times y\cot\theta$




$A = y(B + y\theta + y\cot\theta)$ --- (i)

&

Perimeter $= B + 2 \times \pi y\theta + 2y\cot\theta$ -- (ii)

Now, $\cot\theta = \frac{1.5}{1} = 1.5$

$\theta = 0.588$

$n = 0.017$

$v = 3 m/s$

From Manning's formula,

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

$$\Rightarrow R = \left(\frac{vn}{S^{1/2}}\right)^{3/2} = \left(\frac{3 \times 0.017}{0.0004^{1/2}}\right)^{3/2} = 4.072 m$$

$A = \frac{Q}{v} = \frac{250}{3} = 83.33 m^2$

$P = \frac{A}{R} = \frac{83.33}{4.072} = 20.465 m$

From eqn (i)

$83.33 = y(B + y\theta + y\cot\theta)$

$83.33 = y(B + y \times 0.588 + y \times 1.5)$

$83.33 = By + 2.088y^2$ ---- (iii)

From eqn (ii),

$20.465 = B + 2\pi y\theta + 2y\cot\theta$

$\Rightarrow 20.465 = B + 2\pi \times 0.588y + 2y \times 1.5$

$\Rightarrow 20.465 = B + 4.176y$

$\Rightarrow B = 20.465 - 4.176y$

From eqn (iii),

$83.33 = (20.465 - 4.176y) \times y + 2.088y^2$

$\Rightarrow 83.33 = 20.465y - 4.176y^2 + 2.088y^2$

$\Rightarrow 2.088y^2 - 20.465y = 83.33$

On solving,

$y = 3.095$ or $-12.89$ (not possible)

So,

$B = 20.465 - 4.176 \times 3.095 = 7.54 m$

Hence,

Depth $= 3.095 + 1 = 4.095 m$ (1 m free board)

width $= 7.54 m$

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## Chapter-5, Hydraulic Structures in Surface Gravity Irrigation System

1) Headworks - types, functions & components, silt excluder & silt extractor.
2) Condition & Cause of failure of hydraulic structures in alluvial formation.
3) Bligh's, Lanes & Khosla's seepage theory
4) Cross-drainage structures, conditions for their applications & designs.
5) Canal Escapes.
6) Types of canal drops & their design considerations.
7) Function of head & cross-regulators.
8) Design considerations for head regulators.
9) Types of Canal Outlets & their design considerations.
10) Design of pipe outlets.

### ※ Headworks:

→ The structure made to control desired water flow safely to the desired direction at the water source (river, lakes, reservoirs etc) is known as headworks.

→ It serves the following purposes:

(a) It raises the water level in the river, so that the commanded area can be increased.
(b) It regulates the intake of water into canal.
(c) It controls the silt entry into the canal.
(d) It reduces fluctuations in the level of supply in river.

→ Types of Headworks:-

(a) Storage Headwork:-

When dam is constructed across a river to form a storage reservoir, it is known as storage headworks. It stores the water during the period of excess supplies in the river & releases it when demand overtakes the available supplies.

(b) Diversion Headworks:-

→ When a weir or barrage is constructed across a river to raise the water level & to divert the water to the canal, then it is known as diversion headworks.

→ Diversion headwork are common for irrigation projects.

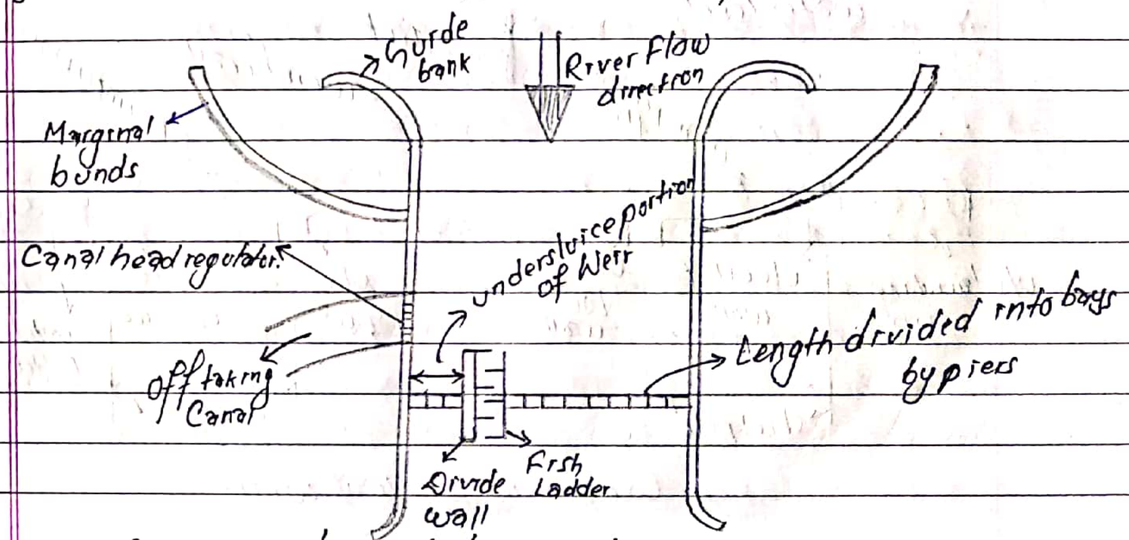
→ Diversion headworks may be temporary or permanent types.

- Temporary → Spurs/bunds are constructed every year after floods. More common in Farmer Managed Small Irrigation System (FMIS).
- Permanent → Weirs or barrage are constructed & made up of concrete for large irrigation project. (Barrage in Bagmati, Sikta irrigation project & Weir in Kankai Irrigation project)

### ※ Components of headworks:-

→ The major components of diversion headworks are,

(a) Weir or barrage
(b) Guide bank
(c) River training works
(d) Marginal bunds / Spurs
(e) Canal head regulator
(f) Divide wall
(g) Fish Ladder
(h) Impervious floor
(i) Flexible Apron
(j) Crest
(k) Pervious Floor
(l) Under Sluice
(m) Inverted Filter
(n) Sheet piles
(o) Shutters/Gates



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## Weir:-

The weir is a solid obstruction put across the river to raise its water level & divert the water into the canal.

→ The main difference between storage weir & dam is only in height & duration for which supply is stored. A dam stores the supply for a comparatively longer duration.

→ Weir can be classified as,

(a) On the basis of presence of shutters:-
- Weir without shutter
- Weir with shutter

(b) On the basis of floor design Criteria
- Gravity Weir → Uplift pressure resisted by wt. of wall entirely.
- Non-gravity weir → Uplift pressure is resisted by bending action of reinforced Concrete floor.

(c) On the basis of materials
- Masonry weir with vertical drop
- Rock fill weir with sloping apron
- Concrete weir with downstream glacis.

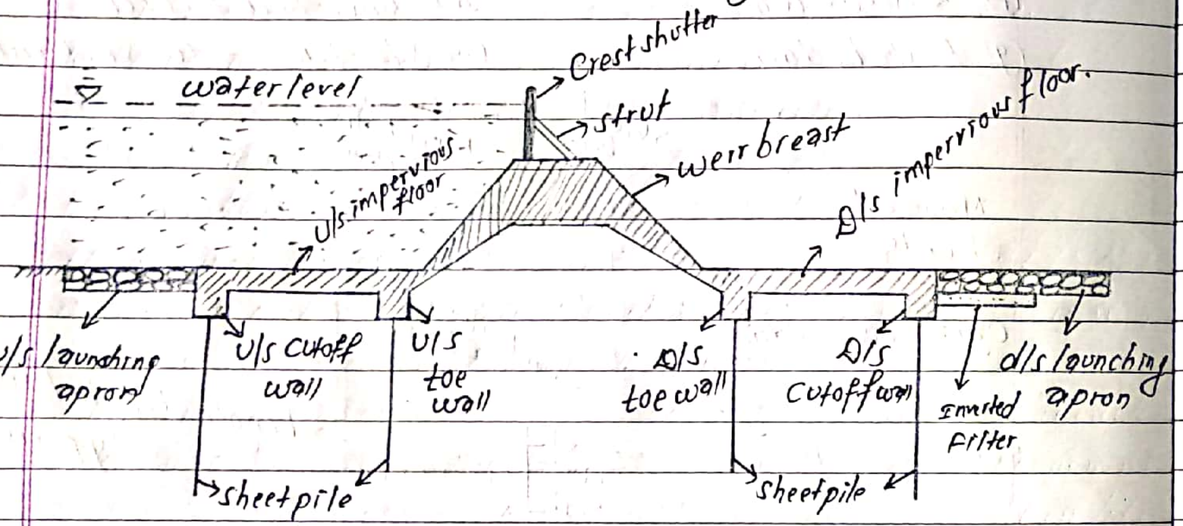



Fig: Component parts of weir.



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## Barrage:-

→ When gates are provided to raise the water instead of placing solid obstruction across the river, the structure is called barrage.
→ Low crest level, less silting, less afflux
→ Bridge for transportation can be used.
→ Effective control over river flow.
→ The components of barrage are shown in figure.

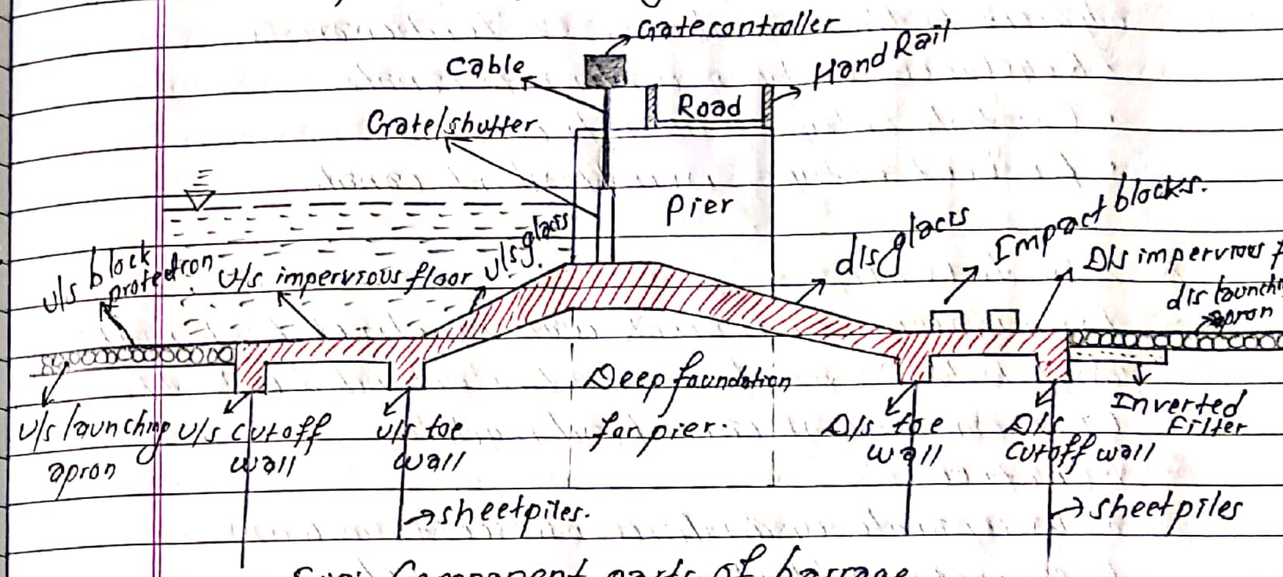



Fig: Component parts of barrage

## River Training Works:-

→ It includes guide banks, marginal bunds, spurs etc.
→ The functions are,
- To provide non-tortuous approach to weir.
- To prevent the river from outflanking the weir.
- To prevent additional area to be submerged due to afflux
- To prevent erosion of river banks.

⇒ Guidebanks:-

Guide banks are earthen embankments with stone pitching in the slopes facing water, to guide the river through barrage

→ Marginal bunds/Spurs:
They are flood embankments in continuation of guide bank designed to contain the floods within the flood plain of river.

✱ Canal head regulator:
These are the structure constructed at the head of canal adjacent to the undersluices. Its function is,
- Regulates supply of water into canal.
- Controls entry of silt into canal.
- Prevent entry of river flood into canal.

✱ Divide Wall:
→ Long, masonry or concrete wall constructed at right angle to the axis of weir. It is extended upto the upstream side of canal head regulator.
→ Function:
a) To separate undersluice portion from weir
b) Increase effectiveness of undersluices portion.
(c) To prevent cross section & flow parallel to weir.
(d) Act as side wall of fish ladder.
(e) Serve as trap for coarser bed material.

✱ Fish Ladder:
Large rivers are generally inhibited by several types of fish, many of which are migratory such fish has found to be moving from U/s to D/s in beginning of winter season in search of warmer water & return to their spawning ground U/s, slightly before monsoon in may & June. If no arrangement is made in barrage to enable their migration, their life goes in danger.

✱ Under-Sluices:
→ Opening at low level in part of barrage in between divide wall & canal head regulator.
→ These openings are controlled by gates.
→ The functions of under-sluices are
a) To control silt entry into the canal
b) To protect downstream from hydraulic jumps.
c) To lower the highest flood level
d) To maintain a clear & well defined river channel approaching the canal head regulator.

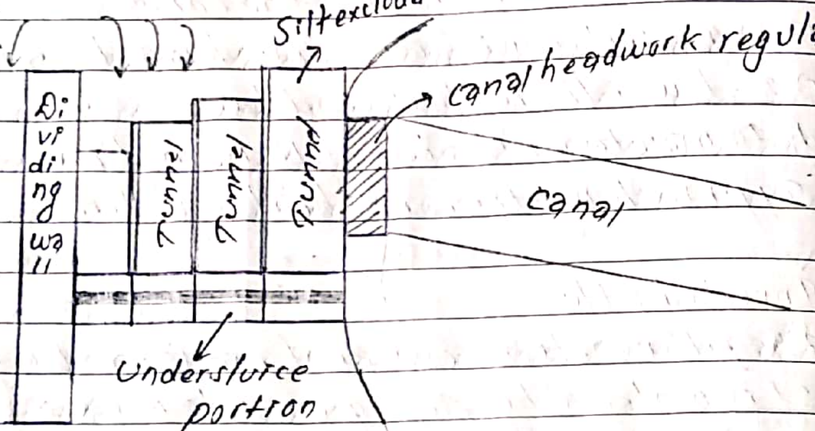
✱ Inverted filter:
→ The filter material consists of coarse sand & gravels.
→ It is protected by placing concrete block of sufficient weight & size, over it.
→ Functions
- It checks the escape of fine soil particles in seepage water
- Prevents from piping failure.

✱ Sheet piles:
→ There are generally three or four sheet piles.
- U/s piles
- Intermediate piles
- D/s piles
→ Function:
- protect barrage from scour.
- To reduce uplift pressure in barrage floor.
- To increase the seepage path.
- To check exit gradient.

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## * Silt Excluder:-

→ Silt excluder is a structure constructed in bed of river, u/s of head regulator to attack the river bed water & divert the same into the d/s of river. Its main function is to prevent entry of silt into the canal.




→ The tunnel near to canal regulator is more in length.

## * Silt Ejectors:-

→ They are also called silt extractors & are provided to extract silt from canal water after the silted water has travelled a certain distance in offtaking canal

→ These works are therefore constructed on the bed of canal & little distance d/s from head regulator.

→ They consists of curved tunnels located across the canal which starts along the axis of canal & turn towards the bank into the escape channel. The silted water is discharged into d/s side of river from weir.

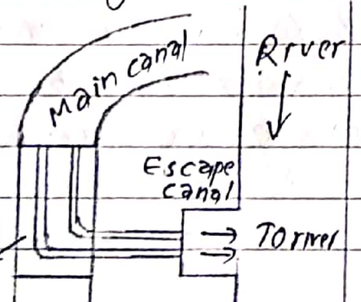



Fig: plan of Silt Ejectors



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## * Conditions & Causes of failure of hydraulic Structures:-

→ The seepage flow of water beneath the foundation of hydraulic structure causes the failure of structure either by piping or uplift

(a) piping / Undermining:-

→ When the seepage water retains sufficient residual force at the emerging d/s end of the work, it may lift up the soil particles. This increases the porosity of soil by removal of soil beneath the foundation. The structure may ultimately subside into the hollows so formed, resulting in the failure of structure.

→ prevention of piping failure.

(i) By providing sufficient length of impervious floor so that the path of percolation is increased & exit gradient is reduced

(ii) providing piles at u/s & d/s end of impervious floor.

(b) Uplift:-

→ The water seeping below the structures exerts an uplift pressure on the floor of the structure. If this pressure is not counter balanced by the weight of concrete or masonry floor, structure will fail by a rupture of a part of floor.

→ preventive measures,

(i) Providing sufficient thickness of impervious floors.

(ii) Providing pile at u/s of impervious floor so that uplift pressure is reduced at d/s side.

→ The surface flow may also cause the failure of structures in following two ways.

(a) By suction due to hydraulic jumps

→ Due to weir, hydraulic jump is developed on its d/s side which causes suction or negative pressure & act in the direction of uplift pressure. This may cause failure of floor by rupture due to suction.

→ Preventive Measures:-
(i) Providing additional thickness of impervious floor to counterbalance the suction pressure due to hydraulic jump.
(ii) Constructing floor as monolithic concrete mass instead of different layers of masonry.

(b) By scouron upstream & downstream of weir:-
→ The u/s & d/s ends of impervious floor may get scoured to considerable depth during floods. This may cause damage to impervious floor if no preventive measures are taken.
→ Preventive measures:-
i) Providing piles to below calculated scour depth at both u/s & d/s ends.
(ii) Providing launching apron of suitable length & thickness at both u/s & d/s end of impervious floor.

## ※ Bligh's, Lanes & Khosla's Seepage theory:-

### * Bligh's Seepage theory:-
→ According to Bligh's theory, water creeps along the bottom contour of the structure. The length of path of water is called length of creep & loss of head is proportional to length of creep.
→ Bligh's theory makes no discrimination between horizontal & vertical creeps.
→ Creep length:- The path traced by the percolating water.
→ Hydraulic Gradient:- The loss of head per unit creep length.
→ The head loss is inversely proportional to the creep length.

$$\text{head loss} \propto \frac{1}{\text{Creep length}}$$

→ For prevention of piping failure,

$$\frac{H}{S} \leq \frac{1}{C}$$

where, H = Hydraulic Head
S = Horizontal distance
C = Safe exit hydraulic gradient.

→ Safety against uplift pressure,
thickness of floor ($t$) $= \frac{H}{G-1}$

[H = Hydraulic head
G = Sp. gravity of material]

With FOS of 4/3,

$$t = \frac{4}{3} \times \frac{H}{G-1}$$

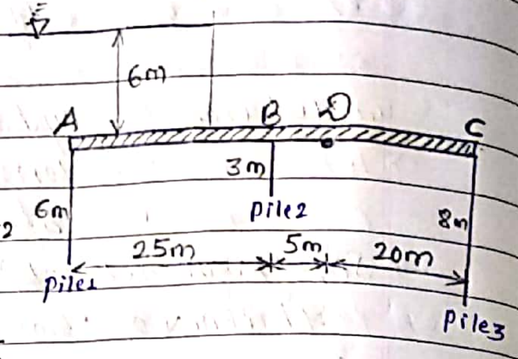
→ Limitation of Bligh's Seepage theory:-
a) This theory has not made any distinction between vertical & horizontal creep.
b) This theory didnot explain the exit gradient.
c) This theory has no distinction between the outer & inner faces of sheet piles or intermediate sheet piles.
d) The loss of head is not taken as same proportional as creep length.
e) The spacing between two piles donot specified.

### * Lane's weighted Creep Theory:-
→ From the analysis of 200 dams all over the world, Lane's concluded that horizontal creep is less effective in reducing uplift than vertical Creep.
→ Therefore, he suggested a factor of 1/3 for horizontal creep & 1 for vertical creep.
→ Horizontal length is considered all the sloping contacts less than 45° & vertical length is considered all the vertical contacts plus sloping contacts greater than 45°.

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E. Find the residual hydraulic head & required floor thickness at point D.

→




(a) By Bligh's theory,

Creep length = 6×2 + 25 + 3×2 + 25 + 8×2
= 84m

Hydraulic gradient = $\frac{H}{S} = \frac{6}{84} = \frac{1}{14}$

Now, Creep length upto point D = 6*2 + 25 + 3×2 + 5 = 48m

Head loss at D = $48 \times \frac{6}{84} = 3.43$ m

Residual head = 6 − 3.43 = 2.57m [Assume, $G_1 = 2.24$]

Thickness of floor = $\frac{4}{3} \times \frac{H}{G-1} = \frac{4}{3} \times \frac{2.57}{2.24-1} = 2.763$m

(b) By Lane's weighted Creep theory,

Creep length = $6\times2 + \frac{25}{3} + 3\times2 + \frac{25}{3} + 8\times2 = 50.67$m

Hydraulic gradient = $\frac{6}{50.67}$

Creep length upto D = $6*2 + 25/3 + 3*2 + 5/3 = 28$

Head loss at D = $28 * \frac{5}{50.67} = 3.31$m

Residual head at D = 6 − 3.31 = 2.69m

Thickness of floor = $\frac{4}{3} \times \frac{H}{G-1}$

$t_f = \frac{4}{3} * \frac{2.69}{2.24-1} = 2.892$m



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## ✻ Khosla's Seepage Theory:-

→ The main principles of khosla's theory are,

(i) Seeping water below a hydraulic structure doesnot follow the bottom profile of impervious floor as stated by Bligh but each particle traces its path along a series of stream lines & equipotential lines.

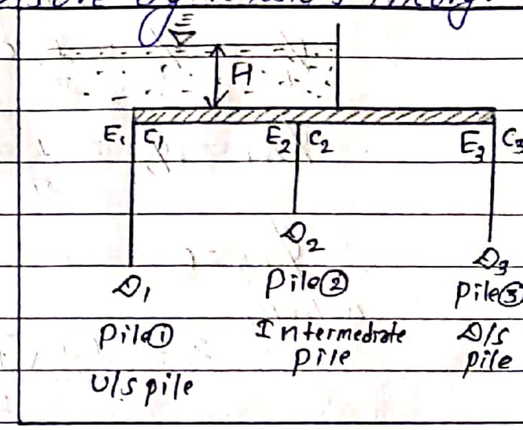
(ii) The seepage water exerts force at each point in the direction of flow & tangential to the streamline. This force has the maximum disturbing tendency at the exit end.

(iii) The steady seepage in vertical plane for homogeneous soil can be expressed by laplacian Equation.

(iv) It is necessary to provide resonably deep vertical cutoff at d/s end of floor to prevent undermining.

v) If intermediate sheet piles are smaller in length, outer ones were ineffective.

## ✻ Calculation of percentage pressure by khosla's theory:-




(a) For u/s pile,

$\phi_{E1} = 100\%$

$\phi_{D1} = 100 - \phi_D$

$\phi_{C1} = 100 - \phi_E$

Where, $\phi_D = \frac{1}{\pi} \cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) \times \frac{\pi}{180}$

$\phi_E = \frac{1}{\pi} \cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) \times \frac{\pi}{180}$

Where, $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$, $\alpha = b/d$

where, b = total horizontal distance
d = pile depth

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(b) For intermediate pile,

$$\phi_{E2} = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_1 - 1}{\lambda}\right) \times \frac{\pi}{180}$$

$$\phi_{D2} = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_1}{\lambda}\right) \times \frac{\pi}{180}$$

$$\phi_{C2} = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_1 + 1}{\lambda}\right) \times \frac{\pi}{180}$$

where, $\lambda_1 = \frac{\sqrt{1+\alpha_1^2} - \sqrt{1+\alpha_2^2}}{2}$ & $\lambda = \frac{\sqrt{1+\alpha_1^2} + \sqrt{1+\alpha_2^2}}{2}$

Here, $\alpha_1 = b_1/d$ and $\alpha_2 = b_2/d$

$d$ = pile depth
$b_1$ = distance of pile from U/S pile
$b_2$ = distance of pile from D/S pile.

(C) For downstream pile,

$$\phi_{E3} = \phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 2}{\lambda}\right) \times \frac{\pi}{180}$$

$$\phi_{D3} = \phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 1}{\lambda}\right) \times \frac{\pi}{180}$$

$\phi_{C3} = 0$

where,

$$\lambda = \frac{1 + \sqrt{1+\alpha^2}}{2}, \quad \alpha = b/d$$

* Correction for percentage of pressure in pile,

(i) Correction for mutual interference of piles:-

$$C = 19\sqrt{\frac{D}{b'}} \times \left(\frac{d+D}{b}\right)$$

Where, $b'$ = distance between two piles
$b$ = Total floor length



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$d$ = depth of pile on which effect is considered. floor of
$D$ = Depth of interfereniced pile from bottom of desired pile.

→ Sign convention
- positive for points in rear or backwater.
- Negative for the points on forward direction of flow.

(ii) Correction for thickness of floor:-

→ Thickness correction for C = $\frac{\phi_D - \phi_C}{\text{RL of floor} - \text{RL of D}}$ * thickness of floor at C

Thickness correction for E = $\frac{\phi_E - \phi_D}{\text{RL of floor} - \text{RL of D}}$ * thickness of floor at E.

→ Sign convention,
+ve for point in right side of pile
-ve for point in left side of pile.

(iii) Correction for slope:-

→ $C = C_s * \left(\frac{b_s}{b_1}\right)$

Where, $C_s$ = slope correction factor
$b_s$ = slope distance
$b_1$ = distance bet$^n$ two piles.

→ Sign Convention
+ve for downward slope
-ve for upward slope.

| Slope | Correction Factor |
|---|---|
| 1:1 | 11.2 |
| 2:1 | 6.5 |
| 3:1 | 4.5 |
| 4:1 | 3.3 |
| 5:1 | 2.8 |
| 6:1 | 2.5 |
| 7:1 | 2.3 |
| 8:1 | 2 |

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## * Exit Gradient:

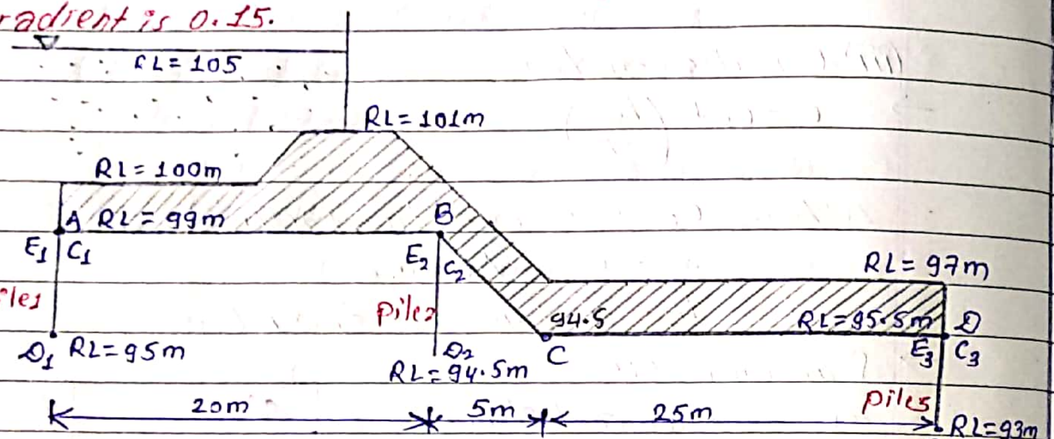
→ Hydraulic or pressure gradient of subsoil flow or seepage flow at d/s or exit end of floor.

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

Where, $\alpha = b/d$ & $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$

Where, $b$ = floor length
$d$ = depth of vertical cutoff
$H$ = pressure head

Q Calculate the uplift pressure at key points in figure shown below using Khosla's theory. Check the exit gradient & thickness of floor at A, B, C & D as shown in figure. The safe exit gradient is 0.15.




→ For U/s pile,

Total length of floor, $b = 20+5+25 = 50m$

Depth of U/s pile $d = 100-95 = 5m$

$$\alpha = b/d = \frac{50}{5} = 10$$

$$\lambda = \frac{1+\sqrt{1+\alpha^2}}{2} = \frac{1+\sqrt{1+10^2}}{2} = 5.52$$

$$\phi_E = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right) \times \frac{\pi}{180^\circ} = 0.28 = 28\%$$



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$$\phi_D = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right) \times \frac{\pi}{180^\circ} = 0.195 = 19.5\%$$

Now,

$\phi_{E1} = 100\%$

$\phi_{D1} = 100 - \phi_D = 100 - 19.5\% = 80.5\%$

$\phi_{C1} = 100 - \phi_E = 100 - 28 = 72\%$

→ Correction for $\phi_{C1}$

(i) Correction at $C_1$ due to mutual interference of piles:-

$$C = 19\sqrt{\frac{D}{b'}}\left(\frac{d+D}{b}\right)$$

Where, $D = 99-94.5 = 4.5m$

$d = 99-95 = 4m$

$b' = 20m$ & $b = 50m$

So, $C = 3.426\%$ (positive)

(ii) Correction at $C_1$ due to thickness of floors.

$$C = \frac{\phi_{D1} - \phi_{C1}}{RL\text{ of floor} - RL\text{ of } D_1} * 1 = \frac{80.5-72}{100-95} = 1.7\% \text{ (positive)}$$

(iii) Correction due to slope is zero.

Corrected $\phi_{C1} = 72 + 3.426 + 1.7 = 77.126\%$

→ For intermediate pile,

$\alpha_1 = \frac{b_1}{d} = \frac{20}{6.5} = 3.077$

$b_1 = 20m$, $b_2 = 30m$
$d = 101-94.5 = 6.5m$

$\alpha_2 = \frac{b_2}{d} = \frac{30}{6.5} = 4.615$

$\lambda = \frac{\sqrt{1+\alpha_1^2} + \sqrt{1+\alpha_2^2}}{2} = 3.979$

$\lambda_1 = \frac{\sqrt{1+\alpha_1^2} - \sqrt{1+\alpha_2^2}}{2} = -0.743$

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$\phi_{E_2} = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_1 - 1}{\lambda}\right) \times \frac{\pi}{180} = 0.644 = 64.44\%$

$\phi_{D_2} = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_1}{\lambda}\right) \times \frac{\pi}{180} = 0.5598 = 55.98\%$

$\phi_{C_2} = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda_1 + 1}{\lambda}\right) \times \frac{\pi}{180} = 0.4794 = 47.94\%$

→ Correction for $\phi_{E_2}$

(i) Mutual interference due to pile 1

$D = 99 - 95 = 4m$, $d = 99 - 94.5 = 4.5m$

$b' = 20m$

$C = 19\sqrt{\frac{4}{20}}\left(\frac{4+4.5}{50}\right) = 1.444\%$ (-ve)

(ii) Correction due to thickness of floors

$C = \frac{\phi_{E_2} - \phi_{D_2}}{RL\text{ of floor} - RL\text{ of } D_2} * \text{floor thickness}$

$= \frac{64.4 - 56}{101 - 94.5} * 2 = 2.584\%$ (negative)

Corrected $\phi_{E_2} = 64.44 - 1.444 - 2.584 = 60.372\%$

→ Correction for $\phi_{C_2}$

(i) Mutual interference with pile 3

$D = 99 - 93 = 7m$

$d = 99 - 94.5 = 4.5m$ $b' = 30m$ & $b = 50m$

$C = 19\sqrt{\frac{7}{30}}\left(\frac{4.5+7}{50}\right) = 2.111\%$ (positive)

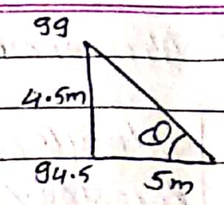
(ii) Due to floor thickness,

$C = \frac{\phi_{D_2} - \phi_{C_2}}{RL\text{ of floor} - RL\text{ of } D_2} * 2 = \frac{55.98 - 47.94}{101 - 94.5} * 2 = 2.492\%$ (+ve)

Correction में D ed लिदा floor को bottom पोट लिने

(iii) Correction due to slope.

$C = C_s * \frac{b_s}{b_1}$, $b_s = 5m$, $b_1 = 30m$




$D = 1 : \frac{5}{4.5} = 1 : 1.11$

For slope of 1:1, $C_s = 11.2$

So, $C = \frac{11.2 \times 5}{30} = 1.867\%$ (Positive)

Corrected $\phi_{C_2} = 47.9 + 2.111 + 2.492 + 1.867 = 54.37\%$

→ For d/s pile,

$b = 50m$

$d = 97 - 99 = 4m$

$q = \frac{b}{d} = \frac{50}{4} = 12.5m$, $\lambda = \frac{1 + \sqrt{1 + 12.5^2}}{2} = 6.77$

$\phi_{E_3} = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 2}{\lambda}\right) \times \frac{\pi}{180^\circ} = 25.3\%$

$\phi_{D_3} = \frac{1}{\pi}\cos^{-1}\left(\frac{\lambda - 1}{\lambda}\right) \times \frac{\pi}{180} = 17.7\%$

→ Correction for $\phi_{E_3}$

(i) Mutual interference with pile 2

$D = 95.5 - 94.5 = 1m$

$d = 95.5 - 93 = 2.5$

$b' = 30m$ & $b = 50m$

$C = 19\sqrt{\frac{1}{30}} * \left(\frac{1 + 2.5}{50}\right) = 0.243\%$ (negative)

(ii) Correction due to floor thickness

$C = \frac{25.3 - 17.7}{97 - 93} \times 1.5 = 2.85\%$ (negative)

(iii) No correction due to slope.

Corrected $\phi_{E_3} = 25.3 - 0.243 - 2.85 = 22.207\%$

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The corrected % pressure at key points are,

| u/s pile, | Intermediate pile | d/s pile |
|---|---|---|
| $\phi_{E1} = 100\%$ | $\phi_{E2} = 60.372\%$ | $\phi_{E3} = 22.207\%$ |
| $\phi_{D1} = 80.5\%$ | $\phi_{D2} = 56\%$ | $\phi_{D3} = 17.7\%$ |
| $\phi_{C1} = 77.126\%$ | $\phi_{C2} = 54.37\%$ | $\phi_{C3} = 0\%$ |

Difference in head betn pond level & d/s floor = 105 - 97 = 8m

Uplift pressures at $D_1 = 0.805 \times 8 = 6.44$ m

$C_1 = 0.771 \times 8 = 6.168$ m

$E_2 = 0.6037 \times 8 = 4.83$ m

$D_2 = 0.56 \times 8 = 4.48$ m

$C_2 = 0.5437 \times 8 = 4.349$ m

$E_3 = 0.22207 \times 8 = 1.776$ m

$D_3 = 0.177 \times 8 = 1.416$ m

$C_3 = 0$

→ Exit Gradient

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

$d = 97 - 93 = 4$m

$H$ = Maxm seepage head = 105 - 97 = 8m

$b = 50$m

$\alpha = b/d = 50/4 = 12.5$m

→ $\lambda = \frac{1+\sqrt{1+\alpha^2}}{2} = 6.77$

Then, $G_E = \frac{8}{4} \times \frac{1}{\pi \times \sqrt{6.77}} = 0.245 > 0.15$ (unsafe)

→ Thickness of floor.

Thickness reqd at $A = \frac{\text{Uplift at } A}{G-1} = \frac{6.168}{2.24-1} = 4.974 > 1$m (unsafe)

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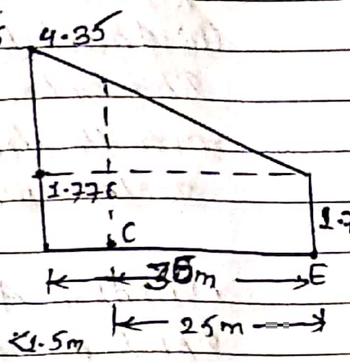
Thickness required at $B = \frac{4.35}{2.24-1} = 3.508$m $>$ 2m (unsafe)

Uplift pressure at $C = 1.776 + \frac{4.35 - 1.776}{30} \times 25$

$= 3.921$m

Thickness required at $C = \frac{3.921}{1.24}$

$= 3.162$m $>$ 2.5m (unsafe)




Thickness required at $D = \frac{1.776}{1.24} = 1.432 < 1.5$m (safe)

## * Cross-Drainage structures, conditions for their applications & designs.

→ A cross drainage structure is a structure which is constructed at a crossing of a canal and natural drain, so as dispose of drainage water without interrupting the continuous canal supplies.

→ Types of Cross-Drainage works

i) Irrigation canal passes over the drainage

ii) Irrigation canal passes below the drainage

(iii) Drainage & canal intersect each other at same level.

→ Consideration for selection of Cross-Drainage works:-

a) When the bed level of canal is much above the HFL of the drainage, an aqueduct is the obvious choice.

b) When the bed level of drain is well above FSL of canal, superpassage is provided.

c) When drainage and canal cross each other practically at same level, a level crossing may be preferred.

d) Suitable canal alignment

e) position of water table & availability of dewatering equipment.

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* Irrigation Canal passes over the drainage:-

(a) Aqueduct:-
The hydraulic structure in which irrigation canal is passing over the drainage is known as aqueduct. This structure is suitable when bed of canal is above HFL of drainage.

b) Siphon Aqueduct:-
The hydraulic structure in which irrigation canal is passing over the drainage but the drainage water cannot pass clearly below the canal is known as siphon aqueduct. It flows under siphoned action. This structure is suitable when bed of canal is below the highest flood level in the drainage.

* Irrigation Canal passes below the drainage

(a) Superpassage:-
→ The hydraulic structure in which the drainage is passing over the irrigation canal is known as superpassage. This structure is suitable when bed level of drainage is above the FSL of canal. The water of canal passes clearly below the drainage.

(b) Siphon Superpassage:-
→ The hydraulic structure in which the drainage is taken over the irrigation canal, but the canal water passes below the drainage under siphonic action is known as siphon-superpassage. The structure is suitable when bed level of drainage is below the full supply level of the canal.



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c) Canal Siphon:
If two canal cross each other & one of the canal is siphoned under the other, then hydraulic structure at crossing is called canal siphon.

* Irrigation Canal & Drainage intersect at same level:

(a) Level Crossing:-
When the beds of the drainage & canal are practically at same level, then a hydraulic structure is constructed which is known as level crossing. This is suitable for the crossing of large drainage with main canal.

(b) Inlet & Outlet:-
In the crossing of small drainage with small canal, no hydraulic structures are constructed. Simple openings are provided for the flow of water in their respective directions. The number of inlet & outlets are constructed as per requirement.

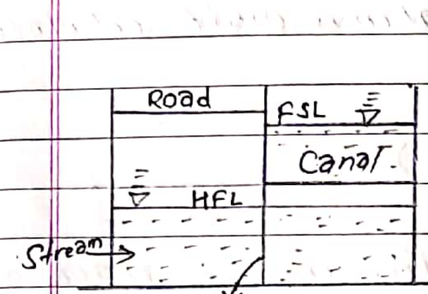


Fig: aqueduct

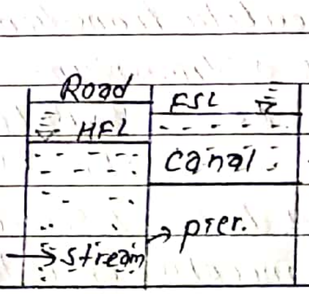


Fig: Siphon aqueduct

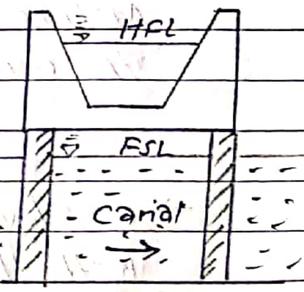


Fig: Superpassage

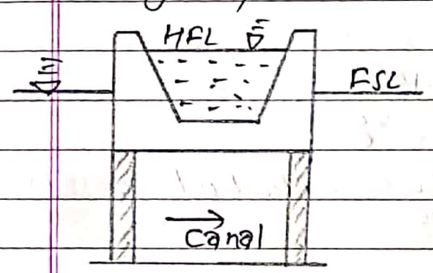


Fig: Siphon Superpassage

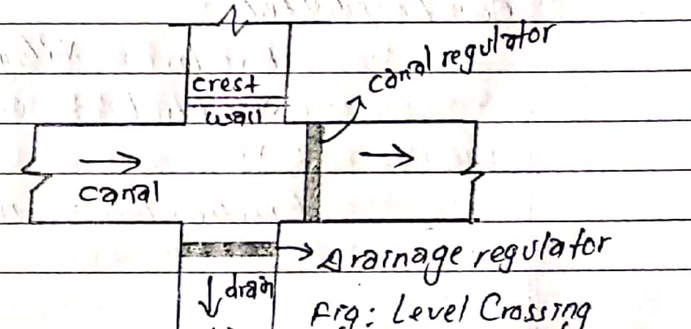


Fig: Level Crossing

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## * Design Consideration of aqueduct & Syphon aqueduct:-

→ Maximum flood discharge:
Maximum discharge of required return period is calculated by hydrological analysis.

→ Fixing waterway:-
Total length of waterway is given by Lacey's equation.

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

→ Head loss through Syphon Barrels:-
It is calculated using unwin's formula:-

$$h = \left[1 + f_i + f_2 * \frac{L}{R}\right]\frac{V^2}{2g} - \frac{V_a^2}{2g}$$

Where, $f_i$ = Coefficient of head loss at entry = 0.505 for unshaped mouth & 0.08 for bell mouth.
$f_2$ = loss of head through barrel due to surface friction.

→ Fluming of Canal:-
Fluming of canal means reducing the width of aqueduct.
Fluming of canal reduces the length of barrels. A splay of 2:1 is provided in contraction & 3:1 in expansion.
Mitra's hyperbolic transition equation is used to calculate the width of transition.

$$B_x = \frac{B_n B_f L_f}{L_f B_n - x(B_n - B_f)}$$

→ Bed level at different sections:-
With the concept of entry loss, friction loss, expansion loss, transition loss, HGL & TEL, bed level at different sections can be plotted.

$$\text{Exit loss} = V_4^2/2g$$

$$\text{Expansion loss} = 0.3\left(\frac{V_3^2 - V_4^2}{2g}\right)$$

$$\text{Friction loss} = \frac{n^2V^2L}{R^{4/3}}, \quad \text{contraction loss} = 0.2\left(\frac{V_2^2 - V_3^2}{2g}\right)$$

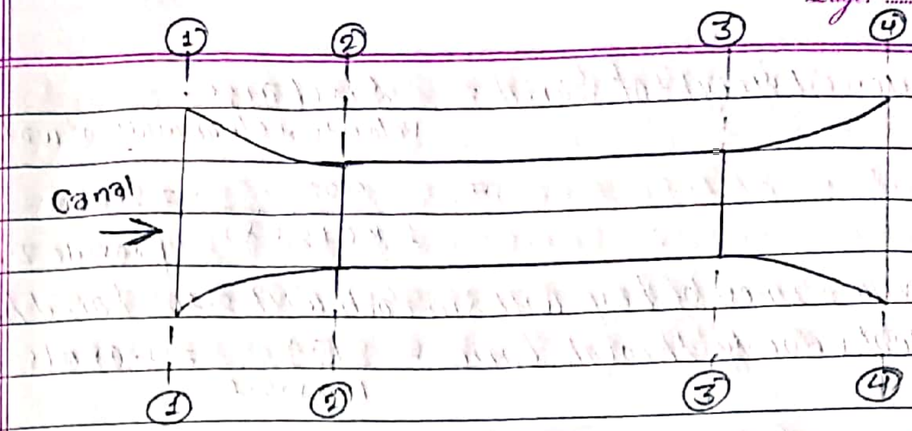



Fig: plan of Adqueduct.

Q. Design the drainage waterways, canal waterway, bed level, transition & head loss in the barrel of suitable Cross drainage work for following data.
Discharge of canal = 50 m³/s., Bed width of canal = 32m
Canal bed level = 200m, Side slope of canal = 1.5:1, High flood discharge of drainage = 400 m³/s, HFL of drainage = 200.6m, Bed level of drainage = 198m & General GL = 200.2m

→ Here, Given,
Discharge of canal = 50 m³/s | Full Supply depth of canal = 1.8m
Bed width of canal = 32 m
Canal bed level = 200 m
Side slope of canal = 1.5:1 (H:V)
High flood discharge of drainage = 400 m³/s
HFL of drainage = 200.6m
Bed level of drainage = 198m
General GL = 200.2m

→ The bed level of canal = 200m < HFL of drainage (200.6m). So, Syphon aqueduct is suitable.

→ Design of drainage waterway,
Lacey's regime perimeter 'P' = $4.75\sqrt{Q} = 4.75\sqrt{400} = 95$m
provide 12 bays of 8m each & 10 nos of pier with 1.5m.
Total length of water way = 12×8 + 10×1.5 = 111m
Let, the limiting velocity through Syphon barrel is 2m/s.

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Required Height of barrel = $\frac{\text{Discharge}}{\text{velocity} * \text{clear width of waterway}}$

$= \frac{400}{2*(12*8)} = 2.08m$

provide 2.1m

Provide 12 nos. of bays with 8m each with 2.1m barrel height.

Actual velocity through barrel = $\frac{400}{12\times8\times2.1} = 1.98 m/s < 2 m/s.$

→ Design of Canal Waterway:

Let, Bed width of canal = 32m

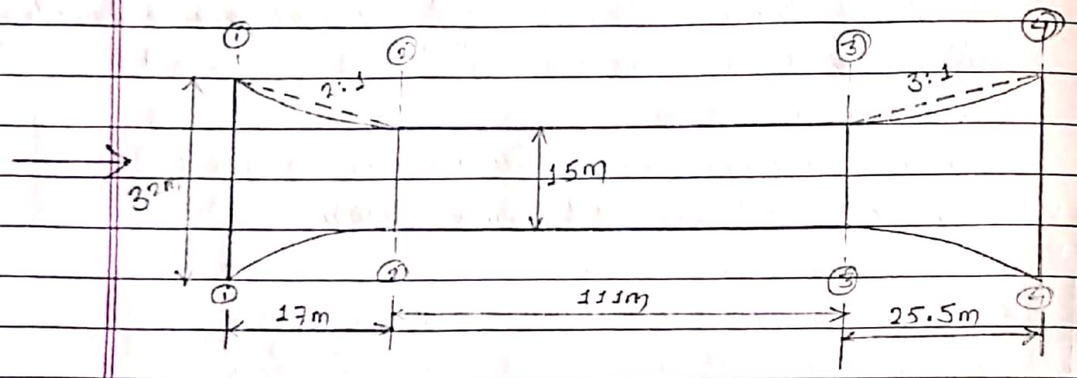
Width is reduced to 15m.

Provide a splay of 2:1 in contraction & 3:1 in expansion transition.

Length of Contraction transition = $\frac{32-15}{2} \times 2 = 17m$

Length of Expansion transition = $\frac{32-15}{2} \times 3 = 25.5m$

Length of flumed rectangular portion = 111m.




→ Design of bed level at different sections:

At section 4-4,

$V_4 = \frac{Q}{A} = \frac{50}{(32+1.5\times1.8)\times1.8} = 0.9 m/s.$

Velocity head = $\frac{V_4^2}{2g} = 0.033m$

RL of canal bed at 4-4 = 200m

RL of water surface at 4-4 = 200 + 1.8 = 201.8m

RL of TEL at 4-4 = 201.8 + 0.033 = 201.833 m.

→ At section 3-3,

The section is rectangular in section & depth of water is 1.8m.

$V_3 = \frac{Q}{A} = \frac{50}{15\times1.8} = 1.85 m/s$

Velocity head = $\frac{V_3^2}{2g} = 0.175m$

Head loss from section 3-3 to 4-4, = $0.3 \times \frac{V_3^2 - V_4^2}{2g} = 0.3\times(0.175-0.033) = 0.042m$

RL of TEL at 3-3 = 201.833 + 0.042 = 201.875m

RL of water level at 3-3 = 201.875 − 0.175 = 201.7m

RL of Bed level at 3-3 = 201.7 − 1.8 = 199.9m

→ At section 2-2,

Head loss from section 2-2 to 3-3, $H_L = \frac{\eta^2 V^2 L}{R^{4/3}}$

$\eta = 0.016$

$R = A/P = \frac{15\times1.8}{15+2\times1.8} = 1.45m$ $[V_2 = V_3]$

$H_L = \frac{0.016^2 \times 1.85^2 \times 111}{1.45^{4/3}} = 0.055m$

$\frac{V_2^2}{2g} = 0.175m$

RL of TEL at 2-2 = 201.875 + 0.055 = 201.93m

RL of water level at 2-2 = 201.93 − 0.175 = 201.76

RL of Bed level at 2-2 = 201.76 − 1.8 = 199.96m

→ At section 1-1,

Head loss from ①-① to ②-② = $0.2 \times \frac{V_2^2 - V_1^2}{2g}$ $\left[\begin{matrix} V_1 = V_4 \\ V_2 = V_3 \end{matrix}\right]$

$= 0.028\times(0.175-0.033) = 0.028m$

$\frac{V_1^2}{2g} = \frac{V_u^2}{2g} = 0.033m$

RL of TEL at 1-1 = RL of TEL at 22 + 0.028
= 201.93 + 0.028 = 201.96m

RL of water level at 1-1 = 201.96 − 0.033 = 201.925m

RL of bed level at 1-1 = 201.96 − 1.8 = 200.125m

⇒ Design of transition:

By Mitra's eqn,

$$B_x = \frac{B_n * B_f * L_f}{B_n L_f - x(B_n - B_f)}$$

For Contraction

Where, $B_f = 15m$ (flumed section)

(normal section) $B_n = 32m$, $L_f = 17m$ [x = distance from flumed section]

$$B_x = \frac{32 \times 15 \times 17}{32 \times 17 - x(32-15)} = \frac{480}{32-x}$$

| x | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 17 | (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bx | 15 | 16 | 17.14 | 18.46 | 20 | 21.81 | 24 | 26.66 | 30 | 32 | (m) |

For Expansion

$B_f = 15m$, $B_n = 32m$, $L_f = 22.5m$, $B_x = \frac{720}{48-x}$

| x | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 22.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bx | 15 | 15.65 | 16.36 | 17.14 | 18 | 18.94 | 20 | 21.17 | 22.5 | 24 | 25.71 | 27.69 | 30 |

⇒ Design of trough

The trough is divided into three equal compartments with 5m each wide having 2 nos. of internal partition wall of thickness 0.3m & 2 nos. of outer wall of thickness 0.4m.

Overall width of trough, length of barrel = 15 + 0.3 × 2 + 0.4 × 2
= 16.4m.

⇒ Afflux or head loss through Syphon Barrels.

$$h = \left[1 + f_1 + f_2 \frac{L}{R}\right] \times \frac{V^2}{2g}$$

Here, $V = 1.98$ m/s

$f_1 = 0.505$

$f_2 = a\left(1 + \frac{b}{R}\right) = 0.00316\left(1 + \frac{0.09}{0.83}\right) = 0.0033.$

$R = A/P = \frac{8 \times 2.1}{2(8+2.1)} = 0.83$

Then, $h = 0.314m$

High flood level on D/s = 200.6m

High flood level on U/S = 200.6 + 0.314 = 200.914m

## ✻ Canal Escapes:-

→ Side canal constructed to remove surplus water from an irrigation canal into a natural drain.

→ The water in irrigation canal may become surplus due to
(i) Some mistake or difficulty in regulation at the head
(ii) Excessive rainfall in upper reaches
(iii) Sometimes, Cultivators may find that the demand of water is over & may close their outlet suddenly

→ There are two types of canal escapes.

(a) Weir Type:- In this type, the crest of the weir wall is kept at RL equal to canal FSL. When water level rises above FSL, it gets escaped.

(b) Regulator type:-

→ In this type, the sill of the escape is kept at canal bed below and flow is controlled by the gates. The regulator type escape can be constructed for the purpose of scouring excess bed silt deposited in the bed reached from time to time.

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## Types of Canal drops & their design Consideration:-

→ Generally, slope of natural ground surface is not uniform throughout the alignment. Sometimes, the ground surface may be steep and sometimes it may be very irregular with abrupt change of grade. In such case, vertical drop is provided to step down the canal bed. Such drops are known as canal falls/drops.

→ Necessity

i) To accounts for difference in natural bed slope of canal
ii) To save us from cutting & filling
iii) To control the seepage in canal.
iv) To increase velocity of water in canal.
v) Used in siphonic super-passage

## Types of Canal drops:-

(a) Ogee falls:-

In this type of falls, water is lowered by providing smooth concave and convex curve as shown in figure. Due to smooth transition, the kinetic energy of flow was not dissipated & hence affected D/s. There was heavy drawdown on upstream.

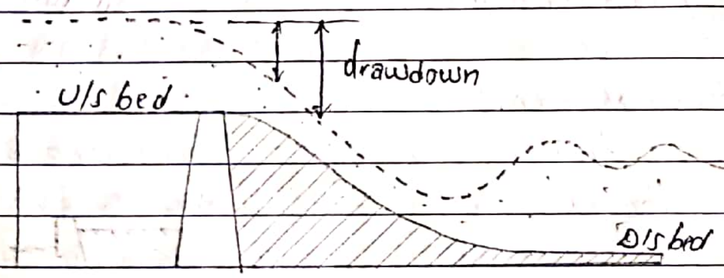



Fig:- Ogee falls.

(b) Rapids:-

→ The rapid fall is suitable when the slope of natural ground surface is even & long. It consists of a long sloping glacis with longitudinal slope which varies from 1 in 10 to 1 in 20.

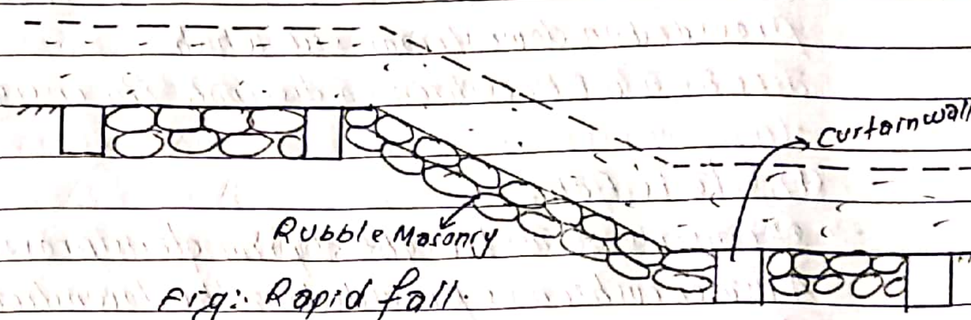



Fig:- Rapid fall.

(c) Stepped fall:-

→ It consists of vertical drops in the form of steps.
→ This fall is suitable in places where the sloping ground is very long & requires long glacis to connect the higher bed with lower bed level.

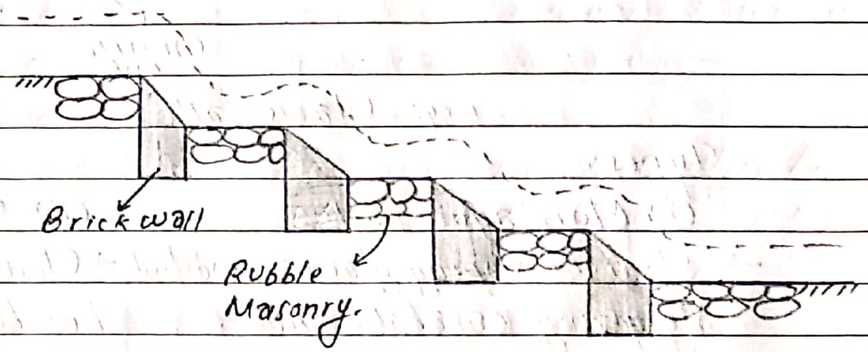



Fig:- Stepped Fall

(d) Trapezoidal Notch Fall:-

→ It consists of a number of trapezoidal notches constructed in a high crested wall across the channel with a smooth entrance & a flat circular lip projecting downstream from each notch to spread out the falling jet.

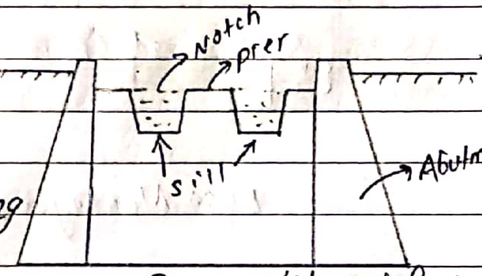



Fig:- Trapezoidal notch fall

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(e) Vertical drop or Sarda fall:-

→ It consists of a vertical drop wall which is constructed with masonry work. The water flows over the crest of the wall. A water cistern is provided on downstream side which acts as a water cushion to dissipate the energy of falling water.

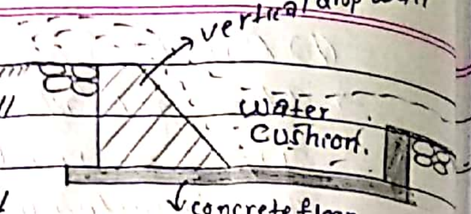



Fig: Sarda fall

(f) Glacis Fall:-

→ It consists of a straight sloping glacis provided with a crest. A water cushion is provided on the downstream side to dissipate the energy of flowing water. Curtain walls & toe walls are provided on upstream & downstream side. This type of fall is suitable for drops upto 1.5m.

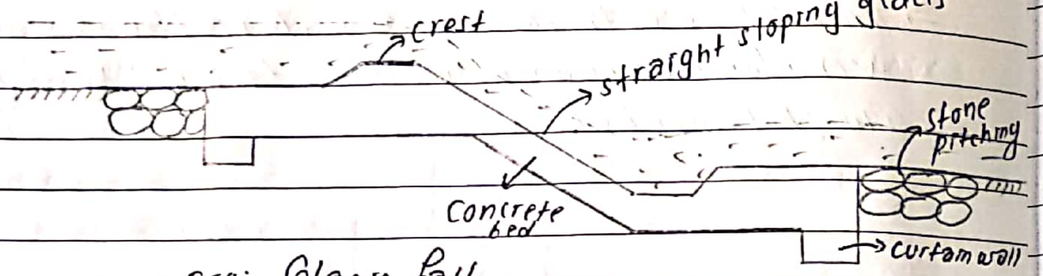



Fig: Glacis fall.

Types:-

(i) Montague fall

→ Straight sloping glacis is modified by giving parabolic shape.

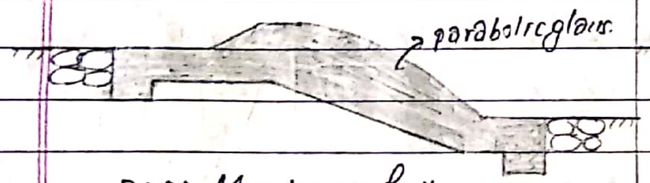



Fig: Montague fall

(ii) Inglis fall

→ Glacis is straight & sloping but baffle walls are provided on the downstream floor to dissipate the energy of flowing water.

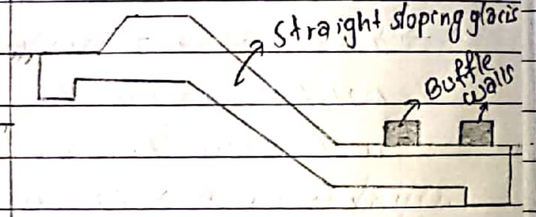



Fig: Inglis fall.



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Q Design a canal drop (Sarda fall) structure for given data.
Design discharge (Q) = 5 m³/s, U/s FSL = 110.5m, D/s FSL = 109.5m
Normal water depth at U/s & D/s = 1.5m, Bed width = 3m,
Bligh's coefficient = 7

⇒ Let, length of crest = bed width = 3m

→ Crest level:-

As Q = 5 m³/s < 14 m³/s. So, provide rectangular crest fall.
Assuming top width ($B_t$) = 0.8m
Then,

$$\text{discharge } (Q) = 1.84 \times L \times H^{3/2} \left(\frac{H}{B_t}\right)^{1/6} = 1.84 \times 3 \times H \times \left(\frac{H}{0.8}\right)^{1/6}$$

$$5 = 1.84 \times 3 \times H \times \left(\frac{H}{0.8}\right)^{1/6} \Rightarrow H = 0.92\text{m}$$

Assuming side slope of 1:1,

$$\text{Approach velocity } (V_a) = \frac{Q}{A} = \frac{5}{(3+1.5)\times 1.5} = 0.74 \text{ m/s.}$$

$$\text{Velocity head} = \frac{V_a^2}{2g} = \frac{0.74^2}{2\times 9.81} = 0.028\text{m}$$

Now, U/s TEL = U/s FSL + velocity head = 110.5 + 0.028 = 110.528m.
R.L of crest = U/s TEL − H = 110.528 − 0.92 = 109.608 m
Height of crest @ above U/s floor = 109.608 − U/s bed level
= 109.608 − (110.5 − 1.5) = 0.608m

→ Shape of crest:-

($B_t$) width of Crest = $0.55\sqrt{d}$
d = height of crest above d/s bed = 109.608 − (109 − 1.5)
= 1.608m

Then, $B_t = 0.55\sqrt{1.608} = 0.7\text{m}$

Thickness at bed = $\frac{h+d}{2} = \frac{(0.92+0.028)+1.608}{2} = 1.278$, keep 1.3m

→ U/s Curtain Wall,

Depth of curtain wall = $\frac{y_0}{3} = \frac{1.5}{3} = 0.5\text{m}$, Provide 0.8m depth of curtain wall.

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Cistern:-

Depth of Cistern $(x) = \frac{1}{4}(H \times H_L)^{1/3}$

$H_L = 110.5 - 109.5 = 1m$

$x = \frac{1}{4} \times (0.92 \times 1)^{1/3} = 0.236m$, provide 0.25m

RL of Cistern $= 108 - 0.25 = 107.75m$

Length of Cistern $= 5\sqrt{H \times H_L} = 5 \times \sqrt{0.92 \times 1} = 4.8m$

→ Impervious floor:-

Maximum static head (Hs) = RL of crest − d/s bed level

$= 109.608 - 108 = 1.608m$

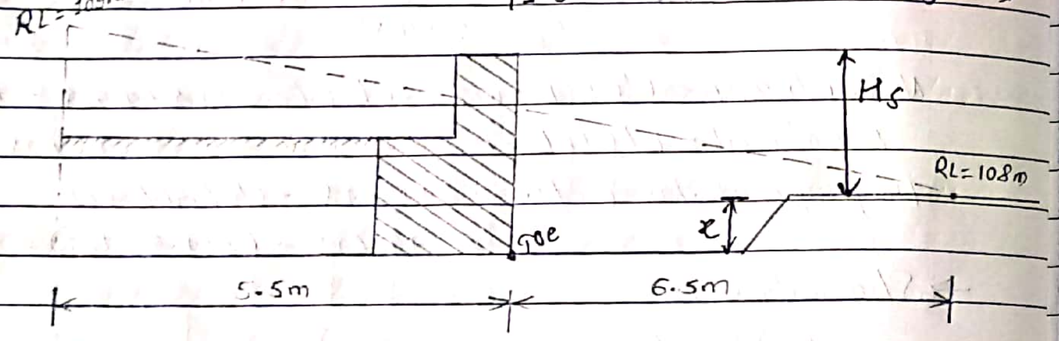
Total required floor length $= C * H_s = 7 \times 1.608 = 11.256m$

(Bligh's coefficient)

Provide 12m length of impervious floor:-

Minimum d/s floor length $= 2(\text{water depth} + 1.2) + H_L$

$= 2(1.5 + 1.2) + 1 = 6.4m$ (say 6.5m)




Maximum unbalanced uplift at the d/s toe of crest

$= 0.25 + \frac{H_s}{12} \times 6.5 = 0.25 + \frac{1.608}{12} \times 6.5 = 1.121m$

Required thickness at d/s of toe of crest $= \frac{\text{Residual head}}{G-1} = \frac{1.12}{2.4-1}$

$= 0.8m$

Provide 0.8m thick concrete with 20cm thick brick layer.

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At 3m from the toe of crest $= 0.25 + \frac{1.608}{12} \times (6.5-3) = 0.72m$

Required thickness at 3m from the toe of crest $= \frac{0.72}{1.4} = 0.514m$

Provide 0.5m thick concrete with 0.2m thick brick layer.

At 5m from toe of crest $= 0.25 + \frac{1.608}{12}(6.5-5) = 0.45m$

Required thickness at 5m from toe of crest $= 0.45/1.4 = 0.321m$

Provide 0.3m thick concrete with 20m thick brick layer & a nominal thickness of 0.3m concrete on U/s.

⇒ D/s Curtain wall:-

Depth of wall $= \frac{Yd}{2} = \frac{1.5}{2} = 0.75m$

⇒ D/s Cutoff wall

Depth of wall $= \frac{Yd}{2} + 0.6 = \frac{1.5}{2} + 0.6 = 1.35m$

Provide 1.5m deep cut off wall for more safe on D/s end of floor.

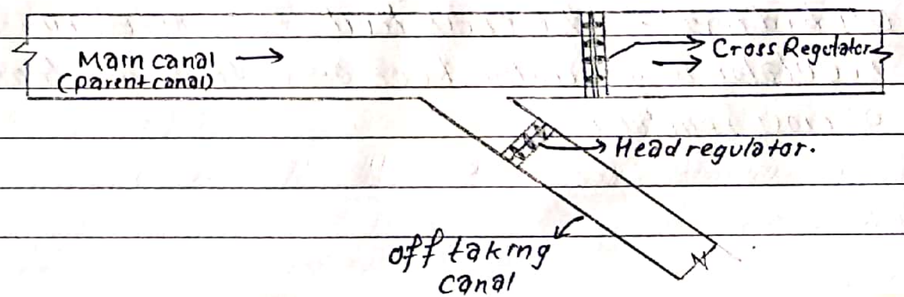
⇒ D/s pitching:-

Total length of D/s pitching $= 13.5 + 2 \times H_L$

$= 13.5 + 2 \times 1 = 15.5m$

Providing pitching slope of 1:1.0.

※ Functions of Head & Cross Regulators:-



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## Head Regulator:-

→ Head regulator is the structure provided at the head of the off taking canal & controls the flow of water entering into this branch canal.

→ Functions:

- To control or regulate the supplies entering the offtaking canal.
- To control silt entry into the offtake canal.
- To serve as a meter for measuring discharge.

## Cross Regulator:-

→ While taking water from main canal to branch canal, it is necessary to ensure the required supply in the offtaking canal even during periods of low flow. The structure constructed for this purpose is called cross regulators.

→ Functions:

- Regulation of canal System
- Raising the water level in the main canal in order to feed the offtake channels.
- To facilitate communication by building a road over the cross regulator with little extra cost.
- To absorb the fluctuations in canal system.

## Design Consideration for head regulator:-

(a) Crest level

The crest level of cross regulator is generally kept at U/s bed level. The crest level of distributary head regulator is generally kept 0.3 to 1m higher than that of cross regulator.

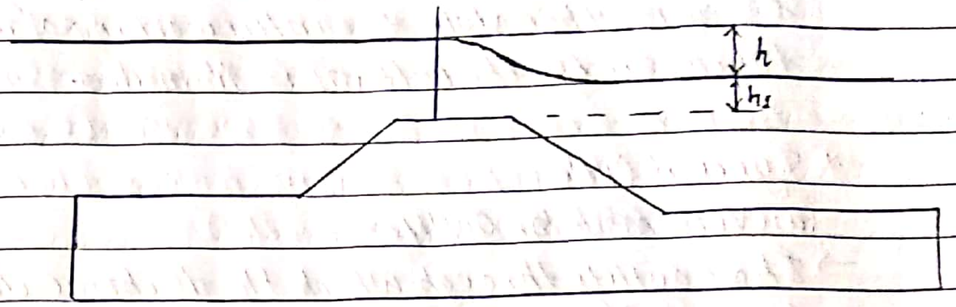
(b) Waterway:

$$Q = B\sqrt{h}\,[1.6h + 3.54h_s]$$

where, B = Clear waterway required

h = Difference of water level, U/s & D/s of crest

$h_s$ = depth of D/s water level in channel above the crest.




(c) Shape of Crest:-

→ The U/s face of crest should be given a slope of 1:1. The D/s sloping glacis should not be steeper than 2:1

(d) Cistern level

→ Level of d/s floor = d/s TEL − Ef2

(e) Length of d/s floor:

→ Length of d/s floor = $5(y_2 - y_1)$

(f) Upstream Cutoff:

Minimum depth of U/s cut off = $y_u/3 + 0.6m$

(g) Downstream Cutoff:

Minimum depth of d/s cutoff = $y_d/2 + 0.6m$

(h) Total floor length:-

It is Calculated using safe exit gradient of khosla's theory.

(i) uplift pressure & floor thickness → Using khosla's theory

(j) Protection Works

Length of protection work U/s = $y_u/3 + 0.6$ & d/s = $y_d/2 + 0.6$

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## * Types of Canal outlets & their design consideration :-

→ A canal outlet also called module is a small structure built at the head of water course so as to connect it with a minor or distributary. The control & maintenance of canals upto the module falls under the jurisdiction of the government & beyond the module, the entire working of water course is taken care by the cultivators themselves.

## * Types of Outlets

(a) Non-modular Outlets :-

→ Those outlets through which the discharge depends upon the head difference between distributary & water course.

→ Eg: Open Sluice, submerged pipe outlet

(b) Semi-modular Outlet :-

→ A flexible outlet in which the discharge is affected by the fluctuations in the water level of distributary channel only.

→ Eg: Pipe outlet

(c) Modular/Rigid Outlet :-

→ A rigid modular is the one which maintain its discharge constant, within limits, irrespective of the fluctuations in the water level of the distributary channel.

## ** Some Terminology related to outlet :-

(a) Flexibility

$$\text{Flexibility} = \frac{\text{Rate of change of discharge of outlet}}{\text{Rate of change of discharge of distributary}}$$

$$F = \frac{(dq/q)}{(dQ/Q)}$$

(b) Sensitivity of Outlet (S)

→ $$S = \frac{\text{Rate of change of discharge in outlet}}{\text{Rate of change of water level in parent channel}}$$

$$S = \frac{(dq/q)}{(dG/G)}$$

(c) Proportionality

When rate of change of discharge of outlet is equal to rate of change of discharge of distributary, an outlet is said to be proportional ($F = 1$).

(d) Setting of Outlet

→ The ratio of depth of sill level of outlet below FSL to full supply depth of distributary is called setting.

## ** Design of pipe outlet :-

(a) Design of free pipe outlet :-

$$Q = C_d A \sqrt{2gH}$$

$C_d$ = Coefficient of discharge (0.62)

$A$ = Area of x-section of pipe.

$H$ = Head measured from F.S.L of distributary to centre of pipe outlet.

(b) Design of Submerged pipe outlet

$$Q = AV$$

$$Q = C_d A \sqrt{2g \times H_L}$$

$C_d$ = Coefficient of discharge (0.73)

$A$ = Cross section of pipe

$H_L$ = Difference in head betn FSL of distributary & FSL of water course

$$H_L = \frac{v^2}{2g}\left(1.5 + \frac{fL}{D}\right)$$

$L$ = length of pipe, $D$ = diameter of pipe

$v$ = velocity of flow, $f$ = Coefficient of friction.

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Q Design an irrigation pipe outlet for following design data.
Full Supply level of Outlet = 0.05 m³/s, FSL of distributary on u/s of outlet = 200m, FSL in watercourses on D/s of outlet = ~~199.92m~~ 199.92m, Depth in distributary on u/s side of outlet = 1.05m

→ Discharge through outlet = 0.05 m³/s
FSL of distributary on u/s of outlet = 200m
FSL of watercourses on D/s of outlet = 199.92m
Depth of distributary on u/s of outlet = 1.05m
Available head to outlet = 200 − 199.92 = 0.08m

→ Since available head is very small, so use non-modular outlet (Submerged pipe outlet)

Let,
$C_d = 0.65$

Then,
$$Q = C_d \times A \times \sqrt{2gH_1}$$
$$\Rightarrow 0.05 = 0.65 \times \frac{\pi d^2}{4} \times \sqrt{2 \times 9.81 \times 0.08}$$
$$\Rightarrow d = 0.278\,m$$

→ Use pipe diameter size of 0.3m = 30cm = 300mm
RL of bed of distributary = 200 − 1.05 = 198.95m
Let top of pipe is at the level of 20cm below the FSL of distributary.

Lower level of pipe = 200 − 0.2 − 0.3
= 199.5m which is greater than RL of bed of the distributary (198.95)

Ch-6 Hill Irrigation:-

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Introduction:
→ Types of Irrigation System in Nepal
(I) AMIS (Agency Managed Irrigation System)
(II) FMIS (Farmers Managed Irrigation System)
→ Hill irrigation System - smaller in size
→ FMIS are greater in number in Hill & Mountain than Terai.
→ About 15000 unit hill irrigation System.

## * Specific Design Considerations in hill irrigation:

1) Headwork → Stone masonry
2) Slope → Variable to match soil condition but steep where cutting is difficult in hard rock.
3) Type of Canal → Contour canal with drop structures are preferred to overcome rock cutting
4) Cross-sectional area → Small x-sectional area
5) Velocity → Design is based on limity velocity & generally high velocity.
6) Cross drainage structures → made up of wood, pipe, Stone masonry
7) Drop structures → It may be cascade, chute, pipe or vertical type.
8) Outlet → Non modular / Semi-modular is preferred.
9) Sediment Ejector → Settling basin is used to control Sediment load
10) Protecting Work:- Minimum typical x-section of canal on hill (for economy). Usually, no filling of canal is accepted

## * Choices of Intake, Control & Regulating Structures.

1) Small scheme → Commanded area 0.5 to 100 hectares.
2) Water Source → Seasonal availability of water for irrigation.
3) Long Canal → When secondary streams are used for water source, relatively long canal is reqd (3-4 KM)
4) Drainage → not a major issue in hill irrigation. Natural drain are used. Little chance of waterlogging.

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5) Cropping pattern ⇒ No new cropping pattern due to poor agricultural support services. Improved seeds & agricultural techniques not available.

6) Intake ⇒ Simple side intake located on river bank
Temporary bush bund diversion type.

7) Frequent floods & high bed loads:
Growing population ⇒ deforestration → Formation of hill slope → Rapid runoff → High flood frequency → Increase in erosion ⇒ Erode material moved by floods → damage of irrigation system.

## Environmental protection measures in hill irrigation

(a) Engineering Measures:
→ Includes main civil engineering structures used for slope stabilization & erosion control in conjunction with bioengineering
- Retaining Wall → Design to stop earth pressure.
- Revetments → To protect base of slope from undermining
- Check dams → To prevent downcutting of runoff water in gullies.
- Drains → To remove surface water quickly & efficiently.
- Stone pitching:

(b) Vegetative Measures:
- Palesade ⇒ Wall made from tree trunks, bamboos etc
- Brush layering ⇒ Live cut branches are interspersed betn layers of soil. As roots grow, they anchor & reinforce the upper soil layer.
- Fascines ⇒ Bundle of sticks
- Bamboo planting

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## ch-2 River Control & Drainage:-

### Waterlogging, Reasons, Effect & their control:

→ Agriculture land is said to be water logged if its productivity gets affected by high water table.

### Reason of waterlogging:
→ Over irrigation
→ Seepage from canals
→ Inadequate surface drainage
→ Obstruction in natural water course
→ Obstruction in subsoil drainage
→ Nature of soil
→ Incorrect method of cultivation
→ Poor irrigation management
→ Excessive rainfall
→ Flat country slope
→ Topography of land

### Effect of water logging
→ Hampers nitrification
→ Normal Cultivation operation become very difficult.
→ Water loving plants grow profusely interfering growth of crops
→ Lead to salinity
→ Restricted root growth

### Prevention of water logging.
→ Canal closures
→ Lowering full supply
→ Lining of canal & water courses
→ Provision of drainage
→ Pumping
→ plantation
→ Restricted Irrigation
→ Crop rotation
→ Method of irrigation with less water

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## * Consideration in the design of surface & Subsurface Drainage System

→ Drainage ⇒ Process of taking out excess water from irrigated land to minimize water logging effect.
→ Necessary in plain terrain having GWT at shallow depth.
→ Network of drain is provided for drainage.
→ Main function of drainage network is to collect the excess water & dispose safely.

## * Types of Drainage:

- Surface Drainage / Open drainage
- Sub-surface Drainage / Closed Drainage. / Tile drainage

## * Surface Drainage:-

→ Drain constructed at land, having open channel flow in drains
→ Types
(a) Shallow drain ⇒ depth of drain ≈ 1.5m
(b) Deep open drain ⇒ depth of drain > 2m
→ Design Consideration:-
- If ground has good natural slope ⇒ No drainage
- Provided for area having mild slope, heavy rainfall & impervious soil.
- Layout ⇒ Alignment should follow natural slope of land
  Slope: 1:330 to 2:330 in hilly region
  1:500 to 1:750 in plain region
- Capacity of drain ⇒ Strom water should drain within 3-5 days
  $\phi$ = 0.054 m³/s/ha to 0.108 m³/s/ha
- Section ⇒ Design as per irrigation cond. Provide cunnette to carry small seepage discharge. FSL is kept at 0.6m below GL

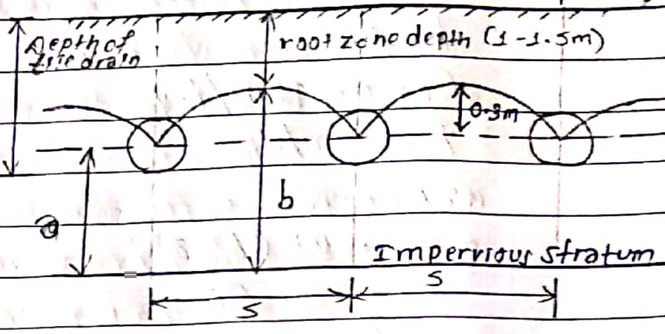
## * Subsurface Drainage:-

→ Drainage of water through underground pipes (tile drain).
→ perforated pipes surrounded with filters.

### ⇒ Depth & Spacing of tile drain

- The tile drains are usually placed at about 0.3m below the desired highest level of water table.
- Spacing of tile drain is,

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




Where, k = permeability of soil
q = Discharge
b = location of highest point of WT from impervious strata.
a = location of centre of tile drain from impervious strata.
Also, q = S * drainage recharge (rainfall)

$$S^2 = \frac{4K(b^2 - a^2)}{\text{Recharge (Re)}}$$

→ Formula for steady flow,
Smooth flow ($\phi$) = 50 $d^{2.57}$ ; $^{0.57}$
Corrugated pipe ($\phi$) = 22 $d^{2.67}$ ; $^{0.50}$
Formula for unsteady flow,
Smooth pipe ($\phi$) = 89 $d^{2.71}$ ; $^{0.57}$
Corrugated pipe ($\phi$) = 88 $d^{2.67}$ ; $^{0.5}$
→ If 1% of avg annual rainfall of a place that is to be drained in 24 hours.

$$q = \frac{1\% \times \text{Annual rainfall} * (S * 1)}{24 \times 3600} \quad m^3/s/m \text{ length of drain pipe.}$$

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Q Design a suitable subsurface drainage 250m x 900m plot. The depth of impervious layer is 10m. The root zone depth is 1m. The drainage recharge is 5mm/day. Saturated Conductivity is 2.5m/day & slope of drainage is 1:100.

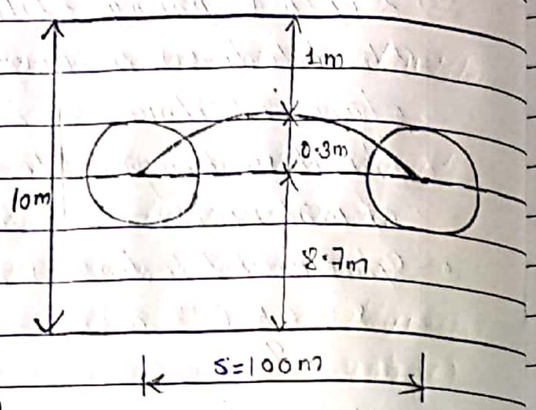
→ Given,

$d = 8.7m$

$b = 9m$

$Re = 0.005m/day$

$k = 2.5m/day$




We know,

$$S^2 = \frac{4k(b^2 - d^2)}{Re}$$

$$S^2 = \frac{4 \times 2.5 \times (9^2 - 8.7^2)}{0.005}$$

$S = 103.05m$

Adopting $S = 100m$.

Now,

$$Q = 100 * 250 * 5mm/day = 0.00144\ m^3/sec.$$

→ For unsteady flow in smooth pipe,

$$Q = 89 d^{2.71} \times S^{0.57}$$

$$\Rightarrow 0.00144 = 89 \times d^{2.71} \times \left(\frac{1}{100}\right)^{0.57}$$

$$\Rightarrow d = 0.04495m$$

$\Rightarrow d = 44.95mm$ ∴ provide 45mm size pipe @ 100m c/c Spacing

Q A tile drainage system draining 12 hectares flow at a design capacity for two days, following a storm. If the system is designed using a DC of 1.25cm, how many cubic meter of water will be removed during this period? Also determine the size of a tile outlet, the tile grade is 0.3%. Assume the rugosity coefficient for the tile drain material as 0.011.

→ Given,

Area of flow (A) = 12 hectares

Drainage coefficient = 1.25cm

Grade of tile = 0.3%

Rugosity Coefficient (N) = 0.011

→ The drainage coefficient is 1.25cm means 1.25cm of water from an area of 12 hectares is entering the tiles per day

In two days, $2 * 1.25 = 2.5cm$ of water from an area of 12 ha is entering the tiles per day.

→ So, Volume of water passing the drain in 2 day

$$= \frac{2.5}{100} \times 12 \times 10^4 = 3000m^3$$

Now, discharge ($Q$) $= \frac{3000}{2 \times 86400} = \frac{5}{288}\ m^3/sec$

As per Manning's eqn.

$$Q = \frac{1}{N} \times A \times R^{2/3} \times S^{1/2}$$

For circular drain of diameter 'D',

$$A = \frac{\pi D^2}{4} \text{ & } P = \pi D.$$

So, $R = \frac{A}{P} = \frac{D}{4}$

Then, $\frac{5}{288} = \frac{1}{0.011} \times \frac{\pi D^2}{4} \times \left(\frac{D}{4}\right)^{2/3} \times \left(\frac{0.3}{100}\right)^{1/2}$

On solving,

$D = 0.131m = 131mm$

∴ Provide 15cm commercially available pipe.

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## Objective of River Training

→ All engineering works which are constructed on river to guide and confine the flow to the river channel, control & regulate river bed configuration, ensuring safe & effective disposal of flood & sediment loads are called river training works.

→ Objective

1) To prevent river from changing its course & avoid outflanking of hydraulic structure
2) To provide safe passage of flood without overflowing its banks & thus prevent flooding of adjoining areas.
3) To ensure effective disposal of sediment load.
4) To provide minimum desired depth of flow ~~di~~ required for navigation.
5) To prevent erosion of banks

## Classification of River Training Works:

1) High Water Training Works ⇒ for quick disposal of max$^m$ floods
2) Low water Training Works ⇒ To provide sufficient water depth for navigation during low flow period
3) Mean Water Training Works ⇒ for efficient disposal of sediment load.

## Methods of River Training Works:

(a) Marginal Embankments or levees:-

→ Earthen Embankment
→ Running parallel to river bank
→ May be constructed on both sides of river depending upon topography
→ Alignment should follow normal meandering pattern of river.
→ Deposition of silt & increase in bed levels.

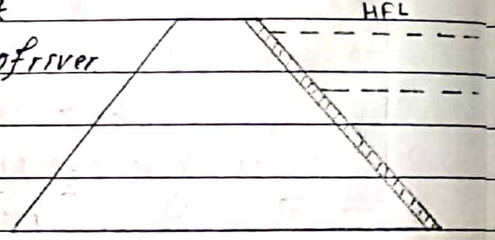


Fig: Embankment

(b) Guide Banks:-

→ Earthen embankment constructed for confining the alluvial river flow within a reasonable waterway & guiding it to a hydraulic structure.
→ Guide banks are made bell mounted for smooth transition.
→ Rivers in alluvial plain are wide. Construction of structure across whole width might be costly. In this condition, guide banks are used.

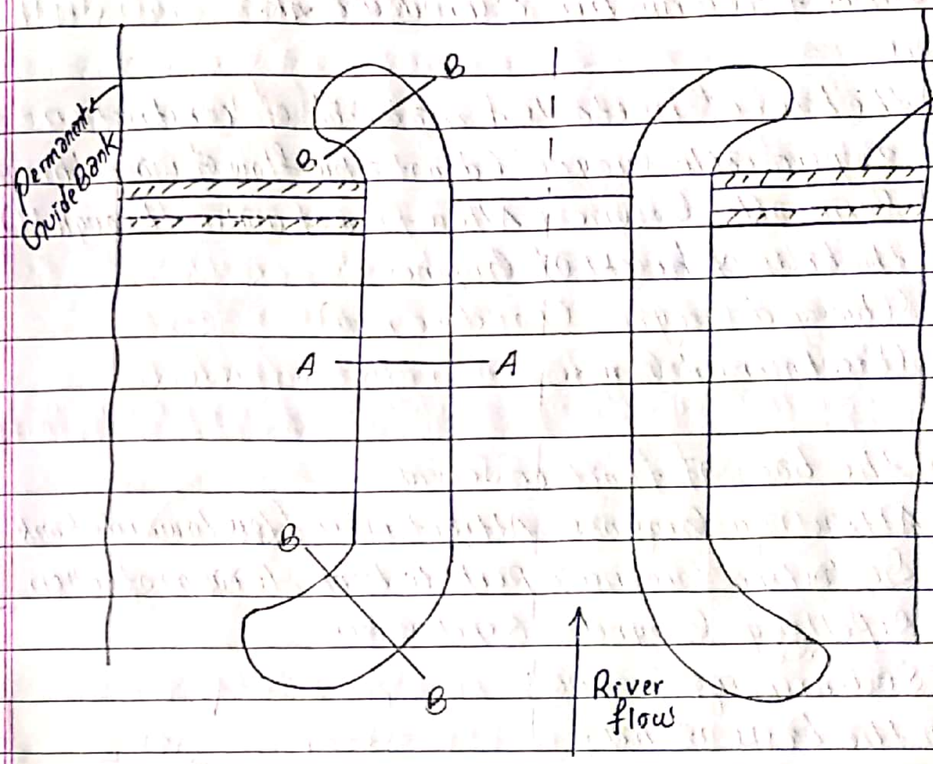


Fig: plan of Guide Bank

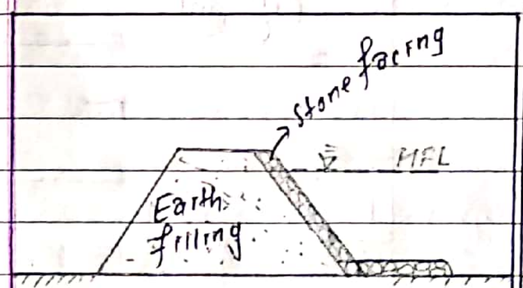


Fig: Section A-A

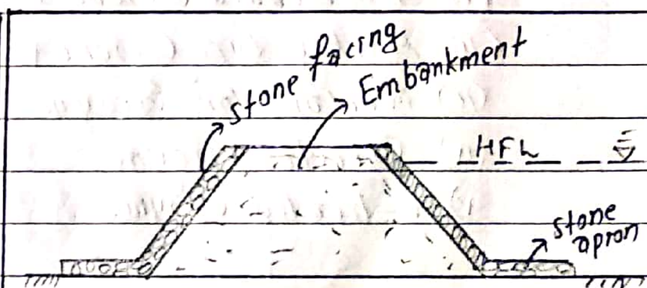


Fig: Section B-B

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(c) Groynes or Spurs:-
→ structure constructed transverse to direction of river flow
→ Also called transverse dyke.
→ Major function of spurs:-
i) Deflection of water current
ii) Reduction of flow velocity
iii) Protection of bank
iv) Silting & reformation of eroded bank.
→ Types
• On the basis of methods & materials of construction
(i) Impermeable Groyne (donot allow flow of water through it)
(ii) Permeable Groyne (Allow flow of water through it)
• On the basis of height of Groynes
(i) Submerged Groyne (For deep river)
(ii) Unsubmerged Groyne

• On the basis of function Served
(i) Attracting Groynes: Attract river flow towards bank
(ii) Deflecting Groynes:- perp^r to bank, local protection
(iii) Repelling Groynes:- Repel water
(iv) Sedimenting Groynes:-
• On the basis of shape
(i) T- headed Groyne
(ii) Hockey type Groyne
(iii) Rectangular Groyne
(iv) Circular Groyne
(v) L-headed Groyne.

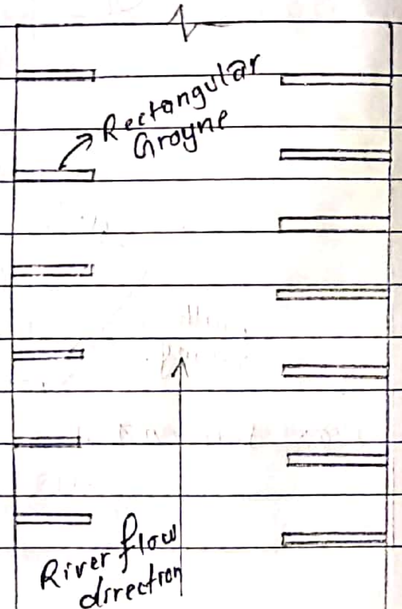


Fig: plan of River with Groyne



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* Design Consideration of Marginal bunds, Guidebanks & Spurs:-
* Design of Guide bank:-
(a) Top level of Guide Bank:-
→ It is governed by HFL, Afflux, velocity heard & freeboard
Top level of Bank = HFL before construction + Afflux + $\frac{V^2}{2g}$ + free board.

(b) Waterway:-
→ Actual waterwidth through which flow takes place at the structure.
$P = 4.75\sqrt{Q}$ (Given by Lacey's)
(c) Length of Guide bank:-
→ As per Gales,
Length of u/s guide bank = 1.25L for Q upto 20,000 m³/sec
= 1.5L for Q > 20,000 m³/sec
Length of d/s guide bank = 0.25L
where, L = length of structure.
(d) Radius of Heads:-
Radius of u/s curve = 0.45L, L = Width of structure.
U/s curve head is extended to subtend an angle of 120° to 145° at its centre.
Radius of d/s curve = ½ Radius of u/s curve
(R = 0.225L)
(e) Shank Portion:-
→ straight portion of guide bank is called shank.
→ Top width of guide bank should not be less than 4m.
→ Side slope shouldnot be steeper than 2:1
→ Minimum freeboard 1.2 to 1.5m

(f) Stone pitching:-
→ Side slope pitched with stone
→ pitching is extended upto 1m above HFL
→ Done on both sides of guide bank near the nose.
→ Rear side of shank is not pitched but coated with earth for vegetation growth.

Thickness of pitching $(t) = 0.06 \times Q^{1/3}$
where, $Q$ = Maxm discharge in cumecs

(g) Launching Apron:
Length of launching apron = 1.5 * Scour depth (D)
Scour depth (D) = $x * R$
where,
$R = 0.47\left(\frac{Q}{f}\right)^{1/3}$ = Lacey's normal Scour depth
$Q$ ⇒ Discharge & $f$ = Silt factor.
For value of 'x'
(a) Nose of guide banks ⇒ $x = 2.25$
(b) Transition from noses to straight portion ⇒ $x = 1.5$
(c) Straight reaches of guide banks ⇒ $x = 1.25$
→ Scour depth is measured from water surface level.
∴ Scour depth below original ground level (D) = $x * R - y$ (water depth)

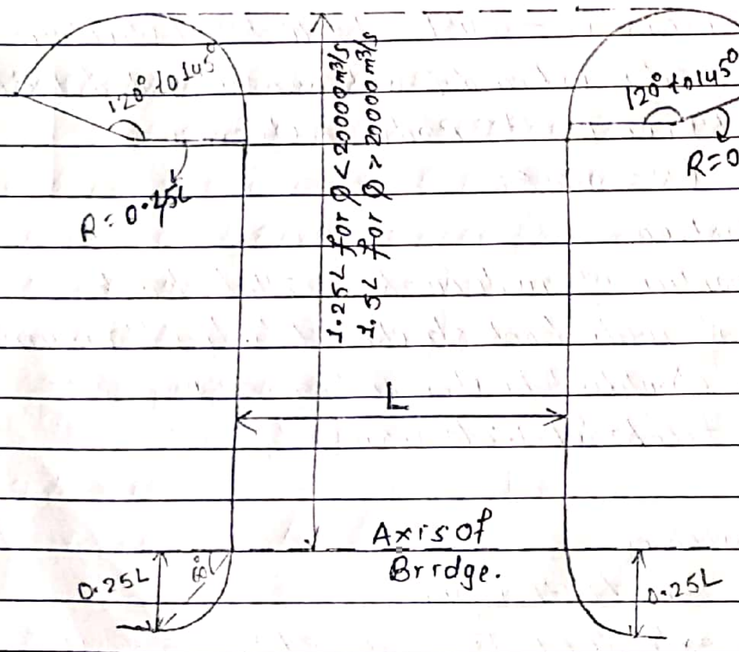



Fig: plan of Guide Bank.

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Q Design the guide banks for a bridge site with the following data.
Maximum discharge = 6000 cumecs
Highest flood level = 104.00m
River bed level = 100m
Average diameter of river bed material = 0.1mm
Design & sketch Bell's Bunds including the launching apron to train the river. Assume plentiful availability of boulders near site.

⇒ Solution,
→ Waterway,
$P = 4.75\sqrt{Q} = 4.75\sqrt{6000} = 368m$
Allowing 20% extra for pers etc. the net spacing bet$^n$ two guide bunds at bridge site = $1.2 \times 368 = 440m$
Here,
$L = 440m$
length of guide bank u/s = $1.25L = 550m$
length of guide bank d/s = $0.25L = 110m$
Radius of u/s curve head = $0.45L = 194m$
Radius of d/s curve head = $0.225L = 99m$
Angle of sweep of u/s head = 130°
Angle of sweep of d/s head = 60°

→ Cross section
Assuming free board of 1.5m and nil value of afflux, & ignoring velocity head. We have,
Top level of guide bank = $104 + 1.5 = 105.5 \approx 106m$
Let us assume top width = 5m
Height of guide bank above river bed = $106 - 100 = 6m$
Let the side slopes be 2:1
We obtained the required section as shown in figure.

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Thickness of stone pitching ($t$) $= 0.06 \times Q^{1/3} = 1.09\,m \approx 1.1\,m$

→ Launching Apron:

Lacey's silt factor ($f$) $= 0.76\sqrt{0.3} = 0.556$

Lacey's Regime Scour Depth ($R$) $= 0.47\left(\frac{Q}{f}\right)^{1/3} = 10.36\,m$

→ At nose of guide bank

$D = 2.25R - y = 2.25 \times 10.36 - (104 - 100) = 19.36\,m$

Length of launching apron $= 1.5D = 1.5 \times 19.36 \approx 30\,m$

Thickness of apron at inner edge $= 1.5t = 1.5 \times 1.1 = 1.65\,m$

Thickness of apron at outer edge $= 2.25t = 2.25 \times 1.1 = 2.475\,m$

→ At transition of guide bank

$D = 1.5R - y = 1.5 \times 10.36 - y = 11.54\,m\ (\approx 12\,m)$

Length of launching apron $= 1.5D = 18\,m$

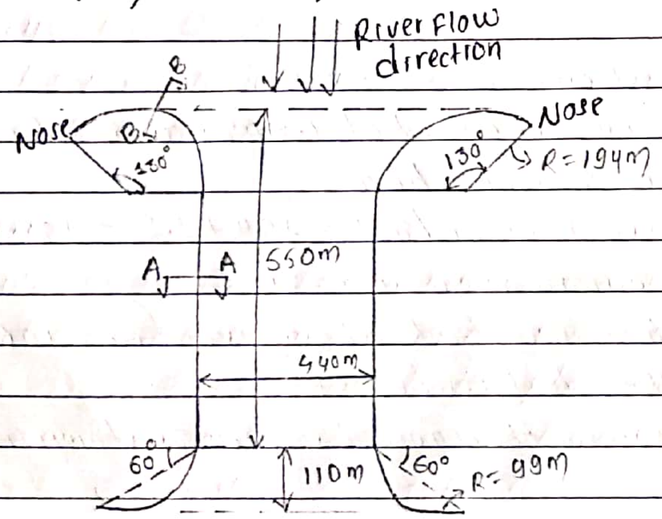
Thickness of apron is kept as same as that of nose.

→ At shank of Guide bank

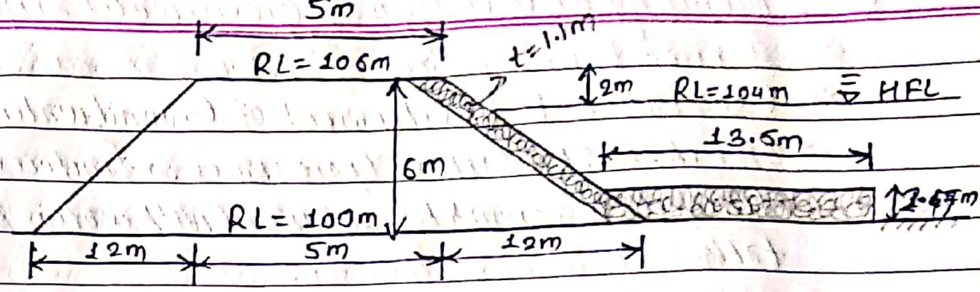
$D = 1.25R - y = 1.25 \times 10.36 - y \approx 9\,m$

Length of apron $= 1.5D = 13.5\,m$

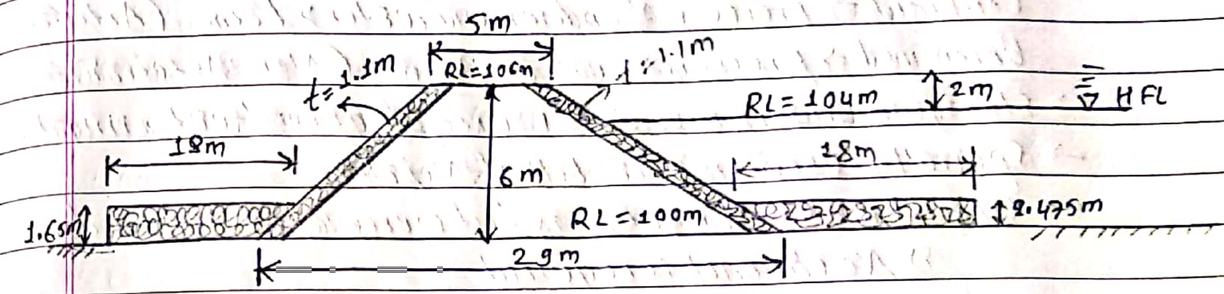
Thickness of apron is kept same as that of nose.




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Cross section A–A.




Cross-section B–B

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# Ch-8 Planning and design of groundwater Irrigation Schemes:-

## ※ Exploration & Development of Ground water:-

→ The depth at which soil porespaces or fractures & voids in rock become completely saturated with water is called water table.

→ An aquifer is underground, water bearing layer of permeable rock.

→ Types of aquifer
Confined ⇒ pressure of underground water > Patm (Artesian)
Unconfined ⇒ pressure equal to Patm (Non-Artesian).

→ Storage in underground is source of ground water irrigation.

→ Specially used in Terai belt of Nepal.

→ Ground water Irrigation is best source of irrigation due to
i) No channel is required
ii) Low investment
iii) Very low silt deposition

## ※ Types of Wells:-

→ An excavated hydraulic hole in earth for bringing ground water to the surface.

→ Types:-

1) Dug Well:-

→ Also called Open well, which is dug down to water bearing strata or confined aquifer.

2) Tube Well

→ Constructed by fixing the pipe below ground surface & passing through different geological formations consisting of water bearing & non-water bearing strata. plane pipe is located at non bearing strata

→ Types: shallow tube well & Deep tube well.

① Shallow Tube Well

→ A tubewell having dug at one strata of unconfined aquifer.

→ 10-25m deep

→ Generally, in Terai region.

② Deep Tube Well:-

→ Drilled upto sufficient depth of water bearing strata

## ※ Components of Tubewell:-

→ A tube well is a type of waterwell in which a long 100-200mm wide stainless steel tuber or pipe is bored into an underground aquifer.

→ Lower end is fitted with strainer & pump lifts water for irrigation

→ The required depth of ~~water table~~ well depends upon depth of water table.

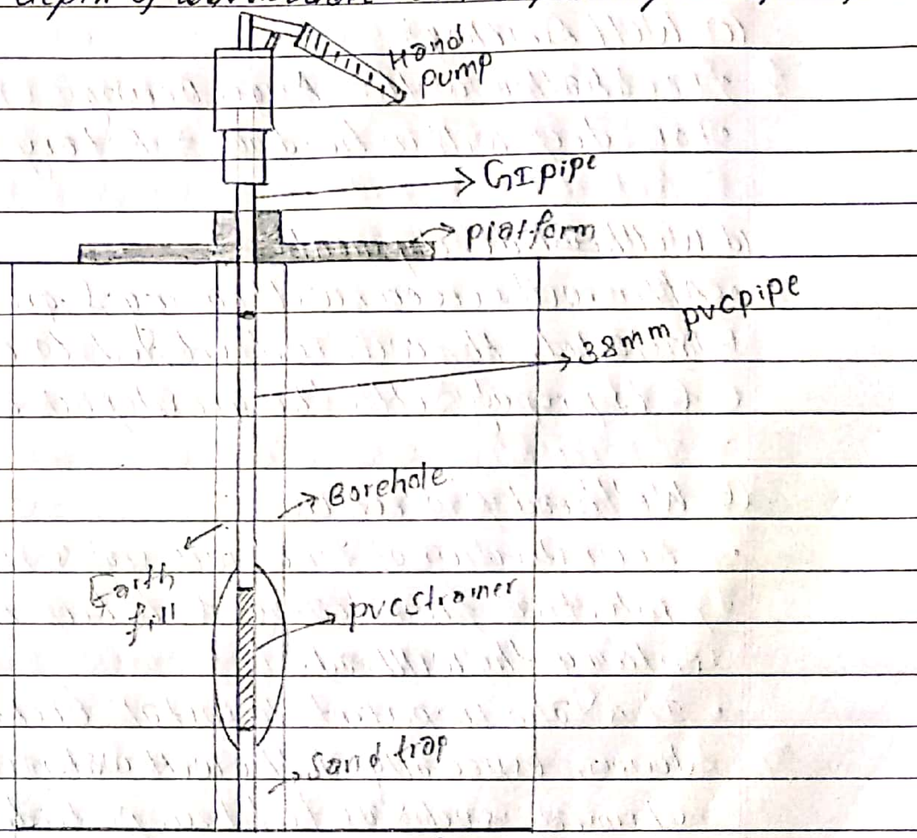



Fig:- Components of tubewell:-

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## Design Considerations of shallow & deep wells:-

(a) Determining location of well
- Depend on purpose (long term supply)
- For drinking & irrigation, groundwater quality & amount important Consideration.
- Hydrogeological assessment to determine location of well.

(b) Water well design & installation:
- Preliminary design
- For large production wells, test hole will be drilled to obtain information about depth of water producing zones, Confining beds, water levels, etc.
- After this, final design is completed.

(c) Well Drilling:
- For shallow well ⇒ Auger Boring
- For deep well in hardrock ⇒ Rotary Drilling.

(d) Well~~head~~ development:
- After well screen, well casing & gravel pack have been installed, the well is developed to clean the borehole & to properly settle the gravel pack around well screen.

(e) Wellhead protection:
- The construction of final well seal is intended to provide protection from leakage & to keep runoff from entering the wellhead.
- It is also important to install backflow prevention devices, especially if the well water is mixed with chemicals such as fertilizer, pesticides etc. near the well.

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## Types & Selection of pumps:-

→ Device for lifting water from lower level to upper level for irrigation are known as irrigation pump.

→ Two types
(i) Centrifugal pump
(ii) Reciprocating pump

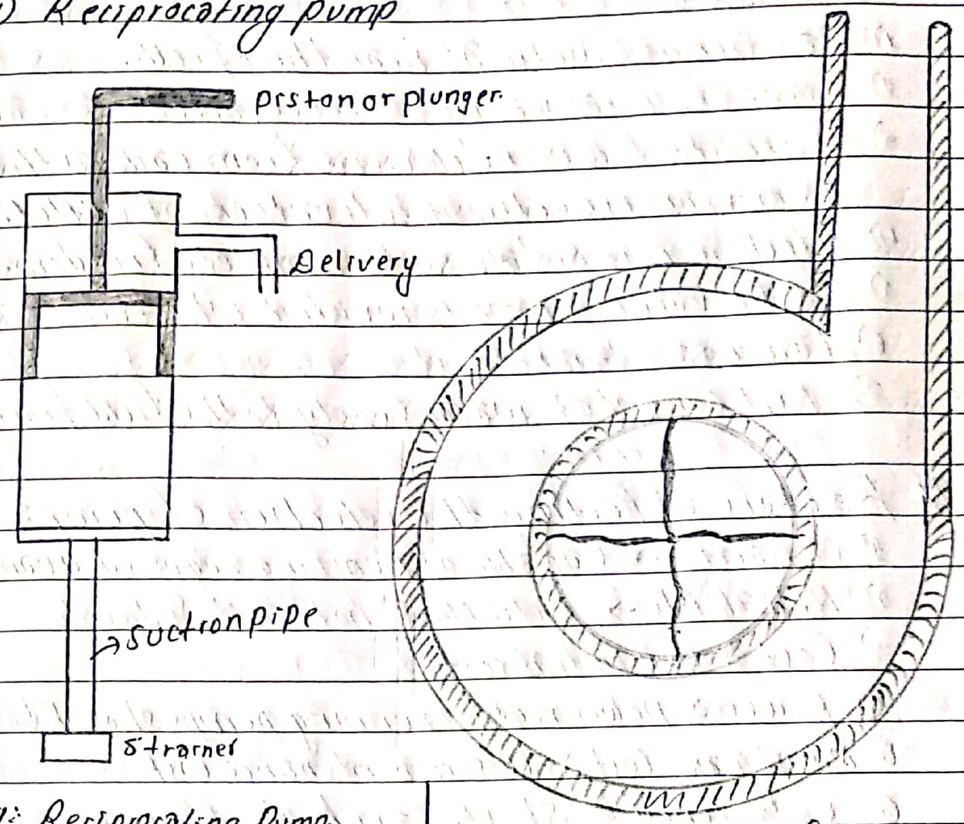



Fig: Reciprocating pump.

→ piston/Displacement pumps
→ Works by means of piston movement which displaced water into a cylinder.
→ Flow is controlled by valve.
→ Types
- Single Reciprocating pump
- Double Reciprocating pump.

Fig: Centrifugal pump.

→ Consists of two parts, rotary element called impeller & a stationary part which is pump casing.
→ Most widely used in irrigation practice. Simple in Construction, easy to operate, low initial cost & produce constant steady discharged.

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## Conveyance & Distribution System in Ground Water Irrigation Schemes:

→ Water is conveyed from the groundwater source to the cropped field using networks of open channels & or pipeline.

→ Advantages:-

1) Farmer get water at near their fields.
2) Seepage, Evaporation & Conveyance loss are avoided.
3) Quantity of water delivered from each outlet remains same, irrespective of elevation of outlet.
4) Pipeline can be laid with complete freedom.
5) Outlet valves can be provided wherever.
6) Low maintenance cost
7) Full control of water supply to the field from well.

## Factors affecting the selection of pump:-

1) Capacity → Capable of pumping required quantity of water.
2) Reliability → Reliable & not fail Suddenly
3) Cost ⇒ low initial cost
4) Power ⇒ Power reqd for running pumps should be available easily.
5) Maintenance Cost ⇒ less maintenance cost
6) Efficiency ⇒ Should have high efficiency
7) Depreciation ⇒ long life & depreciation cost should be small.
8) Labour cost ⇒ low
9) Number of pump
10) Total lift of water required
11) Quality of water to be pumped.

## Design of Underground Pipeline System

→ Refer note on subsurface drainage System.

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## Conjuctive Use of Surface & Groundwater:-

→ The practice of storing surface water in a underground water basin in wet years & withdrawing it from basin in dry years.

→ Conjuctive use of surface & groundwater (S & G water) in planned & Coordinated way lead that the total water resources are used in an efficient & economical way to get maximum agriculture production through irrigation & drainage.

→ Benefit:-

1) Reduce size of canal & Construction Cost:-
2) Proper irrigation even if rainfall is delayed.
3) Groundwater withdrawl → Reduce GWT → No waterlogging
4) Decrease in surface & subsurface outflows
5) Time to time recharge of aquifer.
6) Optimum utilization of water Resources.

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ch-9 Planning & Management of Irrigation Systems:

→ planning is necessary for any project before/ after/ during implementation.

→ The factors affecting irrigation system planning are
1) Source, Hydrology
2) Commanded Area
3) Cropping pattern
4) Duty & Delta
5) Type of canal alignment (Contour, Sideslope & ridge)
6) Cross Drainage structures.
7) Regulation & distribution System
8) Participatory Approach
9) Operation & Maintenance
10) Management through agency (WUA, FIA, FUA)
11) Economy

→ Stages in planning
(a) Preliminary planning including feasibility Study
(b) Detail planning of water & landuse
(c) Design of Irrigation Structures & Canals.

## Operation & Maintenance of Irrigation System:

→ Operation is process of storing, diverting, regulating, measuring, Conveying & applying right amount of water at right place for required duration.

→ Objective of Operation is to distribute the water to crop at right time & right place for design duration, at adequate quantity, least cost & in efficient way.

→ Operation of Irrigation System is done by WUA, GON, jointly by WUA & GON, Private sector etc.

→ Maintenance of irrigation System is necessary to supply rich water to communities for better production. After construction, it becomes necessary to maintain for its proper & efficient functioning.

→ Types of Maintenance
(a) Routine/Regular ⇒ Greasing & Oiling, vegetation removing.
(b) Periodic ⇒ painting, desilting, repair of weir, stilling basin
(c) Emergency ⇒ After disaster
(d) Special/Specific ⇒ Road network, drainage network etc.

## Canal Operation plan:

→ The basic principle of canal operation plan is to organize water delivery in a planned way leading to equitable, reliable & predictable water supply in an irrigation System.

→ Canal Operation plan contains
1) Start & closure of Season
2) Starting Storage
3) Irrigation release schedule
4) Responding to specific situations.
5) DOP (Design Operation plan) prepared at time of design of System
6) SOP (Seasonal Operation plan) to adjust DOP to actual seasonal Conditions.

→ Data required in canal Operation plans are
1) Water resources
   - Availability
   - Storage status
   - Inflows
2) Water Demands
   - Cropping plan
   - Rainfall
3) Canal Status
   - Discharge
   - Water levels
   - Losses
4) Irrigation Schedules
   - Timing
   - Duration

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## Participatory Management:-

→ Participatory Irrigation Management (PIM) refers to the participation of irrigation users (farmers) in the management of entire irrigation System.

→ Objective of participatory Management

1) To promote & secure equitable distribution of water among its users, adequate maintenance of irrigation system, efficient & economical utilization of water to optimize agricultural production.

2) To protect the environment and to ensure ecological balance including sense of ownership of the irrigation System in accordance with the water budget & the operational plan.

3) To bridge the gap between potential created & potential utilized.

4) For prompt attention to problems & resolutions of disputes.

5) For collective involvement in better application & management of agricultural extension services.

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**The End**

**Best of Luck**