

Note Book

Date : 20 / /

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Engineer

Irrigation Engineering

Irrigation

Irrigation is the process of artificial application of water to soil for rising crops.

Need of Irrigation

- Inadequate rainfall
- Uneven distribution of rainfall.
- Crop requirement
- Non-uniform rainfall
- Growing perennial crops.
- Growing number of crops.

Objective of Irrigation

- ensure enough moisture essential for plant growth.
- provide crop insurance against short duration drought.
- Cool the soil & atmosphere to provide to suitable surrounding.
- Wash out harmful salt, chemicals of the soil.
- for better crop production.

Function of Irrigation

- Increasing the output & efficiency of crop production.
- Growth of crops in absence of sufficient natural precipitation.

Advantages of Irrigation.

- Increasing the food production.
- Cultivation of each crops
- Improvement of ground water storage.
- Water supply.
- flood Control.
- Inland navigation

Note Book

Date : 20 / /

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- Protection from famine. (शोकासर्प) → Generation of hydropower
- Elimination of mixed cropping. → Afforestation.

Disadvantages of Irrigation

- Water logging, → no. of cross drainage structure
- Damp climate. are required.
- breeding of mosquitoes. → increase cost of government.
- Water pollution.

History of Irrigation development in Nepal

→ First Canal: Chandra canal → Location: Saptari

→ Construction start: 1979 B.S.

→ Distribution of water start: 1985 B.S.

Juddha Canal → Location: Sarlahi → Construction: 1939-1942 A.D.

Jagadishpur Dam → Location: Kapilbastu → Construction: 1939-1942 A.D.

→ First irrigation policy of Nepal: 2049 B.S.

→ Latest " " " " : 2070 B.S.

Important point used in irrigation

① Arid Region / Arid zone → The area in which no crops can growth without irrigation is called arid zone.

② Semi-arid zone → The area in which some inferior low quality crops can growth without irrigation is called semi-arid zone.

③ Saturation capacity → Maximum moisture holding capacity of soil → All air pores (voids) are displaced with water.

④ Field capacity → Water content after gravitational water has been removed is known as field capacity.

Field capacity = saturation capacity - gravity water

Note Book

Date : 20 / /

Amn

⑤ **Permanent Wilting point** → It is that water content at which the plant will die. (i.e, plant can no longer extra sufficient water for its growth)

⑥ **optimum moisture content (OMC)** → The water content in which crop production is maximum.

⑦ **Paleo watering** → The first watering before sowing the crops.

⑧ **Kor Watering** → The first watering given to the crops when it has growth in few centimeters. → The first watering after sowing crops

Crops	Kor watering / Kor depth	Kor period	Base period
Rice	19 cm	2-4 Weeks	120 days
Wheat	13.5 cm	3-8 Weeks	120 days
Sugarcane	16.5 cm	—	330 days

⑨ **Root zone depth** → Maximum depth of soil strata in which crops spread its root system & derives water from soil.

Crops	Root zone depth (cm)	Note
Rice	90	pH value of irrigation water = 6 to 8.5
Maize	100	pH value of drinking water = 6 to 8.5
Wheat	100	⑩ Available moisture
Potato	60	Available moisture content =
Banana	90	field capacity - wilting point.
Tobacco	80	⑪ overlap allowance
Sugarcane	150	→ Extend of water to be supplied
Cotton	140	for maturing a particular crops

Which extend from one seasons to other seasons is called overlap allowance.

Factor affecting crop water requirement

- climate.
- effective Rainfall.
- Types of soil.
- Base & Crop period
- Canal Condition.
- Cultivation method.
- Types of Crops.
- Method of irrigation

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Irrigation Water Requirement

① **Consumptive Use (C_u)** The amount of water utilized by the plant in transpiration & evaporation from adjacent soils of plant leaves is called Consumptive use. $\rightarrow$ This is also called **evapotranspiration**.

② **Effective Rainfall (R_e)** Rainfall during the growing period of the crop that is available to meet water requirement of crop is effective rainfall.

③ **Land preparation & Leaching Water Requirement (L_p, L_e)** Before seeding (बिउं छर्ने) & transplanting (रोक्ने) certain crops some additional water is required, this is called **land preparation water requirement**. Also some more water may be needed in certain soil to remove harmful salts, this amount of water required is called **leaching**.

$$\rightarrow IWR = CWR + \text{Losses}$$

④ **Irrigation Water Requirement** The amount of water that is to be supplied by irrigation for fulfilling the water requirements of crops is called **irrigation water requirement**.

$\rightarrow$ **Crop Water Requirement** How much water is required to crops.

$\rightarrow$ **Irrigation Water Requirement** How much water is supplied by irrigation

⑤ **Consumptive Irrigation Requirement** The amount of water to be supplied through irrigation to meet the **consumptive use demand** of crops is called **CIR**. $\therefore CIR = C_u - R_e$

⑥ **Net Irrigation Requirement** The amount of water to be supplied at the **root zone** to meet water requirement of crops is called **NIR**. $\therefore NIR = CIR - L_p \& L_e$

⑦ **Field Irrigation Requirement** The amount of water required to be supplied to the field to meet water requirements of the crop is called **FIR**. $\therefore FIR = NIR + \text{water application losses}$

Also,
$$FIR = \frac{NIR}{\eta_{wa}}$$

where, η_{wa} = Water application efficiency

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Date : 20 / /

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Gross Irrigation Requirements The amount of water to be supplied from the Canal outlet to meet water requirements of crops is called GIR. $\therefore \text{GIR} = \text{FIR} + \text{Conveyance loss}$

Also, $\text{GIR} = \frac{\text{FIR}}{\eta_c}$ Where: $\eta_c = \text{Water conveyance efficiency.}$

Crop seasons & principal crops.

① Kharif Crops	② Rabi Crops
→ Crops which are sown at the beginning of south west monsoon summer seasons.	→ Crops which are sown at the winter / non-monsoon seasons.
→ Start from 1 st April to 30 th September.	→ Start from 1 st October to 31 st March.
→ Example: Rice, maize, groundnut, Cotton, bajra, jowar	→ Example: Wheat, potato, mustard, barley, tobacco,
→ Also called Summer crops.	→ Also called winter crops
→ Consume more water.	→ Consume less water

③ perennial crops → Base period lies in both Kharif & Rabi seasons.

→ Example: Sugarcane & Garden Crops. ④ Eight month crop cotton

Crop period Time period betⁿ the sowing & harvesting of crops.

Base period Time period betⁿ the first watering of crop at the time of sowing to last watering before harvesting.

Note: ① Generally, crop period > Base period

② practically, both are taken as same thing.

③ Both are expressed in days.

Crop Ratio = $\frac{\text{Area irrigated in Rabi season}}{\text{Area irrigated in Kharif season}}$	
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Duty

→ Duty of water is defined as the area of land in hectares that can be irrigated by constant supplying $1 \text{ m}^3/\text{sec}$ of water throughout the base period.

→ Mathematically: $\text{Duty (D)} = \frac{A}{Q} = \frac{\text{ha}}{\text{m}^3/\text{s}} = \frac{\text{ha}}{\text{cumecs}}$

Note : $1 \text{ hectare} = 10,000 \text{ m}^2 = 1 \times 10^4 \text{ m}^2$

Factor Affecting Duty

- ① Climate → Temp^r → wind velocity → Humidity → Atm. pressure
- ② Types of soil
- ③ Types of crop
- ④ Topography
- ⑤ Method of irrigation
- ⑥ Canal Condition.
- ⑦ Base period of crop.

Note : Duty is maximum on the field.

→ The duty at outlet point (i.e. at head of water course canal) is called as outlet duty or outlet factor.

Delta

→ The total depth of water required by a crop throughout its base period to attain full maturity is called delta.

→ It is generally measured in cm & m. → Symbol: Δ

Crops	Delta on field	Crops	Delta on field
① sugarcane	120 cm	⑨ Vegetables	4-5 cm
② Rice	120 cm	⑩ Barley	30 cm
③ Tobacco	75 cm	⑪ Pooder	22-5 cm
④ Garden fruits	60 cm	⑫ peas	15 cm
⑤ cotton	50 cm		
⑥ Mustard	45 cm		
⑦ Wheat	40 cm		
⑧ maize	25 cm		

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Date : 20 / /

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Relationship Between Duty, Delta & Base period.

Let $1 \text{ m}^3/\text{sec}$ water can irrigate D hectares land throughout the base period B . & Water requirement of crop is Δ meters.

Now, $D = \text{Duty in ha}/\text{m}^3/\text{sec}$

$B = \text{Base period in days}$

$\Delta = \text{Total depth of water supplied in meter}$

$$\text{Discharge (Q)} = \frac{\text{Volume}}{\text{time}} = \frac{\text{m}^3}{\text{sec}}$$

$$A = \text{Area} = 1 \text{ hectare} = 10000 \text{ m}^2 = 1 \times 10^4 \times D \text{ m}^2$$

$\therefore$ Volume of water applied to the crop for base period B day

$$\text{Volume (V)} = \text{Discharge} \times \text{Time}$$

$$= 1 \text{ m}^3/\text{sec} \times 1 \text{ days}$$

$$= 1 \frac{\text{m}^3}{\text{sec}} \times 24 \times 60 \times 60 \text{ sec}$$

$$= 86400 \text{ m}^3$$

$$\therefore V = 86400 \times B \quad \text{--- (1)}$$

$$\text{Depth of water applied in } B \text{ days} = \frac{\text{Volume (V)}}{\text{Area (A)}} = \frac{86400B}{1 \times 10^4}$$

$$\therefore \Delta = \frac{8640B}{\Delta} \quad \Delta \text{ in m.}$$

$$\text{In conclusion :-} \quad \Delta = \frac{8640B}{\Delta} \quad \Delta \text{ in cm.}$$

Note: if base period increase, duty increase.

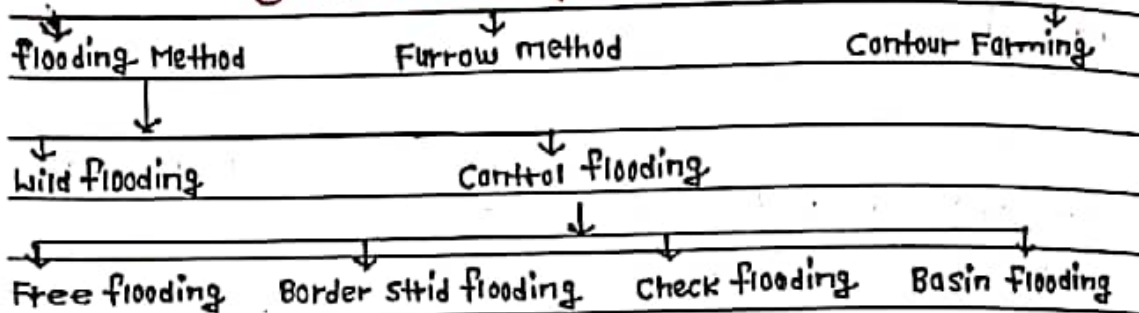
if delta increase, duty decrease.

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Methods of Irrigation

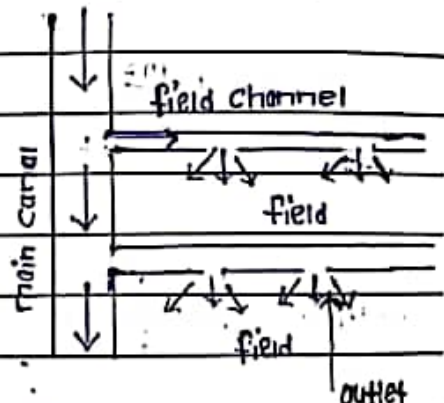
- ① **Surface Irrigation** : Irrigation water applied & distributed over the soil surface. Either by gravity or by pumping.
- ② **sub-surface Irrigation**
- ③ **sprinkler Irrigation**
- ④ **Lift Irrigation**

① Surface Irrigation



① Free Flooding

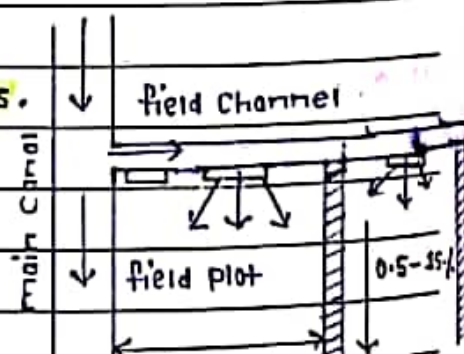
- Land is divided into several plots.
- Water is supplied at higher level & cut off at lower end.
- Water is applied to field without any control structure (border or levees etc).
- Also called Wild Flooding.



- Suitable, if irrigation water is inexpensive.
- In this method, quantity of water is high.
- The application efficiency is low.
- Suitable for flat leveled land.

② Border strip Flooding

- Land divided into a number of strips by the low levees called borders.
- Length = 100 - 400m.
- Width = 10 - 20m.
- Slope = 0.5 - 15%.



- Discharge = 0.015 m³/sec to 0.3 m³/sec.

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⑥ Check Flooding.

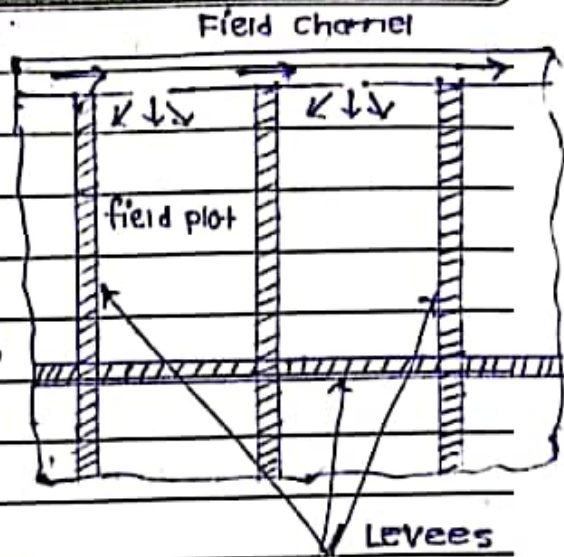
→ Similar to border strip flooding but water controlled by surrounding levees.

→ All levees are connected with cross levees.

→ Levees, wide = 2 to 3 m
(check) height = 25 - 30 cm

→ Applied in level ground.

→ most suitable for permeable soil.



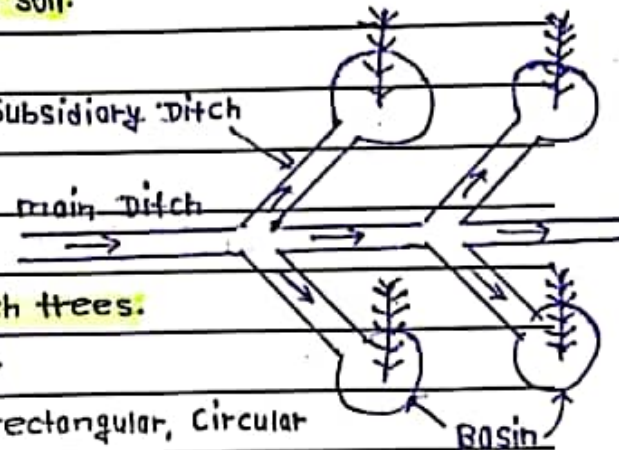
⑦ Basin Flooding.

→ Irrigation water is applied for orchard (बगीचा) trees/garden Parks etc.

→ Water basin are formed for each trees.

→ special type of check flooding.

→ shape of basin can be, square, rectangular, circular or may be irregular.



Furrow Method

→ Furrows are series of long narrow channel in

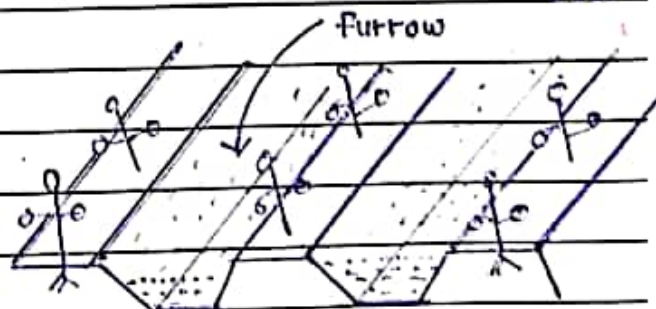
betⁿ rows of plants to be irrigated.

→ Water is applied only in furrow not in entire surface area.

→ Water reaches the roots of plants by percolation methods.

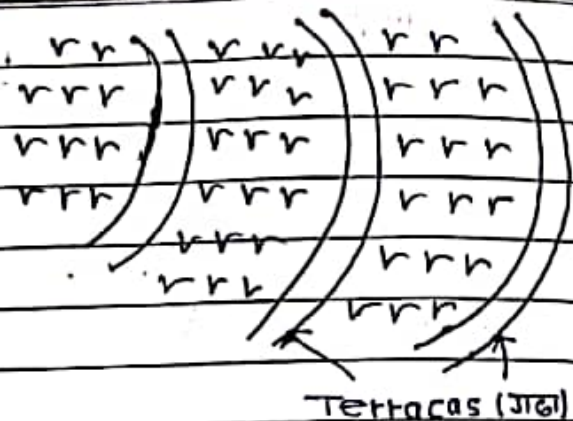
→ suitable for crops may get injured due to contact with water.

→ For example; Cauliflower, potato etc.



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Contour Forming



② sub-surface Irrigation

- | | | |
|----------------------------------|-------------------------------------|---------------------------|
| ① Natural sub-surface irrigation | ② Artificial sub-surface irrigation | ③ Drip/Trickle irrigation |
|----------------------------------|-------------------------------------|---------------------------|

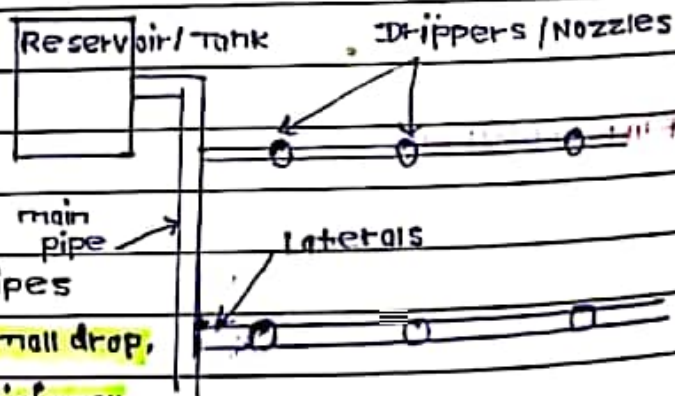
→ Leakage from pond, lake, river etc.

→ Water is supplied beneath the land surface through pipe networking.

Sub-surface Irrigation : In sub-surface irrigation water is applied to the crops directly at the root zone of the crops. Water is not applied from surface & it is applied below ground surface. This method is costly & difficult.

Drip Irrigation

→ Irrigation water is directly applied to the root zone of crops with the help of network of pipes & nozzles, form of small drop.



→ High application efficiency.

→ less evapo-transpiration losses, percolation losses.

→ High cost of installation, operation & maintenance.

Note: minimum height of soil above the network pipes for artificial sub-surface irrigation. = 40 cm

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③ Sprinkler Irrigation

→ Application of pumps.

→ Water is applied to the land in the form of spray.

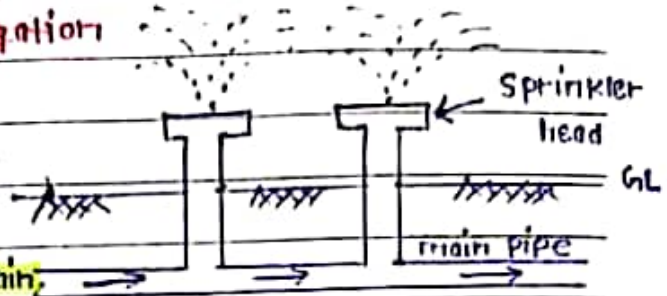
→ It is also known as artificial rain.

→ upper most part of the sprinkler irrigation is rotating head.

→ Applied where topography is undulating, irregular. → Shallow roots

→ Applied where quantity of water is not sufficient to carry surface irrigation. → Applied where land gradient is steeper. →

Note : General pressure in rotating head = $1.4 - 2.1 \text{ kg/cm}^2$



Advantages & Disadvantages of Irrigation Methods

Surface Irrigation

Advantages	Disadvantages
→ No Control over water,	→ No Control over water.
→ Initial cost is less,	→ Wastage of water.
→ Not required skill manpower.	→ Chances of water logging.
→ Not required high technology.	→ Crop suffer from water.
→ Very easy to supervise.	→ chance of erosion of soil.

Sub-surface Irrigation

→ No wastage of water.	→ Initial cost is more.
→ Control over water.	→ Required skilled manpower.
→ chance of erosion of soil is less.	→ Required high technology.
→ chance of destruction is less.	→ Very difficult to supervise.
→ Fertilizer mixed with water.	→ Chance of clogging nozzles.

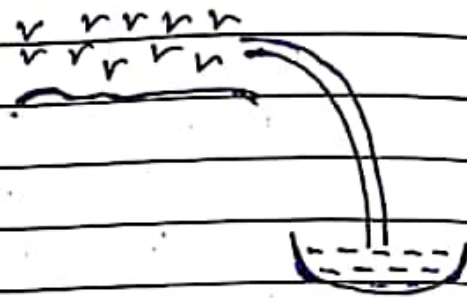
Sprinkler Irrigation

→ Eliminated the seepage losses.	→ High initial cost.
→ Land levelling is not required.	→ Effect of wind.
→ Saving water & labor.	→ Require electrical power.
→ Efficient use of land.	→ Abrasion & clogging of nozzles.
→ Frost & climatic control.	→ Frequent supervision required.

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④ Lift Irrigation

→ The method of irrigation the field with **lifting water** from the available source at low level.



Canal & Canal Design

Canal Canal is the **artificial open conduit** either lined or unlined which is **used to convey water**.

Types of Canal

[A] Based on the nature of source.

① Permanent canal / Perennial canal

→ **Runs throughout the year.**

→ Consists of permanent diversion structures.

② Inundation canal / Non-perennial canal

→ **Runs only in monsoon seasons.**

→ Does not consist of permanent diversion structures.

→ Water is available only during the flood periods.

[B] Based on the financial output

① Protective canal

→ **protection from famine.** → Make the government.

② Productive canal

→ **Generate revenue.** → Make private company.

[C] Based on the type of soil

① Alluvial canal → Canal **passes through alluvial soil.**

② Non-alluvial canal → Canal **passes through rocky plains.**

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Date : 20 / /

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I Based on Function

- ① Irrigation canal : Constructed to supply water for irrigation.
- ② Power canal : Constructed for hydropower generation.
- ③ Feeder canal : Constructed to feed two or more other canals.
- ④ Navigation canal : Constructed for water transportation.
- ⑤ Drainage canal : Excavated to drain water of water logged area.

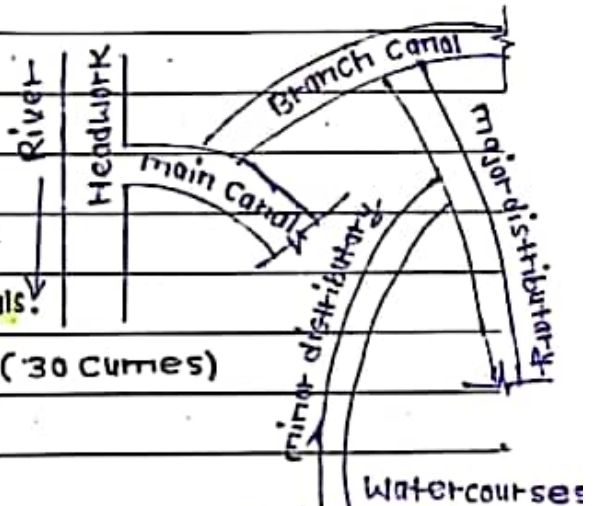
E Based on Lining

- ① Unlined canal
- ② Lined canal

F Based on Discharge

① Main Canal

- Takes off water directly from river or reservoir, or headwork.
- It carries water in large amount to feed the branch & distributary canals.
- Very high discharge $> 30 \text{ m}^3/\text{sec}$ (30 cumes)
- Usually no direct irrigation.



② Branch Canal

- Takes off water from main canal.
- Supply water to major & minor distributary.
- Discharge $> 5 \text{ m}^3/\text{sec}$. (5-30 cumes)
- No direct irrigation.

③ Major Distributary

- Takes off water from branch canal & sometime also from main canal.
- Supply water to minor distributary, watercourses & field channel.
- Discharge : $0.25 - 5 \text{ m}^3/\text{sec}$. → Generally, used for direct irrigation

④ Minor Distributary

- Takes off water from major distributary & sometime also from branch canal.
- Supply water to field channels / watercourses.
- Discharge $< 0.25 \text{ m}^3/\text{s}$.

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⑤ Watercourses / Field channels

- Small channels excavated by cultivators in irrigation field.
- These channels fed by distributary & branch canal.
- Irrigated to field.

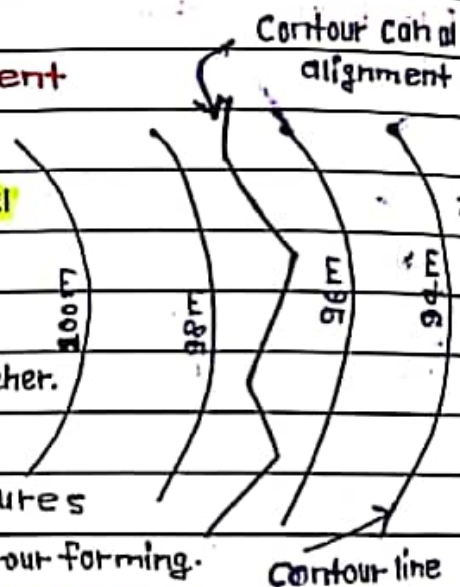
⑥ Based on Canal alignment

Canal Alignment The center line of canal is known as canal alignment. → Canal alignment should be shortest as possible. → Cross drainage structure & religious areas should be avoided from canal alignment.

Types of Canal Alignment

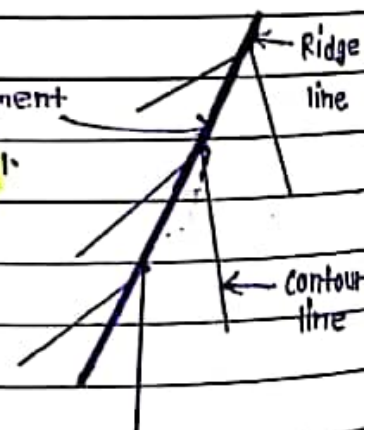
① Contour Canal

- Canal is aligned roughly parallel to contour line of area.
- Irrigation is done only one side of canal, because other side higher.
- Mostly used in hilly area.
- Various Cross-drainage structures are required. → Suitable for contour forming.
- sometime it is called single bank canal.



② Watershed canal / Ridge canal

- Canal is aligned along Ridge line.
- Irrigation is done on both side of canal.
- It is suitable for plain area.
- minimum cross drainage structure are required.
- It is mostly used in irrigation.
- Best canal alignment.



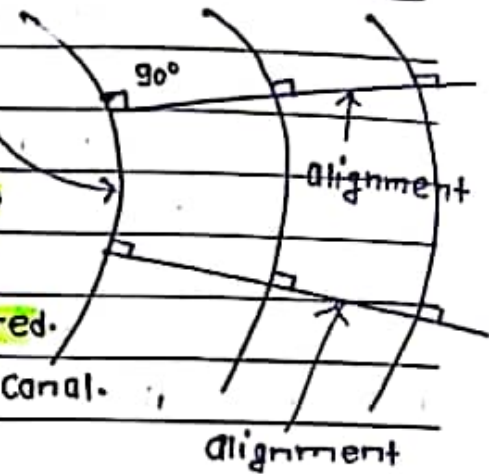
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Date : 20 / /

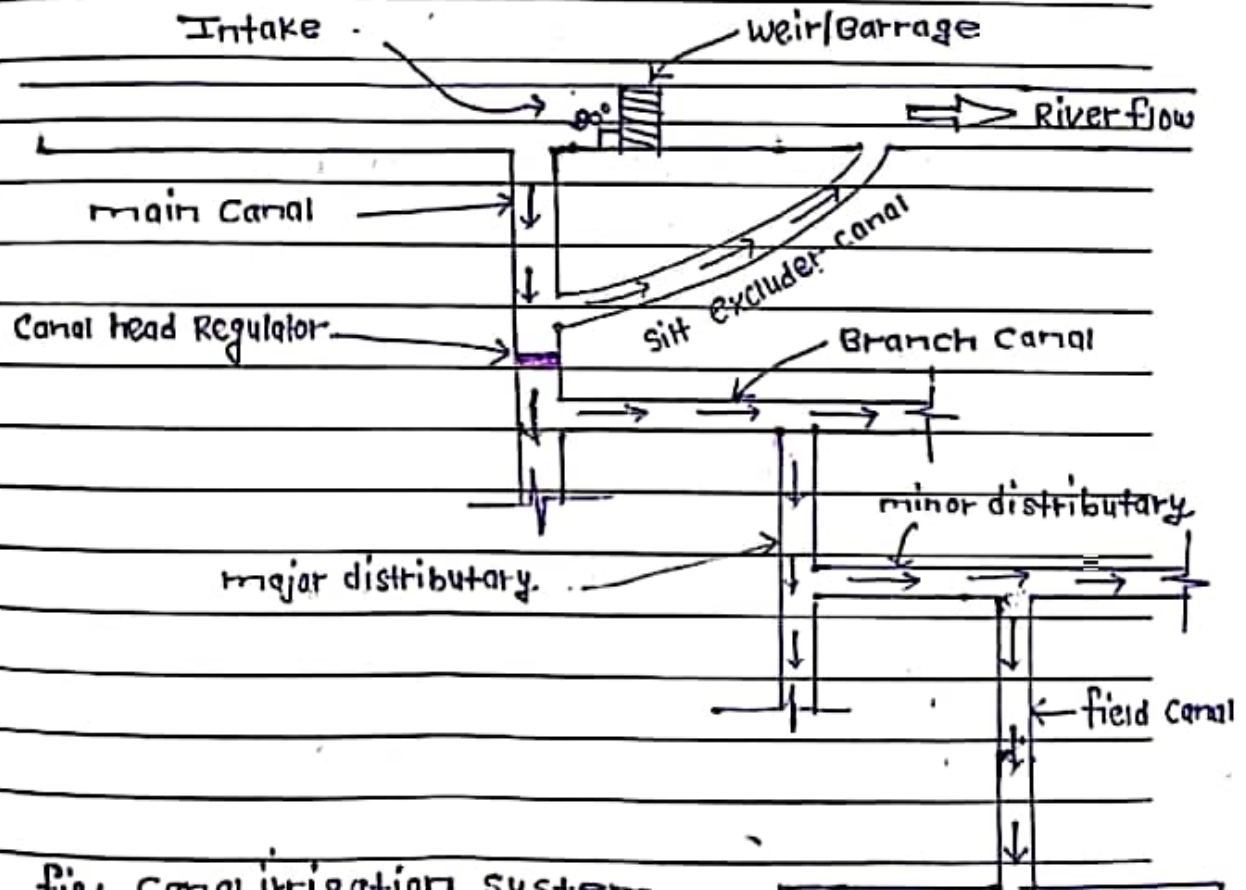
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③ side slope canal

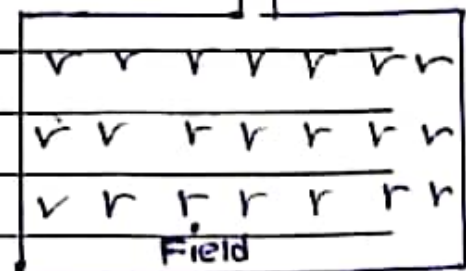
- Canal is aligned at Contour line right angle to the contour line.
- The canal runs roughly parallel to the natural drainage.
- Cross-drainage work are not required.
- Irrigation is done on both side of canal.
- Double bank canal.



Components of Canal Networks



fig; Canal irrigation system.



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Head Works

The hydraulic structures constructed at the head of canal to divert required amount of silt free water to store & divert water are called headworks.

Types of Head Works

① Diversion Headworks

→ It serves to divert the required supply into the canal from river.

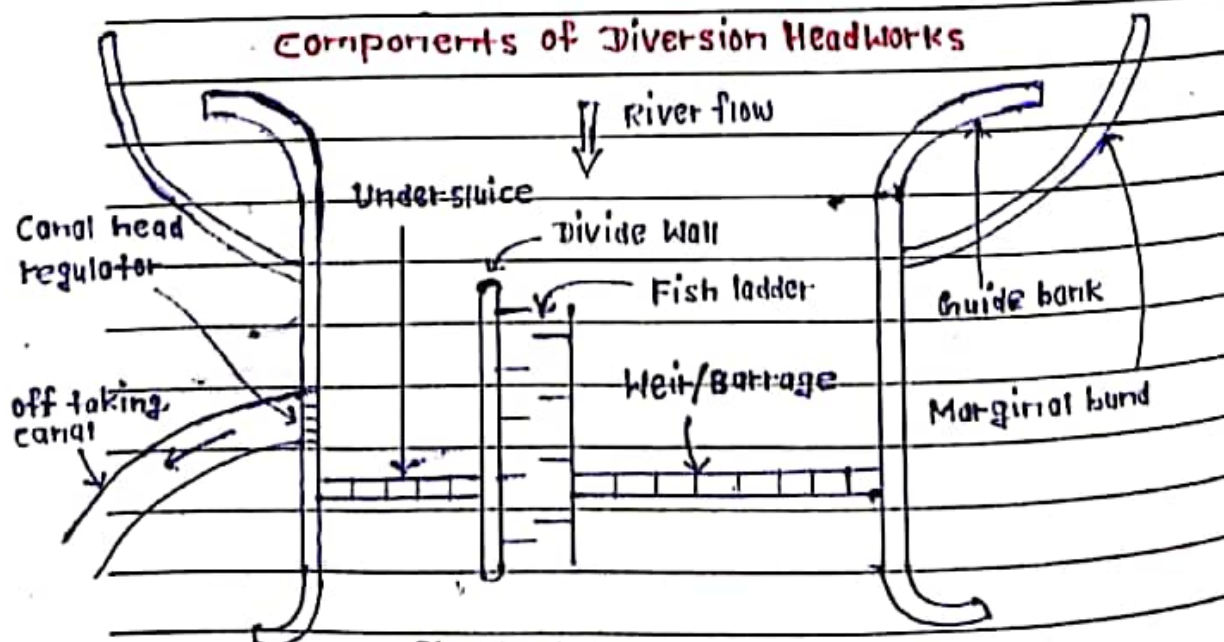
② Storage Headworks

→ It stores water during the period of excess supply in the river & released it when demand overtakes the supply.

Function of Diversion Headworks

- To divert the river water into canal.
- To rise the water level.
- To withdraw required amount of water from river.
- To control the silt entry into the canal.
- To pass the flood.

Components of Diversion Headworks



Fig; Headwork

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Date : 20 / /

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① Weir & Barrage.

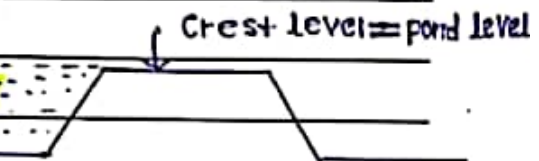
Weir	Barrage
→ Higher crest level.	→ Lower crest level.
→ Not consists of gates.	→ Consists of gates.
→ The primary purpose is not control flood.	→ The primary purpose is control flood.
→ They are used where sediments are relatively smaller in size.	→ They are used where sediments are relatively larger in size.
→ Cost of construction is low.	→ Cost of construction is high.
→ silting in upstream is high.	→ silting in upstream is low.
→ It can't connected with the roadway.	→ It can be connected with the roadway (Koshi barrage)

Weir: It is a solid barrier structure

constructed transverse to the river

flow in which the ponding of water

achieved mainly by the raised crest.



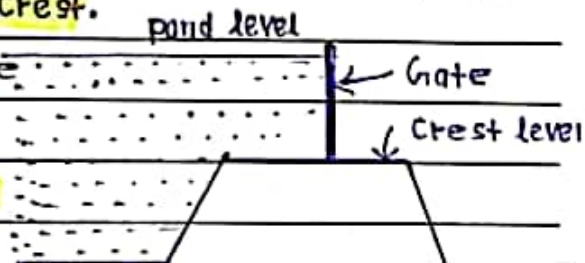
Barrage: It is a hydraulic structure

constructed transverse to the

river flow in which the ponding of

water achieved mainly by the

gates.



Note: An ideal case, Angle betⁿ intake & barrage = 90°

→ But, best favourable, " " " " " = 110° (practically used)

② Canal head regulator—

→ A structure which is constructed at the head of the canal to regulate the flow of water into the canal is known as canal regulator.

→ Consists of gates

→ To maintain flow & water level in canal.

Answer

Functions of canal head regulator

- It regulates the supply of water entering the canal.
- It controls the entry of silt into the canal.
- It prevents the river floods from entering the canal.

③ Divide Wall

The divide wall is the concrete or masonry wall which is constructed perpendicular to the weir axis & which separates weir portion & undersluice portion.

Functions of Divide Wall.

- Separates the undersluices from weir proper.
- Create a still pocket near the canal head regulator.
- To control cross current in front of canal head.
- Increase the effectiveness of the undersluice portion.

④ Undersluice

Undersluice is the part of the diversion structure which is mainly constructed to flush the sediment deposited near the head regulator.

⑤ Fish ladder

Fish ladder is constructed to allow the movement of fish along the river or U/s or D/s around the weirs.

- Fish move U/s to D/s in winter & D/s to U/s in summer.
- Main principle of ladder is to reduce velocity.

Note : Fish can not travel in opposite direction if the velocity of water is greater than 0.3 m/sec.

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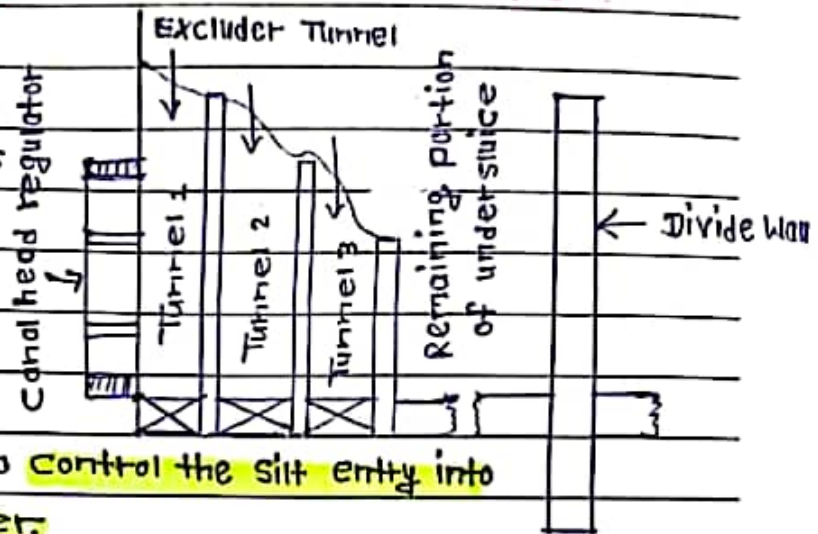
⑥ **silt control Devices** : control the silt entry in canal.

Two types

① **silt excluder**

→ It is the structures provided in the river bed & upstream of head regulator.

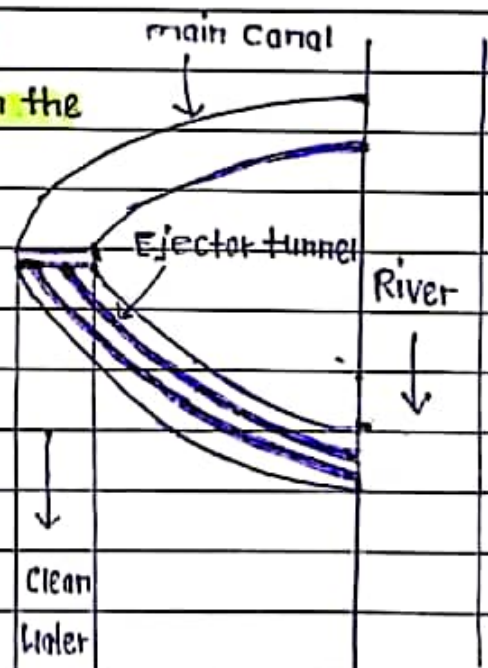
→ The main purpose of silt excluder is to control the silt entry into the canal from river.



→ parallel tunnel along the river length.

② **silt ejector or silt extractors**

→ It is the structure provided in the canal bed & downstream of head regulator.



⑦ **River training structures**

River training structures are required at the headwork side to avoid the change in path of river, to make river water flow in specific path, to save river banks from cutting & many other purpose.

① **Marginal bunds/Embankments**

→ Embankment constructed along the river.

→ It is constructed roughly parallel to the river.

→ It is also called dyke or levees.

Fig : plan of silt ejector

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⑥ Guide bank

→ It is also known as **bell's bund**.

→ It is provided to guide the river water flow in a specified path.

⑦ Spurs / Groyne

→ spurs are provided to **avoid cutting of the river bank** due to flood.

Canal standards (cross section of an irrigation canal)

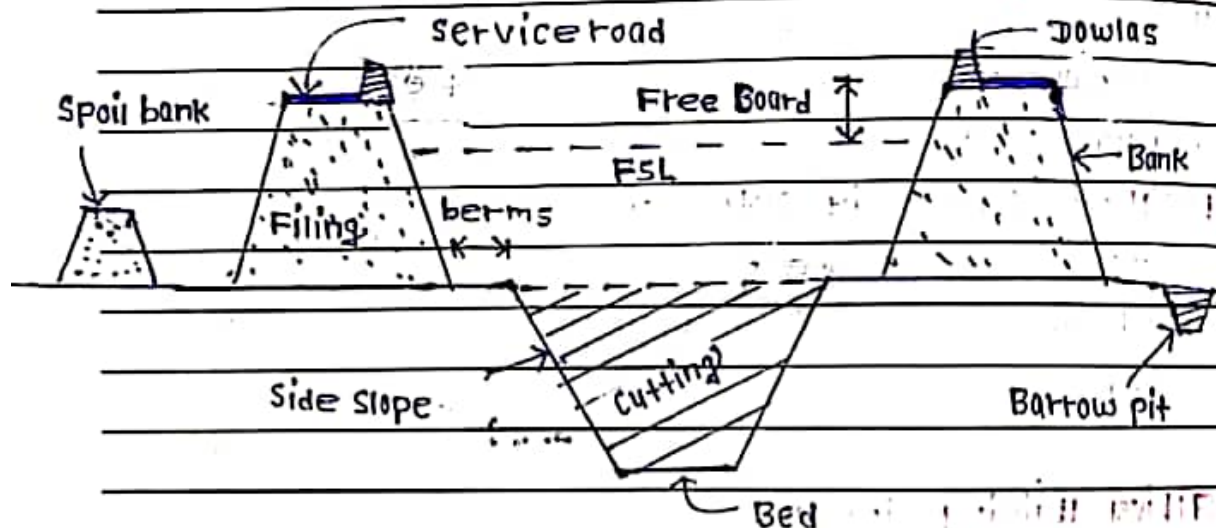


Fig: Typical cross-section of canal.

① Berms

→ **Horizontal distance of land** between inner toe of bank to top edge of cutting is called berms.

→ It provides additional strength to bank.

→ It **protect banks from erosion**.

→ It help in providing wider water.

Note: Minimum width of berms = 0.6 m

② Free Board

→ **Vertical distance** between F.S.L (Full supply level) & top of bank is called free board.

→ It depends size of channel.

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Date : 20 / /

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→ Free board is depends on discharge.

Discharge (m^3/s)	Free Board (m)	Note: Minimum Value of
< 0.3	0.3 (minor)	free board in canal = 0.9m
0.3 - 1	0.4	③ Banks
1 - 5	0.5 (major)	→ primary purpose of banks is
5 - 10	0.6 (branch canal)	to retain water.
10 - 30	0.9	

④ service Roads

→ provided for the inspection purpose & communication.

→ They provided above FSL of the channel.

⑤ Dowlas

→ measure of safety in driving. → provided above inspection road.

→ Generally, height = 0.3m & Wide = 0.6m at the top.

⑥ side slope

→ side slope in cutting is slightly more then side slope in filling.

→ side slope in cutting = 1H : 1V to 1.5H

→ side slope in filling = 1.5H : 1V to 2H : 1V

⑦ spoil banks

→ if volume of cutting is more then volume of filling, the extra earth is disposed normally parallel to canal on the edge of embankment which is known as spoil bank.

⑧ Borrow pit

→ if volume of earthwork in filling is more then volume of cutting, the extra earth taken from borrow pit.

→ width $\leq \frac{1}{2}$ width of canal. → Depth $\nless 1m$.

→ provided along center line of canal. ⇒ Internal borrow pit

→ provided outside the canal. ⇒ External borrow pit.

⑨ Balancing depth

→ if volume of cutting is equal to volume of filling, this depth is considered as balancing depth.

→ It is also known as economical depth.

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Lining of Canals

- Laying of hard surface around the Canal cross-section.
- prevent erosion of bed & side slope of canal due to high velocity of water.

Canal lining Materials

① Hard surface lining

- cement & concrete lining.
- plaster lining.
- brick & tile lining.
- Boulder lining.

② Earth type lining

- Compact earth lining.
- Soil Cement lining.

Advantages of Lining

- seepage control.
- prevention of water-logging.
- Increase in channel capacity.
- Increase in command area.
- Reduction in maintenance cost.
- Elimination of flood dangers.

According to PDSP (Planning & design strengthening project)

Lining type	Maximum Velocity (m/s)	
Dry stone	1.0	
Dry brick	1.0	
Dressed masonry	2.0	
Brick	1.5	
Random Rubble	1.5	
Unreinforced Concrete	2.5	
Shotcrete.	2.5	

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Date : 20 / /

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According to the book "Irrigation engineering & hydraulic structure by S.K. Garg.

Type of lining	Permissible Velocity (m/sec)
Cement concrete lining	1.0 to 2.5
Burnt clay tile lining	1.8
Boulder lining	1.5

For unlined Canal Section

Type of soil	Permissible Velocity (m/sec)
Light loose sand to average sandy soil	0.3 - 0.6
sandy loam, black cotton soil, ordinary soil	0.6 - 0.9
Mooram, Hard soil etc.	1.0 - 1.1
ordinary soils.	0.6 - 0.9
Rock & gravel	1.5

Design of Irrigation Canals

For design of irrigation canal, the method/formula used for design depends on type of canal, i.e., lined or unlined. The common formula used for design of irrigation canal are; Manning's formula, Chezy's formula & Kutter's formula. [A] Design of Non-artificial Canal

① Manning's Formula

→ This is most commonly used formula for canal design.

$$\rightarrow \text{Discharge (Q)} = A \times \frac{1}{n} R^{2/3} S^{1/2}$$

Where; A = flow area

n = Manning's roughness constant = Manning's rugosity coefficient.

R = Hydraulic mean radius = $\frac{A_{\text{reg}}}{\text{Wetted perimeter}}$

S = Longitudinal Slope or bed slope

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

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② Chezy's Formula

$$\rightarrow \text{Discharge (Q)} = A \times C \sqrt{RS}$$

Where: A = flow area

C = Chezy's Constant

R = Hydraulic mean radius

S = channel bed slope.

$$V = \text{Velocity of flow} = C \sqrt{RS}$$

③ Kutter's Formula

$$\rightarrow Q = A \times V \rightarrow Q = A \times \left(\frac{1}{\frac{1}{h} + 23 + 0.00155} \right) \times \sqrt{RS}$$

$$\left(\frac{1 + (23 + 0.00155) \times \frac{h}{\sqrt{R}}}{S} \right) \times \sqrt{RS}$$

Where: h = Kutter's rugosity coefficient.

④ Bazin's Formula

$$\rightarrow Q = A \times V \rightarrow Q = A \times \left(\frac{157.6}{1.81 + \frac{m}{\sqrt{R}}} \right) \times \sqrt{RS}$$

Where: m = Bazin's Constant

Value of Rugosity Coefficient

Very good	Good	Low	Poor
0.0225	0.025	0.0275	0.03

Rugosity Coefficient of different materials

Wood	0.012 - 0.019
Concrete	0.012 - 0.022
Asphalt	0.013 - 0.016
Brick	0.014 - 0.017
Gravel	0.017 - 0.033

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[B] Design of Alluvial Canal

Kennedy's Theory	Lacey's Theory
→ Vertical eddies which generated from the bed of channel only.	→ Vertical eddies which generated from the bed & side of channel.
→ Introduced critical velocity	→ Introduced silt factor
$V_0 = 0.55 m D^{0.64}$	$f = 1.76 \sqrt{m}$
→ Not give bed slope formula.	→ Give bed slope formula
→ Kutter formula use for finding mean velocity.	→ own formula use for finding mean velocity.
→ Regime channel.	→ True, initial, final regime.
→ Design is based on trial & error method.	→ Does not involve trial & error method.

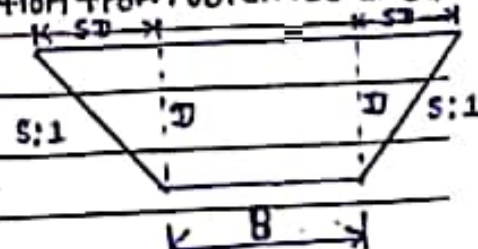
Drawbacks in Kennedy's Theory.

- Silt grade & silt charge were not defined.
- Kennedy's not give any slope equation.
- He aimed to find out only regime condition.
- Kennedy's use Kutter's eqn for determination of mean velocity.
- Design by trial & error method.
- Only applicable to irrigation channel.

Design procedure by Kennedy's Theory.

- Assume suitable depth of canal.
- Determine the critical velocity $(V_0) = 0.55 m D^{0.64}$
- Determine the area $(A) = \frac{\text{Discharge } (Q)}{\text{Velocity } (V)}$
- Determine the channel cross section from obtained area.

$A = BD + SD^2$
 $P = B + D\sqrt{5}$


- Determine hydraulic mean radius

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

Answer

- ⑥ Calculate actual mean velocity (V), by Kutter's formula etc.
- ⑦ $V_0 = V$ (OK), otherwise assumed depth again & Repeat.

Design procedure by Lacey's Theory

- ① Determine silt factor, $f = 1.76 \sqrt{m_r}$
- ② Determine the Velocity, $V = \left[\frac{Q f^2}{140} \right]^{1/6}$
- ③ Determine the area of channel section, $A = \frac{Q}{V}$
- ④ Determine Wetted perimeter, $P = 4.75 \sqrt{Q}$
- ⑤ Determine hydraulic mean depth, $R = \frac{5(V^2)}{2(f)}$
- ⑥ Determine bed slope, $S = \frac{f^{5/3}}{3340 Q^{1/6}}$

Geometric parameters for Different Canal Sections.

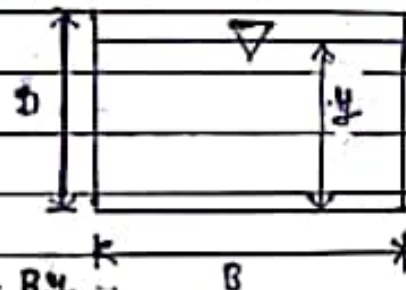
① Rectangular section

→ Area $A = B \times y$

→ Wetted perimeter $P = B + 2y$

→ Top Width $T = B$

→ Hydraulic mean Radius $R = \frac{A}{P} = \frac{By}{B+2y}$



② Triangular channel

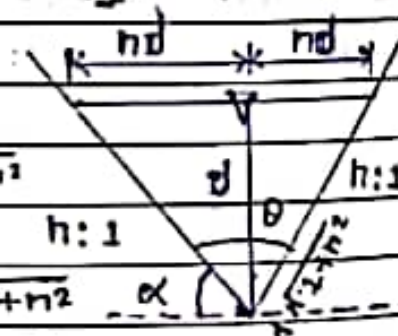
→ Area $A = 2 \times \frac{1}{2} n d^2 = n d^2$

→ Wetted perimeter $P = 2 \times d \times \sqrt{1+n^2}$

→ Top Width: $T = 2 \times n d$

→ Side slope $= \sqrt{d^2 - (nd)^2} = d \times \sqrt{1+n^2}$

→ Hydraulic mean Radius $R = \frac{A}{P} = \frac{n d^2}{2 d \sqrt{1+n^2}}$



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Date : 20 / /

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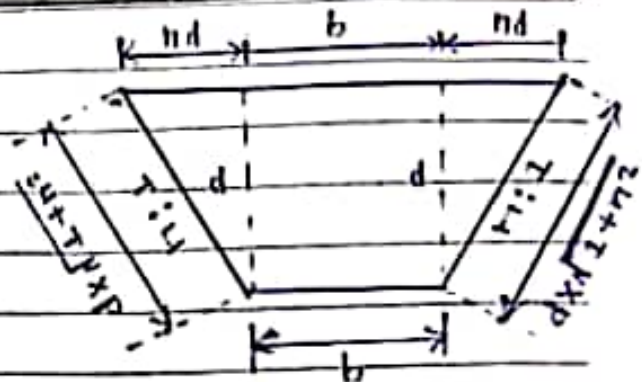
③ Trapezoidal channel

$$\rightarrow A = bd + nd^2$$

$$\rightarrow P = b + 2d\sqrt{1+n^2}$$

$$\rightarrow T = b + 2nd$$

$$\rightarrow R = \frac{A}{P} = \frac{bd + nd^2}{b + 2d\sqrt{1+n^2}}$$



Economic canal section

→ The **Wetted perimeter is minimum**.

→ For given discharge, this canal has minimum cross-sectional area

→ for given cross-sectional area, this canal has max^m discharge capacity

① Economic Rectangular section

$$\rightarrow A = 2y^2 \rightarrow P = 4y \rightarrow R = \frac{y}{2} \rightarrow D = \frac{B}{2}$$

② Economic Triangular section

$$\rightarrow h = 1, \rightarrow \alpha = 45^\circ \rightarrow \theta = 90^\circ \rightarrow R = \frac{d}{2\sqrt{2}}$$

③ Economic Trapezoidal section

$$\rightarrow \text{Top width} = 2 \times \text{side slope length} \rightarrow R = \frac{y}{2} \rightarrow \text{side slope} = 60^\circ$$

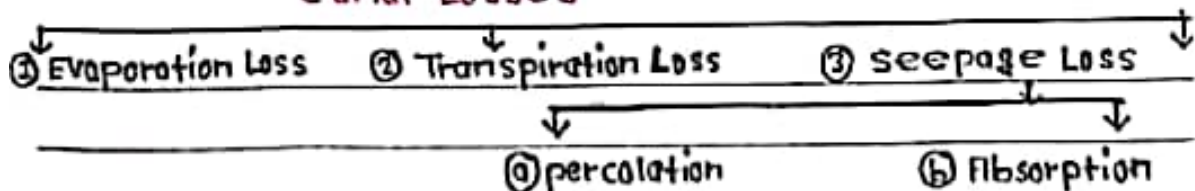
④ Economic circular section

$$\rightarrow \text{flow depth} = 0.95 \times \text{diameter}$$

$$\rightarrow \text{Hydraulic mean depth} = 0.29 \times \text{diameter}$$

$$\rightarrow \text{Angle with center} = 5.37 \text{ radians} = 308 \text{ degrees}$$

Canal Losses



① Evaporation Loss

→ **Small** percentage of total loss in canal.

→ **1-2%** (maximum 7% in summer)

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② Transpiration Loss

- Loss of Water through the plants, vegetation & weeds.
- Control by keeping the banks clean from the growth of vegetation & weeds.

③ Seepage Loss

- Major portion of loss in an unlined canal.

④ Percolation

- If water table is close to the channel bed, flow of water to water table from canal bed.

⑤ Absorption

- If water table is at a greater depth from channel bed, the water seeping from the channel is unable to reach the ground water reservoir, but saturation is formed round the channel section.

Types of Maintenance of Canal

① Routine or regular or normal maintenance

- Normally done annually.
- Generally two times before Rabi & Kharif crop.
- Maintenance of intake, operational gate, removal of weeds, rodents & debris.

② Deferred maintenance

- Including any work necessary to regain the lost flow capacity in canals, reservoirs & structure when compared to the original design.

③ Special maintenance

- Including repairs of damage caused by major disaster such as floods, earthquakes & typhoons.
- Also known as emergency maintenance.

Answer

④ Periodic maintenance

→ It is done quarterly, half yearly or yearly basis to get proper service from the canal. Reshaping of canal, lining of canal, maintenance of structure, removal of sediment deposits etc.

Minimization of Losses in Canals

- Lining of irrigational canal.
- maintenance of irrigation canal.
- Removal of Vegetation & Weeds from Canals
- Using short Length Canal.
- Sprinkler & drip irrigation system can be used.

Canal Structure

- | | |
|-----------------------------|-----------------|
| ① Cross Drainage structures | ④ Escapes |
| ② Regulators | ⑤ Canal outlets |
| ③ Falls/drops | |

Cross Drainage structures

The structure constructed at the crossing point for the easy flow of water canal & drainage in the respective direction are known as Cross drainage structures.

→ The nature of cross-drainage structure may be different at different place, depending upon the bed of canal.

Types of Cross Drainage Structures

1. Canal passes over the drainage

The irrigation canal passes over the drain, if Full supply level (FSL) of canal is above high flood level (HFL) of drain.

→ Irrigation canal is taken over the drainage.

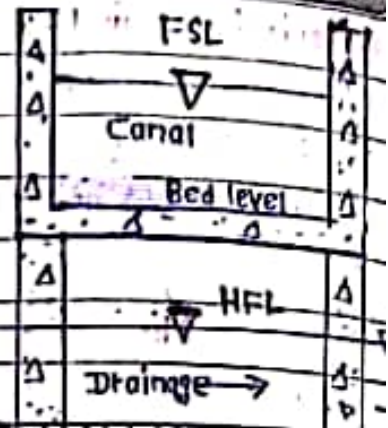
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(a) Aqueduct

→ Bed level of canal is higher than the high flood level (HFL) of drainage, then the cross-drainage structure provided is said to be aqueduct.

→ Drainage water passes clearly below the canal.

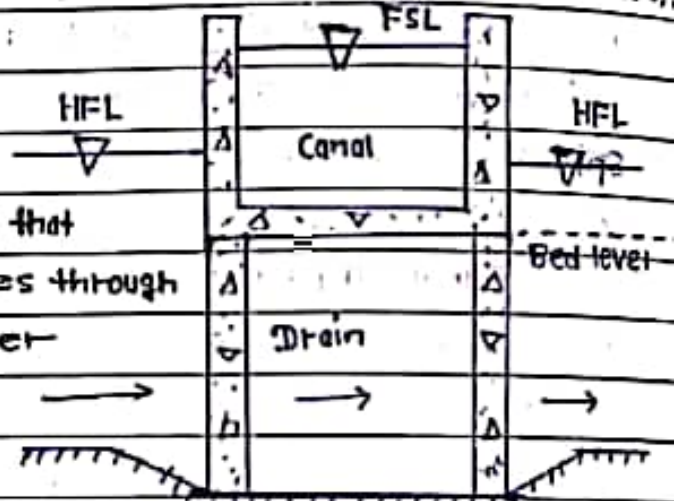
→ drainage water flow freely under gravity. (open channel flow)



(b) Siphon aqueduct

→ Bed level of canal is lower than high flood level (HFL) of drainage, so that the drainage water passes through the aqueduct barrels, under syphonic action, then the structure provided is known as siphon aqueduct.

→ Drainage water flow under pressure.



(c) Drainage passes over the canal.

The drainage passes over the canal, if High Flood level (HFL) of drainage is above Full supply level (FSL) of canal.

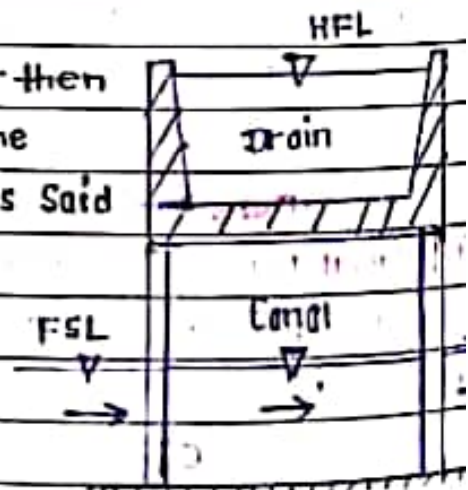
(a) Super passage

→ Bed level of drainage is higher than the Full supply level of canal, then the cross drainage structure provided is said to be super passage.

→ Canal water passes clearly below the canal.

→ Reverse of aqueduct.

→ Canal water flow freely under gravity.



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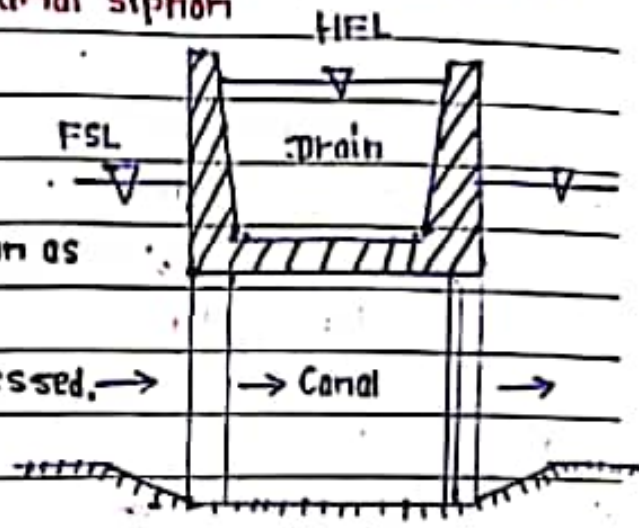
(A) siphon super passage / canal siphon

→ Bed level of drainage is lower than the full supply level of canal, then the structure provided is known as canal siphon.

→ Flooring of canal is depressed.

→ Canal water flows under pressure.

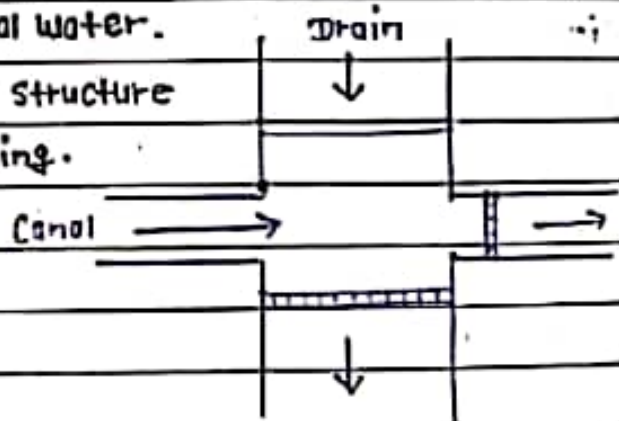
→ Reverse of siphon aqueduct.



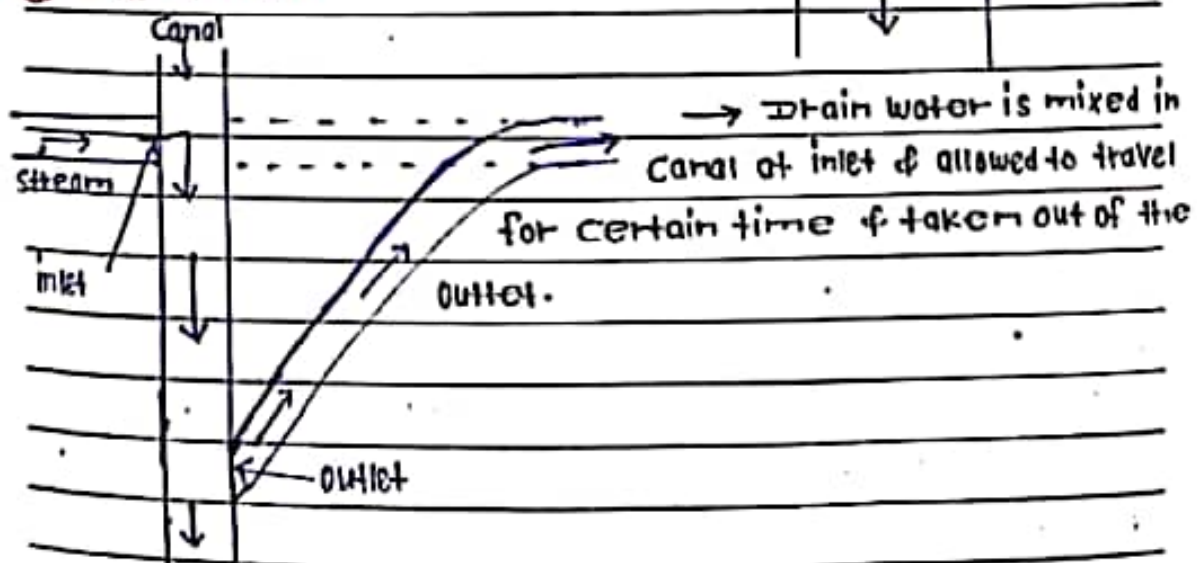
(C) Drainage admitted into Canal

The bed level of canal is equal to the bed level of drainage. Drain water mixed with canal water.

(A) Level Crossing → the structure provided is called level crossing.



(B) Inlet & Outlet



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Regulators

→ Regulators are constructed to distribute the water to branch canal, distributaries to provide the required discharge at the required time.

Types of Regulators

① Canal head regulator

→ Canal head regulators is provided at the head of main canal to withdraw the required amount of discharge from the river.

→ There is only one canal head regulator in canal system.

② Head regulator / Distributary head regulator

→ Regulator constructed at the off taking point, or head of distributary or off taking canal.

Functions

→ To control discharge of off taking canal or branch canal.

→ To control the entry of silt into off taking canal.

→ To serve as meter for measuring discharge.

③ Cross Regulators / Distributary Cross regulators

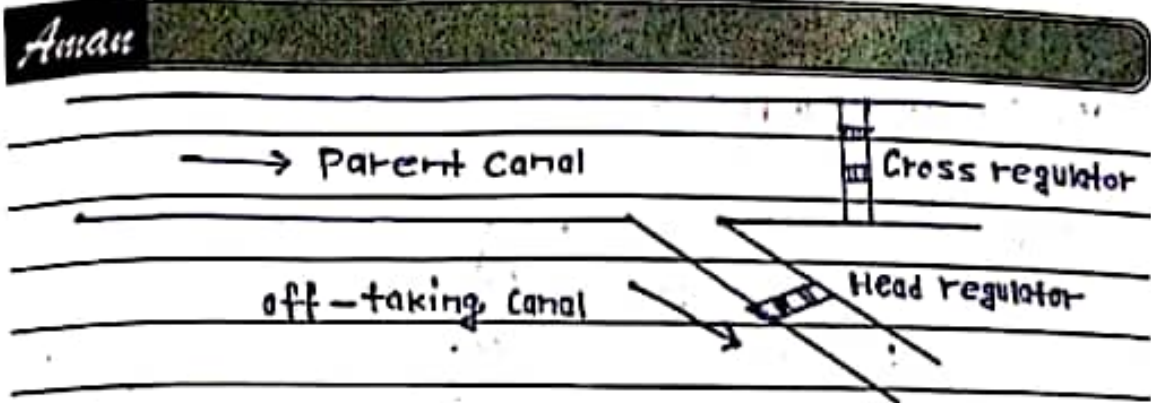
→ Regulator constructed in parent canal downstream of an off-taking canal.

Functions

→ To control the flow of water in entire canal irrigation system

→ To act as discharge meter to measure discharge flowing in the parent canal.

→ When water level in main canal is low, it helps in heading up water on the upstream & to feed off-taking channels to their full demand in rotation.



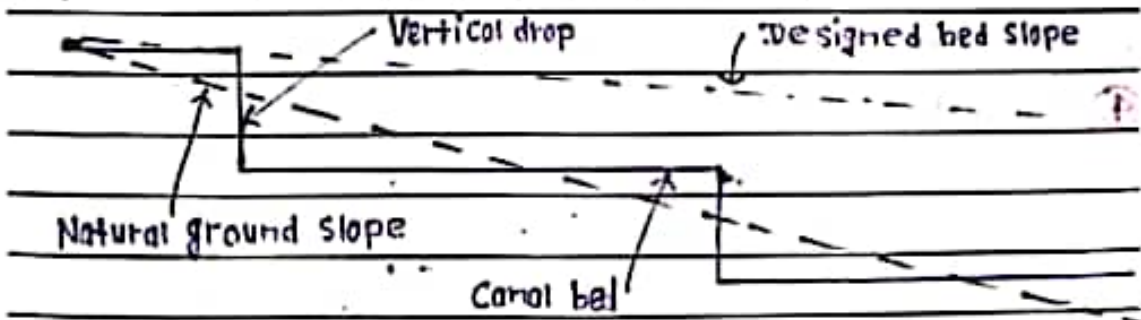
Falls & Drops Structures

→ Whenever the available natural ground slope is steeper than design bed slope of channel, the difference adjusted by constructing vertical fall in canal bed at suitable intervals.

→ Such a fall in a natural canal bed without any structure will not be stable. & to retain this fall, a masonry/concrete structure is constructed. Such structure is called canal fall.

→ Canal fall should be provided with energy dissipating structure.

→ Fall & drop structure are more required in watershed & side slope canal as compared to contour canals.



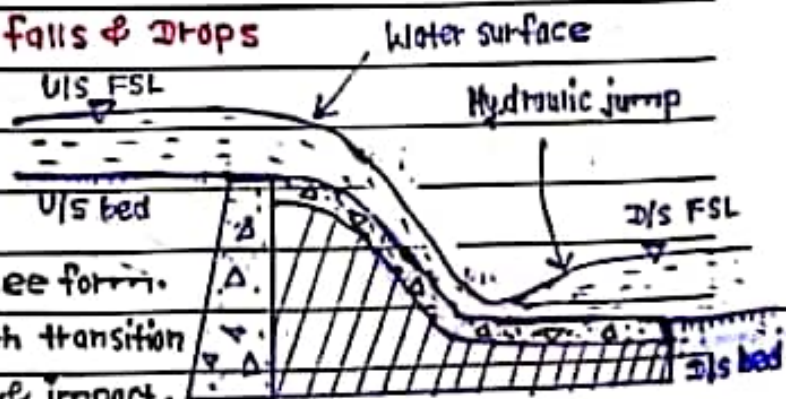
Types of falls & Drops

① Ogee Fall

→ This type of fall has gradual convex & concave surface. i.e., ogee form.

→ Ogee provide smooth transition & reduce disturbance & impact.

→ A hydraulic jump is formed which dissipates a part of K.E.



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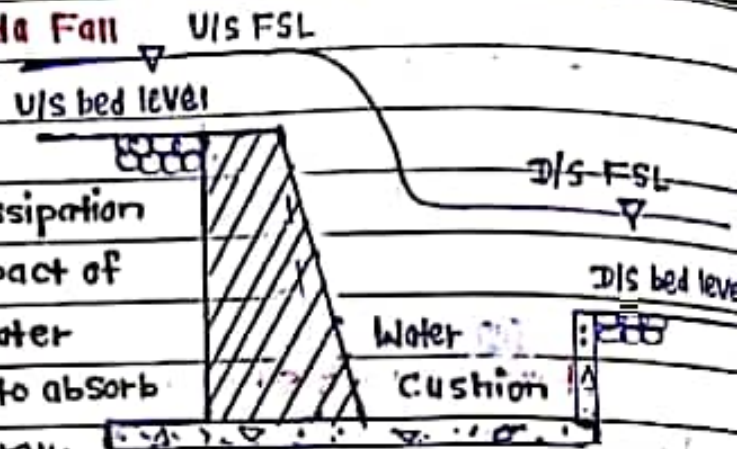
② Vertical fall / Sarda Fall

→ the water drops vertically.

→ The energy dissipation is achieved by impact of drop on the floor, water cushion is provided to absorb the impact of energy.

→ Suitable for discharge upto $15 \text{ m}^3/\text{sec}$.

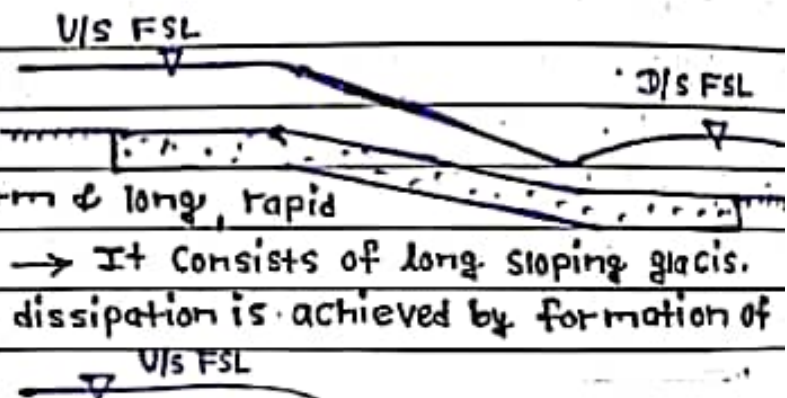
→ Suitable for drop height upto 1.5 m .



③ Rapid Fall

→ The slope of natural ground surface is uniform & long, rapid fall is suitable. → It consists of long sloping glacis.

→ The energy dissipation is achieved by formation of hydraulic jump.

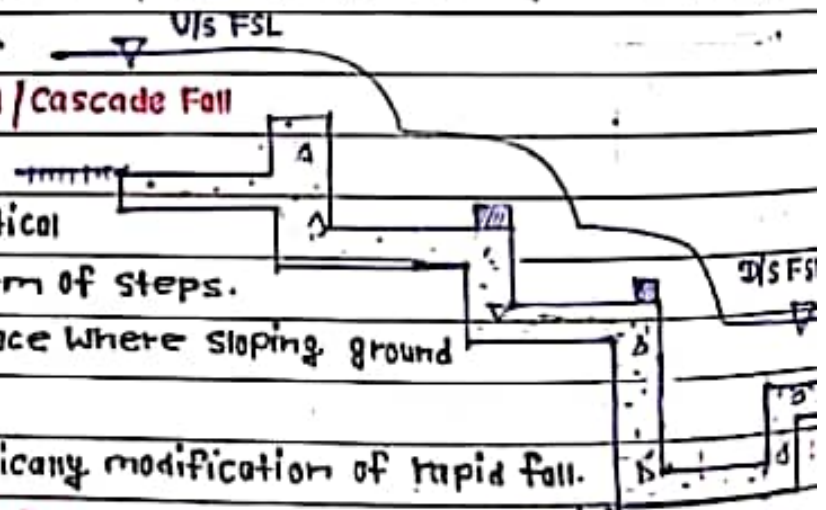


④ Stepped Fall / Cascade Fall

→ It consists of series of vertical drops in the form of steps.

→ Suitable in place where sloping ground is very long.

→ It is practically modification of rapid fall.

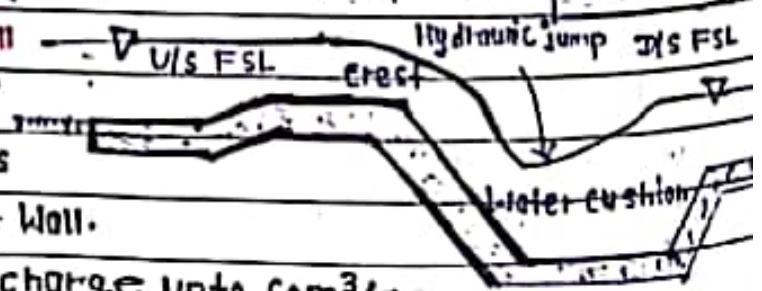


⑤ Straight glacis Fall

→ It consists of straight sloping glacis provided with crest wall.

→ suitable for discharge upto $60 \text{ m}^3/\text{sec}$.

→ drop height = 1.5 m .



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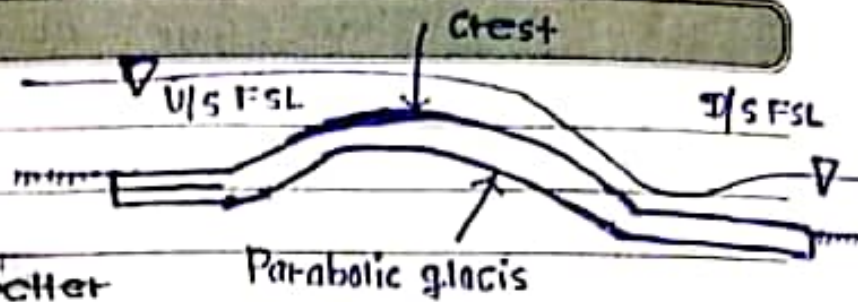
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⑥ Montague Fall

→ The profile is slightly modified to parabolic type for better energy dissipation.

→ difficult to construct & costly.

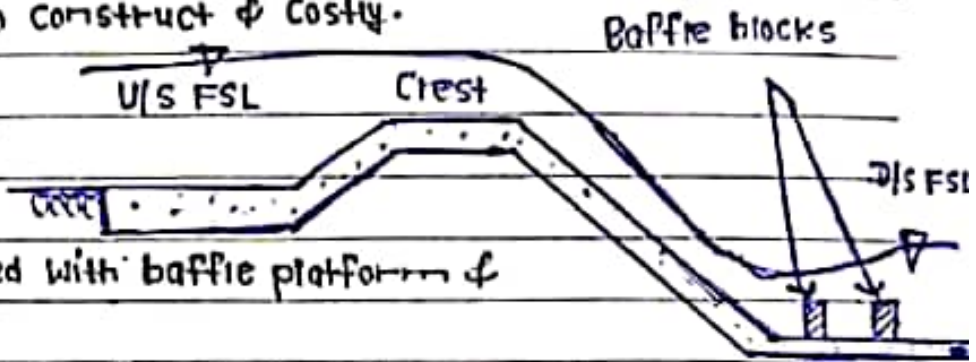


⑦ Baffle Fall

→ A straight glacis type

for when added with baffle platform & baffle wall.

→ quite suitable for all discharges & drops more than 1.5m.



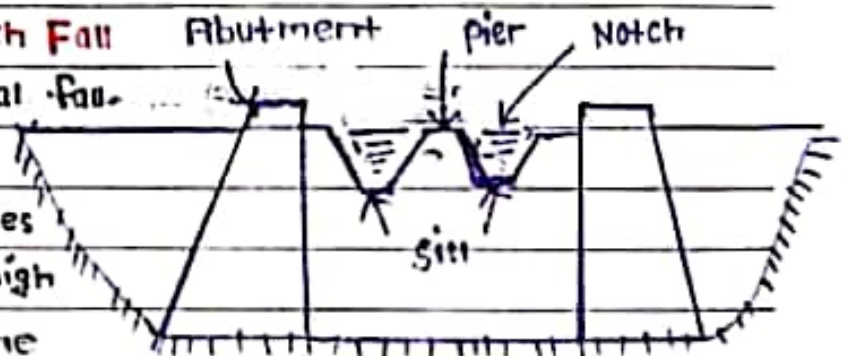
⑧ Trapezoidal notch Fall

→ The trapezoidal fall

consists of number of trapezoidal notches constructed on a high Crest Wall across the

channel with a smooth entrance & flat circular lip projecting downstream from each notch to spread out the falling jet.

→ These falls do not affect the depth of water in the canal on upstream of the fall.



Canal Escapes

→ It is a side channel constructed to remove surplus water from an irrigation channel into a natural drain.

→ surplus due to

① Mistake in design or operation.

② Difficulty in regulation at the head

③ Excessive rainfall in upper reaches.

④ outlet below channel bed level.

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Types of Escapes

① Surplus escape

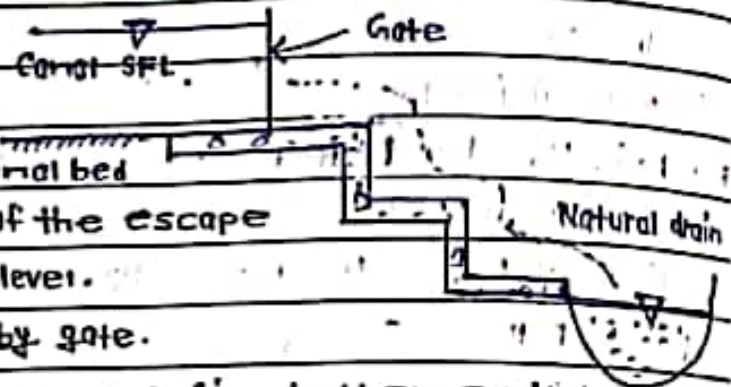
→ It is also called

regulator type.

→ In this type sill of the escape is kept at canal bed level.

→ flow is controlled by gate.

→ preferred now days. → Give better control.

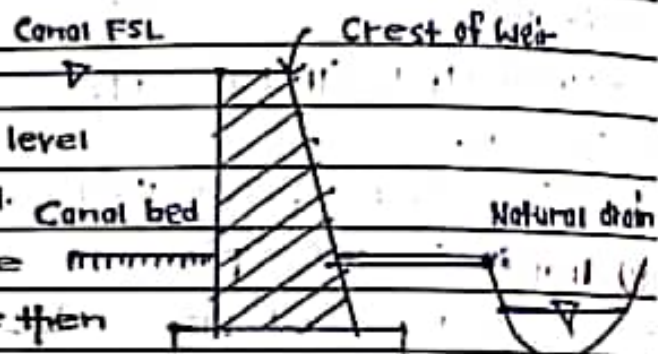


② Weir/Tail escape

→ The crest of the weir wall is kept at same level as Full supply level of canal.

→ When water level in the channel become more than designed FSL, the water spills out.

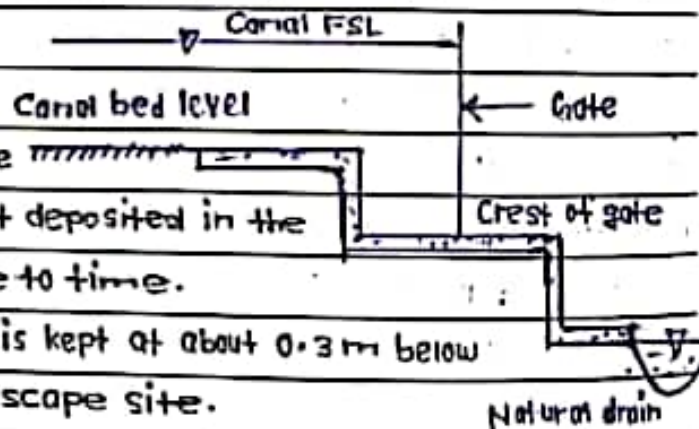
→ tail escape provided at the tail end of the canal.



③ Scouring escape

→ This escape is constructed for the purpose of scouring of excess silt deposited in the head reaches from time to time.

→ sill of the regulator is kept at about 0.3 m below the canal bed level at escape site.



Outlets/Modules

→ Canal outlet is a small structure built at the head of watercourse. → It is provided to supply water to the watercourses from the distributary.

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Types of outlets.

① Non-modular outlets

→ Discharge depends upon the water level of distributary & water course. → The discharge through the outlet varies with change in water level of watercourse & distributary both. eg; open sluice,

② Semi-modular outlets or Flexible modules

Drowned pipe outlet
→ Discharge depends only water level of distributary & not water course. → The discharge changes with the change in water level of distributary only. example; pipe outlet, open flume etc.

③ Modular outlets or Rigid modules

→ Discharge is constant & does not depend on the water level of distributary & watercourse. → Example; Gibb's module, Khanna module, Foote module etc.

Spillways

Spillway is a structure constructed at a dam site for effectively disposing surplus water from the reservoir.

→ Just after the reservoir gets filled upto the normal pool level, water starts flowing over the top of the spillway crest.

→ Spillway constructed on the dam body or outside dam body.

→ Spillways are also constructed on canals to release excess water in the canal.

Need of Spillways

→ To remove surplus water from the reservoir.

→ To save the dam from failure due to overflow of water.

→ To remove excess water from the canal.

→ To dissipate the energy of water flows in main channel.

Component of Spillway

① Control Structure : major component of a spillway which regulates the outflows from the reservoir.

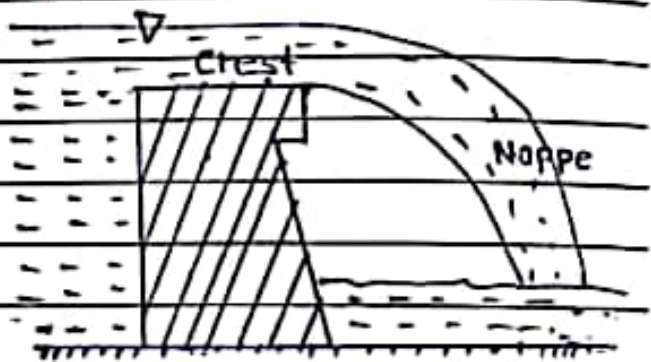
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- ② **Discharge channel** main function of this is to convey the water safely from the reservoir downward to the river.
- ③ **Terminal structure** Energy dissipators provided on the downstream side of the spillway.
- ④ **Entrance & outlet channel** Entrance channel to draw water from the reservoir & convey it to control structure
Outlet channel to convey the spillway flow from the terminal structure to river channel below the dam.

Types of spillways

① Straight drop Spillway

- Simplest type of spillway.
- Water drops vertically from crest of spillway.
- The downstream face of spillway is vertical or nearly vertical.



- It is provided on low height dams or thin arch dams.
- To avoid erosion on the downstream, a plunge pool is provided.

$$\rightarrow \text{Discharge (Q)} = C_d \times L \times H^{3/2}$$

Where: C_d = coefficient of discharge

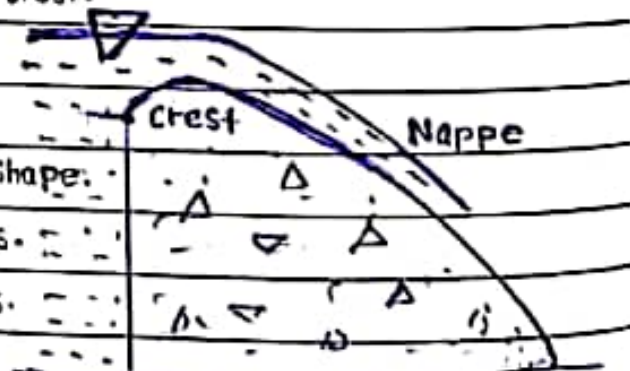
L = length of spillway.

H = head over spillway crest.

$$\therefore Q \propto H^{3/2}$$

② Ogee or overflow spillway

- The surface of spillway over which water flows has ogee shape.
- Suitable for all types of dams.
- Generally used for high dams.



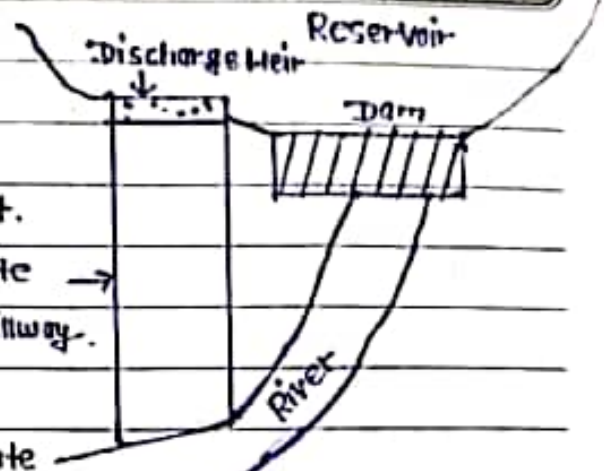
$$\rightarrow Q = C_d \times L \times H^{3/2}$$

$$\therefore Q \propto H^{3/2}$$

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③ Chute or Trough spillway

- chute spillway. consist of a steeply sloping open channel.
- placed along a dam abutment.
- The flow over a chute spillway, is super critical flow.

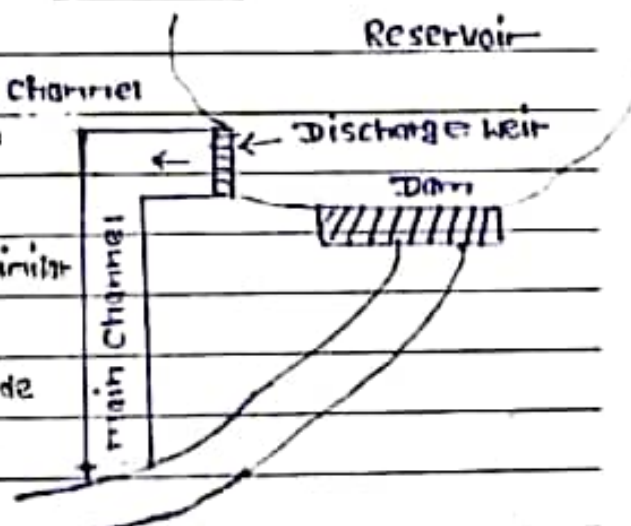


- The direction of flow in a chute spillway is perpendicular to the axis of discharge weir.

$$\rightarrow Q = C_d \times L \times H^{3/2} \quad \therefore Q \propto H^{3/2}$$

④ Side channel spillway

- Water first flow in side channel
- Side channel & then turns 90° & then flow in main channel.
- Except side channel, it is similar to chute spillway.
- The choice betn chute & side channel spillway depends on site condition.

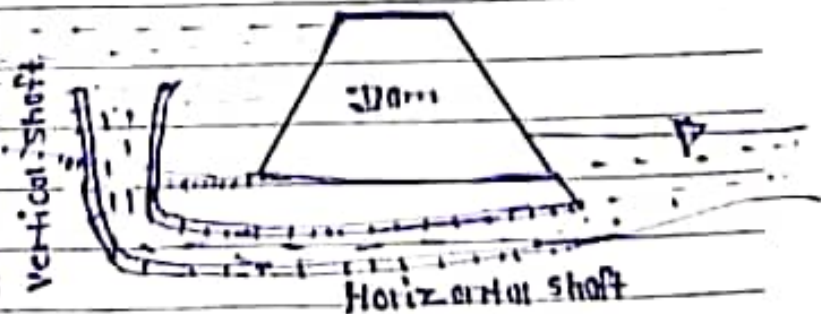


- Water in main channel flows parallel to the direction of discharge weir

$$\rightarrow Q = C_d \times L \times H^{3/2} \quad \therefore Q \propto H^{3/2}$$

⑤ Shaft spillway

- Water enters into a vertical shaft which conveys this water in horizontal tunnel which finally discharges water into the river downstream.



- It is also called morning glory spillway.
- Most beautiful spillway.

Answer

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

Where; C_d = coefficient of discharge

A = Area of shaft.

H = Head difference

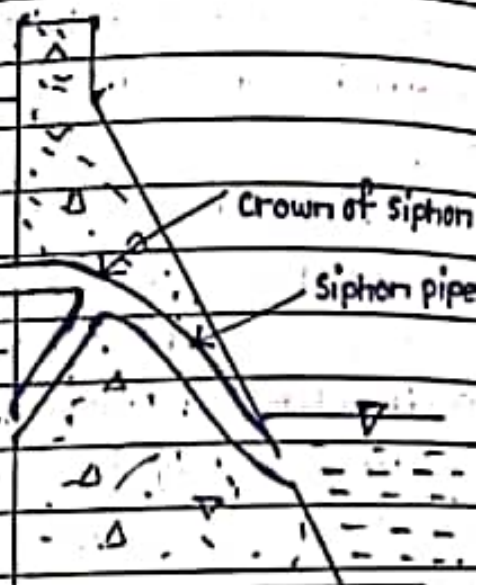
⑥ Siphon spillway.

→ Consists of siphon pipe, one end of which is kept on the upstream Air Vent & in contact with reservoir, while other end discharge water on the downstream side.

→ When the Valley is narrow & no space is available

for constructing a separate spillway, siphon pipes can be installed in the dam body.

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



River Training

River training work can be define as the hydraulic structure constructed in the river so as to train & regulate the flow in desired way. → main purpose is to establish the river channel along certain alignment.

→ River training work is generally required when the river is meandering type.

Objective of River Training

→ To protect river banks from erosion.

→ To ensure effective disposal of sediment load.

Aim

- To provide minimum water depth required for navigation.
- To provide safe passage of the flood discharge without overtopping the banks.
- To protect the surrounding area from flooding.
- To prevent the river from changing its path.

Classification of River Training

① High Water Training

- Also called as training for discharge.
- Primary purpose of flood control.
- The structure constructed for the purpose of quick & safe disposal of floods during high flood period to protect the adjoining land from inundation.

② Low Water Training

- Also, called as training for depth.
- Purpose of providing sufficient water depth in the channels during low water periods for navigation or transportation purpose.

③ Mean Water Training

- Also called as training for sediment.
- The structure constructed for the efficient disposal of suspended load & bed load & preserve the channel in good shape.

Method of River Training

① Marginal embankments or Levees or dykes

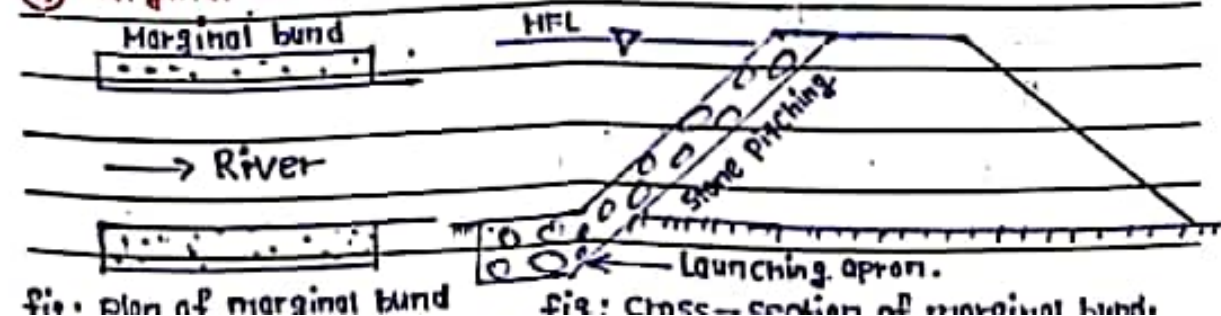


Fig. Plan of marginal bund

Fig. Cross-section of marginal bund

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→ It is an embankment structure which runs parallel to the river either on both sides or on one side for some suitable length.

→ These embankments prevent the entry of the flood water to adjoining towns, important land etc.

→ A levees or dyke is mainly used for flood control mainly by controlling the river & not by training the river.

Ⓐ Guide Banks or Guid bunds or 'Bell's bunds'

→ The guide banks are the embankment structure constructed along the river to guide the river flow in the axial path.

→ Guide banks prevent the meandering of river.

→ They are constructed upstream of every hydraulic structure like bridge, weir, barrage etc.

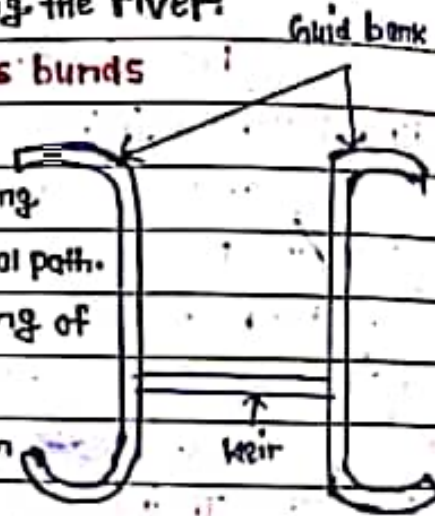


fig: plan of guid bank

Ⓑ Spurs or Groynes

A Spurs is the structure which is constructed at the bank of the river & is projected towards the river.

→ It is constructed to keep the flow away from the river bank & to avoid the bank cutting.

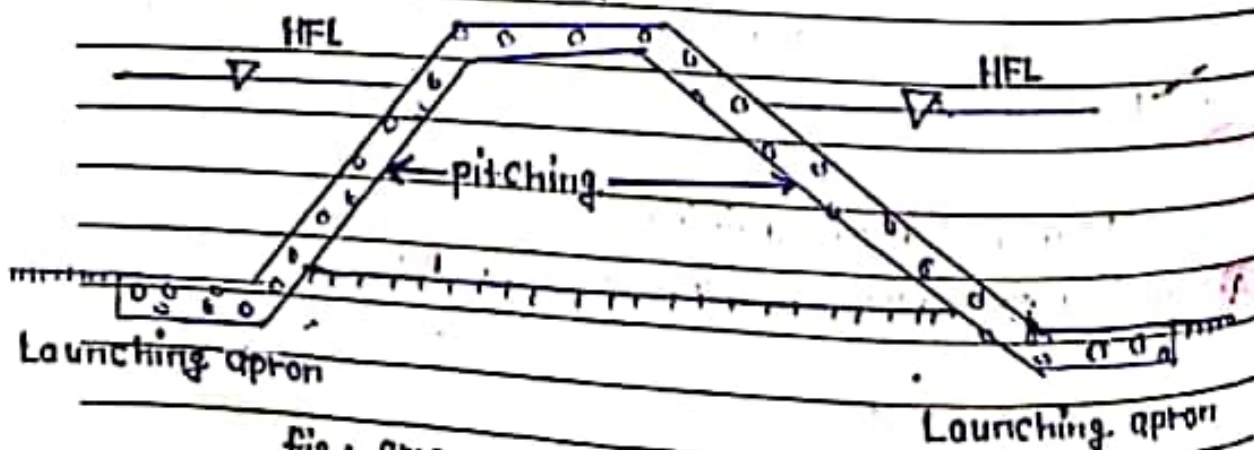


fig: Cross-section of spurs

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Objective of spurs construction

- To train the river along the desired course by attracting or deflecting or repelling the flow in the desired direction.
- To reduce concentration of flow at particular point of attack
- To create slack zone for silting up the area.
- To protect a bank by keeping the flow away from it.
- To contract a wide river for the purpose of increasing the river width for navigation.

Classification of spurs

① Based on the method & materials of construction

④ **Impermeable spurs** These spurs do not allow the flow of water through them. → They consist of either rock fill or core of sand & gravel or alluvial soil available in the river.

→ Top & sides are protected by the pitching of stones & concrete

⑥ **Permeable spurs** These spurs allow the flow of water through them

→ They obstruct the flow & allow the deposition of the sediments carried by the river. → They are also called sedimentation spurs.

② Based on height of spurs

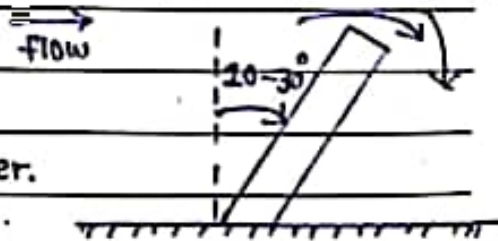
④ **Submerged spurs** if depth of water is sufficient in the river & spurs are in submerged condition.

⑥ **Unsubmerged spurs** if spurs are large enough & are not submerged

③ Based on function

① **Attracting spurs**

- pointing on the downstream of river.
- They attract flow of water.
- They create the scour holes on the downstream.
- Provided on the opposite side of bank which is to be protected.
- They make acute angle with direction of flow.

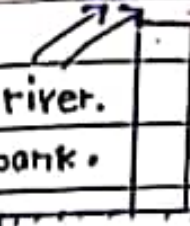


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Flow

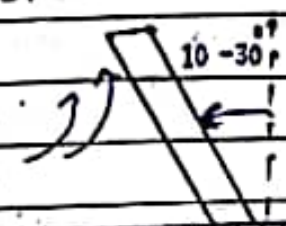
(ii) Normal Spurs

- They are aligned perpendicular to river.
- They deflect the water away from the bank.
- They are also called as deflecting spurs.
- These are the mostly used type of spurs.
- They make right angle with flow direction.



(iii) Repelling Spurs

- pointing on the upstream of river.
- They repel flow away from the bank.
- They create still water pocket on upstream side & suspended sediment gets deposited in the pocket.
- They make obtuse angle with flow direction.
- They are more effective & do not cause any problems as compared to the attracting groynes.

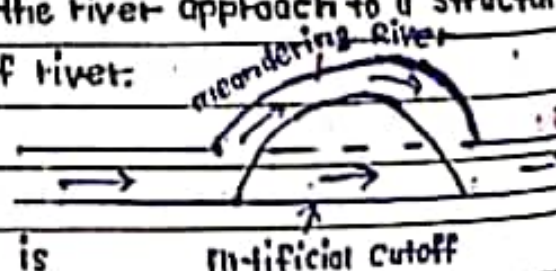


Note: spacing for convex bank — 2 — 2.5 times, length of spurs.
for concave bank — equal to length of spurs:

(iv) Artificial Cutoff

An artificial cutoff is constructed in the meandering river to direct the flow along the fixed watercourse.

- It is constructed when the meander is regularly increasing & valuable land & property, is about to be wasted.
- It is used for straightening the river approach to a structure.
- Artificial cutoff decrease length of river.



(v) Pitched Island

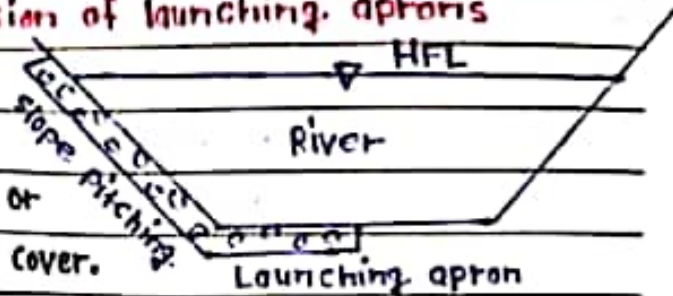
A pitched island is a artificially constructed island in the river bed & is protected by stone pitching.

- Due to the turbulence constructed in the vicinity, the river channel around the island gets deepened & thus, attracting the river water towards itself & holding the water permanently.

Answer

(F) pitching of banks & provision of launching aprons

→ Banks of the river are directly protected by the stone pitching, or by concrete blocks or by brick lining, or by vegetative cover.



→ The slope of the pitching may vary from 1V : 1H to 1V : 2H.

→ The launching apron may also be provided to prevent the scour at the toe.

Water Logging

Water logging is the process due to which the productivity of the crops gets decreased due to rise in water table. Water logging results in ill aeration & salinity, that is why growth of plants is affected.

III Aeration : plant needs different nutrients like nitrates, phosphate for their growth & development. nitrates are provided by bacteria under a process called nitrification. these bacteria need oxygen for their survival. the supply of oxygen gets cut off when land becomes ill aerated resulting in death of bacteria & fall in the production of nitrates. as a result, the growth of plant reduce.

Salinity : When water table rises up to the root zone of plant, there is evaporation by capillarity. due to this, the salt present in water get deposited in the root zone of crops. the concentration of these alkali salt present in the root zone of crop has corroding effect on the plant which prevent growth & ultimately, plant fades away. such soil is called saline soil & the phenomenon is called salinity.

Effect of Water Logging

→ Rise of salt.

→ Fall of temperature

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- Disease of crops.
- Decrease in capillary water.
- Affecting soil nutrients.
- Growth of weeds & aquatic plants.
- Difficulty in cultivation.
- Defective air circulation.
- Effect on human health.

Causes of Water Logging

- over & Intensive irrigation.
- Impervious obstruction.
- seepage from canal system.
- seepage of water through adjoining high lands.
- Excessive rains.
- Submergence due to floods.
- Irregular or flat topography.

Preventive Measures of Water Logging

- Reducing intensity of irrigation.
- Adopting crop rotation.
- Provision of artificial drainage system.
- Improving natural drainage of the area.
- Lining canals & watercourses.
- Introduction to special irrigation method.
- optimum use of water.
- providing intercepting.

Remedial measure of Water Logging

- Construction of surface drains.
- Construction of subsurface drains.
- Construction the outlets.
- Leaching.

Status of Irrigation Development in Nepal

Total area of country = 147181 ha

Answer

Water Resources & Hydropower potential of Nepal

- Nepal is gifted with large water potential as compared to the size of the country.
- There are more than 6000 rivers in Nepal.
- The four major river basins in Nepal are Koshi, Gandaki, Narayani, Karnali & Mahakali river basins.
- Average annual runoff within the country is 225 Billion cubic meter
- Ground water in the country is approximately around 11.5 Billion cubic meters.

Water Resources potential of Karnali province

- The exact water resource potential of Karnali province alone is not to the information of author.
- The major water resource in Karnali province is Karnali river.
- The river originates from south of Mansarovar & Rakas lakes in Tibet, China
- The river flows through Karnali province.
- The river also flows through Sudurpashchim province.
- The major river system in Karnali river basin are West seti river, Bheri river, Humla Karnali, Mugu Karnali, Sinja, Tila, Lohore & Thuli god.
- The average annual runoff in Karnali river at Chisopani is estimated to be 44 Billion cubic meters.
- The ground water potential in Karnali basin is around 3.36 Billion cubic meters per year.
- The Karnali province is also gifted with number of lakes.
- Rara lake, Shy-phoksundo lake, Burbule lake, Sarpu Dha (Rukum), Mata tal, etc.
- There are 936 lakes & ponds in Karnali province.

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According to "Water & energy Commission Secretariat" (WECS)

Province	Power potential (MW)	% Power potential
Koshi	22,619	31.2
Madhes	275	0.4
Bagmati	10,568	14.6
Gandaki	14,981	20.7
Lumbini	2,677	3.7
Karnali	13,702	18.9
Sudurpashchim	7,772	10.6
	72,544	100

Earlier, Estimated Gross hydropower potential of Nepal is 83,000 MW. The latest study, 72,544 MW.

Hydropower potential of Karnali province

The WECS has conducted hydropower at recent. As per the report, the gross hydropower potential of Karnali province is 13,702 MW, which is 18.9% of the total hydropower potential of the country. The rivers which contribute to the hydropower potential in the province are mainly Karnali & Bheri.

There are no. of projects under study & under construction in the basin. There are number of projects with capacities ranging from 0.5 to 1000 MW.

Aman

Er. Iswar Rawat

Engineer

Highway Engineering

Transportation Engineering

→ The application of scientific principle & knowledge for planning function design, operation & management of facility for safe, rapid, comfortable movement of people & goods.

→ Movement of people is known as **passenger transportation**.

→ Movement of goods is known as **freight transportation**.

Roles of Transportation system

→ social development.

→ Industrial development.

→ Economical development.

→ Cultural development.

Modes of Transportation system

[A] Primary Modes

① Land Way: ^{Roads}
→ (a) Road Way: Highway, Street (Bus, car, container etc).
→ (b) Rail Way: Rails (train, wagon, container etc).

② Waterway: River, lake, sea, ocean (Ship, boat etc).

③ Airway: Air-route (plane, aircraft, helicopter etc).

④ Spaceway: Space-route (satellite, rocket, etc)

[B] Secondary Modes

① Ropeway: Cable (car, carriage, chair etc)

② Canal: Irrigation Canal (water)

③ Pipe line: pipe (water, gas, sewer)

④ Belt conveyor: Belt (aggregates in crusher plant)

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Major Modes of Transportation system

- ① Roadways/ highway
- ② Airways
- ③ Railways (Janakpur — Jayanagar)
- ④ Waterways (Kali Gandaki river)

Advantages of Road Transport

- Wide geographical coverage.
- Flexibility
- Door to door service
- Time management
- Highest employment potential
- Economy
- personalized travel & service.

Disadvantages of Road Transport.

- Land coverage.
- Accident
- Environmental pollution.
- Energy consumption.
- Problem of parking.

Highway Engineering

- Highway engineering is deals with the art of science & techniques of planning, design, construction & maintenance of roads & highway.

Scope of Highway Engineering

- Highway development, planning & location.
- Highway design (structure, pavement & drainage design)
- Highway maintenance.
- Traffic control & operation.
- Road side development.
- Highway construction materials, equipments & technology.
- Highway finance, economics & administration.

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Historic Development of Road.

→ The oldest modes of travel = Footpaths

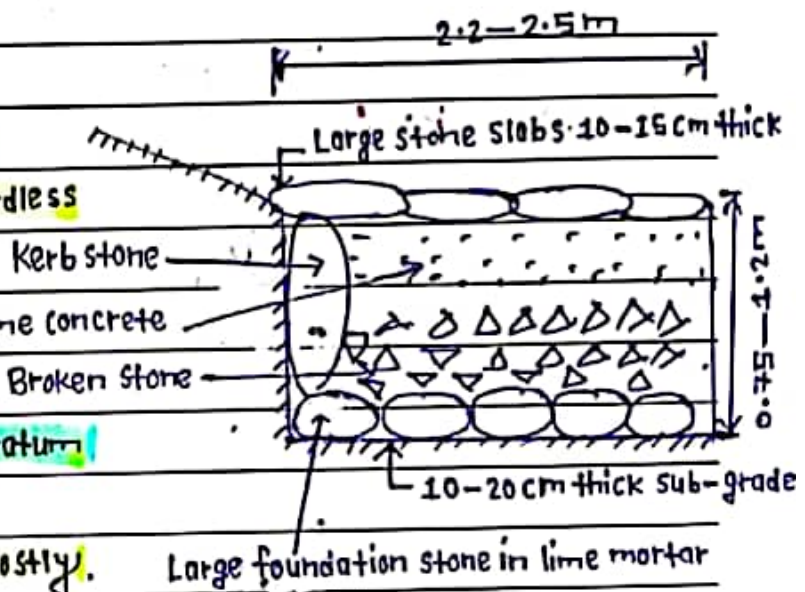
- ① Roman roads (Roman)
- ② Tresaguet Construction (France)
- ③ Macadam Construction (England)
- ④ Telford Construction (United Kingdom)
- ⑤ Macadam roads (England)
- ⑥ Modern roads.

① Roman Roads

→ Straight road & regardless of gradients.

→ They were built after the removal of soft soil & hard stratum was reached.

→ Roads were very costly.



② Tresaguet Construction

→ Pierre Tresaguet (1716-1796) developed

in improvement method of construction in 1764 AD.

→ Lesser thickness

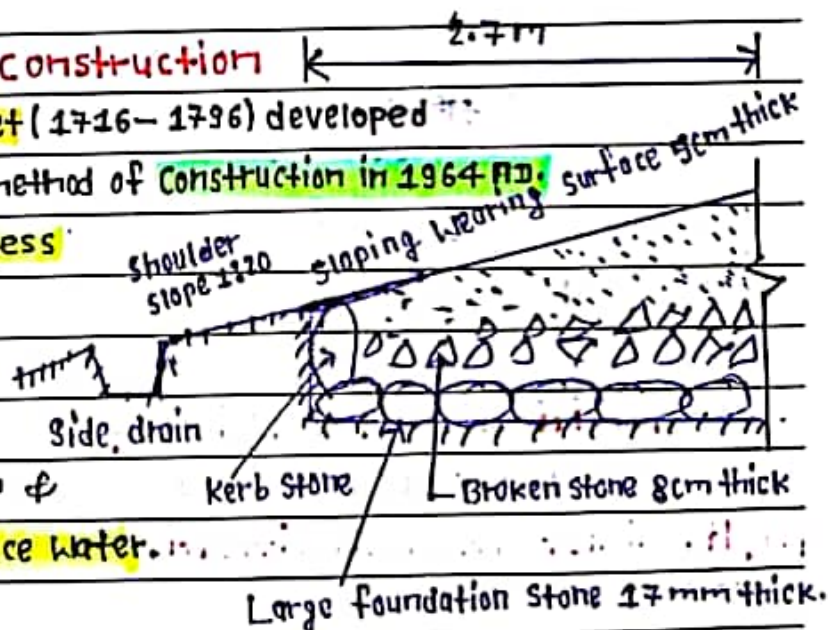
around 30 cm.

→ Consideration

of sub-grade

moisture condition &

drainage of surface water.



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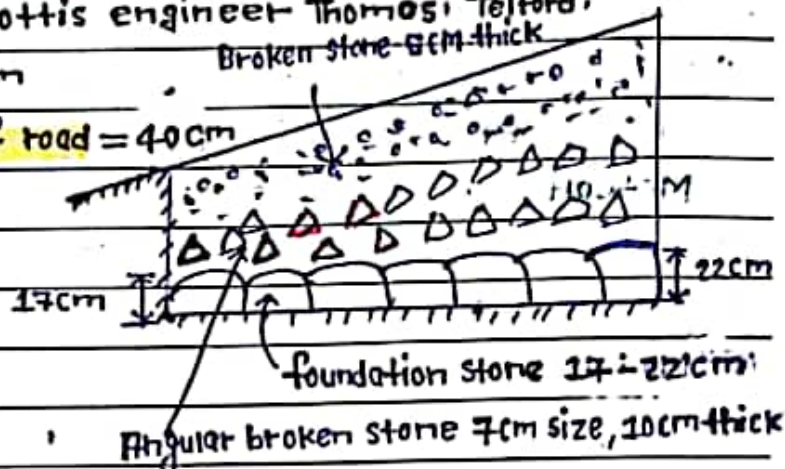
③ Telford Construction

→ developed by scottis engineer Thomas Telford,

→ width of road = 9m

→ Total thickness of road = 40cm

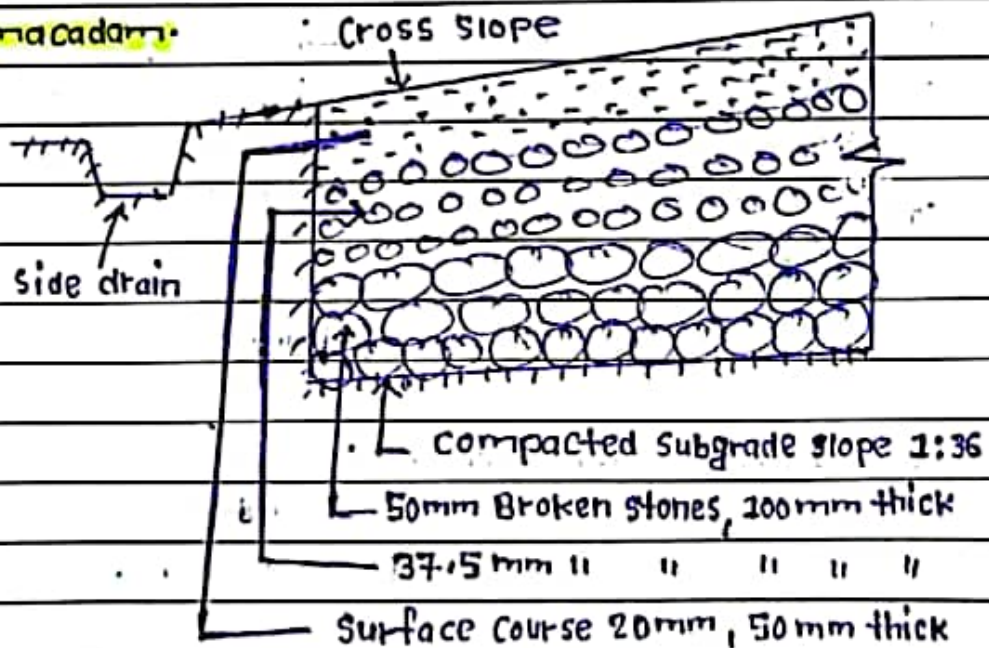
→ Sloping wearing surface (1 in 45) & 4cm thick.



④ Macadam Roads

→ Introduced by

John macadam.



→ Total thickness of sub-base, base & surface course = 25cm.

Classification of Road in Nepal

According to Nepal Road standard 2070

[A] Administration classification

① National Highway

→ main roads connecting east to west & north to south of the nation.

Note Book

Date : 20 / /

Arterial

- These serve directly the greater portion of the longer distance travel.
- They are designated by letter 'H' followed by two digit number.
- There are 80 national highway.
- Example; H01, H20, H80

② Feeder Roads

- connecting district headquarters to national highway
- Important roads of localized nature.
- They are designated by letter 'F' followed by three digit number
- There are 208 Feeder roads.
- Example; F001, F050, F208 etc.

③ District Roads

- Important road within a district serving area of production & market & connecting with each other.

④ Urban Roads

- Serving within the urban municipalities.

Note: In nepal

- National highway & feeder roads are collectively called Strategic Road Network (SRN).
- Department of Road (DoR) is overall responsible for SRN.
- District roads & Urban roads collectively called Local Road network (LRN).
- Department of local infrastructure development & agricultural Road (DOLIDAR) is overall responsible for LRN.

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B Technical Classification

① Class - I

- Highest standard road with divide carriageway & access control (Expressway).
- ADT = 20,000 PCU or more in 20 years perspective period.
- Design speed = 120 kmph in plain terrain.

② Class - II

- ADT = 5000 - 20,000 PCU in 20 years perspective period.
- Design speed = 100 kmph in plain terrain.

③ Class - III

- ADT = 2000 - 5000 PCU in 20 years perspective period.
- Design speed = 80 kmph in plain terrain.

④ Class - IV

- ADT = < 2000 PCU in 20 years perspective period.
- Design speed = 60 kmph in plain terrain.

Note : ADT = Average Daily traffic
PCU = passenger car unit

Basic Requirements of Road Alignment

Highway Alignment

- The position or layout of center line of road on ground.
- There are two types of highway alignment.

① Horizontal alignment : It is the projection of highway alignment on a horizontal plane & covers straight path, horizontal deviations & curves.

- It has two coordinates x & y .

② Vertical alignment : It is the projection of highway alignment on a vertical plane & covers change in slopes & vertical curves.

- It has two coordinate x & z .

Note Book

Date : 20 / /

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Basic Requirement of Road/Highway alignment

- ① **Short** → The alignment should be short as far as practicable.
- ② **Safe** → safe for construction, maintenance from view point of stability & also safe for traffic operation.
- ③ **Easy** → Easy to construct, maintain & vehicle operation.
- ④ **Economical** → Total cost including initial cost, maintenance cost & vehicle operation cost is lowest.

Vehicle Type	PCU
1. Bicycle, motor cycle	0.5
2. Car, Auto-rickshaw, light Van.	1
3. Light (mini) truck, tractor, rickshaw	1.5
4. Truck, bus, mini bus,	3
5. No motorized cart	6

Factors controlling Highway Alignment

① Obligatory points:

→ These are the control points governing the alignments of highway & area of two categories.

Ⓐ obligatory points through which highway is to pass (+ve)

- Intermediate town, → Industrial area, → Hill,
- School/College area, → mine zone, → River
- Tourists spot./Bridge → Health post.

Ⓑ obligatory points through which highway should not pass, (-ve)

- Marshy place, Water logged area, low bearing capacity soils.
- Historically & archeologically important property.
- Restricted zone for national security.
- Costly structural element. → Lake, Pond, etc.
- Densely populated area.

Note Book

Date : 20 / /

Aman

② Traffic

→ The alignment should suit traffic requirements. origin & destination study should be carried out in the area & the desire lines be drawn showing the trend of traffic flow.

③ Geometric Design

→ Geometric design factors such as gradient, radius of curve & sight distance also would govern the final alignment of highway.

④ Economy

→ The alignment finalised based on the above factors, should also be economical.

⑤ Other considerations

→ Various other factors which may govern the alignment are drainage considerations, hydrological factors, political considerations & monotony.

Special consideration on Hilly Area.

- | | |
|-------------|-----------------------|
| → Stability | → Geometric standard. |
| → Drainage | → Resisting length. |

Stages of Road Survey.

① Map Study: Probable alignment can be located. → Desk study.

→ Alignment avoiding Valleys, ponds or lakes.

→ Approximate location of bridge site. → first stage of survey.

→ When road has to pass a hill, possibility of crossing through mountain passes. → Actual site not visited.

② Reconnaissance Survey: Some of the details to be collected during reconnaissance.

→ Valley, Ponds, marshy land, ridge, hills, permanent

Note Book

Date : 20 / /

Answer

- structure, other obstructions, along the route which are not available in map. → Use simple instrument, Abney level, tape, GPS etc.
- Maximum flood level & natural ground level.
 - Soil type & geological features.
 - Sources of construction material. → Walk over survey.
 - When the area is vast or terrain is difficult, reconnaissance may be done by aerial survey.
 - As a result of the reconnaissance, a few alternative alignments may be chosen for further study.

③ Preliminary Survey.

- To survey the various alternative alignment & collect necessary physical information & details of topography, drainage, soil.
- To compare the different proposals in view of the requirements of a good alignment.
- To estimate quantity of earthwork & construction aspects & work out the cost of alternative proposals.
- To finalized the best alignment from all considerations.

④ Detailed (Location) Survey

- The alignment that is finalized by preliminary survey is located on the field by establishing centerline.
- Now the detail survey is carried out for collecting the information necessary for the preparation of plan & construction details for the highway project.
- The data are
 - Topographical detail.
 - Soil profile.
 - Drainage.
 - Rainfall.

Note Book

Date: 20 / /

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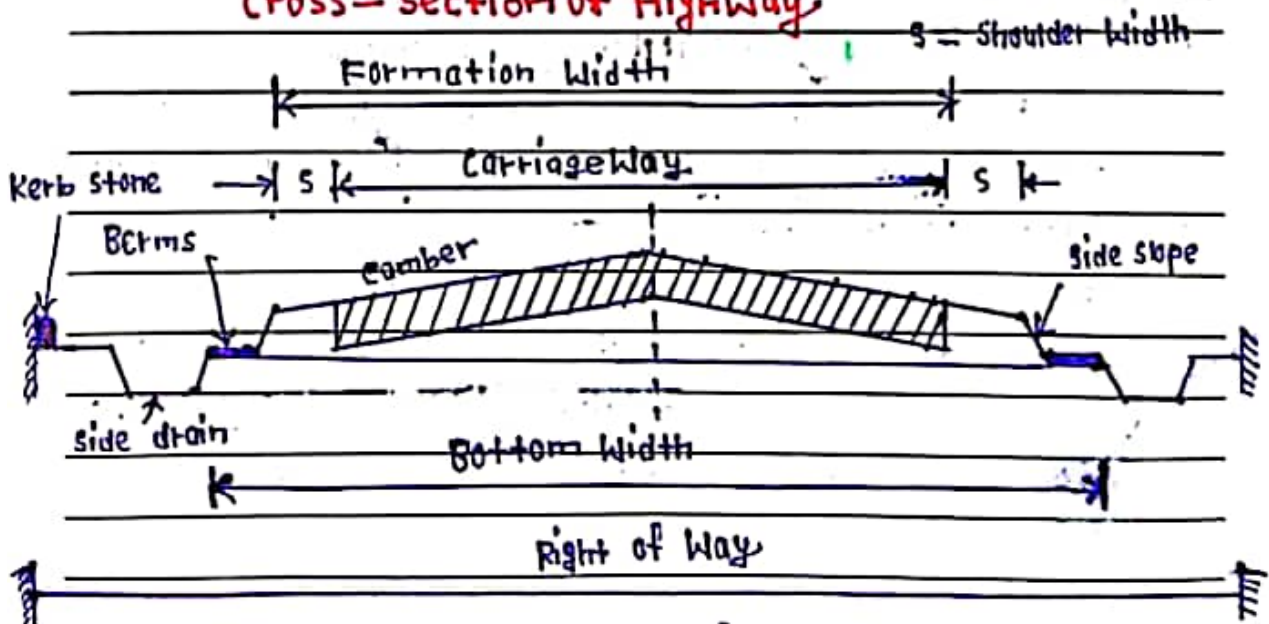
Geometric Design

- The geometric design of a highway deals with the dimensions & layout of visible features of highway, such as alignment, sight distance & intersections,
- In fact it is the design of geometric elements of road with which the road user is directly concerned.
- But it does not deal with the design of pavement, structural & drainage components.

Basic Design Control & Criteria for Design

- Design speed
- Design vehicle
- Topography, physical & manmade features.
- Traffic volume & composition / traffic factors.
- Traffic capacity.
- Road user behavior.
- Environmental & other factors.

Cross-section of Highway



fig; cross-sectional elements of highway

Note Book

Date : 20 / /

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① **Bus Bays** → It is provided by raising kerb to avoid conflict with moving traffic.

→ It should be located at least 75m away from the intersection.

② **Carriageway** → Middle portion of the road which is normally utilized by vehicles.

→ It depends on the width of traffic lane & no. of lanes.

Single lane road	Intermediate lane	Multilane pavements
		width per lane
3.75m (upto 3m in difficult terrain)	5.5m	3.5m

Note : In case of single lane roads it is recommended to have two treated shoulder on either side to make a full width = 5.50m

③ **Formation Width** → Top width of road embankment or bottom width of road cutting excluding the side drains.

→ It includes Carriageway & Shoulders.

④ **Formation Level** → The RL of finished surface of earthwork for a roadway in embankment or cutting.

⑤ **kerb** → Boundary betⁿ pavement & shoulder or island & footpath.

⑥ **Roadway Width** → Width of roadway including carriageway, two time shoulder & separators.

⑦ **Shoulder** → It is the portion of road besides the Carriageway. In rural roads, it is provided along the road edge to serve as an emergency lane for vehicle compelled to be taken out of the pavement or roadway.

NRS 2070

Road Class	Class-I	Class-II	Class-III	Class-IV
minimum shoulder width, M	3.75	2.5	2	1.5

Note : minimum shoulder width on either side of the carriageway should be 0.75m.

Note Book

Date : 20 / /

Aman

⑧ **Footpath** → It is also known as **side walk or foot way**.

→ Normally, footpath is provided in urban road to provide protection to pedestrians & minimize the possibility of accidents. → **Minimum width** = 1.50m

→ **Maximum width** = 3m.

⑨ **Right of Way** → It is area of land required for road & reserved for future development along the alignment.

Road type	Highway	Feeder roads	District roads
Total right of way	50	30	20

⑩ **Camber** → It is the slope provided to the road surface in transverse direction to drain off the rain water.

→ It is also known as **cross slope**.

→ Quick disposal of water from the road surface.

purpose of camber

→ To prevent the entry of surface water into sub-grade.

→ To increasing the strength of pavement, stability of pavement.

→ To remove the rain water from the surface as quickly as possible.

→ To allow the pavement to get dry soon after the rain; Sometimes wet surface may be slipping & unsafe for vehicle operation of high speed.

Note: Usually camber is provided raising the center of carriageway, but in case of horizontal curve outer edge is elevated, allowing water to flow towards inner edge.

Need of camber of pavement depends on

→ Intensity of rainfall.

→ Type of pavement surface.

→ surface of road.

→ impermeability of surface materials.

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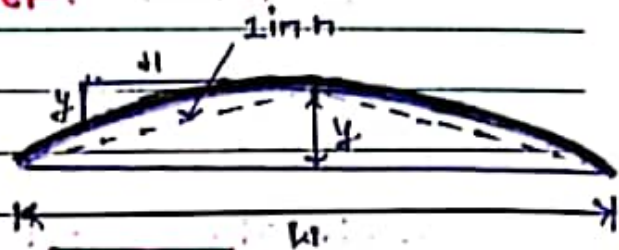
Types of Camber:

① parabolic camber

→ Parabolic Camber consists of a continuous curve.

→ The continuous curve may be either parabolic or elliptical.

→ Provides a steeper surface towards the edge & flatter surface towards the middle portion of highway.



$$y = \frac{2x^2}{nW}$$

→ for flexible pavement

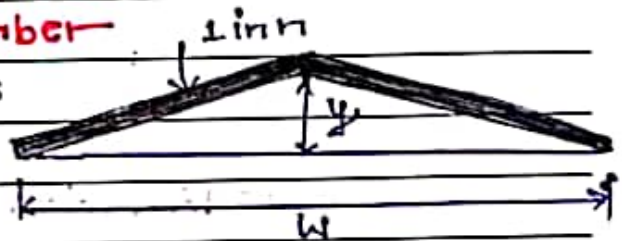
② straight line / sloped camber

→ straight line camber consists two slopes originating from the edges & joining the center of carriageway.

→ It is the simplest type of camber.

→ It can be constructed easily & maintenance also easy.

→ Best suited for cement concrete slab (Rigid pavement).

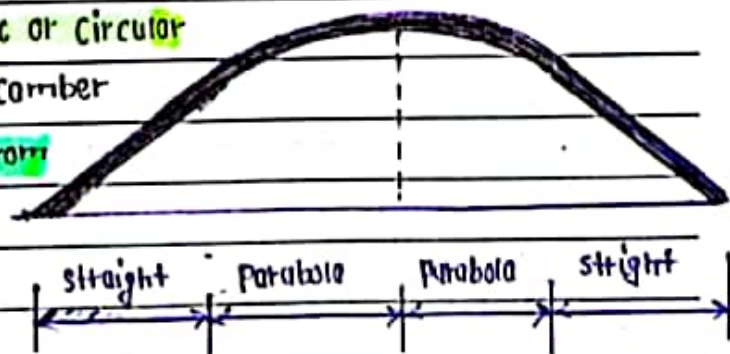


$$y = \frac{W}{2n}$$

③ Composite camber

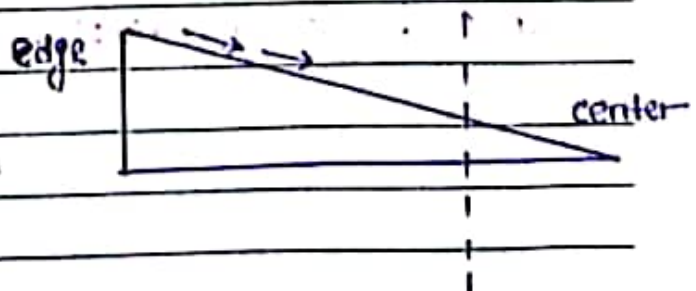
→ It consists of parabolic or circular crown at the center of the camber & two st. slope originates from the edge of road.

→ Best camber.



④ Negative camber

→ When the slope of the road is provided towards center of road then it is called negative camber.



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Features of Camber:

- Drainage provided
- Lane separation.
- Prevent from head & Collision.
- Road appearances.

Note: Main objective of camber — Effective drainage

Disadvantages of High Camber

- Discomfort.
- Velocity of rainfall is high.
- Accident due to over-turning.
- Scouring of pavement surface.
- Decreasing the strength of road surface.

Super Elevation

- At the horizontal curve, the outer edge of the pavement is raised with respect to inner edge to counteract the effect of Centrifugal force is known as super elevation.
- To reduce the tendency of the vehicle to overturn or skid.
- It is also known as cant or banking.
- It is represented by symbol 'e'.

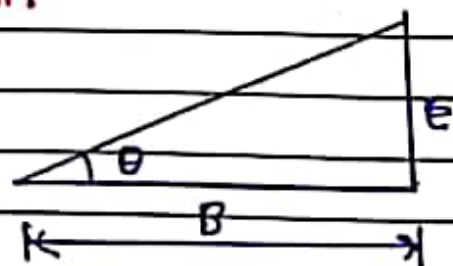
Value of e depends on

- Speed of the vehicle (V)
- Radius of the curve (R)
- Lateral frictional resistance (f).

Analysis of Super Elevation

From fig;

$$(e) \tan \theta = \frac{e}{B} \quad \text{--- (1)}$$



Note Book

Date: 20 / /

Answer

Let, V = speed of moving vehicle on horizontal curve (m/sec)

R = Radius of horizontal curve in meter.

W = Weight of vehicle (kg)

Centrifugal force $(P) = \frac{WV^2}{gR}$ — (2)

g = Acceleration due to gravity (m/s²). = 9.8 m/s²

→ The frictional force developed on the wheel.

$\Sigma F_x (\rightarrow +)$

or, $P \cos \theta - W \sin \theta - F_1 - F_2 = 0$

Now, Frictional force $(F) = fR$

from eqn (3): $P \cos \theta - W \sin \theta - f_1 R_1 - f_2 R_2 = 0$

$P \cos \theta = W \sin \theta + f(R_1 + R_2)$

$= W \sin \theta + f(P \sin \theta + W \cos \theta)$

$\therefore f_1 = f_2 = f$

or, $P \cos \theta - f P \sin \theta = W \sin \theta + f W \cos \theta$

Dividing both side by $W \cos \theta$

or, $\frac{P \cos \theta}{W \cos \theta} - \frac{f P \sin \theta}{W \cos \theta} = \frac{W \sin \theta}{W \cos \theta} + \frac{f W \cos \theta}{W \cos \theta}$

or, $\frac{P}{W} - \frac{f P \tan \theta}{W} = \tan \theta + f$

or, $\frac{P}{W} (1 - f \tan \theta) = \tan \theta + f$

$\therefore \frac{P}{W} = \frac{\tan \theta + f}{1 - f \tan \theta}$ — (4)

$f = 0.0001$

Since: $f \tan \theta \approx 0$

or, $\frac{P}{W} = \frac{e + f}{1 - 0}$ — (5)

$\tan \theta \approx e$

But from eqn (2):

$P = \frac{WV^2}{gR}$

$\frac{P}{W} = \frac{V^2}{gR}$

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Putting the value of P/W in eqn (5)

$$\frac{V^2}{gR} = e + f$$

$$\therefore \boxed{e + f = \frac{V^2}{gR}} \text{ Required expression for super elevation.}$$

Where ; e = super elevation in %.

Maximum $\leq 7\%$ in plain terrain & Rolling terrain. $\left(\frac{1}{15}\right)$
 10% in hill road with no snow.

Minimum e = Camber / cross-slope of that section.
 = rate of Camber of pavement.

f = Lateral frictional factor = 0.15

Sight Distance

Sight distance is the actual length of road over which a driver sitting at a specified height in a vertical plane can see. Objects either moving or stationary on the road surface.

Sight Distance may be obstructed

- Due to sharpness of horizontal curve.
- Due to summit of vertical curve.
- At road intersections some structure at corners obstructing the sight line.

Types of Sight Distance

① stopping sight Distance (SSD)

→ SSD is the minimum distance required within which a vehicle moving at designed speed can be stopped without colliding with an object on the road surface.

→ SSD in down slope > horizontal road.

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Factors Affecting stopping sight Distance

- Speed of Vehicle.
- Efficiency of brakes.
- Frictional resistance betⁿ road surface & vehicle tyres.
- Gradients of road.
- Total reaction time of driver.

PIEV Theory

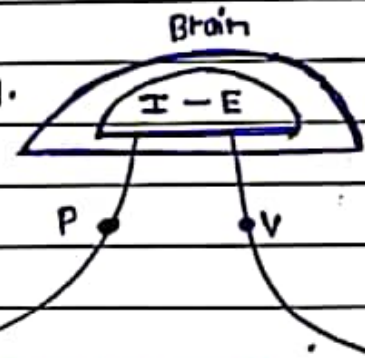
Perception: perceiving through eye & ear etc.

Intellection: Analyzing the situation. i.e. knowledge

Emotion: Time lapsed for emotional feeling like fear, anger etc.

Volition: Time to take final action.

→ **Total reaction time** = 0.5 - 4 second.



② Overtaking sight Distance (OSD)

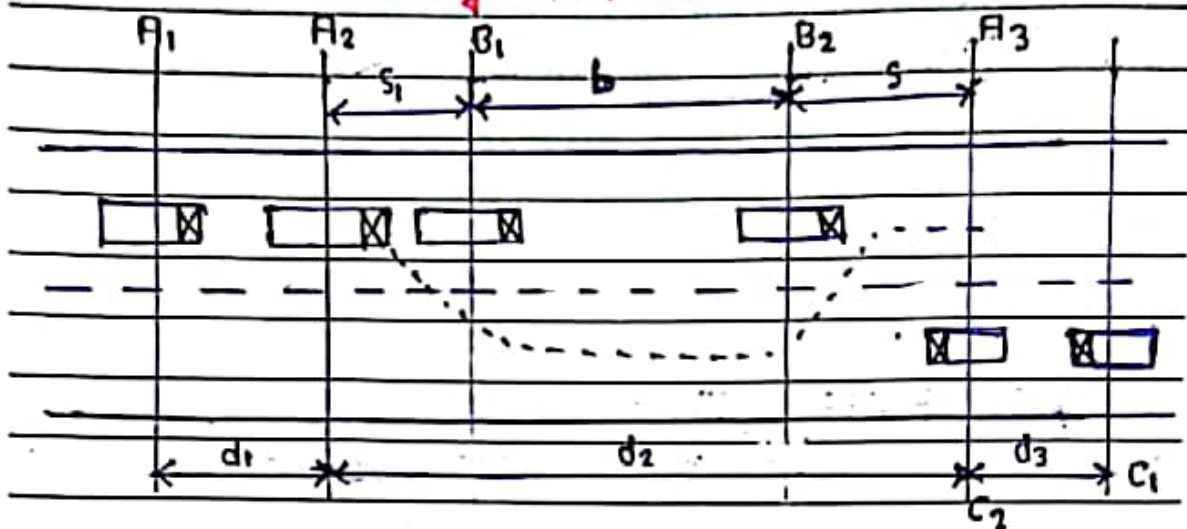
→ The distance visible to the driver of a vehicle intending to overtake another slow moving vehicle without causing any inconvenience or possibility of accident to the traffic in opposite direction is called overtaking sight distance.

Factors Affecting overtaking sight Distance

- speed of overtaking, overtaken & vehicle coming from opposite direction, if any.
- Distance betⁿ overtaking & overtaken vehicles the minimum spacing depends on the speeds.
- Skill & reaction time of the driver.
- Rate of acceleration of overtaking vehicle.
- Gradient of the road.

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Analysis of OSD



→ Vehicle A is fast moving, Vehicle B is slow moving & Vehicle C is moving from opposite direction.

→ d_1 = Distance travelled by overtaking Vehicle A during the reaction time 't' sec of driver from position A_1 to A_2 .

→ d_2 = Distance travelled by Vehicle A from A_2 to A_3 during the actual overtaking operation, in time 'T' sec.

→ d_3 = Distance travelled by on-coming Vehicle C from C_1 to C_2 during the overtaking operation of A.

→ For two lane with two way traffic, $OSD = d_1 + d_2 + d_3$
for single lane, $OSD = d_1 + d_2$

→ minimum length of overtaking zone = $3 \times OSD$

→ maximum length of overtaking zone = $5 \times OSD$

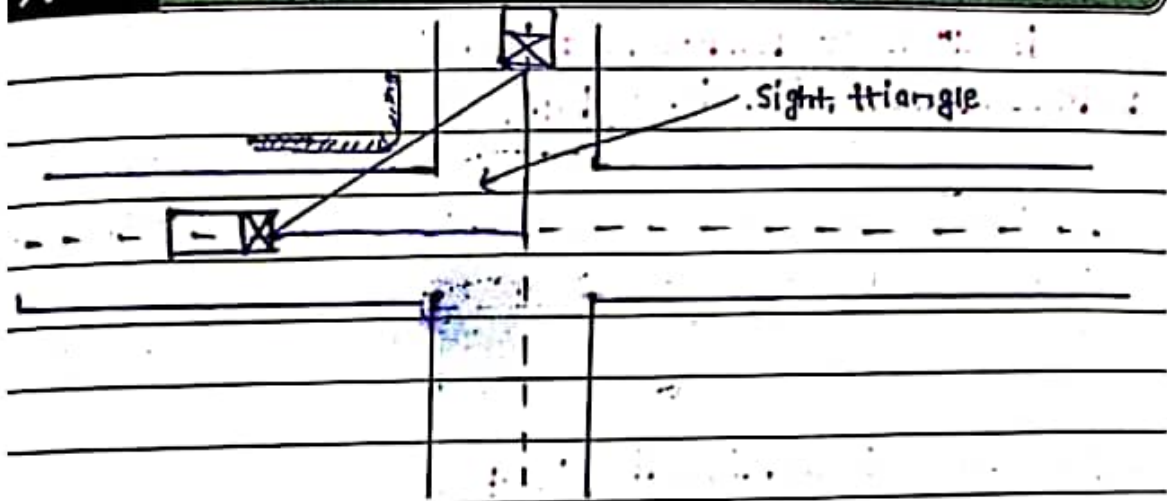
→ minimum length of overtaking zone = $2 \times OSD$ (for single lane)

③ Safe Sight Distance at Intersection

→ It is not possible to provide safe sight distance at intersection due to presence of house, trees or other similar obstruction.

→ The area of unobstructed sight formed by the lines of vision is called the sight triangle.

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Extrawidening

- Extrawidening refers to the additional width of carriageway that is required on a curved section of a road than required width on a straight alignment.
- Normal Circular Curve road = provided on both sides of Carriageway.
- Hill road = only inner side of curve.
- Circular curve with no transition curve = only inner side.

Objectives of Extrawidening

- To provide sufficient visibility during driving on curve path.
- To provide extra space for turning of larger vehicle.
- To maintain safety clearance while two vehicles cross on horizontal curve.
- eliminate the chances of accident.

Off Tracking → An automobile has a rigid wheelbase & only the front wheels can be turned, when this vehicle takes a turn to negotiate a horizontal curve, the rear wheel do not follow the same path as that of the front wheels. This phenomenon is called off tracking.

Note: Radius of curve $> 300m$ → Extrawidening not provided.

On hill road (sharp curve) extra widening is provided inner side only.
Maximum amount of Extra widening provided center of circular curve

Note Book

Date : 20 / /

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Analysis of Extra Widening

① Mechanical Widening (W_m)

→ The widening required to account for the off tracking due to the rigidity of wheelbase is called mechanical widening.

→ Rear wheel not follow front wheel.

→ Mechanical widening $(W_m) = \frac{hl^2}{2R}$ Where, h = no. of lane.

→ Provided on inner edge. R = Radius of horizontal curve
 l = Length of wheelbase

② Psychological Widening (W_{psy})

→ At horizontal curve drivers have a tendency to maintain a greater clearance betn the vehicles then on straight road. therefore extra widening is provided which is known as psychological widening.

→ Psychological widening $(W_{psy}) = \frac{V}{9.5\sqrt{R}}$ Where:
 V = design speed

→ Provided on outer edge

∴ Total widening (W_e) = $W_m + W_{psy}$

Gradient

→ Gradient is the rate of rise or fall along the length of the road with respect to the horizontal.

→ It is expressed as a ratio of 1 in x . (1 vertical & x horizontal)

→ Also expressed as a percentage. i.e. n in 100.

→ Ascending gradient is denoted as $= +n\%$.

→ Descending " " " " $= -n\%$.

Types of Gradient

① Ruling Gradient

→ Also known as design gradient.

→ Gradient decided by designer considering the type of terrain, length of grade, speed of vehicle, balancing cut & fill during construction. → 1 in 20m (hill), 1 in 30 (plain).

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② Limiting/Maximum gradient

→ In some cases, a designer shall be compelled (मजबूर) to use steeper gradients than ruling gradients to prevent the enormous increment in cost.

→ 1 in 15 (hill), 1 in 20 (plain).

③ Exceptional gradient

→ In some un-avoiding situations, it is necessary to provide still steeper gradients at least for short stretches.

→ Exceptional gradients should strictly limit for upto 100m only.

→ 1 in 12 (hill), 1 in 15 (plain).

④ Minimum gradient

→ If the pavement is designed with zero gradients, there could be some problems for drainage of water.

→ So minimum gradient should be provided in the road depends upon the type of side drains also.

→ 1 in 500 for concrete drain. → 1 in 200 for earthen drain.

Transition curve

→ When a non-circular curve is introduced betⁿ a straight & circular curve has a varying radius is known as transition curve.

→ Radius of such curve varies from infinity to some fixed values.

→ Infinity at straight end (tangent point) & desired radius (R) of the circular curve at the other end (junction point).

Objective of Transition curve

→ Avoiding sudden jerk on the vehicle.

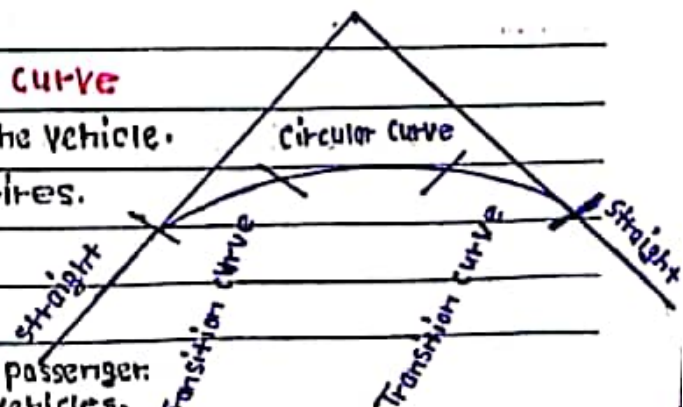
→ minimize wear & tear of tires.

→ Avoid side slipping.

→ Allow high speed on curve.

→ Eliminates discomforts to passenger.

→ Avoid the overturning of vehicles.



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Nepal Road Standard, 2070

Transport Unit

- There are a no. of traffics which uses the road.
- So it is necessary to adopt a certain relationship among the different traffics & their relation is known as traffic unit or transport unit.
- Which is nothing but a normal car, light Van.
- This unit also known as passenger car unit (PCU).

Vehicle type	PCU
1. Bicycle, motorcycle, scooter	0.5
2. Car, auto rickshaw, Light Van, pickup Van.	1
3. Mini truck, tractor, rickshaw	1.5
4. Truck, bus, mini bus, tractor with trailer	3
5. Non-motorized Cart (Bullock carts)	6

Types of Terrain

Type of terrain	% Cross slope	Degree of curve
① plain	0 - 10 %	0° - 5.7°
② Rolling	10 - 25 %	5.7° - 14°
③ Hilly/Mountainous	25 - 60 %	14° - 31°
④ steep	> 60 %	> 31°

HS per NRRS - 2071 BS

- ① Terai → % Cross slope $\leq 25\%$
- ② Hill → % Cross slope $> 25\%$

Vehicle Dimension

Maximum width = 2.50m

Maximum height = 4.75m

Maximum length = 18m

Maximum single axle load = 100.

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Date : 20 / /

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Design Speed

Class	Plain	Rolling	Mountainous	Steep
I	120	100	80	60
II	100	80	60	40
III	80	60	40	30
IV	60	40	30	20

Sight Distance

Speed, km/h	20	30	40	60	80	100	120
Stopping Distance (m)	20	30	50	80	130	190	260

Camber

Pavement type	Cement Concrete	Bituminous	Gravel	Earthen
Camber %	1.5-2	2-5	4	5

Specification for Hair pin Bend in Hill Roads

Minimum design speed = 20 km/h

Minimum radius of curvature = 15m

Minimum length of transition curve = 15m

Maximum longitudinal gradient = 4%

Maximum super elevation = 10%

Minimum straight length betⁿ two successive hair pin bend = 60m

Level of Service (LOS)

→ LOS is a qualitative measure used to relate the quality of traffic service.

→ Also called quality of service or service quality.

→ It refers to the speed, convenience, comfort & security of transportation facilities & services as experienced by users.

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→ There are 6 levels of service.

1. Level of service A (Free flow traffic)
2. Level of service B (steady traffic)
3. Level of service C (steady traffic but limited)
4. Level of service D (steady traffic at high density)
5. Level of service E (Traffic at saturation)
6. Level of service F (Congestion).

Vertical curve

→ A Vertical curve is a curve provided between two intersecting grade lines of highway & railway to smoothen out the change in vertical motion.

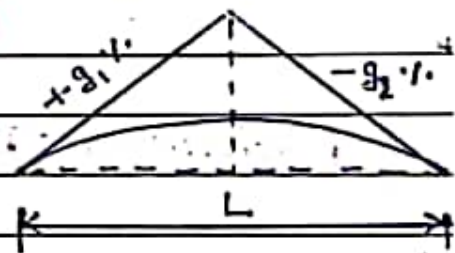
Types of Vertical curve

① Summit curve

→ Two grades meet at the summit.

→ Curve having convexity upward.

→ Crest curve.

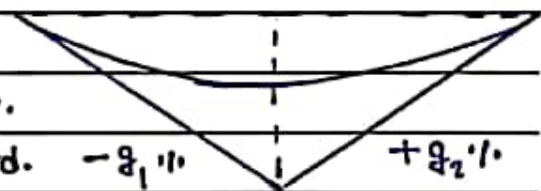


② Valley curve

→ Two grades meet at the valley.

→ Curve having convexity downward.

→ Sag curve.



Floating gradient

→ The gradient that does not require extra tractive effort for the operation of vehicle is known as floating gradient.

→ It occurs in Summit curve.

Length of Vertical curve

$$L = \frac{g_1 - g_2}{r}$$

Where; r = rate of change of gradient.

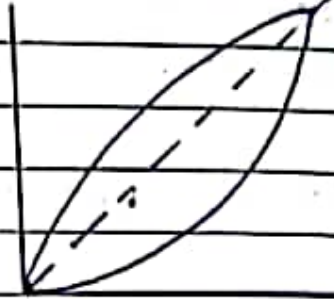
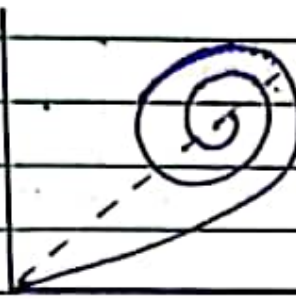
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Types of Transition curve

① Cubic parabola

② Cubic spiral

③ Lemniscate



→ Ideal transition is clothoid.

→ Ideal transition curve for hill road is spiral.

Design length of transition curve

→ Transition curve is designed based on maximum value given for following 3 conditions.

A Based on rate of change of centrifugal acceleration.

$L_s = \frac{V^3}{46.5CR}$	or	$L_s = \frac{V^3}{47CR}$	or	$\frac{0.0215V^3}{CR}$
----------------------------	----	--------------------------	----	------------------------

Where; L_s = Length of transition curve (m)

V = Design speed (kmph)

R = Radius of curve (m)

C = Rate of change of centrifugal acceleration = $\frac{80}{75+V}$ m/s³

→ The value of C = 0.5 — 0.8 m/s³.

B Based on rate of introduction of super-elevation.

$L_s = \frac{eN(W+W_e)}{2}$

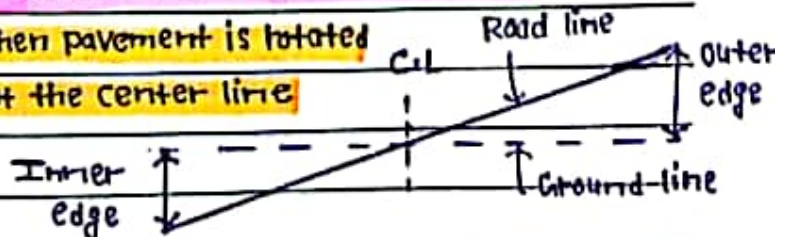
(I) When pavement is rotated about the center line

e = Super-elevation (%)

W = Width of road (m)

W_e = Extra widening

N = Rate of introduction of super-elevation.



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(II) When pavement is rotated about the inner edge

$$L_s = eN(W + W_e)$$

(C) By empirical formula

(I) For plain & rolling terrain

$$L_s = \frac{2.7V^2}{R}$$

(II) For mountainous & steep terrain (Hill)

$$L_s = \frac{V^2}{R}$$

∴ Length of transition curve = Max^m Value obtained from

(A), (B) & (C)

$$\text{Shift (S)} = \frac{L_s^2}{24R}$$

Drainage system

Highway drainage is the process of removing & controlling excess surface & sub soil water within the right of way.

→ This includes interception & diversion of water from the road surface & sub-grade.

Importance of Drainage System

- Managing storm water.
- It helps control erosion.
- Preventing waterborne diseases.
- maintaining strength of construction materials.
- maintaining bearing capacity of soil.

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Road Pavement

→ A **Stable layer** constructed over the natural soil can be defined as a road pavement.

Function of Different Layers

① Sub Grade

- It is the **compacted natural earth**.
- The top of it is called formation level.
- It is layer of natural soil prepare to receive the other layer of pavement
- Loads on the pavements are ultimately supported by the soil sub-grade.
- It should be at least 60 cm above HFL.

② Sub-base Course

- provides additional help in distributing the loads.
- Layer of selected granular soil, stabilized soils or gravels, boulders, broken stones, brick etc.
- To increase the structural support to the base & surface courses.
- The minimum thickness of sub-base course should be 200mm.

③ Base Course

- **Layers of graded materials** (aggregate) provided above the sub-base to transfer the stress to sub grade.
- Minimum thickness of base course should be 150 mm.

④ Surface/Wearing Course

- **Top portion of pavement**.
- To get a smooth, abrasion resistance, dust free, reasonably water proof & strong layer.
- Superior quality of materials is used to construct this layer.
- minimum thickness of surface course should be 20mm.

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Road Machineries

A Earth moving Equipments

- | | | | |
|-------------|-----------|--------------|------------------|
| ① Dozer | ③ Loader | ⑤ Clamshell | ⑦ Trench digger. |
| ② Excavator | ④ Scraper | ⑥ Drag lines | |

B Earth compacting Equipments

- | | |
|------------------------|--------------------------|
| ① Smooth Wheel Rollers | ④ Pneumatic tyred Roller |
| ② Vibrating Rollers | ⑤ Tandem Roller. |
| ③ Sheep foot Rollers | |

Suitability of Equipments

- ① Bull dozer → Shallow excavation.
- ② Scraper → Shallow excavation, dig, haul & discharge in uniform layer of soft soil.
- ③ Power Shovel → Shallow excavation (Hard, stiff soil)
- ④ Dragline → excavation in soft soil. (excavate lower than the existing level)
- ⑤ Clamshell → excavation in soft & medium soil (excavate lower than the existing level).
- ⑥ Hoe → excavation below ground level (excavate lower than the existing level.)
- ⑦ Roller
 - ① Smooth Wheel Roller → Granular soil.
 - ② Sheep foot Roller → Clayey soil.
 - ③ Pneumatic tyred Roller → Fine sand.
- ⑧ Rammer → Smaller area.
- ⑨ Vibrator → Dry, cohesionless granular soil.
- ⑩ Watering → cohesionless soil (compaction)
- ⑪ Grader → Gradient
- ⑫ Bitumen heating device. i.e; decanter
- ⑬ Bitumen distributor
- ⑭ Aggregate spreader

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Road Construction Technology

[1] Labour Intensive Works

- Takes lots of time to complete the road project.
- Quality of work may not be achieved to the required degree.
- Small projects labor intensive work can be adopted.
- Cheap labor & expensive equipment.
- In developing countries like Nepal.

[2] Equipment or Capital Intensive Works

- Take short time period to complete the road project.
- High degree of quality construction.
- Useful in the big project.

Activities & Techniques used in Road Construction

[A] Earthwork

- Site clearance.
- Excavation for cutting.
- Excavation for structural foundation.
- E/W in filling for embankment.
- Excavation for borrow pit.
- Disposal of surplus earth.

[B] Drainage Works

- Side drains
- Causeways
- Sub-surface drain
- Minor bridges
- Culverts.
- Other water management structure.

[C] Structural Works

- Earth retaining structures.
- Landslide stabilization works.
- Bridge protection works.
- Gully control works.
- River training works.

[D] Pavement Works

- Sub-grade preparation
- Sub-base course.
- Base course.
- Wearing course.

[E] Miscellaneous Works

- Road furniture
- Traffic sign / signal / marking, etc.
- Bio-engineering works.

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Road Maintenance & Repairs

- Road maintenance is to preserve & keep the serviceable condition of road as normal as possible & as best as practicable.
- The maintenance operation involve the assessment of road condition, diagnosis of the problem & adopting the most appropriate maintenance steps.

Types of Maintenance Work

① Routine Maintenance

- Maintenance operations of localized nature required continually on any road whatever it's engineering characteristics or traffic volume may be.
- The works are generally done by labor.
- Example; pot hole (gravel road), patch, maintenance of shoulder, grass cutting, drain cleaning, bridge/culvert cleaning, reshaping unlined drain etc.

② Recurrent Maintenance

- Maintenance operation of localized nature & of limited extent carried out at more or less regular intervals of six months to years. With frequency depends on traffic volume.
- Done by use of minor equipment.
- Example; pot hole repair, edge repair, crack sealing, repair of depressions etc.

③ Periodic Maintenance

- Maintenance operations of large extent required only at intervals of several years.
- Examples of activities within this category for a paved road are such as resealing (surface treatment, slurry sealing), resurfacing (thin overlay).

Amran

④ preventive Maintenance

→ Maintenance operation of road surface, geological & geotechnical nature to protect the road way.

→ The activities within this category are sealing of raveling stripping & meandering cracking, sealing of longitudinal & transverse cracks, laying of net on the slopes

→ River bank protection, slope protection with - engineering etc.

⑤ Emergency maintenance

→ Maintenance operation of highway generally done after 10 years or any unfavorable conditions,

→ Example; Reconstruction of pavement, widening of roads, emergency maintenance by flood, landslide etc.

⑥ specific maintenance

→ maintenance required at certain location of road.

⑦ Rehabilitation

→ maintenance cost of road exceeds nearly 50% of the road construction to run the traffic safely & efficiently, then the must be reconstruction.

Different Types of Failure

① **Crazing** → Zig-zag cracking, observed on surface of road.

② **Scorifying** → Loosening of materials from top surface of pavement by mechanical means.

③ **Picking** → Loosening of materials from top surface of pavement by pick axe.

④ **Fretting** → Failure of materials from top surface of pavement by means of failure of binding material

⑤ **Reveling** → Removal of materials from the top surface of pavement by abrasion.

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- ⑥ **Rut** → Depressed portion of Carriageway.
 - **Longitudinal rut** : rut formed by movement of wheel of vehicle.
 - **Cross rut** : rut formed nearly perpendicular to longitudinal rut.
- ⑦ **Reel** → Raised portion of road betⁿ longitudinal rut.
- ⑧ **Pot hole** → Also known as Chauckhole.

Types of Pavement

① Flexible pavements

- Negligible flexural strength in their structural action under loads.
- The lower layer of flexible pavements reflects the deformations upto the surface of layer.

② Rigid pavements

- Worthy (गोत्र) flexural strength.
- Made of plain, reinforced or pre-stressed concrete.

Flexible pavements	Rigid pavements
→ Life span $\approx$ 15 yrs.	→ Life span $\approx$ 30 yrs.
→ Use bitumen → Binder	→ Use concrete → Binder
→ Transfer of load, grain to grain	→ Slab action take place.
→ Take less load.	→ Take more load.
→ More thickness.	→ Less. thickness.
→ Joints are not required	→ Joints are required.
→ Initial cost is less.	→ Initial cost is more.
→ Maintenance cost is more.	→ Maintenance cost is less.

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National Highway of Nepal

नेपाल सरकार, मंत्री परिषद्को मिति २०७६/०२/०६ को निर्णय अनुसार स्वीकृत

राष्ट्रिय राजमार्ग / लोकमार्गको संख्या - ८०

प्रदेश राजमार्ग / लोकमार्गको संख्या - ९२

स्थानीय सडक - ३५

सं.न	संकेत	सडकको नाम	लम्बाई (KM)
१.	NH01	पूर्व-पश्चिम (महेन्द्र) राजमार्ग	१०२८
२.	NH02	मेची राजमार्ग (फेचन - चन्द्रगढी - चारआली - इलाम - फिदिम, गणेशचोक - ताप्लेजुङ्ग - औलाङ्गचुङ्गोला)	३५२
३.	NH03	पुष्पलाल (मध्य पहाडी) राजमार्ग	१०८०
४.	NH04	पितामोड - चन्द्रगढी - भद्रपुर - मेची पुल	१५
५.	NH05	हुलाकी राजमार्ग	१०१६
६.	NH06	तमोर फरीदौर (चतरा - मुलघाट - मझरीरा - अमरापुरडाँडा - गणेशचोक)	१३५
७.	NH07	पफली - जय फौज्जीपुल - रुपनगर, पफली - नयाहा पौखरीपुल - चतरा	६६
८.	NH08	फौज्जी राजमार्ग (रानी - विराहनगर - इटहरी - धरान - धनकुटा - हिले - लैद्युवाघाट - तुम्लिङ्गटार - खाँदणारी - गुम - फिमथान्ना)	३२०
९.	NH09	मदन षण्डारी राजमार्ग (बाहुनडाँगी - शान्तिनगर - धरान - चतरा - गार्डघाट - फहारी - सिन्धुलीमाडी - देहौडा - गौँडाफोट - रामपुर - राम्दी - रिडि - बलफोट - सन्धिखर्क - बिजुवा - सितलपारी - सुर्खेत - बर्दीचौर - सधनपुर - पुडर - जोगबुढा - रूपाल)	१२००
१०.	NH 10	दैउराली - मुढे - चैनपुर - षोहराटार	९२
११.	NH 11	फिफल - श्रीअन्तु - छविसे, इलाम	१९
१२.	NH12	घुर्मी - चतरा - उदयपुर	१६३
१३.	NH13	पि.पी राजमार्ग (पदिवास - सिन्धुली - रुपौट, धुलिखेल)	१६०
१४.	NH 14	गार्डघाट - माहुली खोला - रूपनी - राजविराज - दिक्तेलसुता - निउर, कुनौली - राजविराज - काञ्चनपुर - देविघर - फतेचौर - लमाला - राजविराज	१००

Note Book

Date : 20 / /

Aman			
૧૫.	NH 15	ડાઝર્કે - લુધુ - લાકુરિશાજંગ - ફુશદેવી - પત્રીતી - રાધાનરા	૧૨૮
૧૬.	NH 16	ઝંડી - ઘાગવાનપુર - લદાન - કાઠમાદચોક - ગાર્ડઘાટ - મહુરે - સ્વાર્ણ - સોલુ	૧૪૪
૧૭.	NH 17	ઝોવિસે - મુગિલન - પોસ્પરા (પૃથ્વી રાજમાર્ગ)	૧૭૩
૧૮.	NH 18	બાલાજુ - ત્રિશુલી - ધુન્ધે - સ્વાપુર્ણેસી	૬૫
૧૯.	NH 19	રિડી - બાલકેટ - દંસપુર - (મુઠાન, (મુઠાન - સુર્વેત સડક	૨૨૦
૨૦.	NH 20	માડર - ધીરાદવા, ઝોલાબજમ સિરદા સોંધુરે ડયમપુર, મિન્દ્રેયા - પાટરી - ઘુમી - ધિલેપાની - ઓરપલદુગાં - સલ્તેરી	૧૬૩
૨૧.	NH 21	સિતાપાડીલા - ધાર્કે	૨૪
૨૨.	NH 22	ઠન્કેપર - જાનકપુર - જાટદી - દીરદોસ - નિમચોર - બલદીઘાટ - અપારાદરઘાટ	૪૮
૨૩.	NH 23	દિત્તેલ - સોલુ - જુનવેસી - સ્પદેર - જિરી ઘજાર - તામાખોશી - ધંરીપોર - સ્વાડીચોર	૨૬૧
૨૪.	NH 24	લાનગટ - રાનીવાસ (અર. હિ. ઓ રોડ) - બિષમત - પ્રાદુનમારા - વિ. પી રાજમાર્ગ	૨૬
૨૫.	NH 25	ડુમે - બેટ્રીસ્ટર - ધામે	૧૦૮
૨૬.	NH 26	જમુનિવાસ - બેટેશ્વર - રાજનિતપુર - ફાર્ણ - જાનકપુર	૧૬
૨૭.	NH 27	સિતાપાટી સંલ્યાન કામિન્ડે બાલુવા સંગ્રહી	૪૦
૨૮.	NH 28	મિટામોડ - જાલેશ્વર - પદિવાસ - સુર્વેત - મન્થલી - તામાખોશી - સિંગંદી - તામાખગર - લાલ્ચેગાંક	૨૮૧
૨૯.	NH 29	પંચનવન - જાનની મેડિકલ કોલેજ - મિથિલેશ્વર સર્વેલા - સિરદા - બકરામિજ - રમલદમણ ચોક - દેલ્ખાપોટ મહેન્દ્ર રાજમાર્ગ	૩૦
૩૦.	NH 30	જાનકપુર (મુજેલિયા) ધનુષાધામ - ધારાપાની - રામાયણ સુર્કિટ - તારાપટ્ટી - પચરા - મ. રા. મા. પુલ્લપુર	૩૬
૩૧.	NH 31	દોલ્લાલઘાટ - ચોતારા	૨૫
૩૨.	NH 32	બલપુર - મળંગવા - સોનબર્ણ	૩૦
૩૩.	NH 33	મિજગટ - કાઠમાડો	૬૬
૩૪.	NH 34	કામમાડો - ઘુલીચેલ - દોલ્લાલઘાટ - સ્વાડીચોર - પોદરી	૧૧૨
		(અરનિકો રાજમાર્ગ)	

Note Book

Date : 20 / /

Amara			
34.	NH 35	पिल्लुहवा - मन्जसत - पालैया - मटिहवा	24
35.	NH 36	मन्जपुर - गौर	44
36.	NH 37	हेटौडा - पाजमती - टिपाभैरव - भैरवगढी - रणमनाकुला (पानती राजपवा)	76
37.	NH 38	पाठमाण्डौ पाहिरि - चत्रपवा	87
38.	NH 39	पाठमाण्डौ - चत्रपवा	26
39.	NH 40	सम्भारपुरी - टोम्मा - गुर्जे - विदुर	26
40.	NH 41	सिर्सिया - पवालैया - हेटौडा - भैरव - पालुङ - नौबिसे - ताल्माण्डौ (त्रिभुवन राजपवा)	944
41.	NH 42	ठोरी - भण्डारा - मलेखु - गल्ही - त्रिभुली - चैत्रापती मैलुङ - स्याफुबेसी - रसुवागढी	956
42.	NH 43	मलेखु - धादिङ - सल्यानटार	46
43.	NH 44	ठोरी - भरतपुर - मुग्लिङ, आँबुखैरेनी - गोरखा - धाम्पेसाल, आरुघाट - सिर्दिगास - रोईला भुञ्ज्याङ	300
44.	NH 45	रैपेखैरेनी धाम्पेसाल कावासोती	906
45.	NH 46	भुमही - परासी	5
46.	NH 47	पेलहिया - भैरव - पुरवल - पतुङ - राकदी - स्याङ्गुला पोखरा (सिर्दिगास राजमार्ग)	978
47.	NH 48	तानसेन - रिडी - फोरला	248
48.	NH 49	पतुङ - तानसेन रिडी पामीटक्सार र्वाङ	57
49.	NH 50	जितपुर - तौलिहवा - खुनुवा	30
50.	NH 51	तौलिहवा गोरखिङी सन्धिचारण	73
51.	NH 52	फक्रहवा (भारत सिमा) - रुद्रपुर ; सालमाण्डौ - सन्धीरण - देवीचण, पुरीवाङ - ठोरपाटन	222
52.	NH 53	शालुवाङ - लिवाङ - रोल्पा माडीचौर दारबोट	930
53.	NH 54	फोर्डलावाङ - लमही - अर्जुनखोला - घोराही - हिलेरी - धर्तिगाँउ - भवाङ - लुपुम (वाहिर मार्ग)	299
54.	NH 55	उमेलिया - तुल्सीपुर - शितलपानी - धाम्पे - गुरीगौडा (वाहिर राजमार्ग)	965

Aman			
૫૬.	NH 56	ધારમીર - ચૌરખાલી - જાજરખોટ - વપલંગા - ખુસ્તા	૨૬૩
		જુહારી - મુગુ રાજા (રાજા રાજમાર્ગ)	...
૫૭.	NH 57	દિલ્લુ - ફુડુ - જાજરખોટ - ફુને - દો - તિલ્લે -	૩૧૭
		મરિમ (ધેરી ફરીદોર)	
૫૮.	NH 58	ખમુન્નાદ - બેળાલગંજ - ફોદલપુર - સુર્યેત - રપુલાલ	૫૩૮
		- દિલ્લા (કર્ણાલી રાજમાર્ગ)	
૫૯.	NH 59	મુર્તિયા (શારતીય સિમા) - ગુલરિયા - મુસીગાંઠ - તેળખતી	૧૫૪
		- સુર્યેત - માધિલ્લો ફુડે, શ્વર - ચૈફ - ઘયુલી નાગમા સડક	
૬૦.	NH 60	સુર્યેત - દૈલેય - મહાપુલેય - ગાલ્લે - જાગમા - ગમગદી	
		- બાલચેભાગમા	૩૦૨
૬૧.	NH 61	સુર્યેત તલ્લો ફુડે, શ્વર - સાતરખવા - દુલ્લુ -	૧૬૮
		પિપલખોટ - રપુલાલ - માલમા - જાગમા - ખુસ્તા સડક	
૬૨.	NH 62	રવકરીલા - રિકાપુર - ભમ્મિક - લોડેદાટ - ઘયલપાટ,	૨૩૮
		સાંફેબગર - ચૈનપુર	
૬૩.	NH 63	સાંફેબગર - માર્તદી - ફોલ્ટી	૧૧૧
૬૪.	NH 64	રવોડે - ચૈનપુર (ભમાડ.)	૧૦૮
૬૫.	NH 65	રપુટિયા - દિપાધલ - ચૈનપુર - ડરેભજ્યાડ.	૨૬૬
૬૬.	NH 66	ધનગળી - સદગપુર - પુડર - સ્યાડલે, સતલોમ -	
		વાકતોલી - દાર્ચુલા - દિલ્લુ	૩૫૦
૬૭.	NH 67	- ખાંદમી - મિમદત્ત - બ્રહ્મદેવ - પચેશ્વર મુલ્તાદાટ	૨૦૧
૬૮.	NH 68	શિમાદ - રામપુર - મિલમાલ - ડારુડ. રવોલા	૮૦
૬૯.	NH 69	જગત શમજ્યાડુ - માડલીયાન - પેપરે શમજ્યાડુ -	
		વારીકુના - ફિસાન - ખાપાખોટ - ગણરખોટ સડક, સ્યાંગા	૪૨
૭૦.	NH 70	સેત્રી દોશાન - પેજાડ, - પંચમુલ - ડારુચોર દાળે	૪૬૦
		દેડરાલી, સ્યાંગા	
૭૧.	NH 71	ખાલુપાડ. - બુલાખોટ - રવજદદ - રવરવાડ	૧૭૦
૭૨.	NH 72	દુરખીવાર બદુબગ ત્રિભેળી	૨૩
૭૩.	NH 73	સુકંગા - શર્મામતિ - ટંગાનકુશા દુડે બસુજાંગ, માપા	૨૫
૭૪.	NH 74	ડલામ (બિલોટ) - માડપોરપરી - સુલ્યકપુર, ડલામ	૫૦

Note Book

Date : 20 / /

અમારું			
૬૫	NH75	સ્વર્ણ સાગરસાથા પૃથતચક્ત્રપથ (ઓરંગઝેબી - સોનુ - સત્તેરી ચોરાંગ - દિક્તેત - ઓરંગઝેબી)	૧૩૫
૬૬	NH76	દમક - ચિસાપાની - રવિ	૪૪
૬૭	NH77	મરતાપુર - મહાનગરીય પૃથત ચક્ત્રપથ	૧૦૫
૬૮	NH78	દમક બે.પા ચક્ત્રપથ	૧૦૦
૬૯	NH79	ગોવાર (દાનુષા) ચિસાપાની - મૈનાપતી - પાતાપાની - દુધૌલી - ચિન્દુલી	૨૦
૭૦	NH80	મહેન્દ્ર રાજમાર્ગ બહતીપુર-ચૌક (સિરદા) - વિ.પ્રિ કપાન્સર અસ્પતાલ - બેલસોત - ખટારી, ડડયપુર	૨૦
જમ્મા			૧૪૬૧

Note: oldest of Nepal's highway — Tribhuvan Highway.

Bridge

- A structure constructed over an obstacle to provide the passage.
- If passage is for the movement of traffic is known as road bridge.
- " " " " " " " " train " " " railway "
- If level of bridge is much more than general road is known as over bridge.
- If level of bridge is below the ground level & cover then, it is known as Sub-way.

According to NRS 2045

- Cross drainage Structure whose span > 6m — Bridge.
→ " " " " " " " " < 6m — Culvert.

Characteristics of Ideal Bridge

- Bridge should fit into surrounding landscape.
- Bridge surface should be similar to road surface.
- Bridge should provide passage for services like water pipe, telephone.
- It should be in level.

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- The width of bridge should be sufficient.
- Foundation kept on firm (strong) ground.
- Bridge should carry standard loading with reasonable FOS.
- Bridge should be economical in term of construction & maintenance.

Choice of Location of Bridge site

- A straight reach of river.
- Steady river flow without serious whirs (चक्कर) & Cross Culverts.
- A narrow channel with firm banks.
- Absence of expensive river training works.
- Absence of sharp curves in approaches.
- Absence of excessive construction work under water.
- Suitable high banks above high flood level on each side.
- Rock or other hard strata close to the river bed level.

Classification of Bridges

[A] According to the span (NRS 204.5)

- Minor bridge (span $< 20\text{m}$ but total length upto 20m .)
- Medium bridge (span $< 20\text{m}$ but total length may $> 20\text{m}$.)
- Major bridge (provide whose length & span $> 20\text{m}$)

[B] According to Loading (NRS 204.5)

- Major bridge — IRC Class AA
- Medium or Minor bridge — IRC A
- Temporary bridge — IRC B

[C] According to structure

- RCC T-bridge or RCC simply supported bridge.
- Cantilever bridge (single or double).

Note Book

Date : 20 / /

Aman

- Arch bridge.
- suspended or suspension bridge.
- steel bridge.
- Movable bridge.
- Stayed cable bridge.

(D) According to Materials

- Timber bridge
- RCC bridge
- Float bridge, pontoon bridge or boat bridge.
- Masonry bridge
- Steel bridge.

Component of Bridge

- Foundations for abutments & piers or towers.
- Abutment & piers & towers.
- Decking consisting of girders or trusses or cable & slab.
- Bearing for the girder or trusses.
- Handrail, guard stone etc.
- River training works necessary at U/s & D/s side.
- Approaches to the bridge to connect the road or railway to bridge proper.

Suitability of Bridge

- ① solid slab bridge — span upto 8 m.
- ② Deck girder bridge & slab — span 10 – 20 m.
- ③ T-beam bridge — span 10 – 25 m (cast monolithically).
- ④ Balanced cantilever bridge span upto 25 m.

T-Beam Bridge

- Cast in place, reinforced concrete beams.
- Suitable for 10 – 25 meter.
- T-beam cast monolithically with slab which carry the bridge floor.
- T-beam is generally simply supported over abutments & piers.
- Where traffic is heavy but causes no sudden impacts of the bridge.

Aman

Timber Bridge

- Uses timber or wood as its principal structural material.
- First forms of bridge.
- Used since ancient times.

Tracks & Trails

- A rough path of road, typically one beaten by use for horses, bicycle, pedestrian etc. rather than constructed is known as track.
- Trails are non-motorable road used by foot/mule for the transport of different goods.

Trail Bridge

The bridge provided along the track/trail is known as trail bridge.

Types of Trails Bridge

① Suspension Bridge	② Suspended Bridge
→ Tower taking load exist in this type.	→ No tower exists in this type.
→ Cable are above the tower.	→ Walkway, cables carry load bearing.
→ Both bank should be equal levelled.	→ Both bank may or may not be levelled.
→ It is 20-25% more expensive than suspended bridge.	→ It is less expensive than suspension bridge.
→ It is ancient one & was used in 18th century in Europe.	→ It is less ancient one & was used later on.
→ Walkway deck is hogging type.	→ Walkway deck is sagging type.

③ steel truss bridge

④ Twin bridge

Note Book

Date : 20 / /

Aman

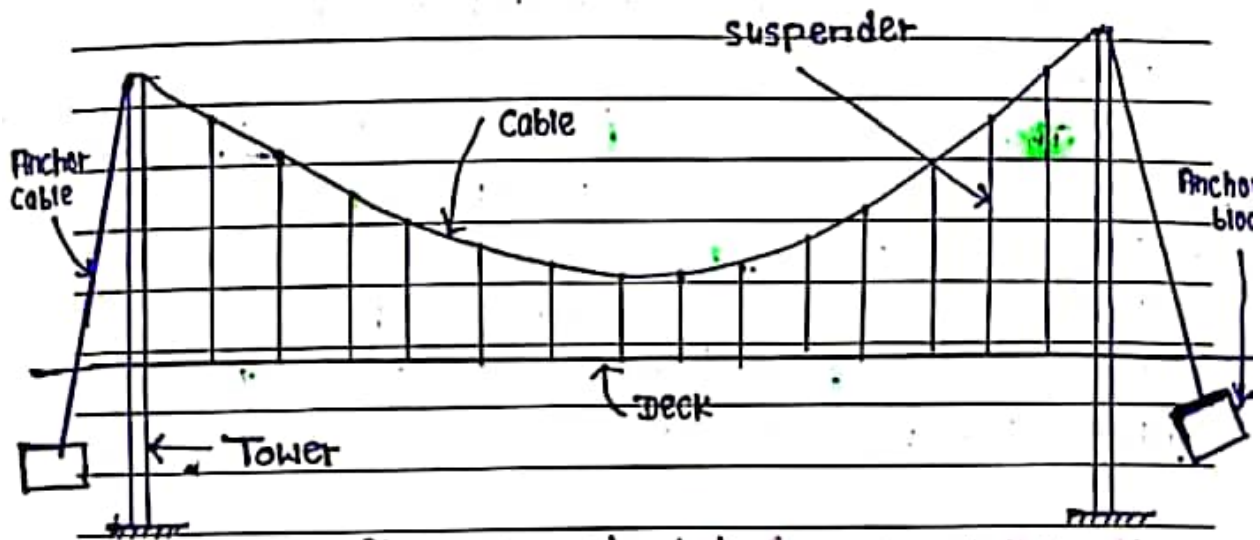


fig: suspension bridge.

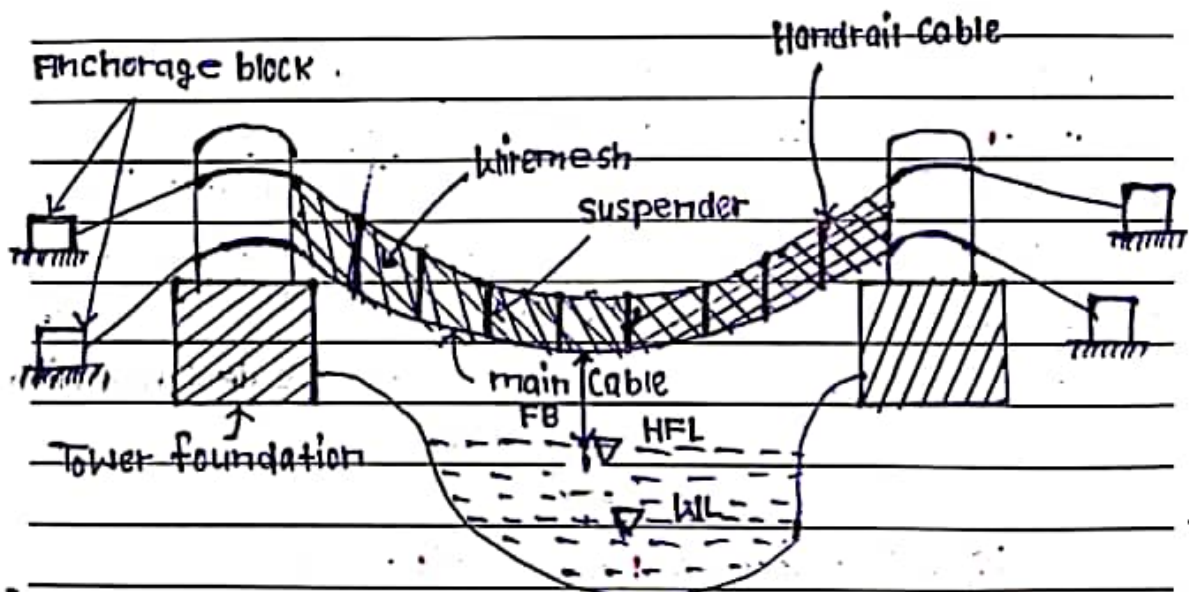


fig: suspended bridge.

Karnali Bridge

- Single tower, Cable-stayed bridge.
- Longest of its type in Nepal.
- Built by international collaboration.
- The bridge spans the Karnali river betⁿ Kailali & Bardia district of Western Nepal.

Note Book

Date : 20 / /

Aman

→ Bridge was constructed by Kawasaki heavy industries of Japan.

→ Inaugurate after six years of its construction, date by the late prime minister Girija Prasad Koirala

→ The single-pillar bridge was constructed by Japanese government.

→ Bardiya national park connected the area, Karnali river.

→ Beautiful scenery (दृश्य) with delicious (स्वादिल) fish have enhanced the beauty of region.

Nepal Bridge Standard 2067

→ All permanent bridges shall be designed life of minimum 50 years.

→ Traffic projections shall be made for a period of 30 years.

→ All permanent bridges shall be designed for a discharge of 100 yrs return period.

→ All permanent road bridges in Nepal shall be designed as per IRC loadings or AASHTO loadings.

→ All bridges in highways & urban road shall be designed with a minimum carriageway width of 7.5m.

राष्ट्रिय गौरवका सडक तथा रेल आयोजनाहरू

क्र.सं	आयोजना	लम्बाइ	२०७७ असार सम्म	सम्पन्न हुने आ.व
१.	पुष्पलाल मधुपट्टाई लिफ्टमार्ग	१८७९KM	४८.९४ %	२०७९/८०
२.	धुलाकी लिफ्टमार्ग	१७९२.४२	५४ %	२०७९/८०
३.	काठमाडौं - तवाङ - मधेश	७२.५	११.११ %	२०८०/८१
	दुतमार्ग			
४.	कालिगढाकी कोरिडोर (उ.द.ली)	४३१	३५.५ %	२०८०/८१
५.	कोशी कोरिडोर (उ.द.ली)	१६२	२१ %	२०८०/८१
६.	कर्णाली कोरिडोर (उ.द.ली)	२८४	२२.५० %	२०७९/८०
७.	रेलवे तथा मेट्रो रेल विचार	१२१७.४	२४.५० %	रुक्मिण नारायणी

Traffic signs

① Regulatory / Mandatory signs

- used to inform the road users of certain laws, regulations & prohibitions to provide safety & free flow to traffic.
- The violation of these signs is a legal offence.
- Most sign, form of a circular disc.
- stop sign (900mm x 900mm) in octagonal shape.
- Give Way sign (equilateral triangle having side 900mm).
- Example; one way traffic, no entry, truck prohibited, dead slow speed limit, cycle prohibited, left right turn prohibited, overtaking prohibited. etc.

② Warning / Cautionary signs

- Used to warn the road users of certain hazardous conditions that exist on or beside the roadway.
- Used to alert drivers to danger or potential danger ahead.
- These signs are equilateral triangle in shape with its apex pointing upwards.
- Example; Left/Right hand curve, left/right hair pin bend, Cycle Crossing, pedestrian crossing, Cross road, Side road, hump, barrier ahead, school zone etc.

③ Informatory signs

- Used to guide the road users along routes, inform them of destination, direction, distance & information about facilities like; rest area, Petrol pump, parkings.
- so that travel make easier, safe & pleasant (सुखद).
- These sign are either rectangular or square in shape.
- They provide information about bus stop, parking places, road ahead, flood gauge, public telephone.

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Parking Study

- ① parallel parking — When widths of lanes are limited.
- ② perpendicular parking — Max^m no. of Vehicles are parked.
- ③ 45° angle parking — Best parking
- ④ 75° angle parking — parking which customer prefer.

Road Marking

- ① Longitudinal lines should be at least 10cm thick.
→ Transverse line should be made in such a way that they are visible at sufficient distance in advance to give road users adequate to response.
- ② pavements marking may generally be of white paint.
→ Yellow colour markings are used to indicate parking restrictions, for continuous center line & barrier line markings.
- ③ Traverse solid line indicates the position of stop lines for vehicular traffic.
- ④ Width of pedestrian crossing should be 2.4 - 4m depending upon the situation.

Expected Life of Road

- 1. Water bound macadam roads (single coat) = 2 years.
- 2. surface dressing (single coat) = 3 years.
- 3. premix bituminous Carpet = 8 years
- 4. Sheet asphalt Surfacing = 8 - 15 years.
- 5. Sheet asphalt = 15 years.
- 6. All Concrete roads = 25 - 40 years.

Note Book

Date : 20 / /

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Intensity of Traffic & suitability of Road

Nature of Traffic	Intensity of Traffic in Ton/m width/day	Suitable Roads
Light	Less than 160	Earth, moolam, gravel, Kankar & stabilized soil road.
Medium	160 - 330	WBM surface dressed, 15cm plain concrete road.
Heavy	330 - 500	Surface dressed (two coat) grouted bituminous macadam 15cm plain concrete road With bituminous carpet
Very heavy	500 - 1400	Bituminous grouted macadam asphalt concrete road, RCC road.
Very heavy	1400 - 3500	Sheet asphalt, 20cm RCC road
Very heavy	3500 - 5000	22.5cm RCC road hard stone paving