4.1) Highway Engineering:

Er. Sabin Pokharel

Transportation:

↳ Movement of goods and people from one place to another with safety, easy, comfort, economical is known as transportation.

↳ Movement of people is known as passenger transportation.

↳ Movement of good is known as freight transportation.

⇒ Modes of transportation:

↳ There are two modes of transportation; they are -

(a) Primary Modes of Transportation: (4 types)

(i) Landways

- Roadways: Road, highway, street (Bus, car, truck, motorcycle)
- Railways: (Train, wagon, container) Rail.

(ii) waterways: Lake, river, sea, ocean (Boat, ship)

(iii) Airways: Air route (Aeroplane, Helicoptor, Drone)

(iv) spaceways: space route (satellite, rocket etc.)

(b) Secondary modes of transportation: (4 types)

(i) Ropeways: cable (car, cabin, chair, gondola, lift)

(ii) pipeline: pipe (water, gas, sewer)

(iii) canal: Irrigation canal (water)

(iv) Belt-conveyor: Belt (aggregates in crushing / crusher plant)

(#) Advantages of road transportation:

→ In context of Nepal, road transport is most suitable & feasible.

↳ Some of the advantages are listed below:-

(1) It has wide geographical coverage.
(2) It has high flexibility and ability to move the vehicles fastly.
(3) It provide door to door service.
(4) It provides quicker and assured deliveries of goods.
(5) It provides highest employment potential.
(6) It is economical for short distance travel.
(7) It is safer in comparision to other modes of transportation.
(8) for the development of other modes, road transportation play a key role.

(#) Disadvantages:

(1) It degrades the Land.
(2) It contributes to environmental pollution.
(3) It consumes huge quantity of non-renewable source of energy.
(4) It produces congestion.
(5) It produces effect on parking.
(6) It is uneconomical for long distance travel.
(7) Repeated no. of accidents daily.

Objectives / necessities of road planning:

(i) To plan road network for efficient & safe traffic operation but at min^{m} cost. Here, the cost of construction, maintenance & resurfacing or strengthening of pavement layers & vehicle operation cost are to be given due consideration.

(ii) To work out financial planning & management system.

(iii) To forecast the future requirement of roads needed.

(iv) To set up priorities & schedule of construction & renewal program in accordance with the available resources.

(v) To divide the overall plan into phases and to decide priorities.

(vi) To arrive at the road system & length of different categories of roads which could provide max^{m} utility. Etc.

Establishing economic & environmental viability :-

↳ The different types of economic analysis are :-

(i) Payback period Method

(ii) Benefit cost ratio (B/C)

(iii) Internal rate of return (IRR), IRR > prevailing interest rate.

(iv) Net present value (NPV)

(v) Present worth Method (PWM)

vi) future worth Method (FWM)

↳ The different types of environmental analysis are –

(i) Degradation of Land

(ii) Environmental pollution

(iii) Soil Disposal

(iv) Harmness to flora & fauna.

(v) Biological effect.

④ Evaluation of alternatives:

steps:

(i) setting of objectives.
(ii) Determining of objectives.
(iii) selecting the best alternatives.
(iv) formulation of ~~environmental analysis~~ real plan.

↳ After economic & environmental analysis, the project which provides the max^{m} benefit will be selected.
↳ social analysis is also used during evalution of alternatives.

Classification of road in Nepal:

→ As per NRS-2070, road is classified into two categories.

① Administrative classification:

↳ As per administrative classification, there are four types of road.

@ Highway or National Highway or Trunk road or Rajmarga:

↳ The road connecting along the length as well as across the width of the country is known as highway.
↳ The major road of the country is known as highway.
↳ Tribhuvan highway is the oldest highway of Nepal. (1956)
↳ In Nepal there are 80 nos. of highway.
↳ Highways are represented by capital letter "H" followed by two digit number.
e.g; H01 for Mahendra Rajmarga (1027.67 KM) from Mechi bridge Jhapa Border to Goddachowki Border Kanchanpur.

(b) Feeder Road (सहायक राजमार्ग)

- These roads departing from highway and connecting to zonal headquarters, district headquarters, economic market center, tourist area are feeder roads.
- In Nepal there are 208 no. of feeder roads.
- feeder roads are represented by capital letter 'F' followed by three digit number.
  E.g; F001 → Birtamod to Chandragadhi (12.53 km).

(c) District Road

- The road within the district is known as district roads.
- District roads are represented by capital letter "DR".

(d) URBAN Road

- The road within the Metropolitan city, sub-Metropolitan city, Municipality, town development Board is known as urban roads.
- The roads of urban (towns) is also known as street.

(ii) Technical or functional classification

- As per technical or functional classification, there are four types of roads.

Class	Average Daily Traffic (ADT)	Design speed
• Class-I (Highest std.) (Express ways)	20,000 PCU or more in 20 years perspective period	120 kmph (in plain terrain)
• Class-II (Arterial Roads)	5000 - 20,000 PCU in 20 years perspective period.	100 kmph (in plain terrain)
• Class-III (collector Roads)	(2,000 - 5,000) PCU in 20 years perspective period.	80 kmph (in plain terrain)
• Class-IV (Local roads)	Less than 2,000 PCU in 20 years perspective period.	60 kmph (in plain terrain)

Rel^n between administrative & functional classification of roads:

	plain and rolling terrain	Mountainous and steep terrain
• Highway	I, II	II, III
• feeder roads	II, III	III, IV

Types of terrain:

Terrain	% cross slope	Degree of curve
• Plain	0-10%	0°-5.7°
• Rolling	10-25%	5.7°-14°
• Mountainous	25-60%	14°-31°
• steep	>60%	>31°

↳ Degree of curve is the angle subtended by arc of 30m Length at center.

Desig speed (Kmph): (NRS-2070)

Road class → / Terrain ↓	class I	class II	class III	class IV
Plain	120	100	80	60
Rolling	100	80	60	40
Mountainous	80	60	40	30
steep	60	40	30	20

@ Equivalency factor (or) Passenger Car Unit (PCU) or Passenger car equivalent (PCE)

vehicle types	PCU
• Bicycle, Motorcycle, scooter, Moped	0.5
• Car, light van, Pickup van, auto rickshaw	1
• Light (mini) truck, tractor without trailor, Rickshaw	1.5
• Mini-bus, bus, truck, tractor, tripper	3
• Non-Motorized vehicles (Bullocks carts)	6

(#) Historical development of road construction in Nepal:

→ During Rana regime there were two office named "Batokaj Goswara" and "Chhembahadel Adda" used for construction of roads, and other civil engineering works respectively.

→ In 1918 AD, an office named "Nayabatokaj Goswara" was used for the construction of new roads in Nepal. Similarly "Batokaj Goswara" was changed to "Purano Batokaj Goswara".

↳ "Banaune Adda" was established in different parts of the country in this period.

↳ An army unit named "Samarjung" was used for the routine maintenance of work under "Purano Batokaj Goswara".

↳ In 1958 AD an old office and new office were merged and office named Public work Directives (PWD) was formed.

↳ PWD had two units named as Normal road & Bridge work.

↳ In 1970 AD PWD was splitted into two departments named "Department of road" and "Department of Building".

↳ In 1958 AD, Tribhuvan Highway (1st highway) was constructed (Tripureshwor - Birgunj)

↳ In 1963 A.D. Araniko highway was constructed.

↳ In 1992 AD, six (6) regional office & 25 division office of DOR was created.

Types of Road planning in Nepal:

(1) National road network planning (NRN planning)

↳ National road planning is the planning of main highways running through the length & breadth of country, connecting major parts of the country, headquarters of regions & large industrial & tourist centers.

→ As per functional importance of road, road are classified into four (4) types.

(a) Strategic road Network (SRN) → Highway / national highway
↳ feeder roads.

(b) District road Network (DRN)

(c) Urban Road Network

(d) Village road Network.

(2) Urban Road Network (URN) planning

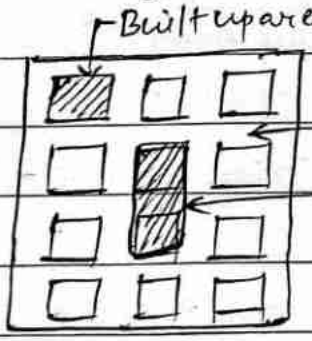
↳ Urban areas are communication centers for the exchange of goods, service and ideas.

→ The road patterns within urban areas are classified as urban roads and will form a separate category of roads to be taken care by the respective urban authorities.

→ Major road patterns developed in urban areas are -

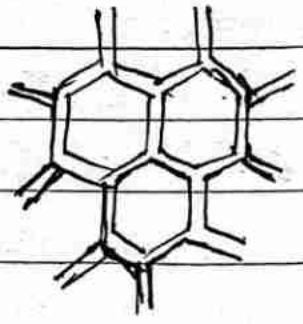
(a) Grid Iron pattern

(i) Rectangular or block



Rect. or block pattern

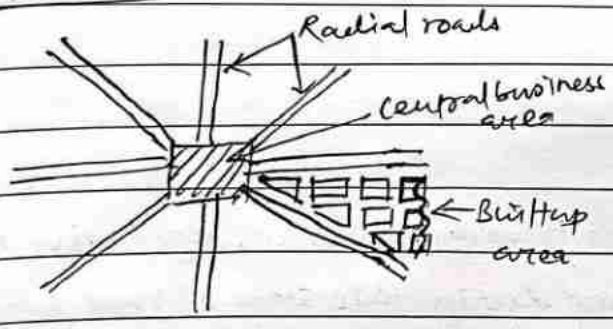
(ii) Hexagonal



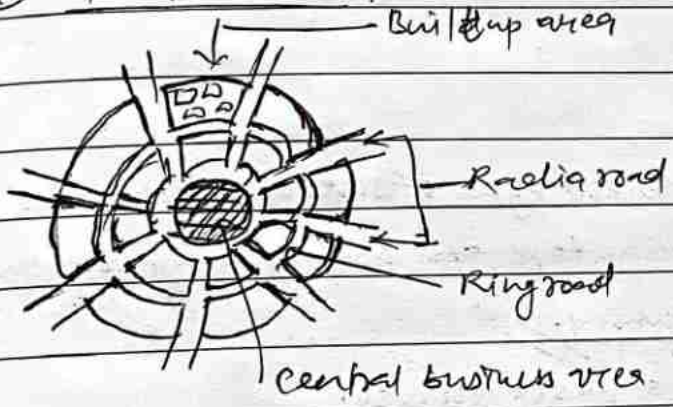
Hexagonal pattern

(b) Radial pattern

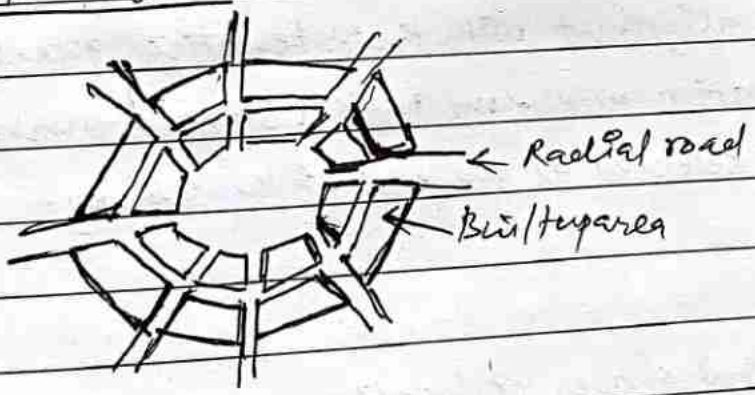
(i) star & block



(ii) star & circular :



(iii) star & grid.



(#) Road survey and quantity calculation:

→ The stages of road survey are;

(1) Map study:
- Also known as desk study.
- The different types of map like topographical map, vegetative map, aerial photographs etc. are used during this stage of road survey.
- Actual site is not visited in this stage.
- Tentative study of site is done during this stage.

(2) Reconnaissance stage (Recci):
- In reconnaissance survey, different types of survey instruments like abney level, GPS, measuring tape are used during survey.
- It is also known as walkover survey.
- Actual site is visited in this stages of survey.

(3) Preliminary Survey:
- The different types of alignment with their tentative quantity calculation & cost estimation are done in this stages of survey.
- One final alignment is selected at the end of the survey.

(4) Detailed survey:
- It is also known as final survey or location survey.
- In this stage of survey, the detail parameters like catchment area, bearing capacity of soil, rainfall intensity, duration of rainfall, frequency of rainfall etc. are studied.
- Benchmark are fixed in this stages of survey.

(#) Components of Trans. system:

→ There are 5 components of TS.

(1) Modes: They represent the conveyances, mostly taking the form of vehicles that are used to support the mobility of passengers or freight.

(2) Infrastructures: It include superstructure which are movable assets that usually have a shorter lifespan.
- for an airport the infrastructure would be an assets such as the runway while superstructure would be terminals & control equipment.

(3) Networks: A system of linked location that are used to represent the functional and spatial organisation of transportation. This system indicates which locations are connected and how they are serviced.

(4) Flows: Movements of people, freight and information over their respective location. flows have origin, immediately location & destination.

(5) Control system: It consists vehicle control & flow control.
- vehicle control refers to the technological way in which individual vehicles are guided on fixed facilities.
- flow control consists of the means that permit efficient & smooth operation of streams of vehicles & the reduction of conflicts between them.

Major disciplines of transportation (scope of transportation engineering):-

① Transportation planning:-

- planning is the process of predetermining future.
- Transportation planning especially involves the development of transportation model which will accurately represent both the current as well as future transportation system.

② Geometric design:

- Deals with the physical proportionally of steer transportation facilities, in contrast with the structural design of the facilities. It includes -
  - cls features
  - Hz. alignment
  - Vt. alignment & intersection

③ Pavement analysis & design:

- It deals with the structural design of roads, both (bitumen & concrete) commonly known as (flexible & rigid pavements) respectively.
- It deals with design of paving material, determination of the layer thickness & construction, maintenance, rehabilitation procedures.

④ Traffic engineering:

- It covers a broad range of engineering applications with a focus on the safety of the public, the efficient use of transportation resources, and the mobility of people & goods.

5) Others :

Other minor slopes of transportation engineering are -

- Public transportation (Mass transit system)
- Economic analysis
- Environment Impact Assessment (EIA)
- Accident analysis & Redn
- Parking study etc.

Hierarchal structure of Road Transport planning :-

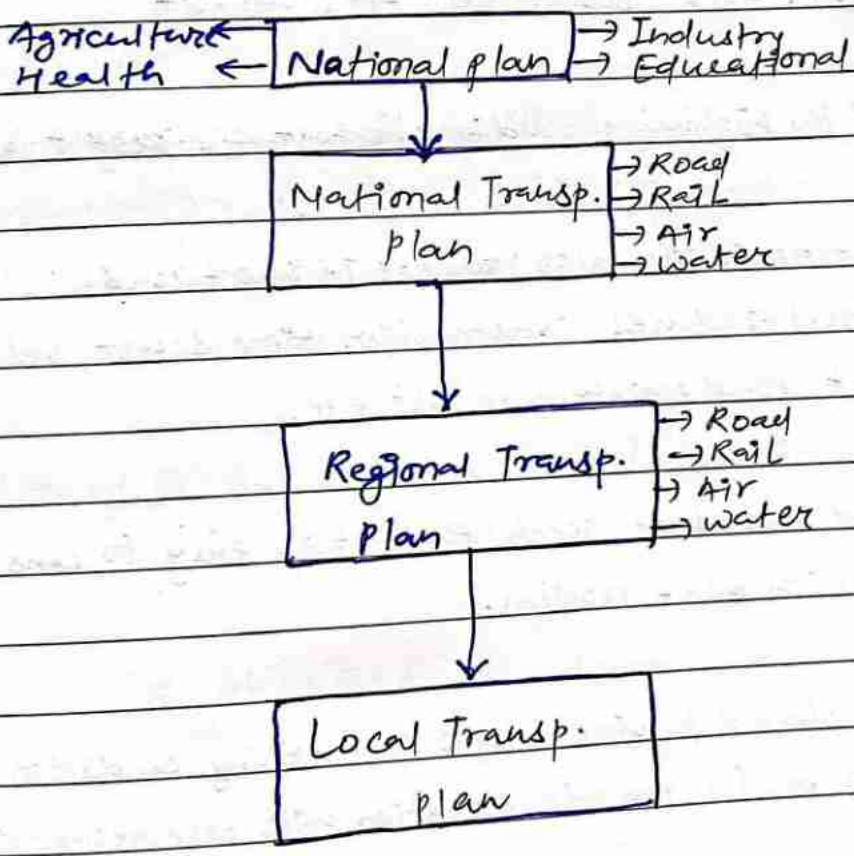


fig:- Hierarchal structure of RTP

Chapter-2

(#) Highway Alignment:

↳ Establishing the centerline of the proposed road in plan, on ground is called highway alignment.

→ It includes two parts-

- Horizontal alignment – It includes straight and curve paths.
- Vertical alignments – It includes change in gradient & vertical curves.

(#) Ideal requirements of highway alignment:

[SESEFC] → short, Easy, safe, Economical, Fit, Comfort

(a) short:- The length of the highway should be shortest & straight as possible.
- Probability of accidents also reduces in short road.
- short alignment reduces construction time & cost, vehicle operation cost, road maintenance cost etc.

(b) Easy:- The alignment should be such that it is easy to construct & maintain with min^{m} problem.

(c) safe:- The alignment should provide easy & safe driving condition.
- It should be safer for traffic operation with safe geometric features.

(d) Economical: The proposed alignment should form a most economical line of communication.

(e) Fit:- The proposed alignment should be fit into the largest general planning of the country.

(6) Comfort: Drivers should feel comfort while driving.
→ Likely passengers should also feel comfort while travelling on this destination.

(#) Factors controlling highway Alignment:

(1) Government requirement:- The highway development project requires heavy initial investment, hence government demands clarity on proper planning, construction & utilization of highway.

(2) Obligatory points:- It acts as control points in highway alignment:
Two types of obligatory points.

(a) Positive obligatory points – Points through which alignment should pass. such as settlement area, existing road bridge site, mountain passes, intermediate town etc.

(b) Negative obligatory points – Points through which alignment should not pass.
such as historical & religious places, marshy land, water logged area, ponds or lakes, border line of country etc.

③ Geometric standard:

- The geometric conditions such as radius of horizontal curve, sight distance, gradient on vertical alignments also affects the alignment of highway.
- As possible good sight distance, large radius on H-curve should be planned for a safety of the traffic.

④ Traffic: The volume, type & traffic expected to use the road & flow pattern of traffic affects the alignment.

⑤ Geological condition: The alignment should pass only through the geologically stable hill slopes.

⑥ Economy: The final alignment should be economical but economy should not negotiate with the quality while working.

⑦ Other factors –

- Existing Right of way of highway
- Political & other consideration
- Monotony of straight roads
- Canal, river crossing & drainage

Structure of the route location process

↳ structure of the route location process is a continuously searching and selecting technique. It is a hierarchially structured process in which bands of (8-16M), corridors of (3-10 KM), route strips of (1-1.5KM), and alignment of (30-50M) are selected.

Region → Bands (8-16M) → Corridors (3-10 KM) – strips (1-1.5KM) → Alignments (30-50M)

factors affecting the structure of the route location process:

(i) Topography
(ii) Geology
(iii) soil condition
(iv) Population distribution
(v) safety
(vi) Decision Mode after EIA.
(vii) political & Environmental factor. etc.

Imp. of Map study in highway survey:

- Map study suggests the likely routes of road.
- The main features likes, river, valley, hills etc. are shown in map these helps to locate obligatory points.
- Map study allows study of almost all information about the site just by sitting on the chair.
- Approximate location of bridge site for river crossing can be done by help of map study. etc.

Chapter 3

Geometric Design of Highway

⇒ The geometrics of highway are the elements of a road which are visible to road users.

- Geometric design deals with the dimensions & Layout of visible features of the highway such as alignment, sight distance, intersection etc.

⇒ Highway geometric can broadly be classified under following:

1) Cross section elements - like camber, shoulder, carriageway, extra widening, super elevation etc.

2) Elements of hz. alignment - Horizontal curvature Length & radius
   - Transition curve
   - sight distance across the road.

3) Elements of Vt. curve - Grade, vertical curve
   - sight distance along the road.

4) Road Intersection - Level or grade intersection
   - Grade separated Intersection

Basic design controls & criteria for design:

Design controls

(1) **Design speed** – It is the most important factor controlling the geometric design of highway.

- Design speed is decided based on the importance of the road class & the type of terrain.
- Design speed is taken as 98th percentile speed.
- It is the speed at which 98% of vehicle moves below this speed.
- The design speed to be adopted for various classes of road is:

Road class	Plain (Kmph)	Rolling (kmph)	Mountainous (Kmph)	steep (kmph)
I	120	100	80	60
II	100	80	60	40
III	80	60	40	30
IV	60	40	30	20

(2) **Design vehicle** – As per NRS 2070, the design vehicle has

Max^{M} Length – 18 M

Max^{M} width – 2.50 m

max^{M} height – 4.75 m

max^{M} single axle load = 100 kN

(3) **Traffic volume and composition:**

- The no. of vehicles passing at a selected points in a unit of time is known as traffic volume.
- It will be uneconomical if we design road for peak flow, therefore reasonable value of traffic vol^{M} is selected as the design hourly volume.

(4) Road user's Behaviour:

↳ Behaviour of road user's affect the geometric design of highway.

(5) Environmental factors:

↳ factor like land scaping, air pollution, noise pollution, aesthetic condition etc. also affect the road geometrics.

(6) future requirements of roads etc.

↳ future requirements for lane addition, expansion etc. Influences geometric design.

(7) Topography:

→ The topography of the terrain conditions influences the geometric design of highway significantly.

→ Terrain is classified according to the percent slope of the country across road alignment.

S.No.	Terrain type	% cross slope	Degree
1	Plain	0-10	0-5.7
2	Rolling	>10-25	>5.7-14
3	Mountainous	>25-60	>14-31
4	Steep	>60	>31

→ The geometric design standards charges according to terrain to keep costs of construction & time of construction under control.

Elements of highway cross-section:

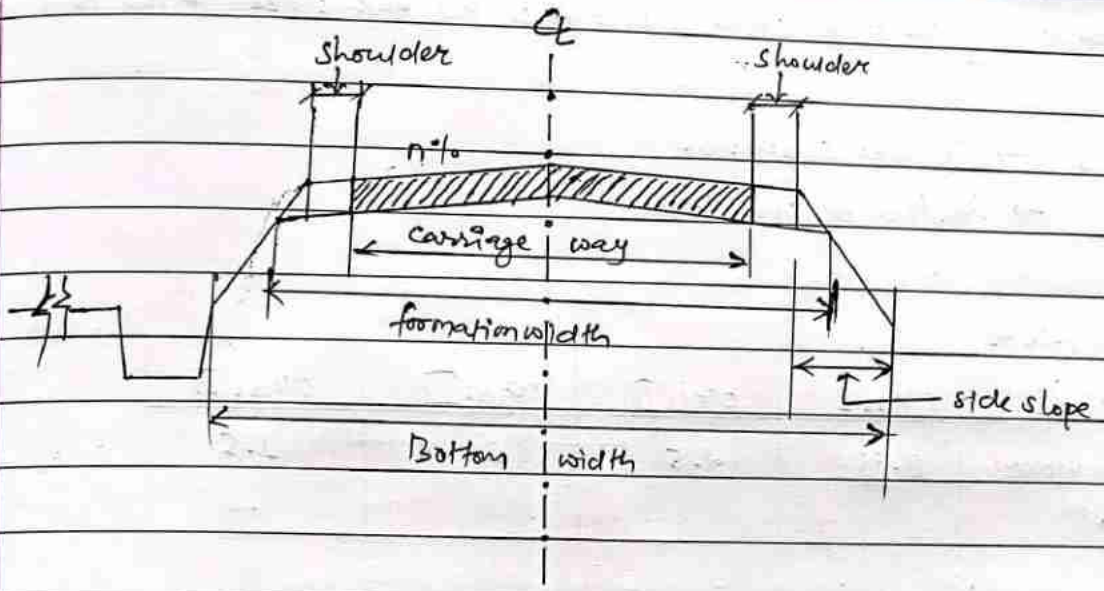


fig. elements of highway cls

(a) Right of way (ROW)

↳ The width of land to be acquired for the road along its alignment is called right of way.

↳ It is acquired before tender stage.

Types of roads	Tot. ROW, m
Highways	50
feeder Roads	30
District Roads	20
city Roads – 4 Lane	50
– 2 lane	30

(b) Width of carriage way or pavement width:

→ It is metalled strip of road used for the vehicular traffic movement.

As per NRS-2070,

① width of single lane road = 3.75 m
② multi-lane pavement width per lane = 3.5 m
③ Intermediate lane = 5.5 m

(c) Shoulder:

↳ Shoulder are additional strip provided on the both sides of the carriage way.

↳ Two types → Treated shoulder
→ Un treated shoulder

As per NRS-2070,

Road class	class I	class II	class III	class IV
Min^M shoulder width, m	3.75	2.5	2	1.5

Advantages of shoulder:

(1) To stand traffic sign & signal.
(2) Provide space for parking vehicle at emergency situation.
(3) During overtaking it serve as extra lane for vehicle.
(4) Improves sight distance.

(d) Footpaths:

↳ They are raised strips constructed along both edges of road & used by pedestrains.

↳ Also called footway or side walks.

As per NRS-2070,

Design hourly flow (Both ways) of 15 minute peak period survey	Min^M footpath width (each side)
upto 500	1.5m
500-1500	2m
1500-2500	2.5m
2500-3500	3m

(d) If the no. of pedestrian in 15 minutes is 300, then the footpath width required as per NRS 2070 is---?

Solution;

Design hourly flow = 15 min. flow x 4

= 300 x 4

= 1200 nos.

As per NRS - 2070 codal provision,

for 500 - 1500 hourly flow,

width of footpath is 2M Ans.

(e) Camber:

↳ Camber is a transverse slope given to the road surface.

↳ It is convexity provided on the X-section of the road.

It is provided for -

1) To drain rain water from the road surface as quickly as possible.
2) To prevent percolation of rainwater from pavements surface.
3) To segregate traffic stream.
4) To provide aesthetic appearance.

Design of camber depends on -

1) Amt. of rainfall
2) Types of road surface
3) Nature of soil.
4) Hydrological analysis

As per NRS - 2070,

Pavement type	Earthen	Gravel	Bituminous	Concrete
Camber	5%	4%	2.5%	1.5 - 2%

(#) Types of camber:

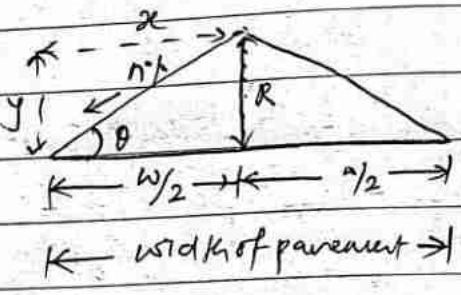
(1) St. line camber:

↳ straight line camber is adopted for very flat slope & generally with cement concrete pavement.

→ for straight line camber,

$$\boxed{y = nx}$$

where, $n = \frac{2R}{W}$



y = vertical height from edge of road to crown.

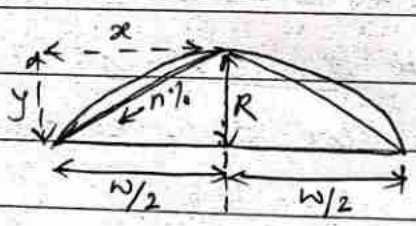
x = horizontal distance from crown towards the edge

(2) Parabolic camber:

↳ Parabolic camber are adopted for very fast moving vehicle and generally with bituminous pavement.

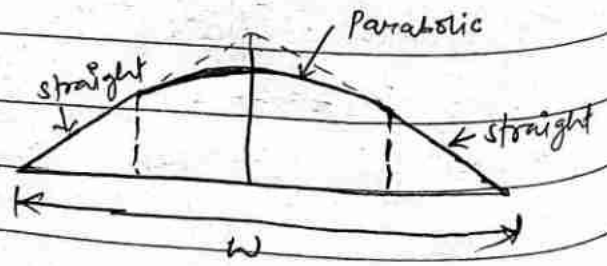
→ for parabolic camber,

$$\boxed{y = \frac{2nx^2}{W}}$$



(3) Composite camber:

↳ The combination st. line camber at edge & parabolic camber at crown is known as composite camber.



(#) Disadvantages of heavy camber:

1) Low quality (earthen & WBM) road erode easily during rainy season.
2) chances of skidding & overturning of vehicle & discomfort during travelling.
3) Tendency of most of the vehicle to use center part of road, so chances of damage in the center part of the road easily & also the road capacity is affected.
4) formation of cross ruts due to rapid flow of water.

Numerical:

(3) for a four lane bituminous road having the camber 3%. what should be the height of crown w.r.to edge if provided with..

(a) st. line camber (b) Parabolic camber

solution:

No. of lane = 4

width of road (w) = 4 x 3.5 = 14m

Camber (n) = 3% = 0.03

Height of crown (y) = ?

(a) for st. line camber;

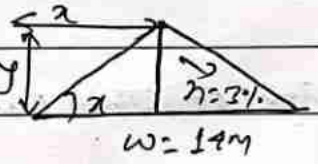
$y = nx$

Here;

$x = 7m$

$\therefore y = 0.03 \times 7$

$= 0.21m$

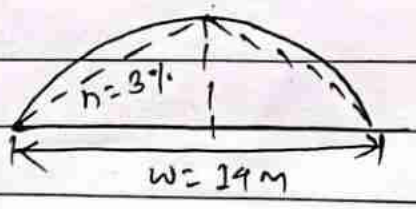


(b) for parabolic camber:

$y = \frac{2nx^2}{w}$

$= \frac{2 \times 0.03 \times 7^2}{14}$

$y = 0.21m$



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(5) If the RL of crown is 412.23 m & 2.5% slope for camber is provided, find the elevation of the edge of pavement & elevation of the center of Lane of road. for road width of 7.5 m

(a) st. line camber (b) parabolic camber

Solution;

(a) Here;

RL of crown = 412.23 m

Camber ~~of~~ slope (n) = 2.5% = 0.025

Ele. at edge of pavement = ?

Elev. at center of pavement = ?

(a) st. line camber:

→ Height of crown w.r.t. edge (y) = nx

$$= 0.025 \times \frac{7.5}{2}$$

$$= 0.094 \text{ m}$$

∴ Elevation ~~of~~ edge of pavement = 412.23 − 0.094

= 412.136 m Ans.

→ Height of crown w.r.t. centerline (y_1) = nx_1

$$= 0.025 \times \frac{7.5}{4}$$

$$= 0.0467$$

∴ Elevation of the center of Lane of road = 412.23 − 0.0467

= 412.183 m Ans.

(b) for parabolic camber:

Height of crown w.r.t. edge $(y) = \frac{2nx^2}{w}$

$= \frac{2 \times 0.025}{7.5} \times \left(\frac{7.5}{2}\right)^2$

$= 0.0938\,m$

∴ Elevation of edge of pavement $= 912.23 - 0.0938$

$= 912.13\,m$ Ans.

Also, Height of crown w.r.t. centerline of lane $(y_1) = \frac{2nx_1^2}{w}$

$= \frac{2 \times 0.025}{7.5} \times \left(\frac{7.5}{4}\right)^2$

$= 0.0234\,m$

∴ Elevation of center of lane of road $= 912.23 - 0.0234$

$= 912.196\,m$ Ans.

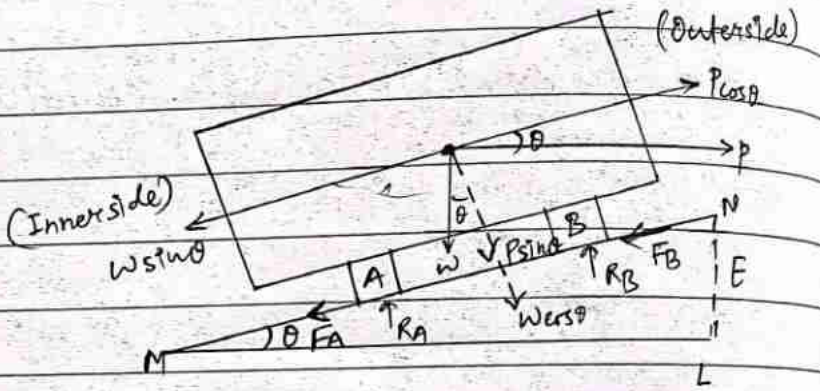
(f) Super elevation:

→ To reduce the tendency of the vehicle to topple or skid, the outer edge of the road pavement is raised w.r.t. the inner edge, thus tilting the road surface from outer edge toward the inner edge. This lateral inclination of road surface is known as super elevation.

→ It is denoted by 'e'.

→ It is also known as cant or banking.

(#) Analysis of super elevation:



Considering equilibrium,

$$P\cos\theta = W\sin\theta + F_A + F_B$$

or, $P\cos\theta = W\sin\theta + R_A f + R_B f \quad \because F_A = f \times R_A$ & $F_B = f \times R_B$

or, $P\cos\theta = W\sin\theta + f(R_A + R_B)$

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

or, $P\cos\theta - FP\sin\theta = W\sin\theta + fW\cos\theta \quad \because R_A + R_B = P\sin\theta + W\cos\theta$

Dividing both side by $W\cos\theta$, then

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

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

$$\therefore \frac{P}{W} = \frac{e+f}{1-fe}$$

Here; Consider $e = 7\%$ & $f = 0.15$ then

$$(1-fe) \simeq 1$$

$$\text{So, } \frac{P}{W} = e+f$$

$$\text{or, } \frac{v^2}{gR} = e+f, \quad v \text{ in m/s}$$

$$\Rightarrow \boxed{R = \frac{v^2}{g(e+f)}}$$

$$\text{Also, } \frac{v^2}{127R} = e+f; \quad v \text{ in kmph}$$

$$\therefore R = \frac{v^2}{127(e+f)}$$

$$\text{or, } \boxed{v = \sqrt{127R(e+f)} \text{ kmph}}$$

for equilibrium superelevation, $f = 0$

$$\boxed{\therefore e = \frac{v^2}{127R}}$$

As per NRS-2070;

- Max^m superelevation to be provided is limited to
  - → In plain & rolling terrain – 7%
  - → In snow bound areas :– 7%
  - → In hilly areas not bound by snows – 10%
- Minm superelevation should be equal to rate of camber of the pavement.

(#) Design steps for super elevation :-

(1) Considering 75% of design speed & neglecting coefficient of lateral friction (f). So,

$$e = \frac{(0.75V)^2}{gR} \; ; \; V \text{ in m/s}.$$

If $e \leq 0.07$. OK otherwise go to step (2).

(2) If $e > 0.07$ from step (1) then take $e = 0.07$ & obtain f by

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

If $f \leq 0.15$, the value is OK. otherwise go to step (3)

(3) If $f > 0.15$ from step (2), calculate restricted velocity V_0 by taking $e = 0.07$ & $f = 0.15$.

$$V_0 = \sqrt{gR(e+f)} \text{ in m/s ; where } V_0 = \text{restricted velocity}.$$

(9) The radius of curve is 140m & the design speed of vehicle is 60 kmph & the coefficient of lateral friction is 0.15 the calculate (a).

(a) super elevation

(b) Coeff. of lateral friction if no superelevation is provided.

(c) equilibrium superelevation.

Solution;

Here;

Radius of curve (R) = 140m.

Design speed of vehicle (V) = 60 kmph

Coeff. of lateral friction (f) = 0.15

(a) super elevation (e) = ?

we know,

$$e+f = \frac{V^2}{127R}; \quad V \text{ in kmph}$$

$$\Rightarrow e = \frac{60^2}{127\times140} - 0.15$$

$$= 0.052 < 0.07 \text{ (o/c)}$$

$\therefore$ super elevation (e) = 5.2%

(b) Coeff. of lateral friction (f) if e = 0;

$$e+f = \frac{V^2}{127R}$$

$$\Rightarrow f = \frac{60^2}{127\times140}$$

$$\Rightarrow f = 0.202 > 0.15 \text{ (Not o/k.)}$$

Change design speed of vehicle for safe operation of vehicle.

If no super elevation is to be provided.

(c) for equilibrium super elevation;

$f = 0$

$\therefore e = \frac{V^2}{127R}$

$= \frac{60^2}{127 \times 140}$

$= 0.202 > 0.07$ (Not OK).

$\therefore$ Provide equilibrium super elevation $(e) = 0.07$ & design speed of vehicle should be changed.

(8) A radius of 250m has been provided in a locality due to site restriction in a national highway of Nepal having the design speed of 100 kmph. Design super elevation. Do you need restriction in speed?

Solution;

Radius of curve $(R) = 250$m

Design speed $(V) = 100$ kmph

super elevation $(e) = ?$

As national highway of Nepal is mixed traffic condition.

So, $e = \frac{V^2}{225R}$ { for mixed traffic condition the super elevation should be fully counteract the centrifugal force for 75% of design speed.

$e = \frac{(0.75V)^2}{127R}$ | $= \frac{100^2}{225 \times 250}$

$= \frac{V^2}{225R}$ | $= 0.17 > 0.07$ (Not safe)

$\therefore$ Adopt $e = 0.07$

then,

$$e+f = \frac{V^2}{127R}$$

$$\Rightarrow f = \frac{100^2}{127 \times 250} - 0.07$$

$$\Rightarrow f = 0.249 > 0.15$$, Not ok, Can't be greater than 0.15.

$\therefore$ Adopt $f = 0.15$.

$\therefore$ Restricted velocity $v_0 = \sqrt{127R(e+f)}$

$$= \sqrt{127 \times 250 (0.07 + 0.15)}$$

$$= 83.57 \text{ kmph}$$

Hence, we need restriction in speed.

(#) Attainment of super elevation (Methods of providing super elevation):

→ Introduction of super elevation on a horizontal curve in the field is an important feature in construction.

→ The full super elevation is attained by the end of transition curve or at the beginning of the circular curve.

→ The attainment of super elevation may be split up into two parts.

(a) Elimination of crown of the cambered section

(b) Rotation of pavement to attain full super elevation.

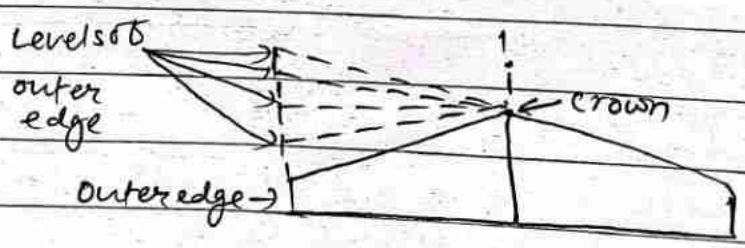
(a) Elimination of crown of the cambered section:

→ This may be done by two methods:

(1) Outer edge Rotated about crown

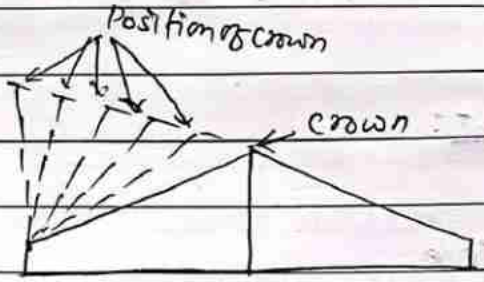
(2) Crown shifted Outwards.

→ In 1st method, the outer half of the cross slope is rotated about the crown at a desired rate such that the surface falls on the same plane as the inner half & the elevation of the center line is not altered.



(a) Outer edge rotated about crown.

- In 2nd method of elimination of crown, known as diagonal curve method, the crown is progressively shifted outwards, thus increasing the width of the inner half of cross section progressively.

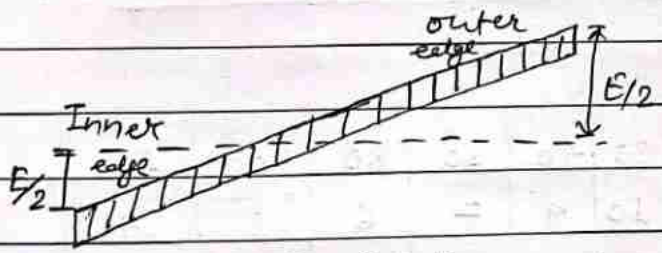


(b) Crown shifted outwards
(Diagonal crown method)

(b) Rotation of pavement to attain full super elevation:

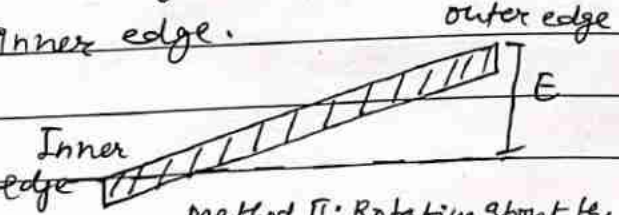
→ This may be done by two methods.

(i) By rotation the pavement X-section about center line, depressing the inner edge & raising the outer edge each by half the total amount of super elevation. i.e. by $\frac{E}{2}$ with respect to center.



Method-I; Rotating about center line

(ii) By rotating the pavement X-section about the inner edge of the pavement X-section raising both the center as well as outer edge of the pavement such that outer edge is raised by the full amt. of super elevation, E w.r.t. inner edge.



Method II; Rotating about the inner edge.

Gradients

Gradients:

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

→ It is generally represented as n% or 1 in n units.

factors affecting gradient:

1) Topography
2) Characteristics of vehicle
   - Less gradient for high loaded vehicle
3) Design speed
4) Drainage
5) Cross-section
6) Bridge site

Types of gradient:

1) **Ruling gradient**: It is the max^{m} gradient within which the designer attempts to design the vertical profile of a road.

As per NRS-2070,

Max^{m} Gradients

Design speed, kmph	20	30	40	60	80	100	120
Gradient, %	12	10	9	7	6	5	4

2) **Limiting gradient**: The gradient steeper than ruling gradient is Limiting gradient.

(c) Exceptional Gradients:

↳ In some extraordinary situation it may be unavoidable to provide still steeper gradients at least for short stretches & in such cases the steeper gradient upto exceptional gradient may be provided. It is limited not exceeding about 100m at a stretch.

(d) Minᴹ gradient:

↳ The gradient provided from drainage point of view is minimum gradient. Generally 0.5% - 1% provided for drainage.

(#) Sight Distance

↳ The sight distance is defined as the actual distance along the road surface which a driver sitting at a specified height in a vehicle can see object either moving or stationary, on the road surface.

Classification:

1. Stopping sight Distance (SSD)
2. Safe overtaking sight Distance (OSD)
3. Intermediate sight Distance (ISD)

(1) Stopping sight Distance

↳ It is the minᴹ distance reqd within which a vehicle moving at designed speed can be stopped without colliding with a object on the road surface.

→ Also called non-passing sight distance.

→ The sight distance at any spot is never less than the minᴹ stopping sight distance.

Factors affecting SSD:

1. Perception / Reaction time of driver
2. speed of vehicle
3. Efficiency of brake
4. frictional resistance between road & wheels of vehicle
5. Longitudinal gradient of road.

Calculation of SSD:

SSD = Lag distance + breaking distance ----- (1)

where, Lag distance → distance covered during reaction ti

$= v \times t$; v = design speed in M/s

$= 0.278\, vt$; v in kmph

Breaking distance → distance covered by vehicle to come to stop after the brake applic

$$\boxed{\text{work done by vehicle} = \text{K.E.}}$$

$$F \times L = \frac{1}{2} m v^2$$

$$wfL \pm wnL = \frac{1}{2}\frac{w}{g} v^2$$ where,

w = wt. of vehicl

f = coeff. of longitu friction = 0.3 to 0.9

for $n = 0$

$$wfL = \frac{1}{2}\frac{wv^2}{g}$$

Braking distance $\Rightarrow \boxed{L = \frac{v^2}{2gf}}$; v in M/s

so, from eq^n (1)

$$SSD = [illegible] \cdot Vt + \frac{V^2}{2gf}$$

If we consider gradient of n%

$$\boxed{SSD = Vt + \frac{V^2}{2g(f \pm n) \times \eta}} \quad ; \eta = \text{efficiency of brake}$$

$$\boxed{SSD = 0.278Vt + \frac{V^2}{254(f \pm n)\eta}} \quad ; V \text{ in kmph}$$

- SSD for 2 way traffic in 2 lane road = S.D.
- SSD for 2 way traffic in single lane road = 2 S.D.

(3) Calculate safe SSD for (a) 2 way traffic in 2 lane road
(b) 2 way traffic in single lane road

V = 80 kmph
Reaction time (t) = 2.5 sec
Coeff. of Longitudinal friction (f) = 0.38

Solution

$$S.D. = 0.278Vt + \frac{V^2}{254(f \pm n)\eta}$$

$$= 0.278 \times 80 \times 2.5 + \frac{80^2}{254(0.38 \pm 0) \times 1}$$

$$= 121.90 m$$

- 2 way traffic in 2 lane road = S.D. = 121.90 m Ans
- 2 way traffic in single lane road = 2 S.D.
  $= 2 \times 121.90$
  $= 243.80 m$ Ans,

(9) Calculate the minimum stoping sight distance of two cars approaching from opposite direction at the speed of 90 kmph & 50 kmph respectively. The reaction time of driver is 2.5 sec. The coefficient of longitudinal friction is 0.40 & the brake efficiency of 50% in either case.

Solution;

Speed of car 1 (V_1) = 90 kmph

Speed of car 2 (V_2) = 50 kmph

Reaction time of driver (t) = 2.5 sec

Coeff. of Longitudinal friction (f) = 0.40

efficiency of brake (η) = 50%

Then,

$$SSD_1 \text{ for car 1} = 0.278Vt + \frac{V^2}{254(f \pm n)\eta}$$

$$= 0.278 \times 90 \times 2.5 + \frac{90^2}{254 \times 0.4 \times 0.5}$$

$$= 222 \text{ m}$$

$$SSD_2 \text{ for car 2} = 0.278 \times 50 \times 2.5 + \frac{50^2}{254(0.4+0) \times 0.5}$$

$$= 83.96 \text{ m}$$

∴ Required stoping sight distance $= SSD_1 + SSD_2$

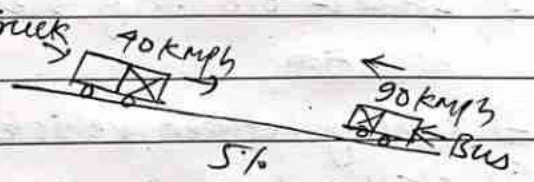
$= 222 + 83.96$

$= 305.96$ m

$= 306$ m

⑨ Calculate the minimum stopping sight distance of truck speed at 40 kmph in a downgrade slope of 5% with bus approaching towards it at a speed of 90 kmph. The reaction time of the driver is 2.5 sec & coeff. of longitudinal friction is 0.35.

solution;



Speed of truck, $V_1 = 40$ kmph

downgrade slope (n_1) = 0.05 = 5%

Speed of bus (V_2) = 90 kmph

~~down~~ upgrade slope (n_2) = 0.05

Reaction time of driver (t) = 2.5 sec

Coeff. of longitudinal friction (f) = 0.35

then, SSD for truck, $SSD_T = 0.278 \times V t + \frac{V^2}{254(f \pm n)\eta}$

$= 0.278 \times 40 \times 2.5 + \frac{40^2}{254(0.35 - 0.05) \times 1}$

$= 48.8\ m$

also; SSD for Bus, $SSD_B = 0.278\, V t + \frac{V^2}{254(f + n)\eta}$

$= 0.278 \times 90 \times 2.5 + \frac{90^2}{254(0.35 + 0.05) \times 1}$

$= 142.27\ m$

$\therefore$ Req'd stopping sight distance $= SSD_T + SSD_B$

$= 48.8 + 142.27$

$= 191.07\ m$ Ans.

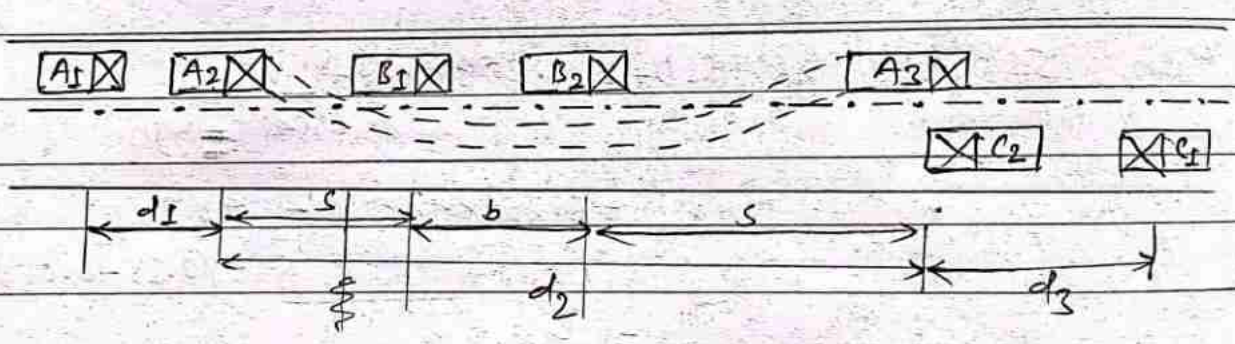
(ii) Overtaking Sight Distance (OSD):

↳ The minimum distance required to overtake the slow moving vehicle by fast moving vehicle is known as overtaking sight distance.

factors affecting the OSD:

1. speed of overtaking, overtaken & vehicle coming from opposite direction
2. spacing between vehicles
3. skill and reaction time of driver
4. Rate of acceleration of the overtaking vehicle
5. Gradient of road.

(#) Analysis of OSD:



where,

↳ vehicle A is overtaking vehicle & A_1, A_2, A_3 are its various positions.

↳ vehicle B is overtaken vehicle & B_1, B_2 are its various positions

↳ vehicle C is coming from opposite direction & C_1 & C_2 are its various positions.

↳ speed of overtaking vehicle = V

↳ speed of overtaken vehicle = V_b

If V_b is not given then

$V_b = V - x$; x ranges from (16-30) kmph

from figure;

$OSD = d_1 + d_2 + d_3$

where, $d_1 = \overset{0.278}{\underset{0}{\int}} V_b \times t$; t = Reaction time of driver

$d_2 = \overset{0.278}{\underset{0}{\int}} V_b \times T + 2s$ = 2.5 sec

where,

s = spacing

$= 0.192 V_b + 6.1$; m

T = overtaking time

$= \sqrt{\frac{14.4s}{A}}$ sec.

A = accel^n of overtaking vehicle (kmph/sec)

$d_3 = 0.278 VT$

$\therefore OSD = 0.278 V_b t + 0.278 V_b T + 2s + 0.278 VT$

for single road, neglecting d_3

$\therefore OSD = d_1 + d_2$

for speed in M/s

$OSD = V_b t + V_b T + 2s + VT$

$s = 0.69 V_b + 6.1$

$T = \sqrt{\frac{4s}{A}}$

- Min^m Length of overtaking zone = 3 x OSD
  Desirable length of overtaking zone = 5 x OSD

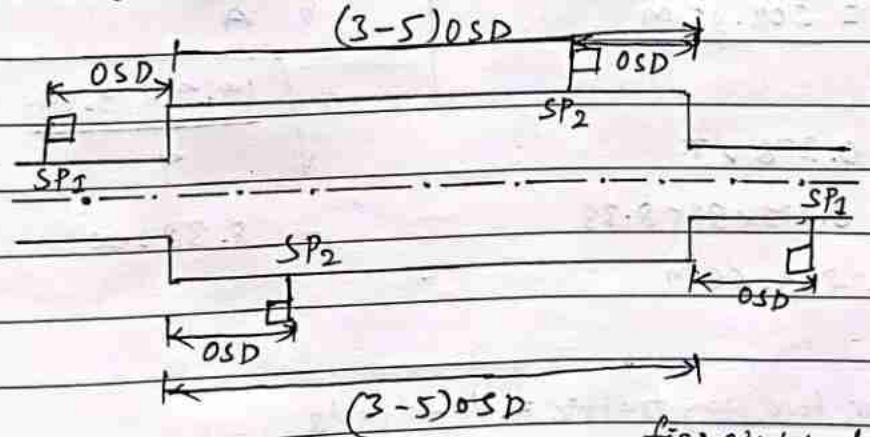


fig: Sketch of OSD zone for single lane two way road.

S_1 = overtaking zone begins
S_2 = overtaking zone ends.

(#) Calculate the overtaking sight distance for the vehicle where speed of overtaking vehicle is 90 kmph & overtaken vehicle is 70 kmph on a two-way traffic road. The reaction time of driver is 2sec. The accelⁿ of overtaking vehicle is 4 kmph/sec. Also calculate the minᴹ Length of overtaking zone. Draw a neat sketch showing the position of sign post.

Solution;

speed of overtaking vehicle (V) = 90 kmph
" " overtaken " (V_b) = 70 kmph
Reaction time of driver (t) = 2 sec
Accelⁿ of overtaking vehicle (A) = 4 kmph/sec
OSD for two way traffic = ?
minᴹ Length of overtaking zone = ?
Desirable " " " " = ?

Now,

$d_1 = 0.278 V_b t$
$= 0.278 \times 70 \times 2$
$= 38.92 m$

$d_2 = 0.278 V_b T + 2S$
$= 0.278 \times 70 \times 8.38 + 2 \times 19.54$
$= 202.15 m$

where,
$S = 0.192 \times V_b + 6.1$
$= 0.192 \times 70 + 6.1$
$= 19.54 m$

& $T = \sqrt{\frac{19.4S}{A}}$
$= \sqrt{\frac{14.4 \times 19.54}{4}}$
$= 8.38 sec$

$d_3 = 0.278 VT$
$= 0.278 \times 90 \times 8.38$
$= 209.66 m$

then, OSD for two way traffic = $d_1 + d_2 + d_3$
$= 38.92 + 202.15 + 209.66$
$= 450.72 m$

Also, Min^{m} Length of overtaking zone = 3 x OSD

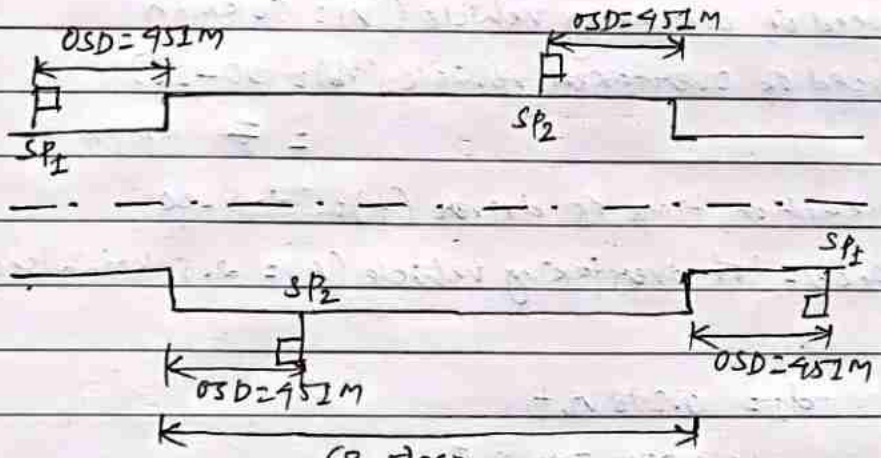
= 3 x 450.72

= 1352.19 M

And, Desirable Length of overtaking zone = 5 x OSD

= 5 x 450.72

= 2253.65 M



= (1352.19 - 2253.65) m

Sketch of OSD zone for two way traffic single Lane.

SP_1 = Overtaking zone begins

SP_2 = Overtaking zone ends

(3) A vehicle is travelling at 90 kmph decides to overtake another slow moving vehicle, calculate OSD for

(a) two lane road in two way traffic

(b) two lane road in one way traffic

Reaction time of driver is 2.5 sec & acceleration of overtaking vehicle is 2.5 kmph/sec.

Solution;

Speed of overtaking vehicle (V) = 90 kmph

$\therefore$ Speed of overtaken vehicle (V_b) = (90 − 16)

= 74 kmph

Reaction time of driver (t) = 2.5 sec

Accelⁿ of overtaking vehicle (A) = 2.5 kmph/sec.

Now, $d_1 = 0.278 V_b t$

$= 0.278 \times 74 \times 2.5$

$= 51.93$ m

$d_2 = 0.278 V_b T + 2S$

$= 0.278 \times 74 \times 10.81 + 2 \times 20.30$

$= 263$ m

Where,

Spacing (s) $= 0.192 V_b + 6.1$

$= 0.192 \times 74 + 6.1$

$= 20.30$ m

Overtaking time (T) $= \sqrt{\frac{14.4s}{A}}$

$= \sqrt{\frac{14.4 \times 20.3}{2.5}}$

$= 10.81$ sec

$d_2 = 0.278 VT$

$= 0.278 \times 90 \times 10.81$

$= 270.46$ m

(a) $\therefore$ OSD for two lane road in two way traffic

$= d_1 + d_2 + d_3$

$= 584.89$ m Ans.

(b) OSD for two lane road in one way traffic $= d_1 + d_2$

$= 319.93$ m Ans.

(iii) Intermediate sight Distance (ISD).

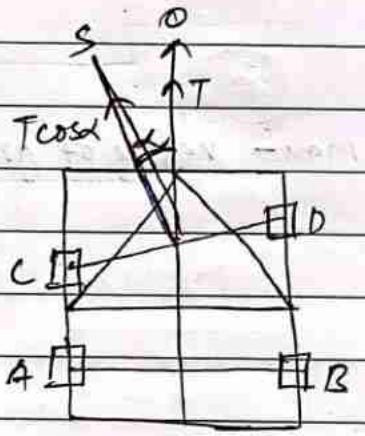
→ Also known as head light sight distance.

$$ISD = 2 \times SSD$$

(#) Grade Compensation and Curve Resistance:

Curve Resistance:

→ While a vehicle is negotiating a horizontal curve, if there is gradient also, then there will be increased resistance to traction due to both curve & gradient.



∴ Curve resistance = $T - T\cos\alpha$

$= T(1 - \cos\alpha)$

⇒ Grade Compensation:

↳ The reduction in gradient at the horizontal curve is known as grade compensation.

As per IRC recommendation;

- Grade Compensation (%) = $\frac{30}{R}$ % where R = Radius of hz. curve
- Max^{m} value of grade compensation = $\frac{75}{R}$ %

(for design adopt min^{m} of two values)

→ Not necessary for grades flatter than 4%.

(9) While aligning a hill road having a gradient of 6%, a horizontal curve of radius 60m is encountered. What will be the value of grade compensation & compensated gradient?

Solution;

Here,

Ruling gradient = 6%

Radius of curve (R) = 60m

$\therefore$ Grade compensation $= \frac{30+R}{R}$ %

$= \frac{30+60}{60}$ %

$= 1.5\%$

Max^{m} value of grade compensation $= \frac{75}{R}$ %

$= \frac{75}{60}$ %

$= 1.25\%$

$\therefore$ Provide a grade compensation of 1.25%

$\therefore$ Compensated gradient = Ruling gradient − Grade compensation

$= 6\% - 1.25\%$

$= \underline{\underline{4.75\%}}$

Curves:

→ Curves are the geometric arcs provided at change in gradient or alignment of the road.

→ Types of curve:

1) Horizontal curves
   a) Circular
   b) Compound
   c) Reverse
   d) Transition
2) Vertical curves
   a) Summit curve
   b) Valley curve

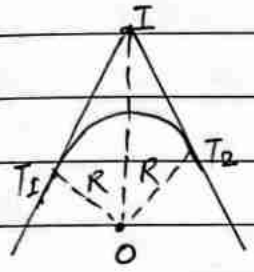


fig. Circular curve

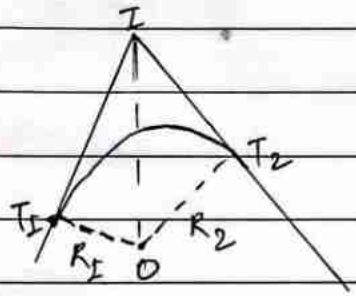


fig.: Compound curve

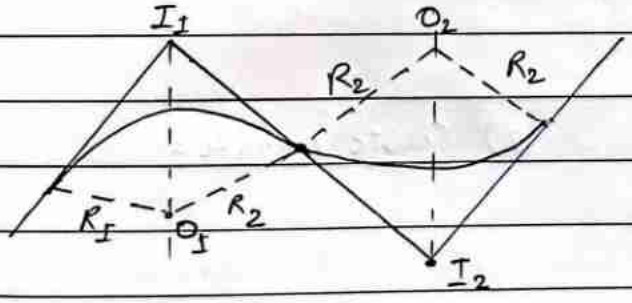


fig.: Reverse curve

Reasons for providing Hz. curve:

1) Topography of the terrain
2) Due to obligatory points such as historical/religious places.
3) To break monotony of driver.
4) Providing access to particular locality.

(#) Transition curve:

→ Transition curve is a curve which has a radius which decreases from infinity(∞) at tangent point to a designed radius at the start of circular curve.

→ It is provided on either side of circular curve.

(#) Types of transition curve:

(1) Spiral or clothoid

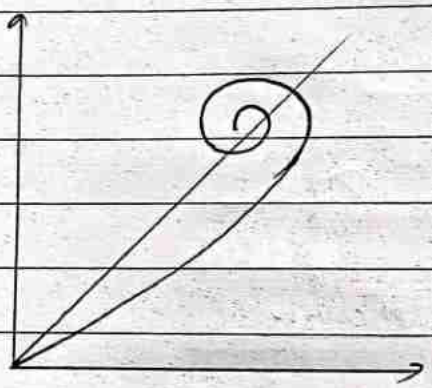


fig.: Spiral curve

2) Bernoulli's Lemniscate

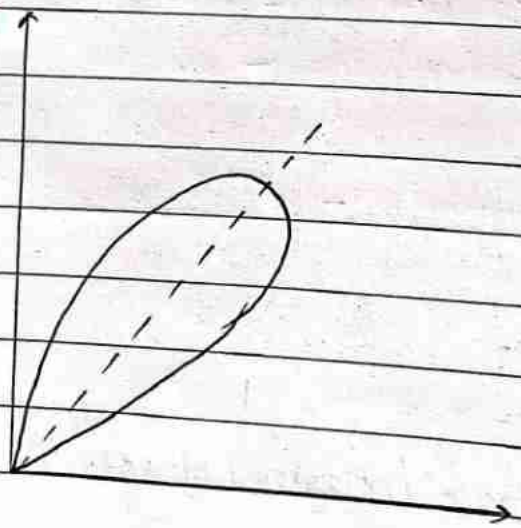


fig: Lemniscate curve

3) Cubic parabola

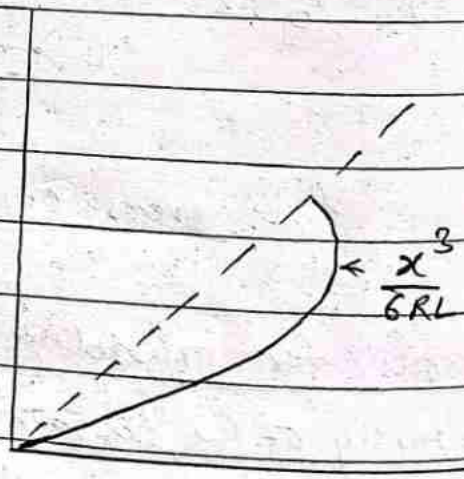
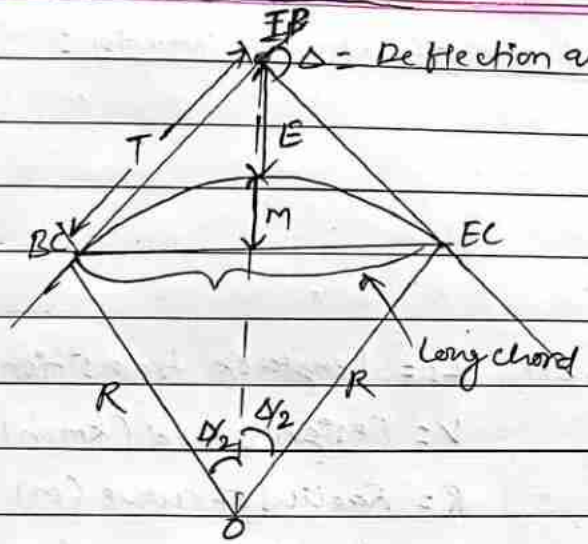


fig: Cubic parabola

(7) Components of simple circular curve:



(1) Tangent length $(T) = R \tan \frac{\Delta}{2}$

2) Length of curve $(L) = \frac{\pi R \Delta}{180^\circ}$

(3) Length of long chord $= 2R \sin \frac{\Delta}{2}$

(4) Apex distance $(E) = R\left(\sec \frac{\Delta}{2} - 1\right)$

5) Mid ordinate $(M) = R\left(1 - \cos \frac{\Delta}{2}\right)$

6) Chainage of beginning of curve = Chainage of IP − Tangent Length

7) Chainge of end of curve: Chainage of BC + Length of curve

(#) Design of transition Curve:

1) By rate of change of centrifugal acceleration:

As per NRS - 2070,

$$L_s = \frac{V^3}{47CR}$$

where, L_s = Length of transition curve
V = Design speed (kmph)
R = Radius of curve (m)
C = Rate of change of centrifugal acceleration
= m/s^3 or $(m/s^2/s)$

$$C = \frac{80}{75+V}, \quad V \text{ in kmph}$$

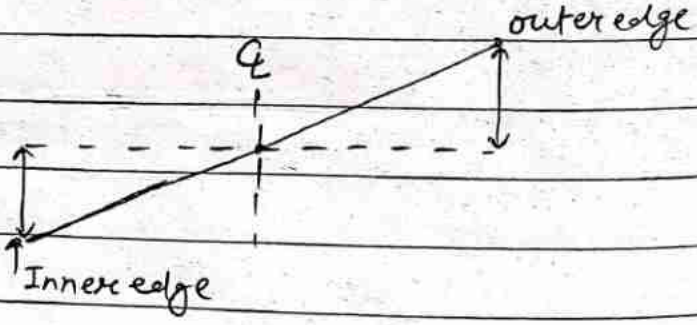
In design, $0.5 < C < 8.8$

2) By rate of introduction of super elevation

N = rate of introduction of super elevation

Its value is
1 in (120-150) = plain terrain
1 in 100 = Built up area
1 in 60 = Hilly area

(a) When pavement is rotated about centerline



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

where,

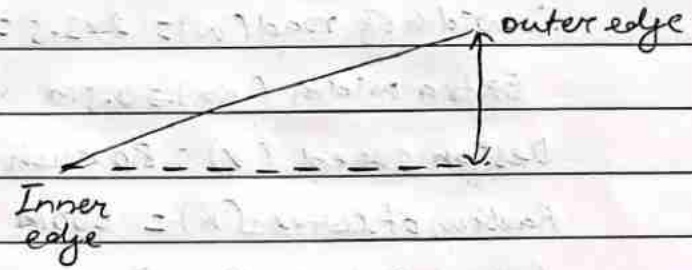
e = super elevation

N = rate of introduction of e

W = width of road

We = extra widening

(b) When pavement is rotated about inner edge.



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

(3) By emperical formula,

(1) for plain & rolling terrain, $l_s = \frac{2.7V^2}{R}$

2) for mountainous & steep terrain, $l_s = \frac{V^2}{R}$

Length of transition curve = max^m value of (1), (2) & (3)

Numerical:

(3) A two-lane national highway passing through the plain terrain has design speed of 80 kmph. The radius of curve is 600m. & the pavement is rotated about the inner edge. The rate of introduction of supereleration is 1 in 80. Design the length of transition curve having extra width of road as 0.5m.

Solution:

Here;

No. of lane = 2

$\therefore$ width of road (w) = 2x3.5 = 7m

Extra width (we) = 0.5m

Design speed (V) = 80 kmph

Radius of curve (R) = 600m

Rate of introduction of super elevation (N) = 80

Terrain type: Plain.

Length of transition curve (Ls) = ?

Calculation of Length of transition curve;

(a) By rate of change of centrifugal acceleration;

$$Ls = \frac{V^3}{47CR} \quad ; \quad C = \frac{80}{75+V} = \frac{80}{75+80} = 0.516 \ m/sec^3$$

$$\Rightarrow Ls = \frac{80^3}{47 \times 0.516 \times 600} = 35.56m$$

Date
Page

(b) By rate of introduction of super elevation:

since pavement is rotated about inner edge,

$$L_s = eN(w + w_e)$$

As NH is mixed traffic condition

$$e = \frac{V^2}{225R} = \frac{80^2}{225 \times 600} = 0.047 < 0.07$$

Provide (e) = 0.047

$$\therefore L_s = 0.047 \times 80 (7 + 0.5)$$

$$= 28.4\ m$$

(c) By empirical formula (IRC)

for plain & rolling terrain

$$L_s = 2.7 \frac{V^2}{R}\ ;\ V \text{ in kmph}$$

$$= \frac{2.7 \times 80^2}{600}$$

$$= 28.8\ m$$

$\therefore$ Length of transition curve = max^m of (a), (b) & (c)

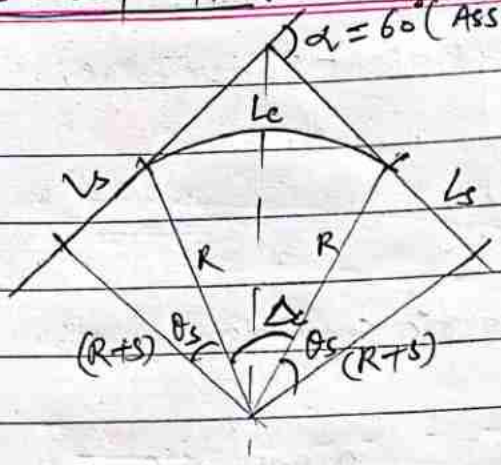
$$= 35.5$$

$$\approx 36\ m$$

Also, shift (s) $= \frac{L_s^2}{24R}$

$$= \frac{36^2}{24 \times 600} = 0.09\ m$$

Extra 9n same question:



Spiral angle (θ_s) $= \frac{L_s}{2R} \times \frac{180^\circ}{\pi} = \frac{36}{2 \times 600} \times \frac{180}{\pi} = 1.72^\circ$

from figure, $\alpha = 2\theta_s + \Delta_c$

$\therefore \Delta_c = \alpha - 2\theta_s$

$= 60^\circ - 2 \times 1.72^\circ$

$= 56.56^\circ$

$\therefore$ ~~Tangent~~ Length of circular curve (L_c) $= \frac{\pi R \Delta_c}{180}$

$= \frac{\pi \times 600 \times 56.56}{180}$

$= 592.29\text{m}$

$\therefore$ Length of curve $= 2L_s + L_c$

$= 2 \times 36 + 592.29$

$= 664.3\text{m}$ Ans.

(#) Extra widening:-

→ In case of horizontal curve when radius is not very large, it is common to widen the pavement slightly than normal width, this increment in width of pavement is called extra widening.

→ Extra widening is req^{d} if radius of horizontal curve is less than 300M.

(#) Reasons of providing extra widening:

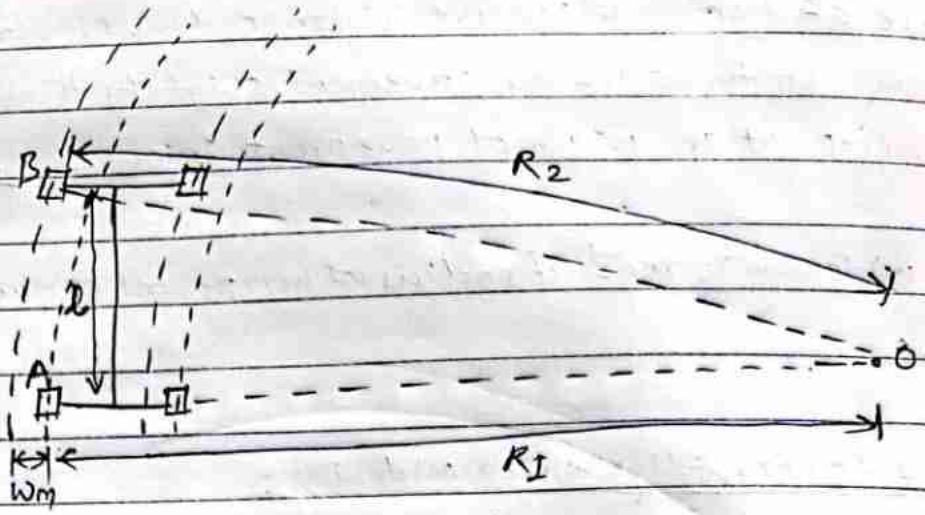
1) Rigidity of wheel base
2) Excessive speed
3) Visibility
4) safety clearance
5) Turning of larger vehicle

- Extra widening shall be applied on both sides of the carriage way, except that on hill roads it will be preferable if the extra widening is done only on the inside.

Analysis of extra widening:

Extra widening = Mechanical widening (provided in inner edge) + psychological widening (outer edge)

Mechanical widening (W_m) = It is required to account for the off-tracking due to the rigidity of wheel base called mechanical widening.



$w_m = R_2 - R_1$

$\Rightarrow \boxed{R_1 = R_2 - w_m}$ — (1)

from figure;

$OA^2 = OB^2 - AB^2$

$R_1^2 = R_2^2 - l^2$

$\Rightarrow (R_2 - w_m)^2 = R_2^2 - l^2$

$\Rightarrow l^2 = 2R_2 w_m - w_m^2$

neglecting w_m^2, since w_m is very small.

$\Rightarrow l^2 = 2R_2 w_m$

$\Rightarrow w_m = \frac{l^2}{2R_2} = \frac{l^2}{2R}$

where, R = mean radius

for single lane road, $w_m = \frac{l^2}{2R}$

for multi lane road, $w_m = \frac{nl^2}{2R}$; n = no. of lane

(2) Psychological widening:

→ The widening required due to psychological tendency to maintain greater clearance between vehicles is called psychological widening.

$$W_{psy} = \frac{V}{9.5\sqrt{R}} \; ; \text{ where,}$$

V = design speed kmph

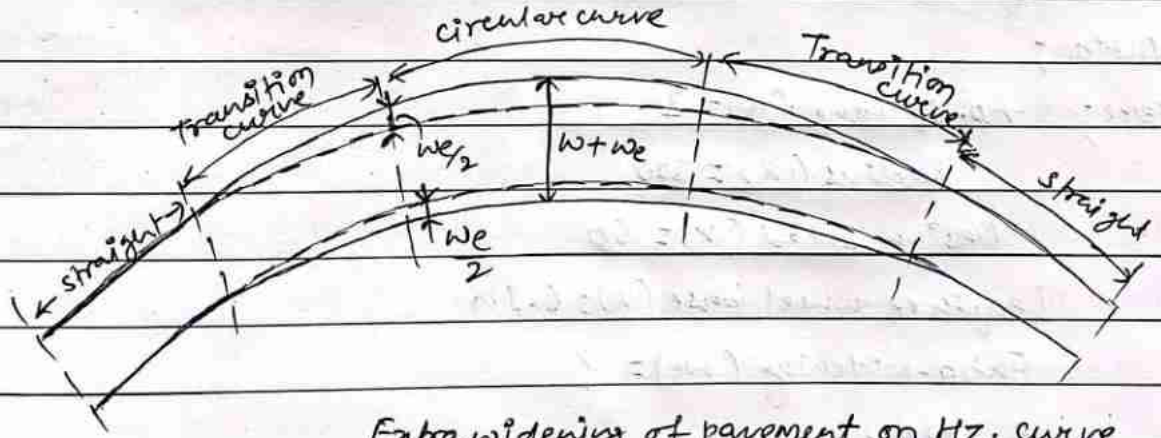
R = Horizontal radius.

∴ Total extra widening = $W_m + W_{psy}$

$$= \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

(#) Methods of Introducing extra widening:

1) Widening on curve with spiral form:

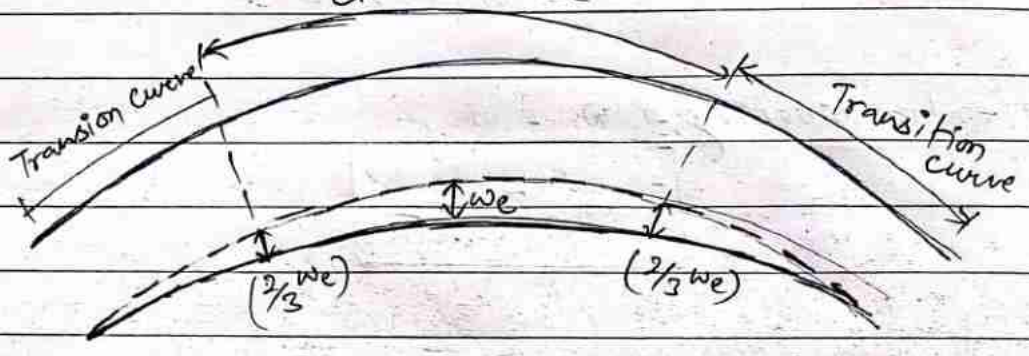


Extra widening of pavement on Hz. curve

2) Widening on curve without spiral:

→ Widening is provided only innerside of road.

↳ Two third of extra widening should be attained before start of circular curve & one third on the curve.



(#) Calculate the amount of extra width for a two lane road having radius of 300m. The design speed of vehicle is 60 kmph. & the length of the wheel base of the vehicle is 6.1m.

Solution;

Here; no. of lane (n) = 2

Radius (R) = 300

Design speed (V) = 60

Length of wheel base (l) = 6.1m

Extra-widening (We) = ?

We know,

$$We = \text{Mechanical widening} + \text{Psychological widening}$$

$$= \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

$$= \frac{2 \times 6.1^2}{2 \times 300} + \frac{60}{9.5\sqrt{300}}$$

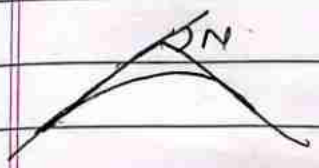
$$= 0.488\,m$$

Vertical Curve:

→ when two straight sections of a road in longitudinal profile meet at a point, vertical curves are provided for smooth travel along the road.

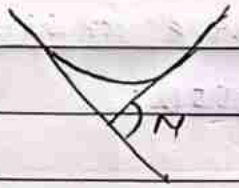
Types

↓ summit curve



→ Curve having convexity upwards

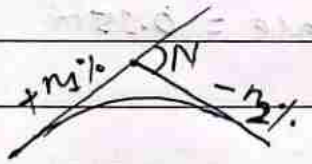
↓ valley curve



→ Curve having convexity downwards

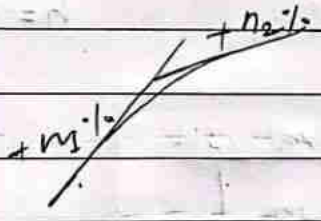
N = Deviation angle; algebraic difference between the grade.

(a)

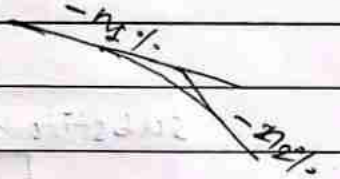


$N = +n_1 - (-n_2)$

$= n_1 + n_2$



$N_1 = n_1 - n_2$



$N = -n_1 + n_2$

$= n_2 - n_1$

Design of vertical Summit curve

↳ Generally, simple parabolic curves are used for the design of summit curve.

↳ Summit curves are designed based on:

(i) stopping sight distance (SSD)

(ii) Overtaking sight distance (OSD)

1) Length of summit curve for SSD:

Case (a): when $L > SSD$;

$$L = \frac{Ns^2}{(\sqrt{2H} + \sqrt{2h})^2}$$

where,

N = Deviation angle

s = stopping sight distance

H = ht. of driver eye level from road surface = 1.2m

h = ht. of object from the road surface = 0.15m

substituting these values;

$$\boxed{L = \frac{Ns^2}{4.9} \text{ m}}$$

Case (b): when $L < SSD$

$$L = 2s - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

$$\boxed{= 2s - \frac{4.4}{N}}$$

(2) for OSD or ISD:

Case (a): L > OSD or ISD

$$L = \frac{Ns^2}{(\sqrt{2H} + \sqrt{2h})^2}$$ where, H = h = 1.2m in OSD or ISD

$$\therefore L = \frac{Ns^2}{9.6}$$

Case (b): L < ISD or OSD

$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

$$= 2S - \frac{9.6}{N}$$

(#) Design of vertical valley curve:

⇒ Valley curve is designed based on;

(a) Passenger's comfort condition;

$$L = 0.38 (NV^3)^{1/2}$$; where,

L = Length of valley curve

N = Deviation angle

V = Design speed (kmph)

(b) Based on head light sight distance:

Case i: $L > SSD$

$$L = \frac{Ns^2}{2h_1 + 2s\tan\alpha}$$

where, $s = SSD$

h_1 = height of head light above pavement (0.75 m = 75 cm)

α = Inclination of rays of light (1°)

using $h_1 = 75$ cm & $\alpha = 1°$

$$\boxed{L = \frac{Ns^2}{1.5 + 0.035S}}$$

Case ii: $L < SSD$

$$L = 2s - \frac{2h_1 + 2s\tan\alpha}{N}$$

$$\boxed{L = 2s - \frac{1.5 + 0.035S}{N}}$$

Adopt max^m value in design between (a) & (b).

(9) Design the length of vertical curve for $n_1 = +2.5\%$, $n_2 = -1.2\%$, OSD = 245, ht. of eye level of driver above the pavement = 1.22m. Assume any suitable data if necessary.

solution;

$n_1 = 2.5\%$

$n_2 = -1.2\%$

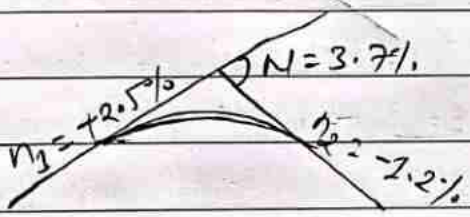
$N = n_1 - n_2$

$= 2.5 + 1.2$

$= 3.7\% = 0.037$

OSD = 245m

Ht. of driver eye above the pavement (H) = 1.22m



from given grade, it forms the summit curve.

Case (a): L > OSD; (In OSD H = h)

$$L = \frac{NS^2}{8h} = \frac{0.037 \times 245^2}{8 \times 1.22} = 227.5m > OSD (= 245m)$$

Not OK.

Case (b): L < OSD

$$L = 2S - \frac{8h}{N}$$

$$= 2 \times 245 - \frac{8 \times 1.22}{0.037}$$

$$= 226.216m < OSD (= 245) \text{ OK.}$$

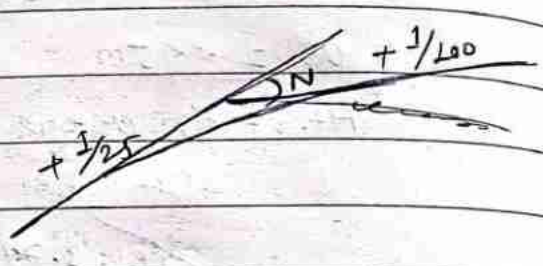
∴ Length of vertical curve formed for summit curve is 226m.

(8) A vertical summit curve is formed when an ascending grade of 1 in 25 ~~meets~~ meets with another ascending gradient of 1 in 100. Design the Length of summit curve for stopping sight distance having design speed of 80 kmph.

Solution;

ascending gradient $(n_1) = +\frac{1}{25}$

ascending gradient $(n_2) = +\frac{1}{100}$



$$N = \left| \frac{1}{25} - \frac{1}{100} \right|$$

$$= \frac{3}{100} = 0.03$$

Design speed (V) = 80 kmph

then,

$$SSD = 0.278Vt + \frac{V^2}{254(f \pm n)\eta}$$

$$= 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times (0.35 \pm 0) \times 1}$$

$$= 127.59 \text{ m}$$

Case a: when Length of summit curve is greater than SSD:

i.e. $L > SSD$

$$L = \frac{NS^2}{4.4} = \frac{0.03 \times 127.59^2}{4.4} = 111.012\text{m} > 127.59\text{m}$$

Not ok.

case ⑤: When the length of summit curve is less than SSD.

i.e. $L < SSD$.

$$L = 2S - \frac{4.9}{N}$$

$$= 2 \times 127.6 - \frac{4.9}{0.03}$$

$= 108.53\,m < 127.59\,(SSD)$ OK.

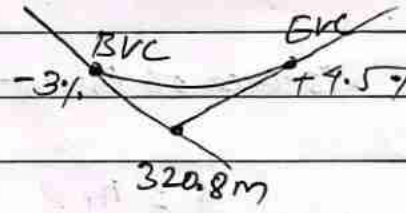
∴ Length of summit curve is 108.53m.

(#) A vertical curve connects a −3% grade with +4.5% grade on a highway at elevation of 320.8m. Calculate the length of curve by comfort & head light sight condition. If the design speed of vehicle is 50 kmph. The curve should be designed at least to provide the visibility of the road to a distance of 250m at night time. Calculate the elevation of beginning, lowest & end point of vertical curve. The head light beam angle & height of the head light from road surface are 1.5° & 0.6m respectively.

solution;

$$N = |-3 - 4.5|$$

$$= 7.5\% = 0.075$$



Length of valley curve

(a) from passenger comfort condition:

$$L = 0.38(NV^3)^{1/2} = 0.38(0.075 \times 50^3)^{1/2} = 36.8 = 37m$$

2) from head light sight distance:

Assume, $L > SSD$

$$L = \frac{NS^2}{2h + 2S\tan\alpha} = \frac{0.075 \times 250^2}{2\times 0.6 + 2\times 250 \times \tan(1.5^\circ)}$$

$$= 327\,m \approx 330\,m > 250\,m(SD) \quad \text{OK}$$

$\therefore L = 330\,m$

RL of Lowest point = 320.8 m

$$\text{Tangent length} = \frac{L}{2} = \frac{330}{2} = 165\,m$$

$\therefore$ RL of BVC $= 320.8 + \frac{3}{100} \times 165 = 325.75\,m$

& RL of EVC $= 320.8 + \frac{4.5}{100} \times 165 = 328.23\,m$

Considering simple parabola;

Distance of lowest point on curve from BVC.

$$x = n_1 R$$

$$= n_1 \frac{L}{N}$$

$$= 3 \times \frac{330}{7.5}$$

$$= 132\,m$$

Elevation of corresponding point on tangent line

$$= RL \text{ of } BVC - \frac{3}{100} \times 132$$

$$= 325.75 - \frac{3}{100} \times 132$$

$$= 321.79$$

$$\text{Tangent correction}(y) = \frac{x^2}{2R} = \frac{132^2}{2 \times \frac{330}{\frac{3}{100}}}$$

$$= 0.792$$

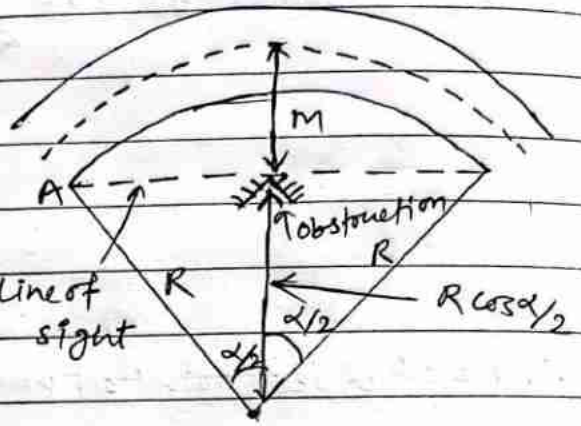
$\therefore$ RL of lowest point on valley curve $= 321.79 + 0.792$

$$= 322.58 m$$

(#) Set-Back Distance:

⇒ The distance required from the center line of the horizontal curve to the obstruction on innerside of the curve to provide adequate sight is called clearance distance or set back distance.

→ setback distance is used to maintain the required sight distance.



Case-I:

$L_c > S$

(i) for single lane road

setback distance from center of carriage way,

$$m = R - R\cos\frac{\alpha}{2}$$

where; $\frac{\alpha}{2} = \frac{180\,S}{2\pi R}$ degree

(ii) for two or more lane road;

setback distance from center of carriage way;

$$m = R - (R-d)\cos\frac{\alpha}{2}$$; where; $\frac{\alpha}{2} = \frac{180\,S}{2\pi(R-d)}$ degree

d = dist. between center line of road & center line of inner lane.

case II: $L_c < S$

$$M = R-(R-d)\cos\frac{\alpha}{2} + \left(\frac{S-L_c}{2}\right)\sin\frac{\alpha}{2}$$

where, $\frac{\alpha}{2} = \frac{180 L_c}{2\pi(R-d)}$

Numerical.

(8) The radius of circular curve is 300M & sight distance required is 80m. Assume Length of curve greater than sight distance & road is two lane. Calculate the set-back distance from the center of carriage way

Solution;

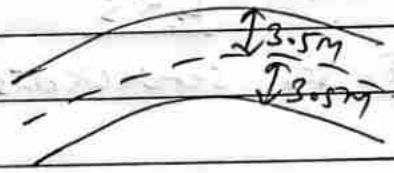
Here;

Radius (R) = 300M

sight distance (S) = 80m

No. of lane = 2

set back distance (M) = ?



$$d = \frac{3.5}{2} = 1.75$$

Given, $L_c > S$

we have,

$$\frac{\alpha}{2} = \frac{180 S}{2\pi(R-d)}$$

$$= \frac{180 \times 80}{2\pi(300-1.75)}$$

$$= 7.68^\circ$$

then, setback distance from center of carriage way;

$$M = R-(R-d)\cos\frac{\alpha}{2}$$

$$= 300-(300-1.75)\cos 7.68^\circ = 4.425\text{m}$$

(9) The radius of circular curve is 650m & sight distance required is 400m. The length of curve is 300m. Calculate the setback distance from -

(a) Center of carriageway

(b) Inner of carriage way

Assume two lane road.

Solution;

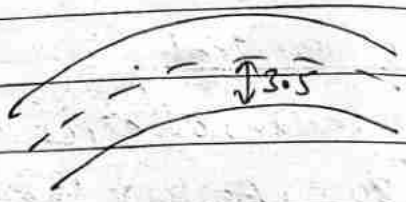
Here;

Radius (R) = 650m

Length of curve (L) = 300 m

Sight distance (S) = 400m

setback distance = ?



$d = \frac{3.5}{2}$

$= 1.75$

from given,

we know,

$$\frac{\alpha}{2} = \frac{180 L_c}{2\pi(R-d)} = 13.25^\circ$$

$L_c < S$

(a) So, setback distance from center of carriage way (M)

$$= R - (R-d)\cos\frac{\alpha}{2} + \left(\frac{S - L_c}{2}\right)\sin\frac{\alpha}{2}$$

$$= 650 - (650 - 1.75)\cos 13.25^\circ + \frac{100}{2}\sin 13.25^\circ$$

$$= 30.46\text{m}$$ Ans.

(b) setback distance from inner edge of carriage way

$M' = M$ - distance between inner edge & center line of road

$= 30.46 - 3.5$

$= 26.96\text{m}$ Ans.

4.1.3 Evaluation of Subgrade

soil

⇒ soil as a non-homogeneous, porous accumulation or deposit of earth material, derived naturally from the disintegration of rock or decay of vegetation.

→ Subgrade soil is the supporting soil beneath pavement & its specia under courses.

→ Subgrade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath.

function of subgrade soil:

1. To give adequate support to the pavement.
2. To provide sufficient strength & stability under adverse cli & Loading conditions.
3. To resist ultimate load of pavement.

⇒ **Desirable properties of subgrade soil:**

a. Adequate stability in adverse condition
b. Maintain permanent strength.
c. Incompressibility.
d. Good drainage properties.
e. Min^{m} change in vol^{m} under adverse weather.
f. Easy in compaction.

(#) CBR Test and it's procedure :-

→ CBR (California Bearing Ratio) Test is the penetration test developed by California state Highway Department.

→ One of the main advantages of CBR method of pavement design is the simplicity of test procedure.

→ CBR test, an empirical test, has been used to determine the material properties for pavement design.

↳ Design of flexible pavement by CBR method is done in 2 steps :

(1) Calculation of CBR value:

$$CBR(\%) = \frac{\text{Load sustained by specimen at 2.5 mm or 5mm penetration}}{\text{Load sustained by standard specimen at corresponding}}$$

→ The penetration of 2.5mm is greater than 5mm.
→ If the penetration value of 5mm is found higher then the test is repeated.
→ If again the penetration value of 5mm is found higher than it's ~~same~~ value is taken.
→ CBR test is done for three times & its average value is taken.

(2) Calculation of thickness of pavement:

↳ The thickness of pavement is given by the formula as:

$$t = \left[\frac{1.75P}{CBR} - \frac{A}{\pi}\right]^{1/2}$$

→ Applicable for the CBR value of the subgrade soil less than 12%.

t = Pavement thickness, cm
P = wheel load, kg

CBR = California Bearing Ratio, Percent

~~P = tyre pressure kg/cm²~~

A = area of contact, cm^2

Different curves A/B/C/D/E/F and G1 have been given based on the load of commercial vehicles.

⊕ Pavement thickness determination :

→ For the determination of pavement thickness by CBR method, the soaked CBR value of the soil subgrade is evaluated. Then appropriate design curve is chosen by taking design wheel load or anticipated traffic into consideration. Thus the total thickness of flexible pavement needed to cover the subgrade of known CBR value is obtained. Thickness of sub base course is the total thickness minus the thickness over the sub-base. Thus, CBR method of flexible pavement design is based on strength parameter of subgrade soil & subsequent pavement material.

(#) Group Index Method :-

↳ Group index value is an arbitrary index assigned to the soil types in numerical equations based on the percent fines, liquid limit & plasticity index.

→ The Group index value of soil vary in the range of 0 to 20.

→ G I no. is found by the eq^{n};

$$GI = 0.2a + 0.005ac + 0.01bd$$

where,

a = portion of soil passing through 75μ sieve greater than 35% but not exceeding 75%.

b = portion of soil passing through 75μ sieve greater than 15% but not exceeding 55%.

c = Liquit limit in excess of 40% but not exceeding 60%.

d = plasticity index exceeding 10 & not more than 30.

The traffic vol^{m} in this method is divideed into three groups:

Trafficic volume	Number of vehicles per day
Light	<50
Medium	50 to 300
Heavy	over 300

Limition of GI method:

→ The GI method of pavement design is essentially an empirical method based on physical properties of the subgrade soil. This method is does not consider the strength characters of subgrade soil & therefore it is open to question regardi the reliability of the design based on index properties of the soil only.

Determination of Modulus of subgrade reaction (K):

⇒ Modulus of subgrade reaction is the reaction sustained by soil sample under rigid plate of standard diameter per unit of settlement.

⇒ The load sustained is directly proportional to the deflection at that point.

$$P \propto \Delta$$

$$\text{or, } P = K\Delta$$

$$\Rightarrow \boxed{K = \frac{P}{\Delta}}$$ where, p = load sustained (KN/m^2)

K = Modulus of subgrade kg/cm^3 (K

Δ = settlement of 1.25 mm

$$\therefore \boxed{K = \frac{P}{0.00125} \quad KN/m^3}$$

Plate load Test:

Plate load test is a field test, which is performed to determine the ultimate bearing capacity of soil & the probable settlement under given load.

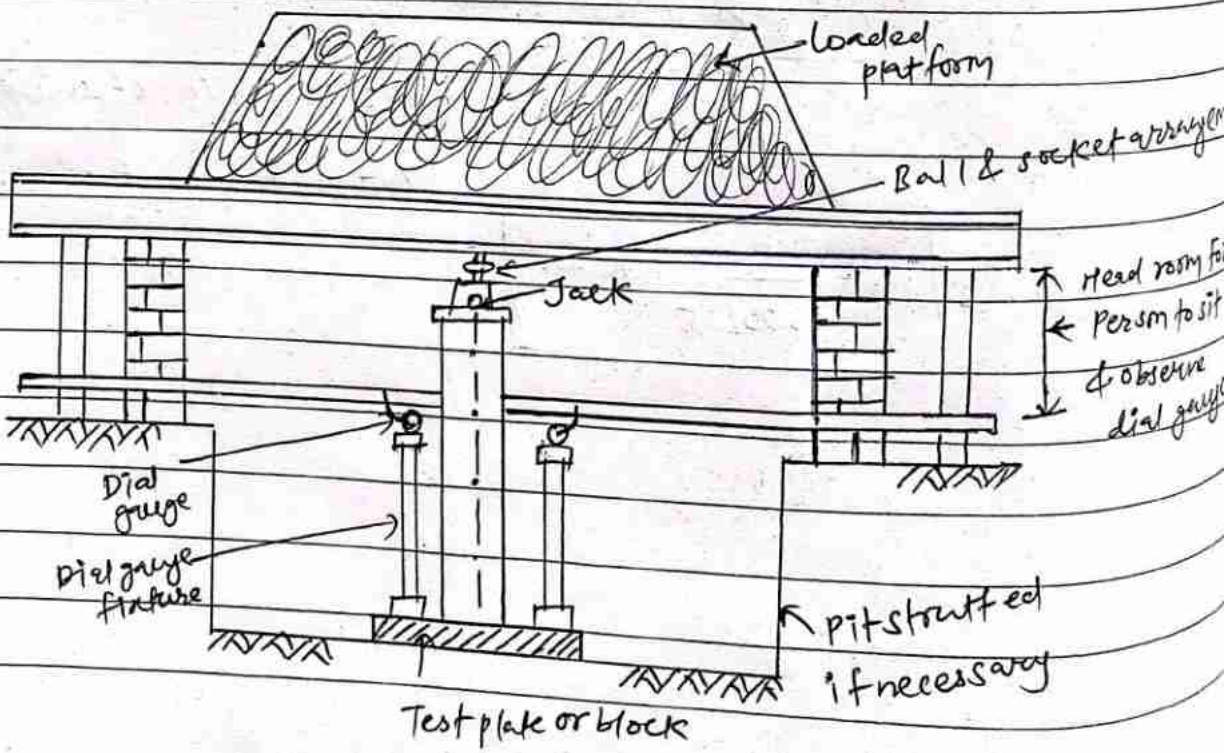
This test is very popular for selection & design of shallow foundation.

Plate Load Test Equipment:

Apparatus Required:

1) Test plate
2) Hydraulic jack & pump
3) Reaction beam / truss
4) Dial gauges
5) Pressure gauge
6) Loading column
7) Necessary equipment for loading platform.
8) Tripod, plumb bob, spirit level etc.

Procedure:



→ Necessary steps to perform plate load test are;

1) Excavate the test pit to desired depth. The pit size should be at least 5 times the size of test plate (Bp).
2) At center of pit, a small hole or depression is created as same size as that of test plate. The bottom of hole is well compacted & the depth of hole should be such that ratio of depth to width of hole is equal to the ratio of depth to width ratio of actual foundation.
3) Generally a mild steel of square shape for square footing & circular shaped for circular footing is used.
The size of plate may vary from 300 to 750mm with min^M thickness of 25 mm.
4) A column is placed at the center of plate & load is applied either by gravity loading or by truss method.
5) Apply seating load of 0.7 T/m² or 0.07 kg/cm² & release before the actual loading starts.
6) The initial reading is noted from dial gauge.
7) The load is then applied by hydraulic jack & increased gradually. The increament is generally $\frac{1}{5}$ th of expected safe bearing capacity or $\frac{1}{10}$ th of the ultimate bearing capacity or any other smaller value.
8) The load increament is noted from pressure gauge & corresponding settlement is noted from dial gauge.
9) After increasing the load, settlement should be observed after 1, 4, 10, 20, 40 & 60 minutes & then after at hourly interval until the rate of settlement is less than 0.02 mm per hour.
10) The increament & data collection is repeated until the max^M load is applied. The max^M load is generally 1.5 times expected ultimate load or 3 times of expected allowable bearing pressure.

(#) Calculation of bearing capacity from plate load test:

→ Plot load vs settlement curve.

→ It is logarithmic graph where load is plotted along x-axis & settlement along y-axis.

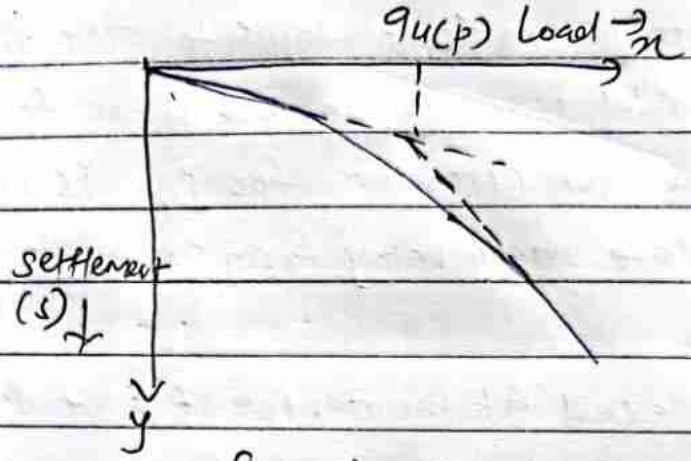


fig: Load vs settlement graph

→ The ultimate bearing capacity is calculated from ultimate load from the plate.

4.1.4 Hill Roads

↳ Hill road can be defined as the road laying between two ends over 25% of cross slope

- Radius of hz. curves in hill roads, (minimum) is calculated by

$$R_{min} = \frac{0.008V^2}{e+f}$$

where, V = design speed, kmph
R = Radius of curve, m
e = Super elevation, m/m
f = coeff. of lateral friction (0.15)

(#) Hair pin Bends:

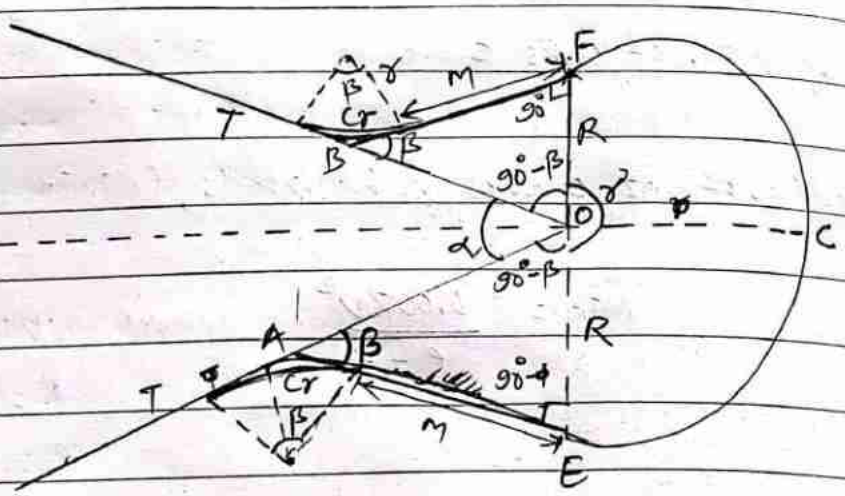
↳ In aligning a hill road, it becomes necessary to attain height at a particular location without substantial covering of horizontal distance. In such cases hair pin bend is provided.

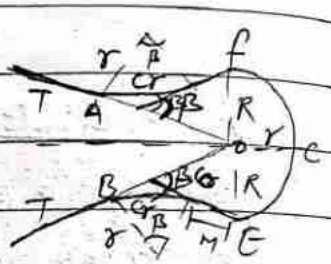
→ Hair pin bends where unavoidable may be designed either as a circular curve with transition at each end or as a compound circular curve.

Design criteria for hairpin bends:

1) Min^M design speed = 20 kmph
2) Min^M Radius of curvature = 15M
3) Min^M length of transition curve = 15M
4) Max^M Longitudinal gradient = 4%
5) Max^M super elevation = 10%
6) Min^M distance between two successive bends of hair pin bends = 60M

(#) Expression for hair pin bends :-





let, T = Tangent Length of reverse curve

R = radius of main curve

β = deflection angle

Cr = Length of reverse curve

C = Length of main curve

M = Transition length between reverse & circular curve

γ = central angle at the center of main curve

A & B are apices of the reverse curve

$$\text{Tangent length of reverse curve } (T)_1 = r \tan\frac{\beta}{2} \quad \text{— (I)}$$

from $\triangle AOE$,

$$AE = T + M$$

$$\tan\beta = \frac{OE}{AE} = \frac{R}{T+M} = \frac{R}{M + r\tan\frac{\beta}{2}} \quad \text{— (II); from (1)}$$

from trigonometry,

$$\tan\beta = \frac{2\tan\beta/2}{1-\tan^2\beta/2} \quad \text{— (III)}$$

from (II) & (III)

$$\frac{2\tan\beta/2}{1-\tan^2\beta/2} = \frac{R}{M+r\tan\frac{\beta}{2}}$$

$$\Rightarrow 2\tan\beta/2\left(M+r\tan\frac{\beta}{2}\right) = R - R\tan^2\beta/2$$

$$\Rightarrow 2M\tan\beta/2 + 2r\tan^2\beta/2 = R - R\tan^2\beta/2$$

$$\Rightarrow (2r+R)\tan^2\beta/2 + 2M\tan\beta/2 - R = 0$$

This is quadratic eqn of $\tan\beta/2$.

$$\therefore \tan\beta/2 = \frac{-2M \pm \sqrt{4M^2 + 4(2r+R)R}}{2(2r+R)}$$

$$\Rightarrow \boxed{\tan\frac{\beta}{2} = \frac{-M \pm \sqrt{M^2 + R(2r+R)}}{2r+R}}$$

Hence, the angle β corresponding to R', r' & M' can be easily determined.

Central angle, $\gamma = 360^\circ - 2(90^\circ - \beta) - \alpha$

$$= 180^\circ + 2\beta - \alpha$$

And length of main curve $\boxed{(C) = \frac{\pi R\gamma}{180^\circ}}$.

Hence, total length of the bend is, $\boxed{S = 2(Cr+M)+C}$

(#) Special considerations in Hill Road Design:

1) Stability against geological disturbances
2) land degradation & soil erosion
3) Destruction & denundation of forest
4) Interruption & disturbance to drainage system
5) Asthetic consideration
6) siltation of water reservoirs
7) Geological disturbances

Design & construction problems in hill road:

- Highly broken relief, steep slopes, deep gorges, water courses.
- Variation in geological condition, hydrological condition & climatic condition
- Unstable slope
- High speed run-off debris flows & flash flood events
- Frequent blasting
- Need of special safety precaution & ~~flash flood events~~ hair pin bends.

(#) Alignment selection criteria of hill road:

→ The hill road alignment should link up the obligatory and control point fitting well in the landscaping & satisfying the geometric requirements.

→ Area prone to landslides & settlements & having unsuitable for hill features should be avoided in alignment.

→ Deep cuttings & costly tunnel should be avoided.

→ The provided sight distance should be at least equal to stopping sight distance.

→ The radius of bend should be enough to turn the longest velicles expected to use atleat road section.

→ The alignment should preferably on the side of hill exposed to sun during winter.

→ As far as possible sharp terrain & hair pin bends should be avoided.

→ Alignment should be preferably along river route.

→ The alignment should cross ridge at the lowest elevation.

→ Route selected should attain the change in elevation by the adoption of ruling gradient in most of the length.

River route and Ridge route on hill roads:

(a) River route: Located along a river valley.

Merits

- Gentle slope
- Low vehicle operation cost
- Availability of water & other construction material

Demerits

- Numerous horizontal curves
- Large no. of cross drainge structures
- Extensive earthwork.
- Massive river training & protection works on the river side.
- steep sloping hillside may be insufficiently stable.

(b) Ridge route: Located along a ridge of hill.

Merits

- Geologically stable
- Zero-Maintenance roads
- Road that exploits the hard surface of hilltop ridges for use as unpaved

Demerits

- steep gradient
- Large no. of sharp curves including hair pin bends
- Extensive rock works
- Construction of special structures like walls, snow fences etc.

Typical cross section of hill roads:

(1) Box cutting → preferred when road bed is unstable but it involves huge earthwork.

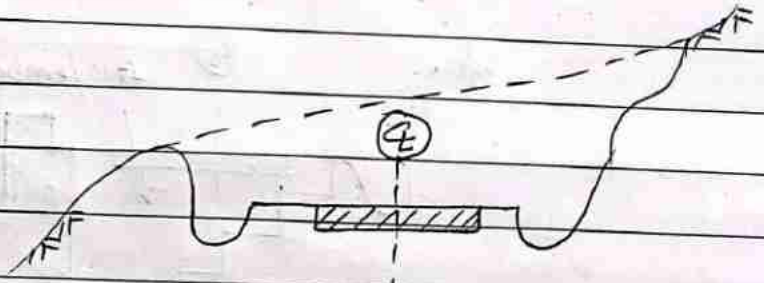
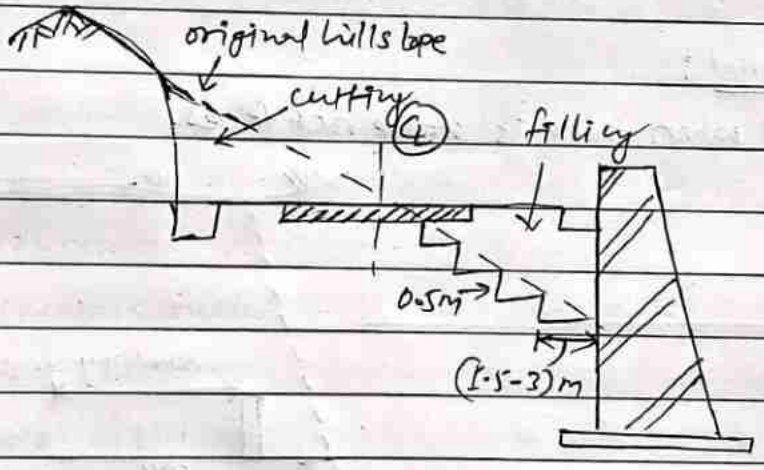


fig: Box cutting

(2) Cut & fill → If hill slope is >2%, cut & fill road is cheaper.



(3) Bench type :- Suitable when the hill is stable itself.

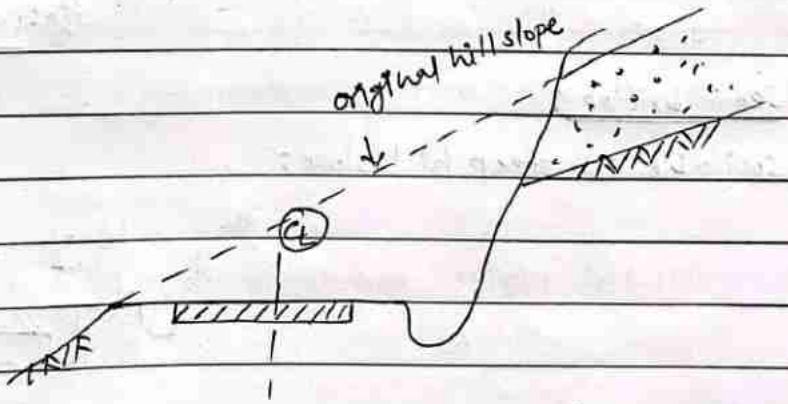


fig Bench type

④ Embankment with retaining walls :-

↳ Preferred on steep slopes over 30-35° where retaining wall increase in stability of embankment & road bed.

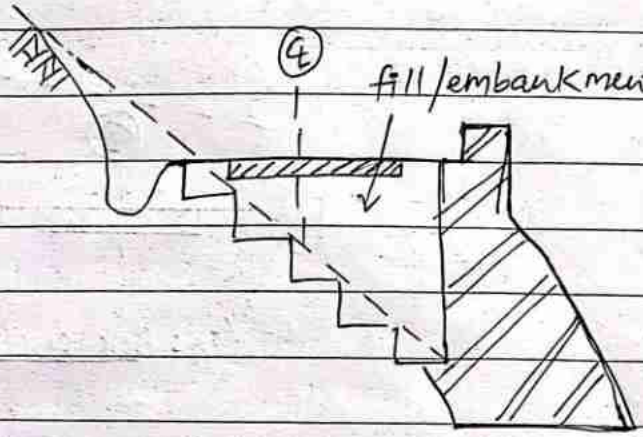


fig: Embankment with retaining wall

⑤ Semi-tunnel :

↳ Provided when there is stable rock faces.

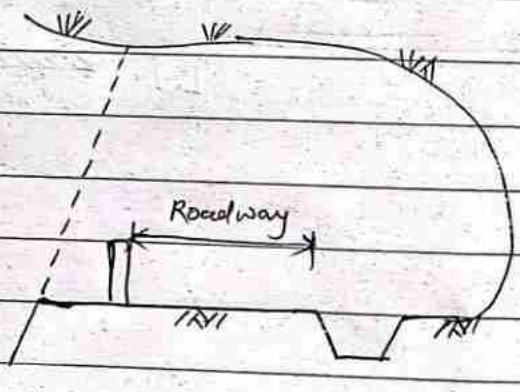
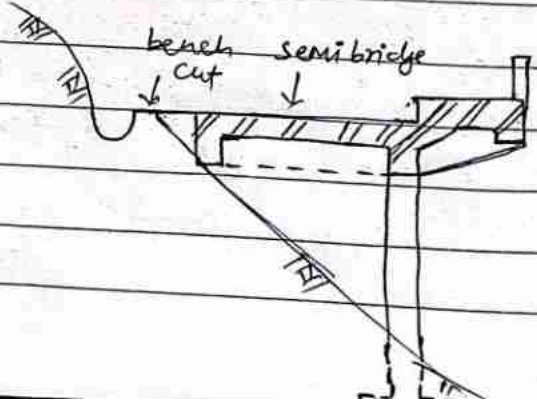


fig: semi tunnel

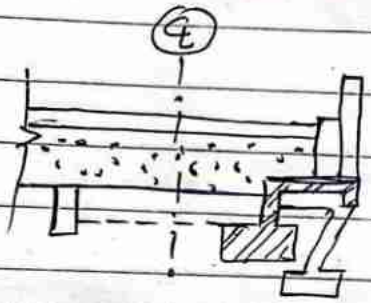
⑥ Semi bridge :

→ suitable in steep hill slope:



⑦ platform:

→ It is usually cantilevered out of the rock on which road way is partially located.



⑧ Special structure in Hill road:

→ Construction of hill roads involves many special structures to retain soil mass, give stability, dissipate energy of surface water etc.

→ following types of special structure are must used.

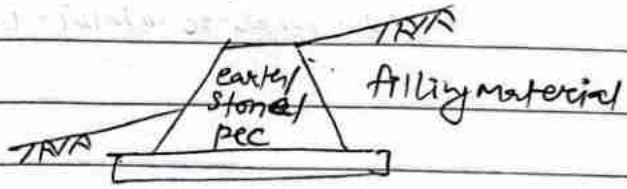
1) Retaining structures
2) River training structures
3) Landslide stabilization structures.
4) Gully control structures
5) Energy dissipation structure

1) Retaining structures:

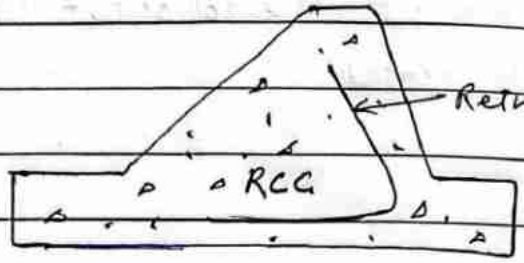
↳ A retaining structure is usually a wall constructed for the purpose of supporting or retaining a vertical or nearly vertical earth bank.

Types:

① Gravity walls — Is low & depends on its own weight to hold back the earth behind it.



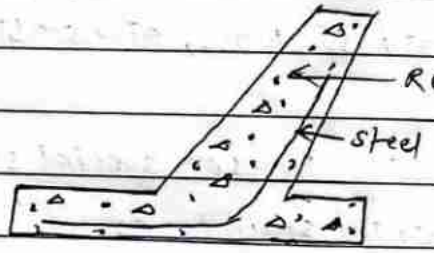
(2) semi gravity retaining walls:



(3) Cantilever RW:

↳ Has relatively thin stem, usually made of concrete reinforced with steel to resist the tensile force. The wall requires significant steel reinforcing in both the footer & the wall structure & steel should extend from footer to wall so that two pieces become one integral unit.

→ Generally economical upto height of 6-8M.

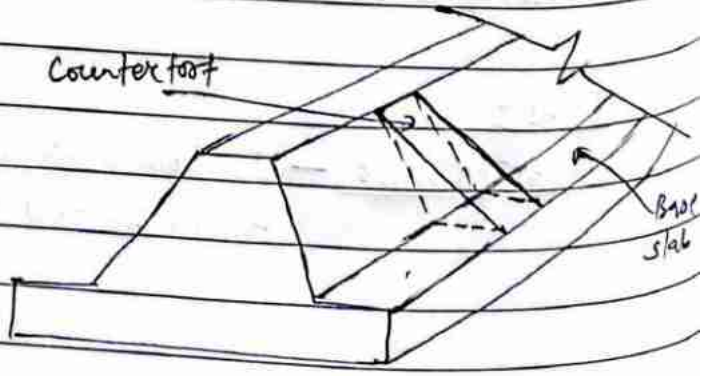


4) Counterfort retaining walls:

→ A counterfort retaining wall is similar to a cantilever retaining wall, but further supported by additional thin triangular shaped walls, or counterforts, built at right angles to the main trend of the wall. The counterforts are spaced at regular intervals along the wall & connect the back of the wall to the top of the footing.

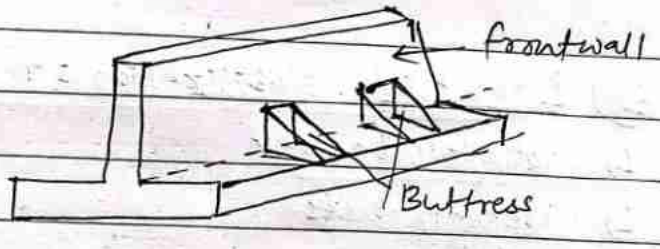
→ economical upto height of 6-8M.

→ Counterfort reduce the SF & BM in the stem & base slab & add strength to retaining wall.



③ Buttressed walls :

↳ Buttressed & counterfort retaining walls are similar, with the main difference that in buttressed walls the vertical brackets are provided in front of wall. The buttresses add strength & help to stabilise the overall wall system.



④ River training structures :-

↳ River training refers to the structural measures which are able to be taken to improve a river & its banks. It can be classified into two types:

1) Transverse protection structure
2) Longitudinal protection structure

1) Transverse protection structure :

↳ They are installed perpendicular to the water courses

(a) Check dams
(b) Spurs
c) Sill
d) Screen dams & beam dams

2) Longitudinal protection structures

↳ They are installed parallel to the river course.

(a) Marginal bunds of levees
(b) Guide bank

Other structures are;

- Revetments
- Rock riprap
- Concrete embankment
- filter blanket etc.

(#) Landslide stabilization structure:

↳ Rockfall barrier
↳ Rockfall nets
↳ Rockfall sheds
↳ Catch trenches
↳ Diversion channels
↳ check dams, baffles
↳ Guide barriers/walls
↳ Terminal barriers, basins

(#) Gully control structure

↳ Gullies are a highly visible form of soil erosion created by running water. They are deep-sided water courses, meters to tens of meters in depth & width, gouged out by surface water flow.

= Control structures:

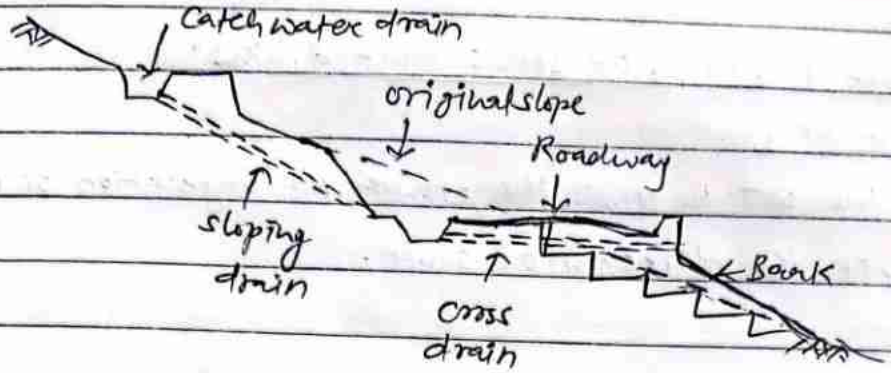
1) Broken rock for gully control
2) Bush, log or timber barriers
3) Brick barriers
(4) Drop structure
5) Chutes

(#) Hill road drainage structure :-

↳ Hill road drainage structure are—

(a) Drainage of water from hill slopes

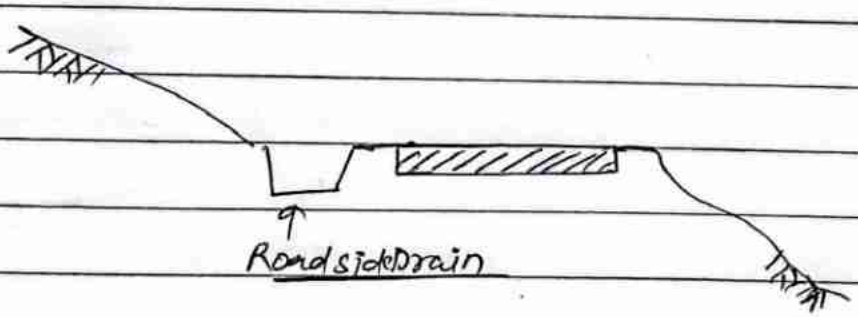
→ Catch drain should be provided to avoid high water velocity.



Lay out of Drainage system

(b) Road side drainage system :

↳ Road side drainage is provided only on the hill side of the road & not on both sides.



(c) Cross drainage in rock cuts

↳ As far as possible, cross drainage should be taken under the road at right angle to it. Small x-drainage catch pits must be provided to collect runoff water & prevent scouring.

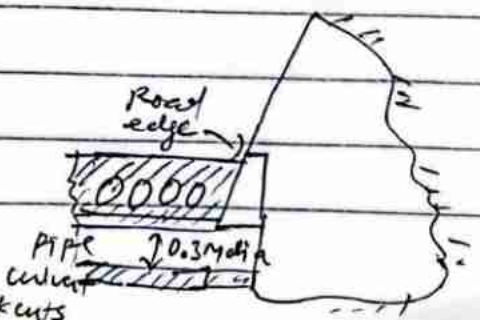


fig: x-drainage in rock cuts

(d) Subsurface drainage

↳ The seepage flow of water on hill roads is one of the major problems during and after the monsoon. The seepage water may cut across the hill side slope above, at or below the road level depending upon several factors.

→ There are two types of subsurface drains;

1) Relief drains

↳ Lower the WT to allow the growth of vegetation or remove surface water in the direction of slope.

2) Interceptor drain:-

↳ They are used on slopes to prevent the soil from becoming saturated and to prevent slippage.

4.5.5 Highway drainage:

(#)

↳ Highway drainage is the collection & disposal of water from road surface, road underneath & vicinity of road.

⇒ Surface drainage system:

↳ Collection & disposal of water from the road surface & adjoining land is called surface drainage system.

⇒ Sub surface drainage:

↳ Collection & disposal of excess soil-water from the sub grade is termed as sub-surface drainage.

(#) Importance of Highway Drainage.

(1) As the moisture content in the soil sub subgrade increases consequently its stability decreases.
(2) Increased moisture causes reduction in strength of pavement materials.
(3) Variation in moisture content of soil also causes considerable variation in vol^ns of subgrade & hence bond failure.
(4) Erosion of soil from top of unsurfaced roads due to surface water.
(5) Pavement failure by the formation of waves & corrugations in flexible pavements is due to poor drainage.
(6) Pavement failure due to frost action in freezing temperature.
(7) Mud pumping in rigid pavement is due to presence of water in fine soil sub-grade.
(8) Excess water on shoulders & pavement edge causes considerable damage.
(9) Sustained contact of water with bituminous pavement causes failures due to stripping of bitumen from aggregates & formation of pot holes.

(#) Requirements of Highway Drainage system :-

↳ following are the requirements of highway drainage system :-

1) The surface water from the adjoining land should not be entering the road way.
2) The surface water from the carriageway & shoulder should not penetrate to sub grade.
3) The side drain should have subficient capacity as well as longitudinal slope to carry away all the surface water collected.
4) Underground water should be drained off by the subsurface drainage system.
5) Flow of surface water across the highway & shoulder should not cause ruts.
6) Ground water table below the subgrade should be at least 1.2 M.

(#) Cross Drainage structures :-

→ whenever streams have to cross the roadway, the structures provided to cross the roadway is known as cross drainage structures.

→ The function of cross drainage structures is to ensure that runoff water is discharged across the road from one side to the other, as quickly as possible without causing undue ponding.

Main types of Cross drainage structures are;

1) Culvert - According to NRS 2027, the drainage structure having span Less than 6m is termed as culvert.

→ It is a closed conduit placed under the embankment to carry water across the roadway. In roadway more than 75% of cross drainage structures are culverts.

Types of culvert :-

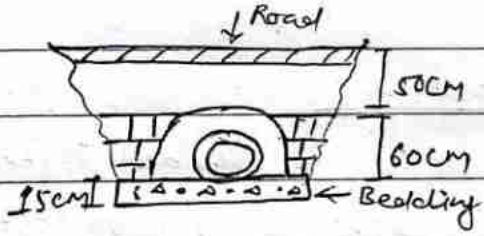
(a) Box culvert

min size 60cm x 60cm

Suitable for;

- High flow
- Debris flow
- foundation soil weak
- Provide at worst condition

(b) Pipe culvert



Suitable for;

- Low discharge
- flat terrain
- no debris flow

(3) Slab culvert:

suitable for;

- High discharge
- Little debris flow
- Rigid pavement

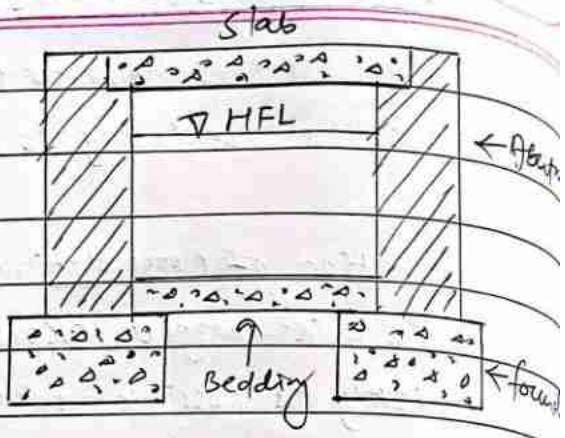


fig: Slab culvert

(4) Arch culvert:

- Provided when
  - Heavy loading
  - High embankment
  - High discharge
  - Little debris flow.

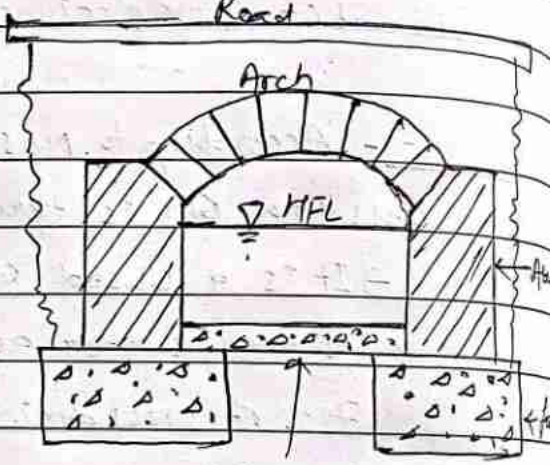


fig: Arch culvert

(B) Causeways

↳ Causeway is provided instead of culvert on less important road which save construction cost. A road causeway is paved dip which allows the flood to pass over it.

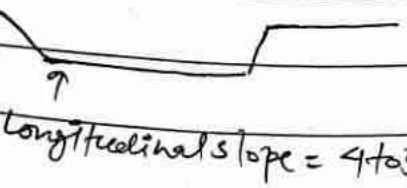
Types of causeways:

1) Low level causeway or flushway

↳ Water flow through the surface of cause way.

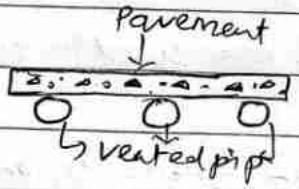
↳ Bed slope should not > than 4%.

↳ It should be almost dry for most of time in year.



(2) High Level Causeway :

↳ Water flow from the surface during flooding & flow under vented pipe during normal condition.



(c) Aqueduct :

↳ It is an open or closed conduit sufficiently above roadway to drain water across the road.

↳ Aqueduct are provided with pillar like support on both sides of the road.

↳ Aqueduct are preferred when culvert cannot be provided.

(d) Inverted siphon

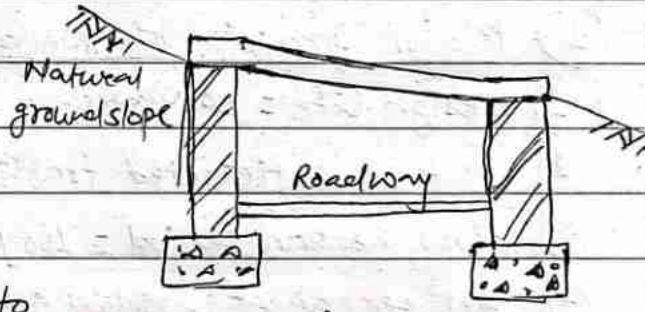


fig: Aqueduct

↳ A structure with lowering an invert Level of conduit across the road to desired Level & both inlet & outlet pits are provided to receive flow from & discharge to down stream respectively.

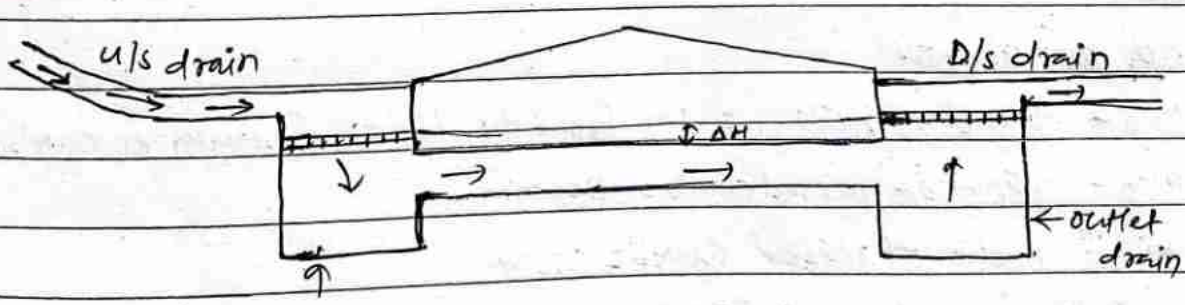


fig inverted siphon

↳ Provided when aqueduct & culvert cannot be provided.

(e) Bridge:

↳ As per NRS - 2070 & Nepal Bridge standard - 2067, it is a cross drainage structures having span greater than 6m.

↳ Bridges are used in runoff drainage system.

Types of Bridge based on span length & total Length of bridges.

Nepal Bridge standard - 2067:

(1) Minor bridge:

Span Length ≤ 25m & total Length of bridge ≤ 50m.

(2) Major bridge: span length > 25m & total length of bridge > 50m

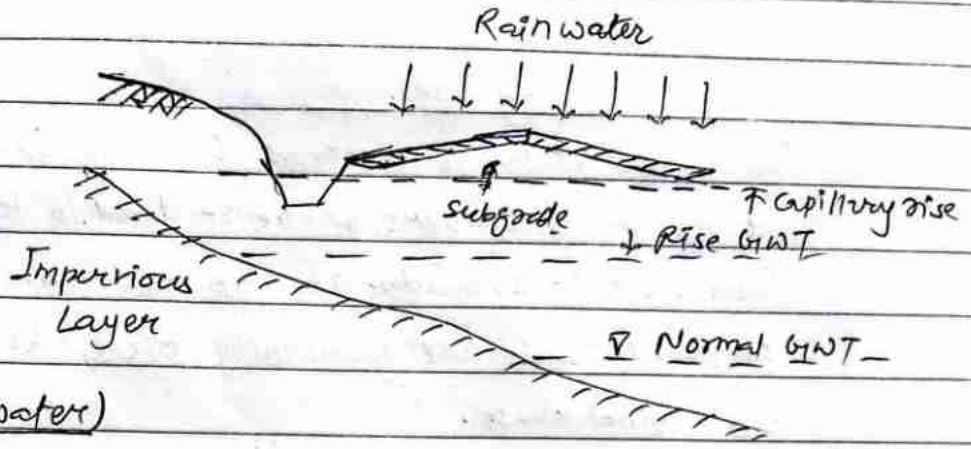
(#) Major provision of Nepal Bridge standard:

1) Design life = 50 years
2) future Anticipated traffic = 30 years
3) flood Return period = 100 yrs.
4) All permanent bridges in Nepal shall be designed as per IRC or AASHTO Loading.
5) All bridges in highways & urban roads shall be designed with minimum carriageway width of 7.5m and that of feeder road is 6m.
6) No permanent.
7) Min^{M} height of railing = 1m from the top of footpath or curb.
8) Min^{M} height of raised curb = 200mm
9) Min^{M} width of raised curb = 450mm
10) Min^{M} free board (F.B.) = 1m

(#) Causes of moisture variation in subgrade soil :-

↳ The main causes of moisture variation in sub grade soil can be grouped as;

1) surface water
2) Subsurface water
3) seepage flow



(1) Surface water (By free water)

- Seepage of water from higher ground level / adjacent land to the road.
- Percolation of water through pavements & shoulders.

(2) Subsurface water (By ground water)

- Fluctuations in ground water table.
- Movement of capillary water & even water vapour
- Percolation of rain water

Surface drainage system

↳ The surface water is to be collected & then disposed off. The water is first collected in longitudinal drains & then water is disposed off at the nearest stream, valley or water course.

Different types of road side drain :-

(1) Rural Highway Drainage

↳ The water which is drained from pavement surface has also to drain across the shoulders before it lead to the side drains. Thus slope of shoulder is more than camber. The side drains of rural roads are generally open, kutcha (unlined) & trapezoidal shape.

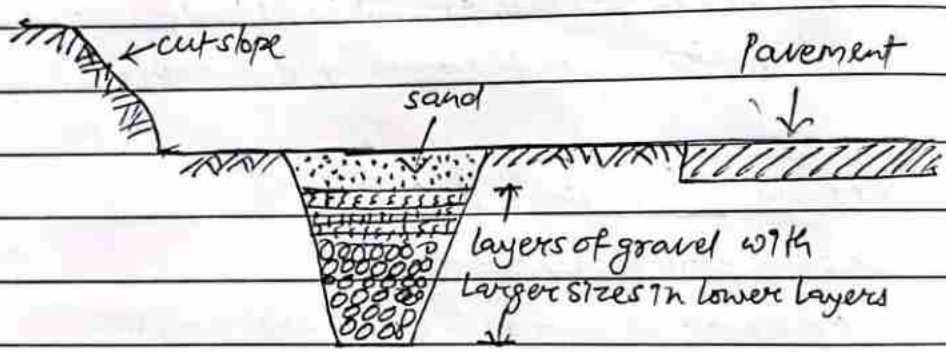


fig: Covered drainage trenches

(2) Urban Highway drainage :

→ Water drained from the pavement surface can be carried forward in the longitudinal direction between the kerb & the pavement for short distances. This water may be collected in catch pits at suitable intervals & lead through underground drainage pipes.

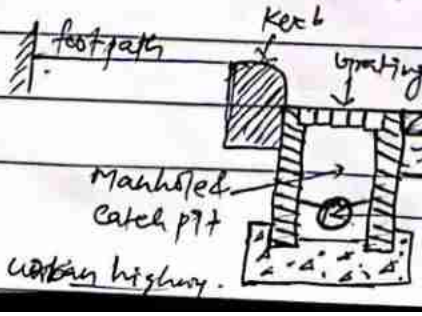
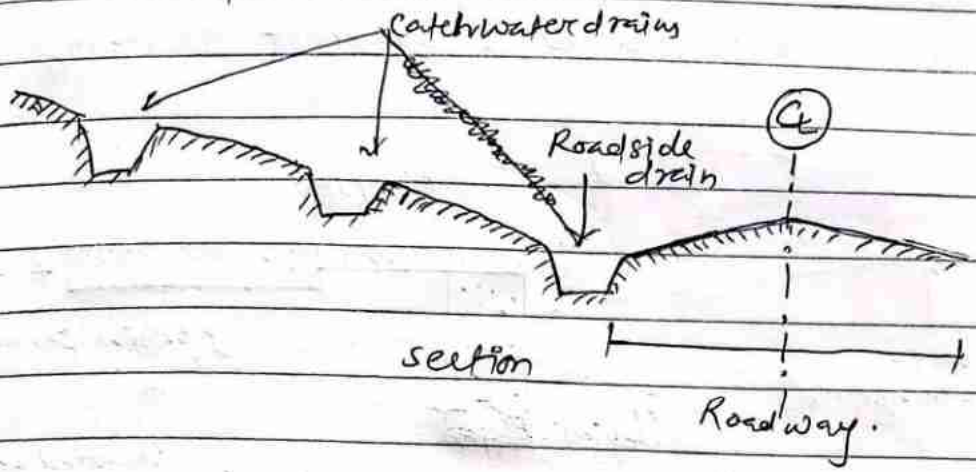


fig. Surface drainage in urban highway.

③ Drainage in hill roads:-

↳ Drainage of surface water is more important in hill roads. for efficient diversion & disposal of water flowing down the hill slope, the shape is carefully chosen & numerous intercepting catchwater drains should be provided.



Subsurface Drainage system:

↳ Collection & disposal of subsurface water is termed as sub-surface drainage. Subgrade is the foundation layer of road whose strength & stability decreases with increase in moisture content & vice versa.

Controls of subsoil water are;

1) Drainage of infiltrated water:

↳ Infiltration is the process by which water on the ground surface enters the soil. Infiltrated water becomes the part of subsurface runoff which results failure of subgrade soil due to moisture variation during the action of infiltration. So, it is important to provide proper drainage facility for infiltrate water.

(2) Control of seepage flow:

↳ When the general ground as well as impervious strata below are slopping, seepage flow is likely to exist. If the seepage zone is at depth less than 0.6 to 0.9m from the sub grade Level, longitudinal pipe drain in trench filled with filter material & clay seal may be constructed to intercept the seepage flow.

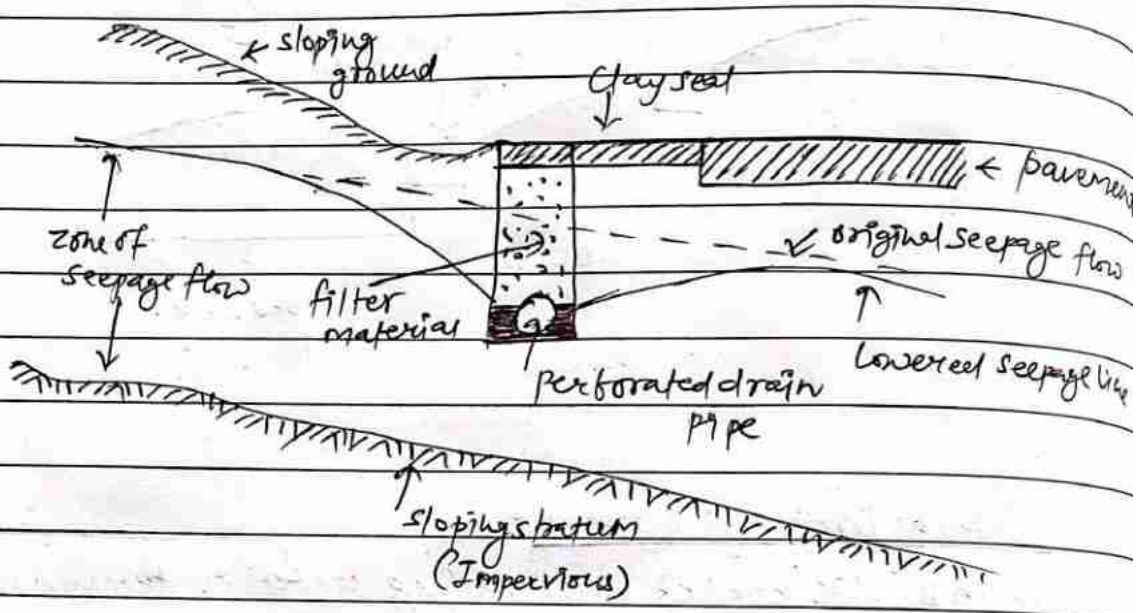


fig: Control of seepage flow

(3) Lowering of water table:

→ If GWT is more than 1.2M below the sub grade of road, it does not require any subsoil drainage. But if it is closer than this, lowering of water table in necessary.

If the soil is relatively permeable, it may be possible to lower the high water table by merely construction of longitudinal drainage trenches with drain pipe & filter sand.

for less permeable soil, lowering of WT may not be adequate at the center of pavement or in between two longitudinal drains. Hence in addition, transverse drain ~~off the~~ may have to be provided in order to effectively drain off the water & thus to lower

the water table upto the level of transverse drains.

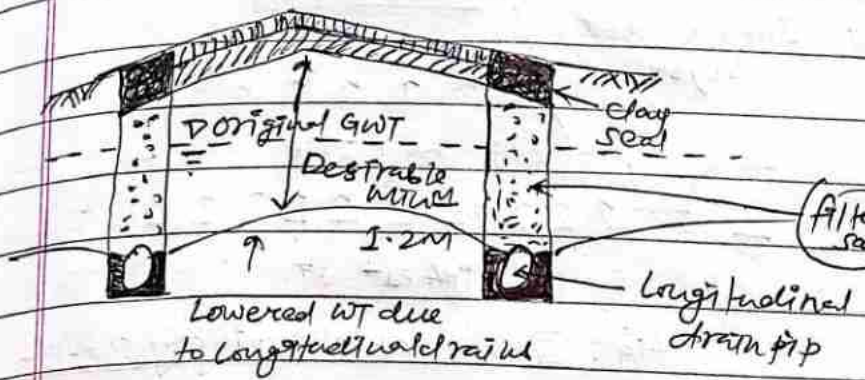


fig: Lowering high WT in permeable soils

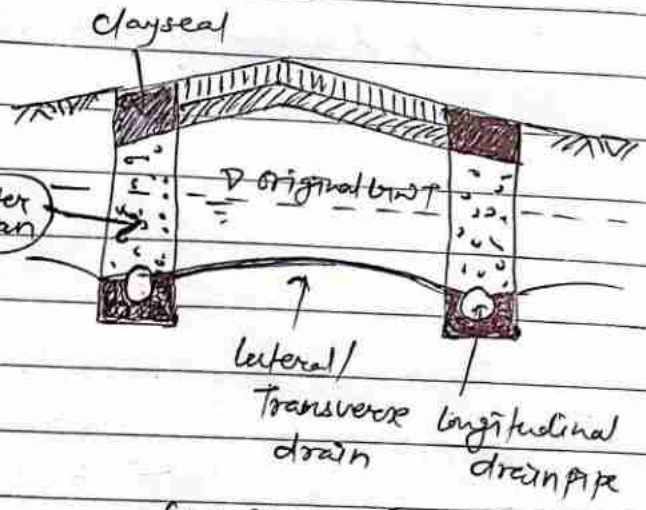


fig:- Subsurface drainage with transverse drains.

④ Control of Capillary rise:-

4) If the water reaching very near the subgrade due to capillary rise is likely to affect the strength, steps should be taken to arrest the capillary rise of water.

Two methods for the control of capillary rise;

1) A sufficient thickness of granular material is provided during the construction of embankment, between the subgrade & the highest level of subsurface water table.

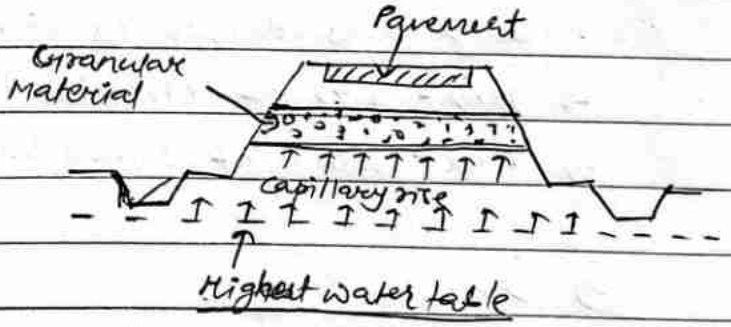


fig: Granular capillary cut off

Some of capillary cutoff layers are
→ Heavy duty tar felt
→ Polythene envelope → Bituminous stabilized soil.

(ii) Capillary cutoff by inserting an impermeable or a bituminous layer in the place of granular blanket.

→ Capillary cut-off should be placed at least 15 cm above the ground level or standing water level, whichever is higher.

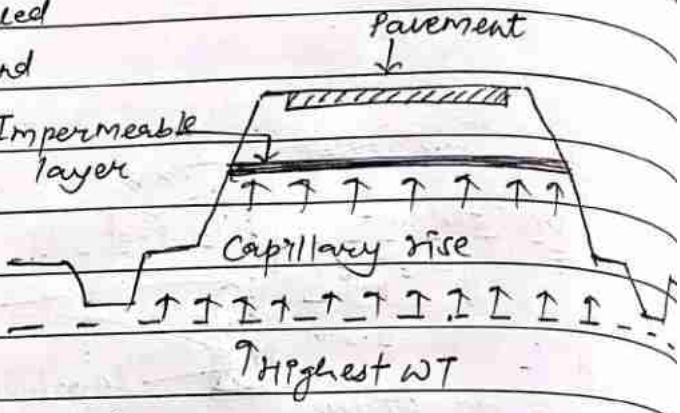


fig: Impermeable capillary cut-off

(iii) factors to be considered in designing subsurface drainage system to check seepage flow:-

(1) Depth of trench:

→ It depends on soil type, impervious stratum level etc.

(2) selection of back fill material:-

→ Improve the interception ability of the drain.

(3) Holes in the perforated drain pipe:

→ Holes should be sufficient small to prevent the filter material from being washed into the pipe & plug the holes.

→ Max^{m} size of circular holes = D_{85} (filter)

→ Max^{m} width of slotted holes = $0.83\ D_{85}$ (filter)

(4) Diameter of pipe:

→ It depends upon the amount of water to be drained off.

control of erosion is directly proportional to the dissipation of energy which ultimately means the reduction of velocity of flowing water.

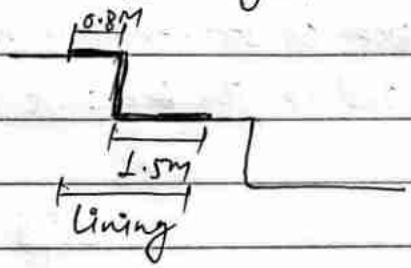
(#) Energy Dissipating structures & its types :-

↳ At outlet of cross drainage structures there is always higher velocity than non-scouring velocity which should be adequately controlled & the cost of same might go up to 25% of the cost of total drainage structures.

→ Hence, at outlet we provide energy dissipating structure for protection of drainage system.

⇒ Different energy dissipating structures are —

1) Turfing
2) Cobble, gravel at bed
3) Erosion control stone lined Channels / Lining of drain & ditch check.



④ Road rip-rap outlet basin (Road rapids)

→ The riprap is placed at the outlet of high velocity culvert, to reduces the exit velocity by expanding the flow over the riprap length & width & forming a hydraulic jump.

⑤ fall or drop structures :

→ It is provided where the bed slope of existing drainage way is very high. The main hydraulic design problem is to determine the minimum permissible length of step.

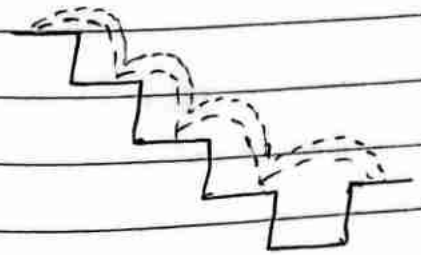


fig: fall or drop structure

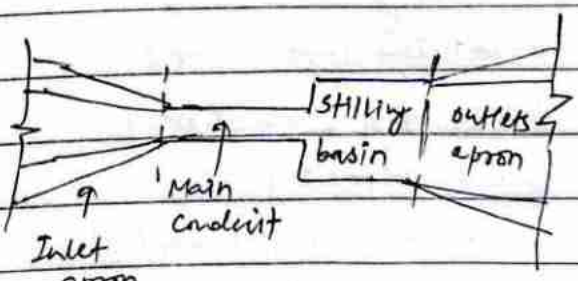


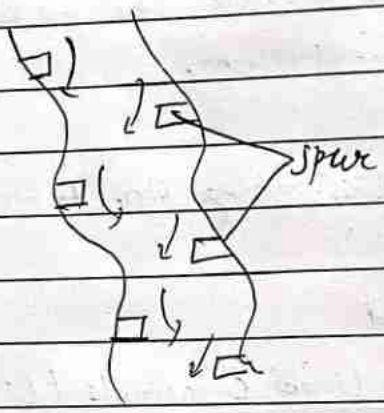
fig. Road rapids plan

⑦ Water cushion :- It is a pond of water constructed below high water fall to protect the water from scour & to destroy the energy & velocity of falling water.

⑥ Bank protection spurs & Checkdams :-

→ These structures are especially used in river routes.

→ Spur is a structure constructed transverse to the flow & extended from bank to the river channel.



→ Check dams are constructed across the stream having higher bed slope to reduce the bedslope in a particular section.

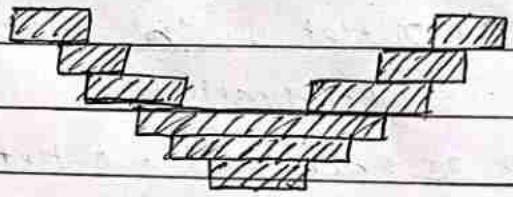


fig : Gabion Check dams

⑧ Slope stabilization

① Turfing (vegetation)
② Terracing
③ Jute netting
④ Studding
⑤ Retaining structures
⑥ Grouting, anchoring
⑦ slope pitching
⑧ Erosion control Mats/Blankets

Erosion control structures :-

→ water emerging out of culverts & other c/s structures generally will have the velocity higher than the non-scouring velocity for the soil around it. & thus erosion of drainage structures takes place.

→ Some erosion control measures are —

① Lining of drain : The side slope of drain is lined with turf & bottom is covered with cobbled gravels of the desired size.

② Vegetation : Soil erosion control is improved by allowing vegetation to grow in the fill slopes, side borrow and shoulder portion of road ways. Quick growing plant varieties are selected for the purpose.

③ Slope pitching, Lining & protection walls :

Various types of slope protection works like stone pitching, plain concrete, RCC, timber etc. may be provided.

④ Geotextiles :- A geotextile is typically defined as any permeable textile material used to increase soil stability, provide erosion control or aid in drainage.

- Use to improve soil characteristics.

⑤ Bituminous treatment : It is used for erosion control in a number of ways.

(1) Asphalt Mulch treatment technique

(2) Laying & Compacting Asphalt Mixing.

Simplified steps for Design of surface Drain:

(1) Assume the frequency or return period.

(2) Calculate the weighted runoff coefficient (C).

(3) Calculate the time of concentration (T) by adding time of entry & time of flow (T_2).

$$T = T_1 + T_2$$

(4) from the Intensity-duration frequency curve, the rainfall Intensity (I) is found in mm/hr to duration (T) & frequency or return period.

(5) Drainage area is calculated & expressed in hectare (Ha).

(6) The runoff qty. $(Q) = \frac{CIA}{360}$

(7) Cross sectional area of drain $(A) = \frac{Q}{V}$

where, V = allowable velocity in the drain

(8) The req^d longitudinal slope (S) of the drain is calculated using Mannings formula adopting suitable value of roughness coefficient

Quantity estimation of surface runoff:-

(9) Hydrological Analysis:-

→ Peak run off water for highway drainage is widely computed by Rational formula. which is given by;

$$Q = \frac{CIA}{360}$$

where, Q = run-off (m^3/sec)

C = runoff coefficient

I = Intensity of rainfall (mm/hr)

A = drainage area (Ha)

- Runoff coeff = Ratio of runoff to rate of rainfall.

$$C = \frac{A_1C_1 + A_2C_2 + A_3C_3 + A_4C_4 + \cdots}{A_1 + A_2 + A_3 + A_4 + \cdots}$$

$C_1, C_2, C_3, \ldots$ = runoff coeff. for resp. area

$A_1, A_2, A_3, \ldots$

- Intensity of rainfall - varies from time to time during whole period of rain.
  - Unit of rainfall intensity is mm/hr or cm/hr.

According to British Ministry of Health,

$$I = \frac{760}{t+10} \quad \text{(for storm duration 5-20 minutes)}$$

$$I = \frac{1020}{t+20} \quad \text{(for storm duration 20-100 minutes)}$$

- Time of concentration (t) = Time req^d for storm water to run from the farthest point of the area to reach the point ~~for~~ which the max^m run-off to be estimated.
  → It includes inlet time & time of flow.

Inlet time;

$$\text{time of entry} = \left(0.885 \times \frac{L^3}{H}\right)^{0.385}$$

L = length, km

H = level diff between 2 pts.

$$\text{Time of flow} = \frac{\text{length of sewer}}{\text{velocity of flow}}$$

(5) Hydraulic Analysis :-

Assuming the allowable velocity of flow, the cross sectional area of the drain is found from relation,

$$A = \frac{Q}{V}$$

By using Mannings formula the longitudinal slope of drain is obtained,

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

where,

V = average velocity (m/sec)

n = Mannings roughness coefficient

R = hydraulic radius (m)

S = longitudinal slope of channel.

4.1.6

Highway Materials

& 70 - 80% of PPC.

By vol^{M}, aggregate generally accounts for 92-96% of Bituminous concrete.

↳ The material used for the construction of highway is termed as highway material. The nature, quality and some other properties of these materials are differ from building materials.

Road construction Materials

- Mineral materials
  - subgrade
  - fine Aggregate
    - natural sand
    - stone dust
  - Coarse aggregate
    - stone chips
    - Gravel
    - Crushed stone aggregate
    - Blast furnace Clay
    - Brick ballast
- Binding materials
  - stonedust or cohesive soil
  - cement, lime etc.
  - Bituminous tar, various plastic polymer
- Other materials
  - Paints
  - Geotextile
  - Gabion wire
  - Timber
  - Reinforcement
  - Brick, Boulder/ stone

Road aggregate:

↳ Aggregate is the composition of sand, gravel, crushed stone, other materials into desired proportion which mainly serve as a base course in road pavement. It includes binding materials.

Classification of road aggregate:-

1. Based on size
   - (a) Coarse aggregate - Pass through 75mm Is sieve & entirely retain on 4.75mm
   - (b) fine aggregate - Pass through 4.75mm Is sieve & entirely retain on 600µ Is sieve
   - (c) All in aggregate - Mixture of fine & coarse aggregate.
2. Based on types of rock:
   1. Aggregate obtained from igneous rock
   2. Aggregate obtained from sedimentary rock
   3. Aggregate obtained from metamorphic rock

(3) Based on surface texture

(1) Glossy aggregate
(2) Smooth aggregate
(3) Granular aggregate
(4) Rough aggregate
(5) Crystalline aggregate
(6) Honeycombed aggregate
(7) Porous aggregate

(4) Based on strength:

(1) Hard aggregate
(2) Soft aggregate

(5) Based on shape:

(1) Rounded aggregate (% void = 33%)
(2) Irregular aggregate (% void = 35 to 37%)
(3) Flaky aggregate (least dimension is less than $\frac{3}{5}$ th of its mean dimn

(4) Angular aggregate (% void = 38% - 45%)
(5) Elongated aggregate (whose greatest dimension (i.e. length) is greater th
$\frac{9}{5}$ th times their mean dimension)

(6) Based on surface moisture:

(1) very-very dry aggregate
(2) Dry aggregate
(3) Saturated surface dry aggregate
(4) wet or moist aggregate

Desirable properties of Road aggregate:

→ In order to access the suitability of stone aggregate for specific road construction, it is important to their specific properties;

(a) **Strength** – should be sufficiently strong to withstand the stresses due to traffic wheel load.

(b) **Hardness** – They should be hard enough to resist the wear due to abrasive action of traffic.

(c) **Toughness** – It is defined as the resistance to impact. Severe harm is quite common when heavily loaded steel tyred vehicles move on the water bound macadam & adequate impact resistance aggregate to be used.

(d) **Durability** – Durability is the resistance to weather action or abi to remain strong over long period.
– The stone used in pavement should be durable.

(e) **Shape & size** – It is well known that flaky & elongated particle w have less strength & durability when compared with cubical, angular or rounded particles of the same stone

(f) **Adhesion with bitumen**:- The aggregate used in bituminous paveme should have less affinity with water when compared with bituminous materials.

(g) **Cementation**: Aggregate must possess binding (cementing) property in presence of moisture, specially used in WBM roads

Test for Road aggregates:

(1) **Abrasion test:** This test is carried to find out abrasion resistance of aggregates.

Different tests for aggregates for abrasion test are –

(a) Los Angles abrasion test
(b) Deval abrasion test
(c) Dorry abrasion test

(a) **Los Angles abrasion test:** It is carried out to evaluate the hardness also toughness

Principle:

To find the percentage wear due to the relative rubbing action between the aggregated steel balls used as abrasive charge. ~~and also to~~

Apparatus:

(1) Los Angeles Machine (Internal diameter of cylinder 70 cm & length
(2) Abrasive charge (Cast iron spherical ball of 48 mm dia.)
(3) Sieve - 1.7mm
(4) Balance of capacity 5kg or 10 kg
(5) Drying oven
(6) Tray etc.

Procedure:

→ LA Machine consists of hollow cylinder closed at both ends. The internal diameter is 70 cm & length is 50 cm. The cylinder is mounted on a support such that it rotates about its horizontal axis
→ Initial weight of specimen 5 - 10 kg is taken depending upon gradation group.
→ Test requires cast iron spheres having diameter of 48 mm & weight of 390 - 445 gm.

- The no. of steel spheres (abrasive charge) is decided based on the grading of aggregates (A to F)
- The machine is rotated at a speed of 30-33 rpm for 500-1000 revolutions.
- On completion the specimen is removed & screened through 1.7mm sieve.

Observation:

Initial weight of sample = W_1

weight retained on 1.7mm IS sieve = W_2

∴ Loss of weight = $W_1 - W_2$

And abrasion value = $\frac{W_1 - W_2}{W_1} \times 100\%$

Test is performed 3 times & average value is taken

Recommended value:

1. for Cement concrete pavement, % wear ≤ 16%
2. for bituminous surface, % wear ≤ 30%
3. for bituminous base course, % wear ≤ 50%

(b) Crushing Test:

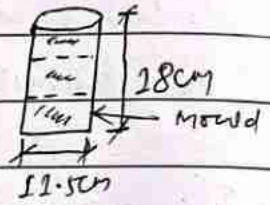
↳ It is made to determine the mechanical strength of aggregate.

Principle :-

↳ In this test, aggregate is put under gradually applied load & resistance to crushing is measured.

Apparatus :

(1) Test mould - cylindrical measure having internal diameter of 11.5 cm & height 18 cm.

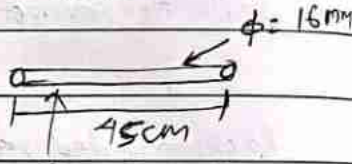


(2) Tamping rod of 16mm dia & 45 cm long.

(3) Aggregate of sized 10 to 12.5 mm.

4) Sieve - 10 mm & 12.5 mm IS sieve

5) Balance of capacity 5kg & accuracy 1 gm.



Tamping rod.

Procedure :-

- Dry aggregate passing through 12.5 mm & retained on 10 mm sieve is taken about 3.25 kg i.e. W_1 & is filled in the cylindrical mould in three layers.
- Each layer is being tamped by 25 nos. of gentle blow with rounded end of tamping rod.
- The plunger is placed on the top of specimen & load of 40 tonnes applied at a rate of 4 tonnes per minute by the compression machine
- The crushed aggregate is removed & sieved on 2.36 mm IS sieve.
- Weight of material passed through 2.36 mm sieve $= W_2$

So, Aggregate Crushing value $= \frac{W_2}{W_1} \times 100\%$

- Min^{m} two tests are carried out & take average value of them.

for surface course, crushing value $\leq 30\%$
for base course, " " $\leq 45\%$

(c) Impact test:

- It is carried out to evaluate the toughness of the stone aggregate when subjected to repeated impacts.
- This test has been standardized by ISI.

Apparatus & Materials

1. steel cylindrical cup of dia. 10.2cm & depth 5cm of thickness 6.3mm.
2. A metal hammer of 13.5kg to 14 kg attached with vertical guides (free fall from 38.5cm height)
3. Tamping rod 10mm in diameter & 230cm long.

Procedure:

- Aggregate sample passing through 12.5mm IS sieve & retained on 10 mm IS sieve is taken & heated at 100 to 110°C & then cooled at room temp^{re} for about 4 hrs.
- The sample is placed to the cylindrical cup in three layers, each layer being tamped by 25 nos. of gentle blow of tamping rod.
- The hammer having weight 13.5-14 kg is allowed to fall freely from height of 38 cm on the specimen.
- After subjecting the test specimen to 15 blows, the crushed aggregate is sieved on 2.36 mm sieve.

let w_1 be the weight of specimen placed in cup & w_2 be the fine formed after blows then impact value is given by,

$$\text{Aggregate Impact value (AIV)} = \frac{w_2}{w_1} \times 100\%.$$

→ 3 min^{m} tests are performed & average value of them is taken.

Check:-

Impact value ≤ 10% → exceptionally strong

Impact value (10-20)% → strong

Impact value (20-30)% → satisfactory

Impact value > 30% → poor

Impact value; for wearing course < 30%

for bituminous macadam ≤ 35%
for water bound macadam ≤ 40%
} base course

④ Soundness Test:

→ This is the durability & weathering test conducted on aggregates.

→ To ascertain the durability of aggregates, they are subjected to an accelerated soundness test.

Procedure:-

→ Aggregates of a specified size are subjected to cycles of alternate wetting ~~& drying~~ in a saturated solution of either sodium sulphate or magnesium sulphate for 16 to 18 hrs at 20° & then drying in air or in an oven at 110°C & cooled at room temp°.

- After five cycles, the loss in weight of the aggregate by fragmentation is determined by sieving out.

- The loss in weight should not be more than 12% in case of sodium sulphate solution & 18% in case of magnesium sulphate solution.

⑤ Shape Test

→ Aggregate particle may have three types of shapes namely rounded, angular & flaky.

- Flakiness Index test
- Elongation Index test.
- Angularity Number.

⑥ Specific gravity & Water absorption test

→ Is done to determine water absorption value of stone.
Stone absorbing more water, are more porous & thus weak & therefore unsuitable unless found acceptable as per crushing & hardness test.
- Stone aggregate should not absorb more than 0.6% of water

Procedure:

→ Take about 2 kg of dry aggregate, put it in a wire basket & immerse it in water for 24 hours.

→ Aggregate is taken out from the water & it is made surface dry with the help of cloth & weighted, say W_1 (i.e. weight of saturated sample)

→ Now aggregate is put in a drying oven at 100°C to 500°C & kept there for 24 hrs.
Again take weight of the sample.
This will be dry weight, say W_2.

→ The water absorption capacity = $\frac{W_1 - W_2}{W_2} \times 100\%$

→ for road surfacing, water absorption capacity of aggregate should lie 0.1 to 2%

→ for road base, 4% may be accepted.

7) Gradation test (sieve / screen / mechanical analysis)

8) Bituminous Adhesion test or stripping test

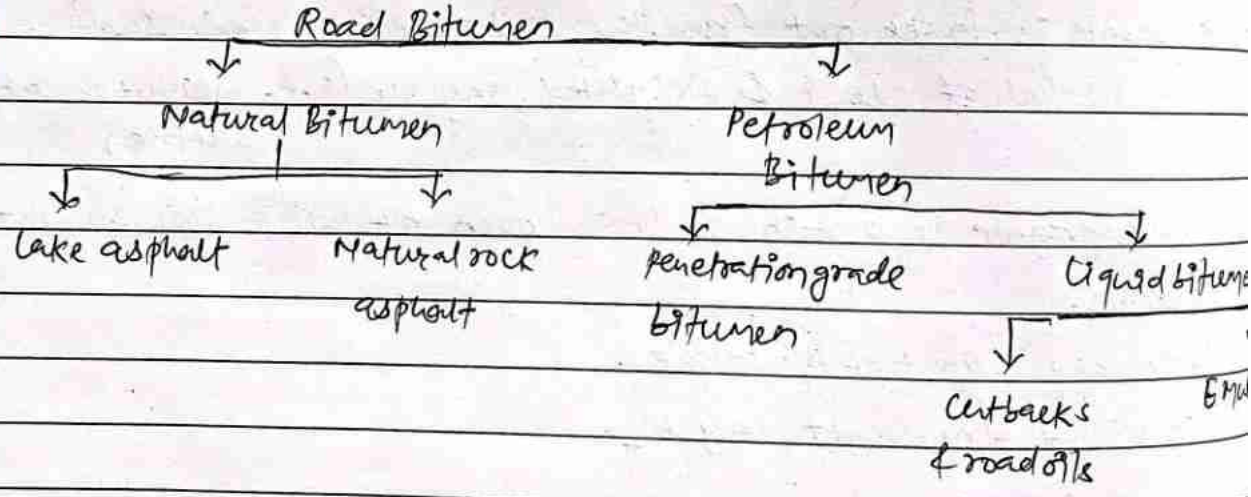
Binder (Bituminous road binder)

→ Bitumen is a non-crystalline or viscous material having adhesive properties consisting essentially of hydrocarbons.

→ Bitumen is a petroleum product obtained by distillation of petroleum crude.

→ It is black or dark brown in colour.

→ Bitumen is the main binders used in road construction which is obtained from petroleum.



(#) Desirable properties of Bitumen:

(1) Adequate viscosity
(2) The bituminous material should not be highly temp^{E} susceptile.
(3) Bitumen should not strip off from the road aggregate in presence of water.
(4) Adequate affinity & adhesion between the bitumen & the aggregate.

(#) By-product of Bitumen:

↳ The product obtained by mixing of bitumen with other liquid or materials is called by-product of bitumen.

(a) Cut-back: It is a solution of bitumen in a volatile or partly volatile solvent such as Kerosene / Creosote & Naptha, high boiling point light oil etc.
- Addition of solution lowers the viscosity of bitumen.

(b) Emulsion: Bitumen emulsion is a mixture of water, bitumen & emulsifying agent. Normally bitumen does not dissolve in water. But when heated bitumen & water mixed together & agitated the bitumen disperses in water in the form of globules of about 2 micron diameter & prevented from flocculating and setting by electrostatic charges provided by emulsifiers. Soap is mostly used as emulsifiers.

Types of Emulsion:

(1) Rapid setting
(2) Medium setting
(3) Slow setting

Application of Bitumen:

1. Surface treatment
2. Recycling
3. Used in soil stabilization
4. Used in patch repair works on bituminous road.
5. Can be used in wet condition.
6. Used for tack & prime coat during construction of pavement.

Advantages of Emulsion:

- Do not require petroleum solvent to make it liquid.
- In most cases asphalt emulsions can be used without additional heat
- It contributes to energy conservation
- It can be used in wet conditions.
- Environmentally friendly than cutbacks.

Tests on Bituminous Binder:

1. Penetration test (for consistency)
2. Ductility test
3. Viscosity test
4. Float test
5. Softening point test
6. specific gravity test
7. flash & fire point test (for safety)
8. solubility test
9. spot test
10. Loss on heating test
11. water content test (for purity)

① Penetration test

⇒ It is carried out to determine consistency of bituminous material. It is degree of fluidity at a particular temp^{re}.

Apparatus

① A penetrometer consisting of a needle assembly with a total wt. of 100gm & device for releasing & locking needle at any position.
② Time measuring device with accuracy ±0.1sec.
③ Dial gauge to read penetration value.

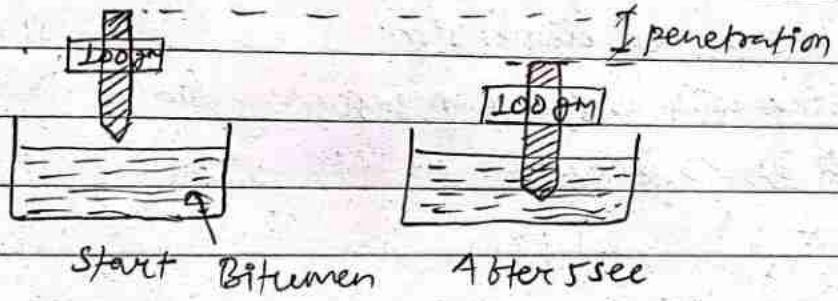


fig: Penetration test concept

Procedure

- Softened the bitumen to pouring consistency, stirred thoroughly & poured into containers at ab depth at least 15mm in excess of expected penetration.
- The sample contained is then placed in temp^{re} controlled water bath at a temp^{re} of 25°C for one hour.
- The sample with container is taken out placed on the testing table of penetrometer, bring the needle in contact with the surface of the sample.
- At least 3 penetration test are made on this sample by testing at distance at least 10mm apart & mean of these measurement is reported as penetration value.

- The bitumen grade is specified in terms penetration value 80-100 or 80/100 grade bitumen means that the penetration value of the bitumen is in the range of 80 to 100 at standard test conditions.

(2) Ductility test

→ It gives adhesive property of bitumen & its ability to stretch.

Apparatus

(1) Briquette of standard dimension
2) Pulling device with distance measuring dial
3) water bath arrangement

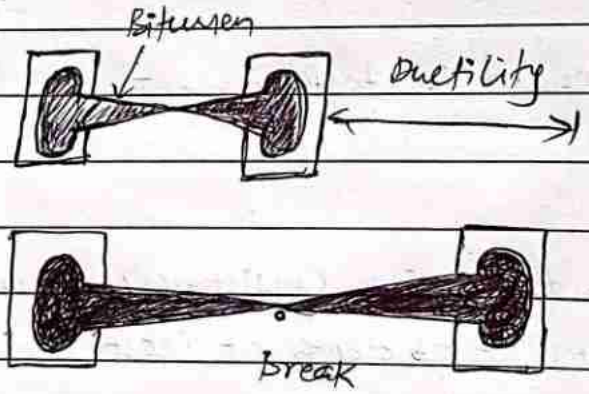


fig: Ductility test

Procedure:

↳ Softened the bitumen sample & powred in the briquette assembly & then placed on brass plate.

↳ whole assembly is allowed to cool in air & then in water bath maintained at 27°C.

- The side of mould are removed, the clips hooked on the machine & the pointer is adjusted to zero.
- Two clips were pulled horizontally at the rate of 50 mm/min & the distance is noted at the point of breaking thread. The distance in cm gives the value of ductility of bitumen.
- The ductility value should not be less than 50 cm for satisfactory performance of bitumen.

But acc to ISI, Min^{m} ductility value is 75cm.

(#) Bituminous Mixes:

⇒ The composition of aggregates (coarse & fine aggregates with bitumen or other bituminous materials (like cutback, emulsion etc.) with or without mineral filler which is used for road pavement construction is called bituminous mixes.

⇒ Desirable properties of bituminous mixes;

(a) stability
(b) Durability
(c) workability
d) flexibility
e) skid resistance
(f) Must have sufficient voids in compacted mix.

Different types of bituminous mixes:

1. Surface dressing
2. Premix carpet
3. Mixed seal surfacing
4. Otta-seal
5. Bituminous Macadam
6. Bituminous Concrete
7. Stone-mixed asphalt
8. Asphalt concrete
9. Cold mixes & hot mixes
10. Dense bituminous Macadam (DBM)

- **Design of Bituminous Mixes**

↳ Steps to be followed for rational design of a bituminous mix are.

1. Selection of aggregate
2. selection of aggregate grading
3. Determ of specific gravity of aggregate
4. Proportioning of aggregates
5. Preparation of specimen
6. Determination of specific gravity of compacted specimen.
7. Stability test on compacted specimen.
8. selection of optimum bitumen content.

(#) **Road tar:** Road tar is a viscous liquid, black in color with adhesive properties obtained by fractional distillation of crude tar.

→ Crude tar is produced by destructive distillation of organic materials like coal, wood, shale etc. in the absence of air.

Differences between Bitumen & Tar :-

Bitumen	Tar
→ It is the product of fractional distillation of crude oil.	→ It is the product of destructive distillation of coal.
→ It has black to dark brown colour.	→ It has black to dark brown colour.
→ It is soluble in CS_2 & CCl_4.	→ It is soluble in toluene.
→ It has better weather resisting property.	→ It has poor weather resisting property.
→ It is less temp^{re} susceptible.	→ It is more temp^{re} susceptible.
→ It contains less free carbon.	→ It contains more free carbon.

(#) Asphalt Concrete (AC)

→ Asphalt concrete is a dense-graded premixed bituminous mix which is well compacted to form high quality pavement surface course. The asphalt concrete consists of well maintained gradation of course aggregate, fine aggregate, mineral filler & bitumen. It is designed by Marshall Method to fulfill the requirements of stability, density, flexibility & voids.

Adv. of AC :	Disadv. of AC
1) Durability	1) Costly
2) Imperviousness	2) Need for sophisticated machinery
3) Good skid resistance	3) very high bitumen content
4) Better load-spreading property	

4.1.7 Traffic Engineering:

⇒ According to Institute of Traffic Engineers (U.S.A), "Traffic engineering is that phase of engineering which deals with planning & geometric design of streets, highways, abutting lands & with traffic operations thereon, as their use is related to the safe, convenient & economic transportation of persons & goods."

(#) Scope of traffic engineering:

↳ The basic object of traffic engineering is to achieve efficient free & rapid flow of traffic, with least no. of traffic accidents.

following are the main ~~objective~~ scope of traffic engineering;

(a) Traffic characteristics
- (i) Road user characteristics
- (ii) Vehicular characteristics

(b) Traffic studies and analysis
- (i) Traffic v&q studies
- (ii) Speed studies
- (iii) OD studies
- (iv) Traffic flow characteristics
- (v) Parking studies
- (vi) Accident studies

(c) Traffic operation: Control and Regulation
- (i) Traffic control device
  - Traffic sign
  - Traffic signal
  - Road markings
  - Traffic Island

(iii) Traffic Regulation

(d) Planning area & Analysis
- Traffic policies

(e) Geometric Design:
↳ sight distance, horizontal & vertical alignments
↳ Design of interseetion, parking terminals etc.
↳ Lighting

(f) Traffic administration and management:
↳ Engineering
↳ Enforcement
↳ Education

(Inter-relationship between Human / Machinery / Environmental Elements)

↳ TE deals with road user (human, driver/pedestrian traffic), traffic (Mechanical / pedestrian) & environmental factors (rain, fog dew etc.)

- All three elements have own importance as well as certain relationship which are described below:

(a) Road user characteristics

(1) Physical characteristics
↳ Directly related with vision, hearing, strength & general reaction to the traffic situations.

(2) Mental characteristics
↳ It includes knowledge, skill, intelligence, experience, & literacy of the road users.

(c) Psychological characteristics

↳ It includes the emotional factors such as fear, anger, attentiveness, superstition, impatience, attitude towards traffic maturity.

(2) Vehicular characteristics (Machinery):

(a) static characteristics

- Dimension (i.e. length, width, height etc.) of vehicle.
- Gross weight of axle & wheel load
- Min^{m} turning radius
- height of head light

(b) Dynamic characteristics:

- Main dynamic characteristics of vehicles are speed, acceleration & braking characteristics.

(3) Environmental factors;

↳ This includes certain environmental factors such as atmospheric condition and locality.

↳ The atmospheric condition such as weather, rain, climate can change the human behaviours & locality may be shopping center, cinema hall or other places of distractions.

Traffic operation & Regulations :

Traffic Regulation :

↳ GOM has made certain rules and regulation to control the traffic on the road.

→ The traffic regulations & Laws cover the following four phases :-

① Driver Controls

- This includes driving licenses for vehicles, driving tests & min^{M} requirements for eligible driver, financial responsibility & civil disability.

② Vehicle Controls

- This includes. vehicle registration, requirements of vehicles, equipment & accessories, max^{M} dimensions, weight, fitness & inspection of vehicles.

③ Flow regulations

- Regulations of traffic flow have been laid down such as directions, turning & overtaking etc.

④ General Controls

- Other general regulations & provision are made to report accidents & recording & disposing traffic violation cases.

Traffic control devices.

↳ The various devices used to control, regulate & guide traffic are called traffic control devices.

↳ The traffic control devices are;

(a) Traffic sign
(b) Traffic signals
(c) Road markings
(d) Islands
(e) Variable message sign
(f) Rumble strips

(a) **Traffic sign** :- A traffic sign is a device mounted on a fixed or portable support where by a specific message is conveyed by means of words or symbols for the purpose of regulating, warning or guiding traffic.

Purposes of traffic sign :

1) To give timely warning of hazardous situations when they are not self-evident.
2) To regulate traffic by imparting messages to the drivers when to stop, give away or limit their speeds.
3) To supply information on highway routes, directions & points of intere

Types of traffic sign:

(1) **Regulatory or Mandatory sign**

- These signs are used to inform the road users of certain laws, regulations & prohibitions to provide safety & free flow to traffic

- There are A01 to A33 types of regulatory sign.
- Most of them take the form of circular disc, although two signs, the stop sign (900mm x 900mm octagonal shape) & the give way sign (equilateral triangle having side 900mm), have distinctive individual shapes.

These signs are classified under the following sub-heads;

(i) stop & give way signs
(ii) prohibitory signs
(iii) No parking / stopping signs
(iv) speed limit & vehicle control signs
(v) Direction control sign etc.

(2) Warning or Cautionary sign:
- These signs are used to warn the road user of certain hazardous conditions that exist on or beside the roadway.
- It is used to alert drivers to danger or potential danger ahead.
- Warning signs are B01 to B48 types.
- Are equilateral triangle having apex pointing upward.
- Warning signs are school ahead, Narrow bridge, slippery road, Cross roads, falling rocks, left/right hand curve etc.

(3) Informatory sign:
- These signs are used to guide the road users along routes, inform them of destination, direction, distance & inform about facilities.
- These signs are classified under following sub-heads;

(i) Direction & place information signs.
(ii) facility information signs
(iii) Parking signs
(iv) flood gauge
(v) other useful information signs etc.

(#) Traffic signals:

↳ A traffic signal is defined as any power operated traffic control device, or a sign by which traffic is warned or directed to take some specific action.

→ The main requirements of traffic signal are to draw attention, provide meaning & time to respond & to have minimum waste of time.

// Adv. of TS:

1) They can provide for an orderly movement of traffic.
2) They can reduce the frequency of certain types of accidents.
3) Traffic signal can increase traffic handling capacity of the intersection
4) Traffic signal dispense with police control & can thus be economical
5) At signalized intersection, pedestrains can cross the road.

// Disadv. of TS:

1) Excessive delay to vehicles may be caused, particulary during off peak hours.
2) Read end type accidents may be increased.
3) failure of signal due to electric power failure.
4) Drivers may be induced to use less adequate & less safe routes to avoid delays at signals.

(#) Types of TS:-

(1) Traffic control signal
   - (a) fixed time signal
   - (b) Manually operated signal
   - (c) Traffic actuated signal – timing of the phase & cycles are changed according to traffic demand.

2) Pedestrain signal
3) special traffic signal

Road Marking:

- Road/traffic markings are mode of lines, patterns, words, symbols or reflectors on the pavement, kerb or on the fixed objects within or near the roadway.

Purpose of road Marking:-

(i) To guide & control traffic on the highway.
(ii) To serve as a psychological barrier.
(iii) To delineate traffic path & its lateral clearance from traffic hazards.

Types of road Marking:

(a) Pavement Marking; Markings done on the carriageway itself like center lines, lane lines, edge lines, stop lines etc.

(b) Object Marking; are applied on objects such as kerb, guard rails, trees, drums, traffic islands etc.

(c) Kerb Marking; are put into indicate parking restriction & Landing zones.

Traffic Island:

→ These are raised area constructed within the road way which can be used for the guidance of vehicular traffic.

Various function of Island:

(i) To increase safety.
(ii) To separate traffic into specified paths
(iii) To segregate the pedestrians and vehicles.
(iv) To reduce the conflict area to minimize hazards.
(v) To divert the traffic from obstacles & expedite the traffic flow.

Types of Island:

(1) Division Island: Are used to separate opposing flow of vehicles on a highway. By thus dividing the highway into two one-way roadway not only the chances of head on collision are eliminated but also other accidents are reduced.

(2) Channelising Islands: Are used to guide the traffic into proper channel through the intersection area.

⇒ Main uses:

(a) The area of possible conflicts between traffic stream is reduced

(b) They are useful when the direction of flow is to be changed

(c) They serve as convenient locations for other traffic control devices.

(d) They serve as refuge islands for pedestrians.

(3) Pedestrian Loading islands: Are provided at regular bus stop & similar places for the safety of passengers. They are raised portion of road used by passengers either for riding on buses or loading the goods on bus.

4) Rotary: A traffic island located in the center of an intersection to compel movement in a clockwise direction & thus substitute weaving of traffic around the island instead of direct crossing of vehicle pathways.

(5) Refuse Islands: Are located in the crosswalks to provide refuse for pedestrians.

Adv. of Rotary:

1. Traffic flow is regulated to only one direction of movement; thus eliminating severe conflicts between crossing movements.
2. Because of lower speed of negotiation & elimination of severe conflicts, accidents & their severity are much less in rotaries.
3. Rotaries are self governing & do not need practically any control by police or traffic signals.
4. They are ideally suited for moderate traffic, especially with irregular geometry, or intersections with more than three or four approaches.

Disadv. of Rotary:

1. All the vehicles are forced to slow down & negotiate the intersection. Therefore, the cumulative delay will be much higher than channelized intersection.
2. Even when there is relatively low traffic, the vehicles are forced to reduce their speed.
3. Rotaries require Large area of relatively flat land making them costly at urban areas.
4. They are not suitable when there is high pedestrian movements.

(#) Design consideration of traffic islands:

→ The total design of traffic islands can be studied in three steps:

1) selection of appropriate island type:-

→ The site & traffic condition in each intersection are different & hence the island type suitable for each requires separate attention. The traffic island selected may vary from barrier type to flush island marked on the roadway surface.

(11) Determination of shape and size of island:

→ The shape of the island & its size in an intersection depends on the geometry & space availability at the same. A proper shape & size of the island (in case of raised islands) must be selected so that it is able to both channelized the traffic and not pose any type of hazard.

(111) Location relative to adjacent traffic lanes

→ The islands must be offset from the roadway by some distance to remove the risk of a vehicle dashing against the same. The width of island is max^{m} at entry & decreases gradually as one moves towards the end of it.

Road Lighting:

Road Lighting is the process of setting the raised source of light on the edge of road or walkway to enable the road users to see accurately & easily the road way & its surrounding at night.

Objectives / Importance of Road Lighting:

1. Illuminated environment for quick movement of the vehicles at night.
2. Aid to police protection & enhanced sense of personal security.
3. Reduction in Nighttime accidents and economic loss.
4. Promotion of business activities & the use of public interaction during night hours.

Factors affecting Night visibility:

1. Size of object
2. Brightness of object
3. Brightness of background
4. Time available to see an object
5. Glare on the eye of the driver
6. Reflecting characteristics of the pavement surface and
7. Amount & distribution of light flux from the lamps.

(#) Design of Lighting system

(1) **Lamps:-** The selection of proper size, type & colour of Lamp depends on various factors in addition to distribution of light flux on the pavement surface.
The commonly used lamps are fluorescent, filament & mercury vapor Lamps.

(2) **Luminaire distribution of light:** The light distribution selected should be one which would produce max^{m} uniformity of pavement ~~surface~~ brightness. The distribution from the Luminare should cover the pavement between the kerb & adjacent area upto 3m to 5m from pavement edge.

(3) **Spacing between light pole:-** spacing between Lamps on straight road should lie between 3 to 5 times the mounting heights. On sharp curve the spacing should be closer than the spacing on the straiget roads.
The spacing of light poles is also influenced by road Layout & type of side features & their illuminat

$$\text{Spacing} = \frac{\text{Lamp Lumen} \times \text{utilization coeff.} \times \text{maintenance factor}}{\text{Average Lux} \times \text{width of road}}$$

(4) **Height and overhang of light poles:**
- Usual mounting heights range from 6 to 10m.
- Overhang on the lighting poles would keep the poles away from the pavement edge but still allows the ~~lamp~~ to be held above the kerb or towards the pavement.

- It is desirable to have higher mounting heights & necessary overhang projections.

Lateral placement:

- Road lighting poles should not be located very close to the pavement edge.
- IRC has specified horizontal clearance required for lighting pole as minimum 30cm & desirable 60cm from raised kerb & min^{M} 1.5m from edge of road having no raised kerb.

Lighting layout:

- On straight road, the lighting layout may be single side.
- staggered on both sides and central type single side system is suitable for only single lane road.
- for wider roads, staggered system on both sides or central system may be adopted.

(#) Intersection:

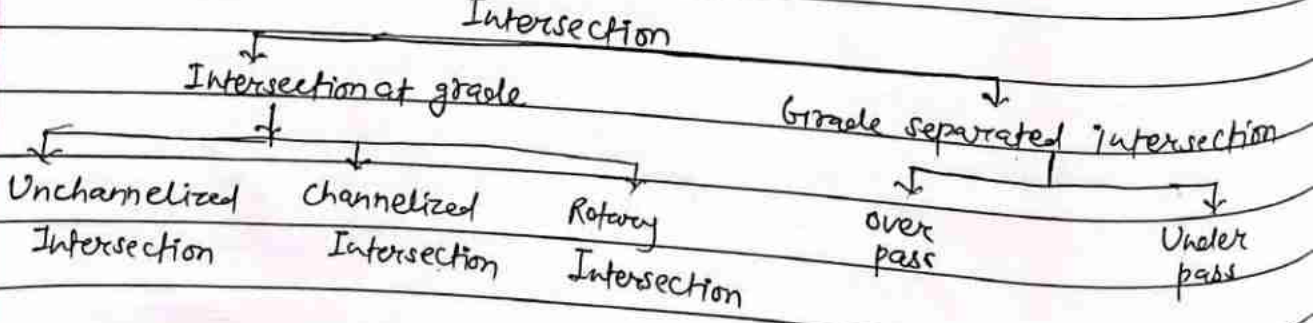
→ An Intersection is defined as the general areas where two or more highway join or cross, within which are included the road way & roadside design features which facilitates traffic movements in that area.

→ It is also known as junction.

Basic requirements of Intersection at grade:

(1) At intersection, the area of conflict should be as small as possible.
(2) The no. of conflicts should be kept to a minimum.
(3) The relative speed & particularly the angle of approach of vehicle should be small.
(4) Adequate visibility should be available for vehicle approaching the intersection.
(5) Sudden change of path should be avoided.
(6) Good lighting at ~~night turning~~ night is desirable
(7) Proper sign should be provided on the road.
(8) Geometric features like turning radius & width of pavement should be adequately provided.

(#) Types of Intersections:

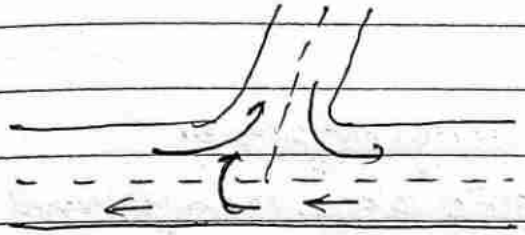


(#) Intersection at grade:

→ An intersection where all roadways join or cross at the same level is known as intersection at grade.

(1) Unchannelized intersections:

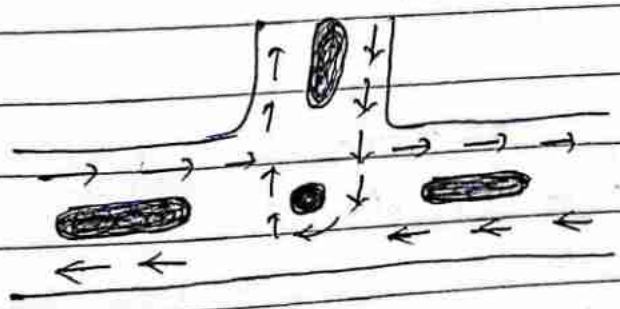
→ An unchannelized intersection is one without island for directing traffic into definite path. In this type of intersection there is no provision of any direction island or central island. Are most dangerous & inefficient.



Unchannelized T intersection

(2) Channelized intersection:

→ The direction of traffic flow at intersection to definite path by means of traffic marking, island is called channelized intersection. Channelized intersection is achieved by introducing islands into the intersectional area, thus reducing the total conflict area available in the unchannelized intersection.
Proper channelization increases capacity, improves safety, provides maximum convenience & gradually establish confidence of the drivers.



Channelized T intersection

Adv. of channelized intersection:

→ By channelization, vehicles can be confined to definite path.
→ Points of conflict can be separated.
→ Angle of merging & diverging maneuvers can be keep minimum.
→ Refuse Island can be provided for crossing the pedestrian traffic.
→ Speed control devices can be installed to force the vehicles reduce their speed before entering the intersection.

(3) Rotary Intersection:

→ It is specialized form of intersection at grade.
→ A rotary intersection or traffic rotary is an enlarged road intersec where all converging vehicles are forced to move round a large central island in one direction (clockwise direction) before they can weave out of traffic flow into their respective directions radiating from the central island.

Advantages of rotary:

(a) Rotary could function itself, no need of traffic police or signal.
(b) No. & severity of road crash is reduced.
(c) Operation cost at rotary is less than at signalized intersection where the vehicles have to stop and proceed.
(d) The capacity of the rotary intersection is the highest of all other intersection at grade.

Limitation of rotary intersection:

(1) It requires Large area of Land.
(2) when the traffic volume is very low, construction of a traffic rotary cannot be justified.
(3) with mixed traffic condition it may be complex.
(4) Even when there is relatively low traffic, the vehicles are forced to reduce their speed.

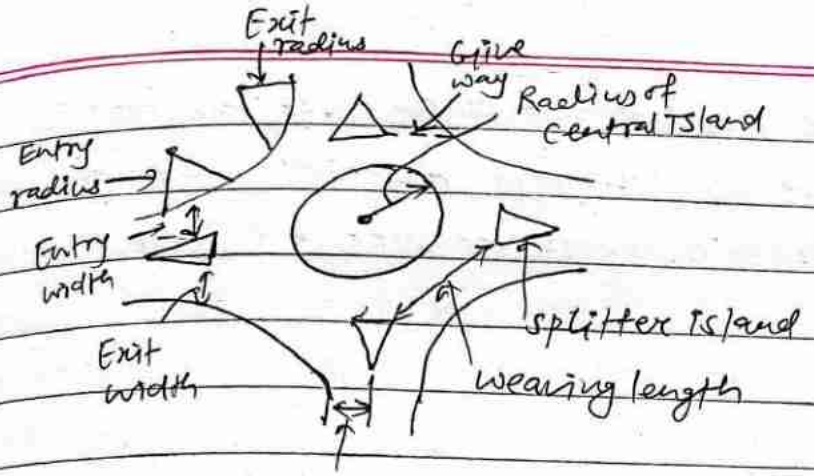


fig: Rotary

Grade separated Interseetions:

→ Interseetion where crossing maneuvers are made at different levels so that the movements in different directions do not conflict with each other is known as grade separated intersection.

Adv

- There are no crossing conflicts.
- Capacity of grade separated roads almost approaches to the full capacity.
- They provide easy means of separation of express ways & free ways from local traffic.
- They provide safety, comfort & convenience to motor traffic and effect saving in operational cost & time of travel.

Disadv

- Grade separation involves very large area.
- It involves lot of expenditure
- It is undesirable in flat or plain terrain.

⊕ Traffic studies:

→ Traffic studies are carried out to analyze the traffic characteristics. These studies help in deciding the geometric design features & traffic control for safe & efficient movem

(a) Traffic volume study
(b) Speed studies
  (i) spot speed study
  (ii) speed and delay study
(c) Traffic flow characteristics
(d) Origin and destination (O&D) study
(e) parking studies
(f) Accident studies

(a) Traffic volume study: It is nothing but the no. of vehicles crossing a section of road per unit time at any selected period. The unit of traffic volume is vehicles per day & vehicles per hour.

Methods of traffic volume study:
1) Manual counting
2) Automatic recorders or counters
3) Moving car method of counting

● Objectives of volume study:
→ It is a true measure of the relative importance of roads.
→ It is used in planning, traffic operation & control of existing facilities
→ This study is used in the analysis of traffic patterns & trends.
→ This study is also fruitful not only in structural design of pavement but also in computing roadway capacity.

→ Pedestrian traffic volume study is used for planning side walks, cross walks, subway & pedestrian signal etc.

(#) Presentation of Traffic volume Data:

→ The data collected during the traffic volume studies are sorted out & presented in any one of the following forms:

(1) Annual average daily traffic of the total traffic.
(2) It is presented as variation, charts showing hourly, daily & seasonal variations.
(3) Traffic flow maps along the routes
(4) volume flow diagram at intersection.
(5) It is presented as trend charts showing over a period of year which can be utilized for future expansion, design & regulation.

(#) O&D study:

↳ The origin & Destination studies of vehicular traffic determines their numbers, origin & destination in each zone under study.
O&D study gives information like actual direction of travel, selection of routes & length of the trip.

● Purpose of origin & Destination study:

(i) Plan the road network & other facilities for vehicular traffic.
(ii) To plan public transportation system.
(iii) To locate intermediate stops of public transport.
(iv) To Locate new bridge as per traffic demand.
(v) Plan the schedule of different modes of transportation for the trip demand of commuters.

● Methods of origin & Destination study:

(I) Roadside Interview method
(II) Home Interview method
(III) workspot Interview method
(IV) Tag on car method
(V) Return post card method
(VI) License plate method

(#) Parking Studies:

⇒ Parking is the act of stopping vehicles & leaving it in unoccupied for more than a brief time.

→ It is one of the most important place in transportation system.

⇒ following are the main aspects which are studied during parking studies

(I) Parking demand
(II) Parking characteristics
(III) Parking space inventory.

Purpose of parking studies:

(1) To determine the capacity of the existing parking capacity.
(2) To estimate the desires & demands of the public for parking facility
(3) To decide the capacity, location & type of future parking facilities
(4) To determine the congestion of the city.

Parking surveys:

→ A parking surveys can be done by following methods;

(1) Inventory studies
2) Label use method
3) Customer Interview method

(H) Ill effects of parking :-

(1) Congestion :- One of the serious ill effects of parking is the loss of street space & abundant traffic congestion.

(2) Crash :- No. of crash during parking operations activities increases.

(3) Obstruction to fire-fighting operations : Parked cars obstruct the movement of fire fighting vehicles & greatly impede their operations. They block access to hydrants & access to buildings.

(4) Environmental pollution :- They also cause pollution to the environment because stopping & starting of vehicles while parking & unparking, results in noise & fumes.

(H) Types of parking :

(1) On street parking : In this type of parking, vehicles are parked on the sides of street itself. Also called kerb parking. This type of parking was allowed in the area of Durbarmarga Kathmandu.

further divided into two types.

(a) Parallel parking
- vehicles are parked along the length of the road.
- Preferred when width of street is limited.

(b) Angle parking
→ May be 30°, 45°
- 60° - Parked at 60° to the dirn of road.
- 90° - vehicles are parked ⊥r to the road.
  - accomodates max'm no. of vehicles for a given kerb length.

(b) Offstreet parking:

↳ When the parking facility is provided at a separate place away from the kerb, it is known as offstreet parking.

↳ The main advantage of this method is that there is no undue congest & delay on the road as in kerb parking.

● Styles of offstreet parking:

(a) Self parking system → The parking of vehicles may be done by drivers or owners himself then this is called self parking system.

(b) Attendent parking system → Vehicles are parked by the attendes is called attendent parking.

(*) Types of offstreet parking facilities are;

1. Surface car parks
2. Multistorey car parks
3. Roof parks
4. Mechanical car parks
5. Under-ground car parks.

(*) Prohibition of parking:

→ Failure to provide suitable parking facility can cause in congestion & frustration. So parking should be prohibited on the following locations:

1. Near side walks
2. In front of door way entrance
3. Within a cross section
4. Within 5M of the fire hydrants
5. In a cross walks
6. On a highway bridge or tunnel
7. Near intersection
8. Narrow streets
9. Pedestrian crossing

Accident (Crash) studies :

→ Accident is defined as phenomenon which may occur with the combination of vehicular traffic, pedestrians etc.

→ The problem of accident is very acute in highway transportation due to complex flow patterns of vehicular traffic, presence of mixed traffic & pedestrians.

Main objectives of accident studies :

1. To study the cause of accident
2. To evaluate the existing facilities & to give support to the proposed design.
3. To justify economically, the proposed improvements.
4. To compute financial loss due to crashes.
5. To provide possible suggestion of control the accident in future.

Causes of Accidents :

1. **Driver :-** Carelessness, excessive speed, violation of rules & regulation, failure to see or understand traffic condition, sign or signal, temporary effects due to fatigue, sleep or alcohol, age & experience of driver may cause accident.

2. **Pedestrian :** Pedestrian violating traffic regulation, careless in using carriageway are causes of crash.

3. **Passengers :** Alighting from or getting into moving vehicles causes crash.

4. **Vehicle defects :-** Lack of regular maintenance of vehicles like failure of brakes, steering system, lighting system & tire burst.

(e) Road Condition:-

→ slippery or skidding road surface, pot holes & ruts, inadequate road marking & unexpected obstruction such as road works, parked vehi

(f) Road design:

→ Defective geometric design like inadequate sight distance, width of shoulder, improper curve design, improper lighting etc.

(g) Weather: Unfavourable weather like fog, snow, dust, smoke or heavy rainfall etc. which restricts visibility.

(h) Animals: Moving animals on the road, stray at road etc.

(#) Accident Studies and Records:

(1) Collection of accident data:

(a) General information such as date, time, person involved etc.
(b) Locations of accidents
(c) Vehicle details
(d) Nature of accident
(e) Road & traffic condition
(f) Accident costs etc.

(2) Accident Report:-

↳ The details about accident should be reported to police authorities to take Legal action.

(3) Accident Record:

→ Accident records may be maintained in the form of location spot maps, collision diagram, condition diagram.

(1) Measures of preventing Road Accidents:

(a) Engineering Measures
   (1) Proper road design
   (2) Design & Maintenance of vehicles

(b) Enforcement Measures
   (1) Speed control
   (2) Traffic control devices
   (3) Training & supervision
   (4) Medical check up

(c) Education
   (1) Training

(d) Encouragement

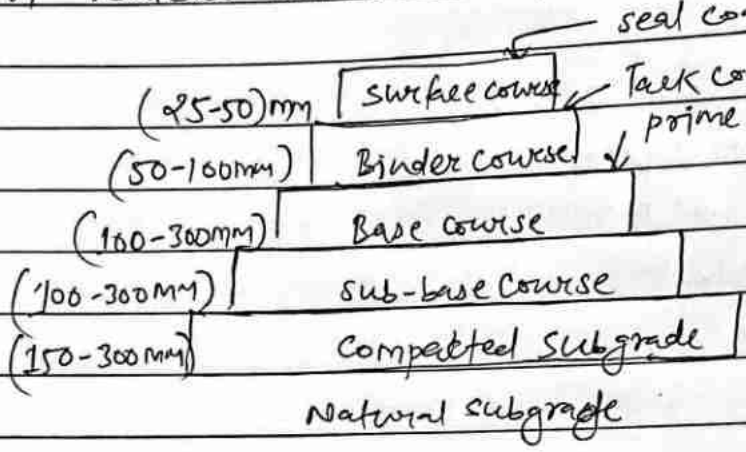
(e) Evaluation / Adjustment

• Overall preventive Measures:

(1) follow Traffic rules
(2) Enforcement of seatbelt
(3) Control speed of vehicles
(4) Improvements in road lighting
(5) widening narrow road sections
(6) Making crash helmets mandatory
(7) Education to public through mass media.
(8) Deployment of two drivers on long routes.
(9) Initiating road safety training campaign in school & colleges.
(10) Standardized training & licensing of drivers.

Road Pavement

Road pavement can be defined as a relatively stable layer constructed over the natural soil for the purpose of supporting & distributing the wheel loads & providing an adequate surface for the movement of vehicles with certain speed safely, comfortably & economically.



fig; layer of pavement

Requirements of Pavement:

1) Sufficient thickness to distribute wheel load stress to a safe value on the subgrade soil.
2) Structurally strong to withstand all types of stresses imposed upon it.
3) Adequate coefficient of friction to prevent skidding of vehicles.
4) Impervious surface, so that subgrade soil is well protected.
5) Long design life with low maintenance cost.

(*) Function of different layers of pavement :-

(1) Subgrade :

→ It is the compacted natural earth & top of it is called formation level.
→ It resist ultimate load of pavement.
→ It provide support to other layer of pavement.
subgrade should possessess the following properties;
(a) Strength
(b) Drainage
(c) Ease of compaction
(d) Permanency of compactionete.

→ The strength of subgrade soils are calculated by following tests;
(a) California Bearing ratio test
(b) California resistance value test
(c) Triaxial compression test
(d) Plate bearing test.

(2) Sub-base course :

→ The sub-base course is the layer of material beneath the base course & the primary functions are to provide structural support, improve drainage & reduce the intrusion of fine from subgrade in pavement structure.
Sub-base course has following function;
(a) To provide additional support to the base & sub base course in distributing the loads.
(b) To minimize the damaging effects of frost action.
(c) To facilitate drainage of free water that might get accumulated below the pavement.

③ Base course:

↳ The base course is the layer of material immediately beneath the surface of binder/wearing course.

→ It provides additional load distribution & contributes to the sub-surface drainage.

→ It may be composed of crushed stone, crushed slag or other untreated or stabilized material.

④ wearing/surface course:-

↳ The surface course is uppermost layer of pavement. Surface course is the layer directly in contact with traffic loads & generally contains superior quality materials.

function of surface course;

ⓐ To provide smooth & uniform riding surface.

ⓑ To resist the pressure exerted by tyres.

ⓒ To reduce the amount of surface water penetration to the pavement.

Prime coat:

→ It is the application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder courses is placed.

→ It provides bonding between two layers.

→ Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, & forms a water tight surface.

⇒ function of prime coat:-

→ The major purpose of prime coat is to protect the underlying layers from wet weather by providing a temporary waterproofing layer.

→ Prime coat must adequately penetrate the base to function properly.

→ Excess prime coat not absorbed into the base after 24 hrs. should be absorbed with blotter sand & removed from the surface.

(#) Tack coat:

→ It is very light application of asphalt, usually asphalt emulsion diluted with water.

→ functions of tack coat;

→ The purpose of tack coat is to ensure bond between the existing pavement surface & a new pavement surface.

→ The higher the viscosity of the bituminous binder in the tack, the higher the reported interface shear strength.

→ Tack coat should be applied in a thin coat & uniformly cover the entire surface, including all vertical surfaces of joints & structures.

(#) Seal coat:

→ Seal coat is a thin surface treatment used to water proof the surface & to provide skid resistance.

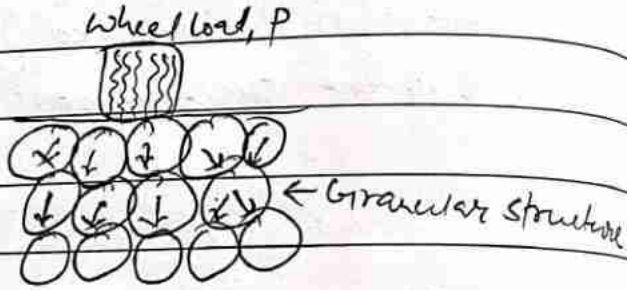
→ The main purpose of seal coat is to fill the pore formed during surface course so that water could not infiltrate inside.

Types of Road pavements:

(a) Flexible pavement

↳ The pavement, which have negligible flexural strength but flexible in their structural action under the loads, are known as flexible pavements.

→ Flexible pavements will transmit wheel load stresses to lower layers by grain to grain transfer through points of contact in the granular structure.



Load transfer in granular structure

(b) Rigid pavement

⇒ Rigid pavements are those which possesses considerable flexural strength. Rigid pavements are made of cement concrete which may be either plain, reinforced or prestressed.

→ The rigid pavements have a slab action & are capable of transmitting the loads stresses through a wider area below.

(c) Semi Rigid pavement:

↳ When bonded materials like pozzolanic concrete (Lime fly ash - aggregate) lean cement concrete or soil cement are used in base or sub base courses the pavement layer has considerably higher flexural strength than the common flexible pavement layers. These pavements are called semi rigid pavement.

Date
Page

Composite pavement:

It is combination of two types of flexible & rigid pavements.

→ In its widely used form, composite pavement consists of cement concrete slab as a bottom layer & bituminous layer as a top layer resulting in an ideal pavement with most desirable characteristics.

→ But this technology is still infancy.

Diff. between flexible pavement and Rigid pavement

S.N.	Description	Flexible pavement	Rigid pavement
1.	Design life	Has life about (10-20) years.	Has life of about 40 yrs.
2.	Maintenance	Needs great input in maintenance.	Needs very little maintenance.
3.	Design precision	less precise because pavements are mainly designed by empirical methods.	more precise because structural analysis technique is used.
4.	surface characteristics	Relatively poor riding quality.	Good riding quality because free from ruts, potholes & corrugations.
5.	Healing Properties	Has self healing properties (recoming to shape).	Doesn't have self healing properties
6.	Initial Cost	Requires less initial cost.	Requires more initial cost.
7.	Resistance to Moisture damage	Poor	Good
8.	Construction	In stages	At a time.
9.	Temperature Variation	Do not produce stresses.	Produces heavy temperature stresses.
10.	Water Penetration	Little	Nil

	Description	Flexible pavement	Rigid pavement
11.	Skid resistance	Decreases with age.	Remains almost same throughout design life.
12.	Glare & Night visibility	Surface is black so no light reflects & hence more street lights are needed for night visibility.	Grey in colour so good for & less street lights are need for night visibility.

(#) Loads and other factors controlling Pavement Design:

(1) Traffic and Loading:

(a) Axle configuration & axle load:-

→ The different kinds of axle load configuration of vehicle is different different countries. standard axle load also vary country to country.

The standard axle load for Nepal is 8.2 tonnes.

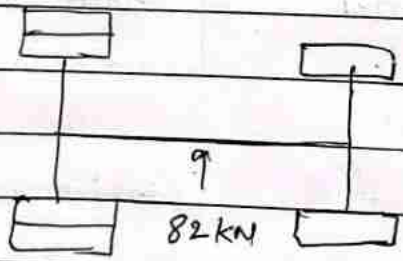


fig: single axle with dual tires

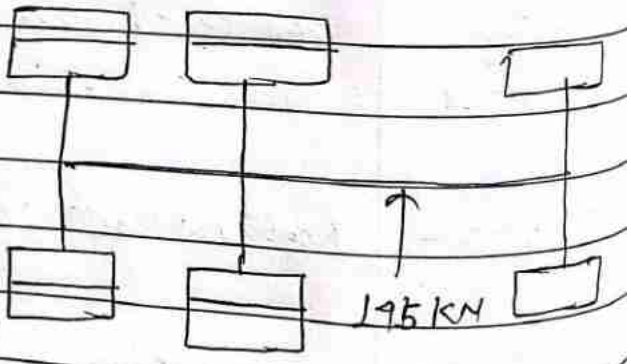


fig: Tandem axles with dual tires

(b) Equivalent factors:

↳ Equivalent factors F is calculated by following eqns;

$$F = \left(\frac{L_a}{L_s}\right)^n$$ where,

L_a = actual axle load, KN

L_s = standard axle load, KN

n = Exponential power

In Nepal $n = 4.5$ & $L_s = 8.2$ tonnes

(c) Repetition of loads:

→ The no. of repetition of loads causes plastic & elastic deformation.

(d) Equivalent single wheel Load (ESWL):

↳ It is single wheel load having the same contact pressure, which produces same value of max^m stress, deflection, tensile stress or contact pressure at the desired depth.

According to semi-rational formula, known as Boyd & foster method,

The ESWL is given by; $\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10}\left(\frac{z}{d/2}\right)}{\log_{10}\left(\frac{2s}{d/2}\right)}$

where, P = wheel load

s = c/c distance between two wheels

d = clear distance between two wheels

z = the desired depth.

(c) Contact pressure:

→ As the depth of pavement increases the tyre pressure decreases & finally diminishes at a specified depth. Therefore the materials used in different layers are of varying quality.

Rigidity factor = $\frac{\text{Contact pressure}}{\text{Tyre pressure}}$

= value is one, less than one or greater than 1

Contact pressure = $\frac{\text{load on wheel}}{\text{Contact area or area of imprint}}$

(b) Contact area:

↳ In real, the contact pressure is greater than tyre pressure for low pressure type.

But in pavement design the contact pressure is assumed to be equal tyre pressure.

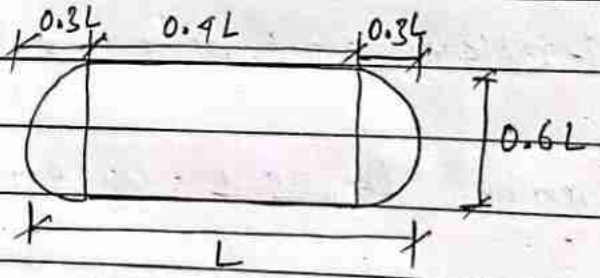


fig: Actual contact area

$$A_c = \pi(0.3L)^2 + 0.4L \times 0.6L = 0.5227L^2$$

$$\therefore L = \sqrt{\frac{A_c}{0.5227}}$$

① Vehicle speed:

↳ Speed is directly related to duration of loading.

→ The greater the speeds, the greater the duration of load.

② Environmental factors

↳ The environmental factors that effect pavement design include temperature and precipitation; both affecting the elastic moduli of various layers.

③ Materials

↳ In the design, the properties of materials must be specified so that the responses of the pavement such as stresses, strains & displacements in critical components can be determined. These responses are then used with the failure criteria to predict whether failure will occurs or the probability that failures will occur.

④ failure Criteria:

→ Number of failure criterions is established to specify different types of distress.

for example;

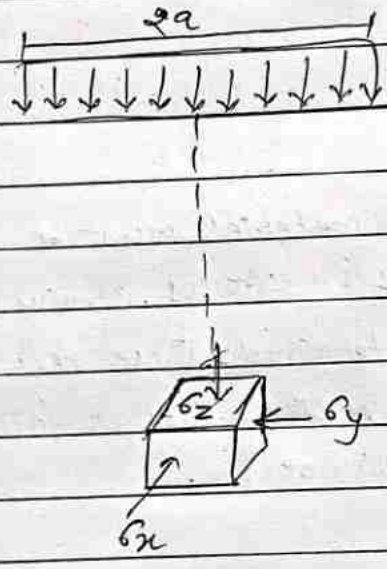
In flexible pavements, fatigue cracking, rutting & thermal cracking are the three principal types of distress to be considered.

And in rigid pavements, fatigue cracking, mud pumping, faulting, spalling, joint deterioration are the principal types of distress.

Design Methods for flexible pavements:

(a) Boussinesq's Theory:

b) The soil mass is assumed to be semi infinite, ideal elastic, isotropic & homogeneous. The vertical stress under a load at any horizontal section decreases from the max^{m} at the point located directly beneath the load to zero at a very large distance from this point.



Stress below a circular loaded plate

The vertical stress (σ_z) at any point below the surface is

$$\sigma_z = p\left[1 - \frac{z^3}{(a^2+z^2)^{3/2}}\right]$$

& The radial (horizontal stress) is given by

$$\sigma_x = \sigma_y = \frac{p}{2}\left[1+2\mu - \frac{2(1+\mu)z}{(a^2+z^2)^{1/2}} + \frac{z^3}{(a^2+z^2)^{3/2}}\right]$$

The vertical displacement at the surface (z=0) under the central applied load is

$$\Delta = \frac{\pi p a}{E}(1-\mu^2)$$

for rigid plate, $$\Delta = \frac{1.18 p a}{E}$$

where, p = applied pressure per unit area.
a = Radius of circular loaded plate
z = Depth
μ = poisson's ratio
E = Modulus of elasticity of soil

(b) Semi-Empirical method (Tri-axial method)

→ Method is developed by kansas state highway department.

Thickness of pavement $(T_p) = \left\{\sqrt{\left(\frac{3PXY}{2\pi E_s \Delta}\right)^2 - a^2}\right\}\left(\frac{E_s}{E_p}\right)^{1/3}$

Here; P = Wheel load, kg
E_s = Modulus of elasticity of subgrade from tri-axial test (kg/cm^2)
a = radius of contact area.
Δ = design deflection (0.25cm)
E_p = Modulus of elasticity of pavement materials (kg/cm^2)
Traffic coeff.; X = 1.5
Rainfall coeff.; Y = 0.9

(#) Vehicle damage factor (VDF):-

↳ The no. of standard axles per commercial vehicle is designated as vehicle damage factor.

→ VDF is a multiplier for converting the no. commercial vehicles to the no. of standard axle loads repetitions.

(#) Design of flexible pavement

(a) Group index method
(b) California Bearing ratio method
(c) stabilometer method
(d) Tri-axial test method (semi-Empirical method)
(e) Mcleod method
f) Burmister method
g) Road Note 31 method
h) IRC method
i) AASHTO method
j) Barber Greenleaf's method

(#) IRC Method

→ Design traffic is considered in terms of cumulative number of standard axle as;

$$N = \frac{365\,(1+r)^n - 1}{r} \times A \times D \times F$$

Where,

r = annual growth rate of commercial traffic

n = design life in years

A = initial traffic at the end of construction

$= P(1+r)^n$

P = no. of

D = lane distribution factor

F = Vehicle damage factor.

After obtaining the cumulative traffic & CBR value, the total thickness of pavement from subgrade is calculated regarding from the graph given by IRC.

(#) Asphalt Institute Method:

→ In Asphalt Institute Method the pavement is regarded as multi-layered elastic system.

$$\left(\frac{t_b}{t_{sc}}\right) = \left(\frac{E_{sc}}{E_b}\right)^{1/3}$$

$$\left(\frac{t_{sb}}{t_{sc}}\right) = \left(\frac{E_{sc}}{E_{sb}}\right)^{1/3}$$

where,

t_{sc} = thickness of surface course

t_b = thickness of base course

t_{sb} = thickness of sub base course

E_{sc} = elastic modulus of surface course

E_b = elastic modulus of base "

E_{sb} = " " " sub base "

(#) Bio-Engineering:

↳ Bio-engineering is use of living vegetation, either alone or in conjuction with small scale civil engineering structures & non Living plant materials, to reduce soil erosion & shallow-seated instability on slopes.

Scope of Bio engineering:

→ Bio-engineering can be applied in different fields;

1) slope stabilization on embankments & cut slopes.
2) Erosion control
3) Wind erosion control
4) Preservation of water resources
5) Waste disposal & public health
6) Reservoirs & dams, buildings, highways, railways etc.

Benefits of Bioengineering:

- Reduces instability & erosion of slopes.
- Increases the slope's factor of safety.
- Cost-effectiveness
- versatility in application (many techniques)
- physical flexibility (can be used anywhere)
- Only the best way to solve some problems (e.g, soil erosion on top of the
- Environmentally & socially advantageous
- Can be managed with the participation of the local people.

- **Bio engineering techniques:**

→ **Use of vegetative Engineering system:**

↳ The structure constructed for the purpose of slope stabilization & protection work with the use of plants or plant materials.

(1) **Grass planting or seeding:**

- Horizontal line of grass planting (suitable for different slopes)
- Vertical line of grass planting (suitable for slopes upto 65° & clay types
- Diagonal line of grass planting (suitable for slopes upto 65° & damp site)
- Chevron & herringbone pattern - suitable for ridge & gullies respectively
- Random grass planting - suitable for slope of 45-65° upto 15m length

(2) **Bush Layering:**

↳ Use of woody stem cutting

↳ Act as barrier preventing the development of rills & trap materials moving slope.

↳ Catch, armour, reinforce

3) **Palisades:**

↳ Use of hard woody stem cutting (vertical) planted along the contour line

↳ strong barrier & trap materials moving down

↳ Catch, armour, reinforce

1) **facines:**

↳ Use of live stem cutting in bundles (hz, vt., or diagonal) like bolster.

↳ Put out root & shoots forming a strong line of vegetation.

↳ Catch, armour, reinforce

5) Bamboo plantation:
→ Using rhizome of bamboo / nrakat, banana)
→ At toe or just above toe wall.
→ Reinforce & support the slope

6) Shrubs Tree planting:
→ shrubs tree planted at regular interval on the slope.
→ Create dense network of roots in the soil.
→ Reinforce, anchord later also help to support slope.

7) Turfing:
→ shallow rooting grass in soil
→ Armour the gentle embankment slope.

(8) Other techniques
• Live wattle fences:
↳ fences with live cuttings placed across the slope, catch material on the gentle slope.

• Jute netting:
↳ Place the woven jute netting on the slope, armouring & Catch small debris.

• Mulching
↳ Temporary measure to help growth of vegetation

• Live check dams
↳ Large woody cuttings planted across gully

Small scale civil Engg. structures:

b) To slove the problems on slope, different types of small scale civil engineering structures are also required along with bioengineering.

Such as –

(a) Retaining walls

- Retain mountain slope, road & slope segment from valley side
- Designed to stop active earth pressure.

(b) Revetment / Breast walls

- Protect the base of slope from undermining or other damage like grazing
- Only for protection, and not for support

(c) Pry wall / Dentition

- Prevent erosion of soft rock bands below the hard rock.
- Protection of scour & under cuttings.

d) Check dams:

- Check the scouring of steep water channels
- Prevent down cutting of runoff water in gulleys.
- Resist active pressure permitting safe discharge of water.

(e) Surface & subsurface drainage:

- Cascades, french drains, catch drains etc.
- Drain or remove the surface & ground water safely & quickly.

f) Stone pitching:

- Stone covering of the slope
- Armors the slope & allow freely drainage withstanding wave velocities.

(7) Wire bolster cylinder:

- Like tube (30 cm dia.) filled with stones.
- Laid in shallow trenches across the slope
- Prevent surface scouring & gullying.

(8) Other civil Engg. technique

- Wire netting
- Reinforced earth
- Rock bolting
- Cement slurry

(#) Limitations of Bio-engineering

1) Root penetration on foundation & drains
2) Risk of topping onto buildings
3) Chocking of water ways with plant growth
4) Accelerates weathering & corrosion, or causes adverse effects on the performance of concrete & steel.
5) Vegetation cannot perform its engineering functions in its initial stage
6) It demands regular repair & maintenance
7) Usually separate nursery needs to be established & manged.
8) Suitable only for shallow (upto 2M) slide & erosion (10 cm)

4.1.9 Road Construction Technology

Activities & Technologies used in road construction:

⇒ Road construction technology is that of engineering which deals with all kinds of activities and technology or operation for changing existing road to the desired shape, slope & to provide all necessary facilities for smooth, safe & efficient traffic movement & operation which also includes the reconstruction of existing roads.

Various activities of road construction include;

① Earthwork and site clearance
- Site clearance
- Earthwork in filling for embankment
- Excavation for cutting
- Excavation for borrow pit
- Excavation for structural foundation
- Disposal of surplus earth

② Drainage works
- Minor bridges
- Culverts
- Causeways
- Side drains
- Other surface & sub surface drainage works

③ Protection works
- Earth retaining structures
- River training works
- Gully control works
- Land stabilization works
- Bridge protection works

④ Pavement works
- Subgrade works
- Sub base works
- Base works
- Surface works

⑤ Miscellaneous works
- Road ancillaries
- Traffic signs / signals / markings etc.
- Bio engineering works

(#) Tools, Equipment and Plants used in Road Construction:-

1) Tools:

(a) shovel (b) spade (c) peak (d) wheel barrows (e) brushes
(f) trowel (g) hand rammer

(2) Equipment

(a) Earth moving equipment

- Excavator (backhoe)
- Dozer (bull dozer, angle dozer, tree dozer)
- Loader
- Scrapper
- Dragline
- Clamshell
- Trench digger

(b) Compaction equipment

- Smooth wheel rollers
- Vibrating rollers
- Pneumatic tyred roller
- Grid roller
- Sheep foot roller
- Rammers
- frog rammer

(c) Levelling equipment

- Grader

(d) Lifting equipment

- Backhoe (for Low load)
- Crane (different capacity)

(e) Transporting equipment

- Dumping trucks (tipper)
- Trucks (flat body)
- Mini-dumpers
- Loaders
- Belt conveyor, Ropeway, bucket conveyor
- Rail wagons

(f) Paving equipment

- Binder spreader
- Binder boiler (Heating kettle)
- Aggregate spreader
- Cement Concrete Mixer
- Bituminous paver
- Cement concrete paver

(g) Plants

- Cement Concrete plant
- Asphalt Concrete plant
- Cold premix mixing plant
- Aggregate crusher plant
- Screening plant
- Washing plant

Field Control of Compaction:-

↳ for adequate quality control in construction, it is necessary to have proper field control in construction.

→ Two field control tests needed are:

- Measurement of moisture content.
- Measurement of dry density

→ Before compaction of earthwork is undertaken, it is always preferred to know the optimum moisture content for the soil, which can be determined by Proctor's field control method. If the moisture ~~control~~ content of the soil during compaction is controlled at OMC then the next control needed is dry density, the desired value of which may be achieved by increasing the number of passes for the selected equipment & the thickness of each layer (sand replacement is widely used). In field it is not possible to achieve 100% results in comparision to standard results obtained in the Laboratory. However by field checks it is possible to control the compaction to achieve the best possible results. Around more than 95% of standard density is generally aimed at in the field compaction.

(#) Mass Haul Diagram:

↳ Mass haul diagram is the graphical representation of the cont. of earthwork involved in road construction & the manner in which the earth to be hauled economically.

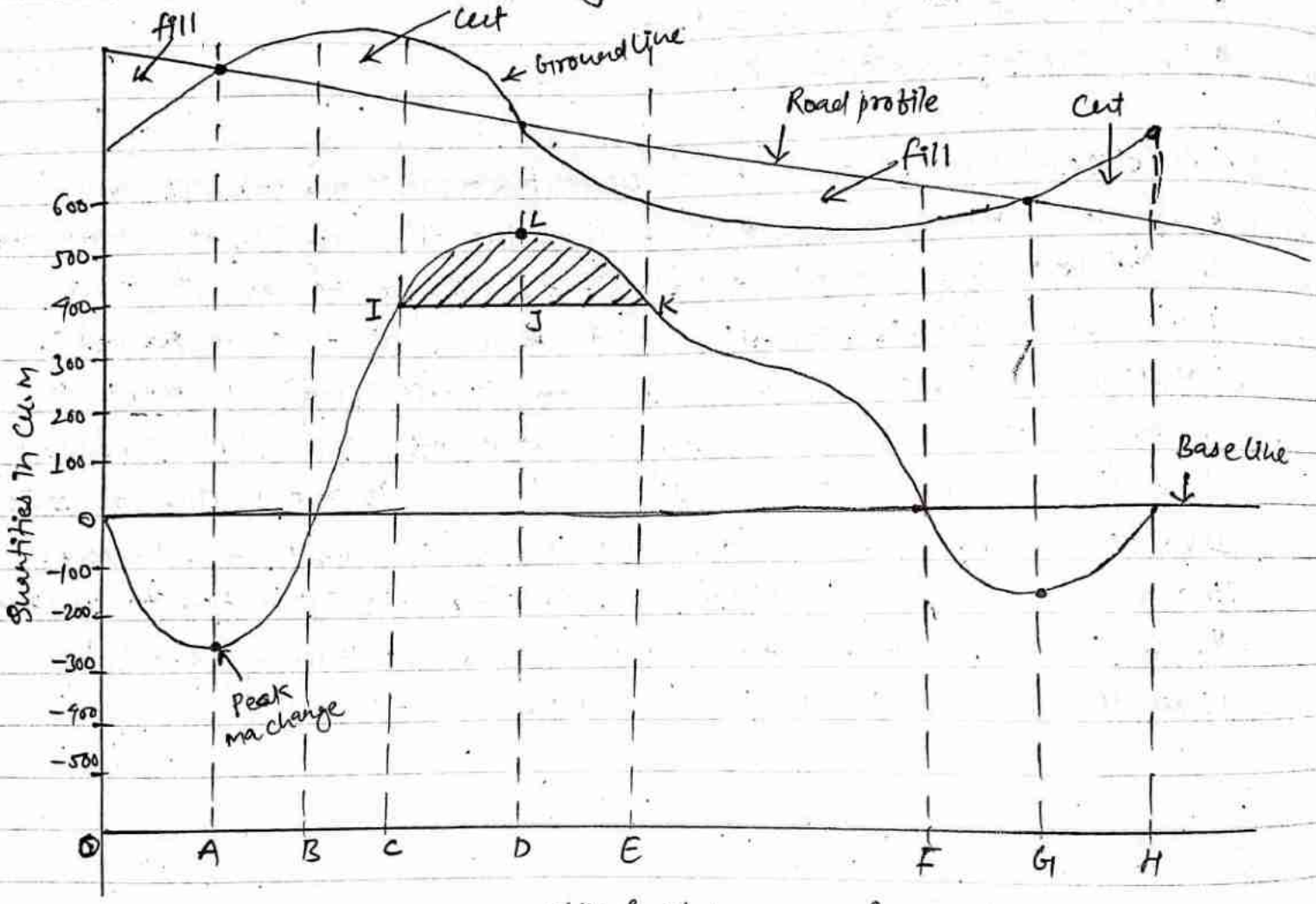


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fig. Mass haul diagram

⇒ The main characteristics of diagram can be summarized as:

1) Plotted below the longitudinal profile of the road.
2) Horizontal distance are the chainages along the center line.
3) The ordinate at any station along the curve indicates the e/w quantity accumulated up to that point & is the summation of the differences between cut & fill.
4) The max^{m} ordinate (+) indicates a change from cut to fill
5) The min^{m} ordinate (-) indicates a change from fill to cut

5) A rising curve at any point indicates ~~heavy~~ an excess of excavation over fill at that point. A falling curve indicates the reverse.

6) If a curve has steep slopes it indicates heavy cuts or high fills. Flat slopes indicates small E/w quantities.

7) A convex loop of mass diagram indicates the haul from cut to fill is from left to right. A concave loop indicates the haul from cut to fill is from right to left.

8) Balance point is a point where the v/m of excavation balances the v/m of embankment.

(9) Any line drawn parallel to base line & intersecting two point within the same curve indicates a balance of cut & fill between these two points.

(10) The area between a balancing line & the mass diagram is a measure of the haul between the balance points.

(11) When the earth excavation & embankment quantities balance at the end of the section, the mass diagram curve would end at the base line at the zero point.

- Free haul is a distance to which the contractor is supposed to move the earth without any additional charge. It is generally 50m.
- Overhaul is the distance in excess of freehaul for which the contractor will be paid extra for each unit of haulage.
- Economic haul distance is a distance to which material from excavation to embankment can be moved more economically than to get material from borrow opening.

(#) Construction of water bound Macadam:

↳ This construction is known after the name of John Macadam.
The term macadam as applied to the road at the present time has come to mean the road surface and bases which are constructed of crushed or broken stone aggregate mechanically interlocked by rolling & the voids filled with screening & binding material with the help of water.
water bound macadam is constructed in thickness ranging from 10-7.5cm.
Generally camber of 1 in 36 to 1 in 48 is provided in WBM roads.

Materials req^{d}:

(a) Coarse aggregate

↳ Crushed or broken stones should be hard, durable & of acceptable shape, free from flaky and elongated particles.

↳ Soft aggregates like overburnt bricks, metal or naturally occuring soft aggregates such as kankar or laterite may also be used.

(b) screenings (filler materials)

↳ Screenings consists of aggregates of smaller size & are used to fill voids in coarse aggregate, should generally consist of the same materials as the coarse aggregate.

(c) Binding Materials:

↳ It consists of fine grained material to prevent ravelling of stones.
Limestone dust may be utilised if locally available.

Equipment:

(a) water tanker (b) grader & (c) Compacting equipment

④ Construction procedure:

① Preparation of subgrade:

→ Careful preparation of subgrade is necessary. The foundation layer is prepared to the required grade & camber & the dust and other loose materials are cleared. The subgrade layer should be well compacted & this underlying layer should be well drained.

② Provision of lateral Confinement:

→ Lateral confinement is to be provided before starting WBM construction.

③ Spreading the coarse aggregate:

→ Coarse aggregate is stacked along the length of the road at suitable intervals either manually or mechanically.

On prepared subgrade, coarse aggregates are spread uniformly to proper profile to even thickness. The WBM course is normally constructed to compacted thickness of 7.5cm except in case of WBM sub base course which is 10 CM.

④ Rolling:

→ After spreading the coarse aggregates properly, rolling is done with 6 to 10 tonnes three wheeled power rollers or vibratory rollers. Rolling is usually started from the edges & progresses towards the center except on super-elevated curves where the rolling begins on the lower edges & progresses towards the higher edge.

⑤ Application of screening:

→ After rolling, screening consisting of stone grit is spread uniformly over coarse aggregate in three or more applications. Spreading, brooming & rolling operations are carried out at the same time & in conjunction with one another. Enough screenings are applied to fill the surface voids.

⑥ Sprinkling of water & wet Rolling (to fill about 50% of total voids):

→ After light dry rolling, the surface of the layer is sprinkled with water & rolled again. The sprinkling & rolling are continued until all voids are filled.

⑦ Application of Binding materials (filler):-

↳ A suitable filler material is then applied at uniform & slow rate in two or more successive thin layers.

⑧ Setting and drying:

↳ The road surface thus prepared is allowed to set overnight. The hungry spots are located & are filled with screenings or binding material lightly sprinkled with water if necessary & rolled.

⑨ Opening to traffic:

↳ The road may be opened to the traffic after a day or two days of the construction so that road may properly set & dry.

(iii) Construction of Cement Concrete Pavement:-

→ The construction of cement concrete pavement is dealt under the following groups:

- Construction of pavement slab → Alternate bay method
  → Continuous bay Method
- Design & placement of joints

⇒ The cement concrete pavement is normally used in urban areas where traffic flow is very much. Due to excellent riding surface & pleasing appearance, the cement concrete roads are very much preferred. The life of cement concrete road is much more than any types of road construction.

(α) Construction of pavement slab:

- Materials

(a) Cement → OPC in general but RHPC may also be used to reduce curing time.

(b) Coarse aggregate → Max^{m} size of coarse aggregate should not exceed one fourth of the slab thickness.

The desirable properties of coarse aggregates are;

Crushing value ≤ 30%
Impact value ≤ 30%
LAA value ≤ 30%
Soundness ≤ 12% in Na_2SO_4
≤ 18% in $MgSO_4$

(c) Fine aggregate → Natural sands are preferred though crushed stones may also be used.

- Plants & equipment:

(a) Concrete Mixer
(b) Batching equipment
(c) Wheel barrows
(d) Internal vibrators
(e) float
(f) Straight edge
(g) belt
h) Brush
i) Edging tool
j) other small tools.

Construction steps:

(I) Preparation of subgrade and sub base:

→ The subgrade is prepared carefully & should be graded & compacted to the desired camber & profile. The prepared surface should be checked at least two days in advance & should be kept moist at the time of placing concrete.

(II) Placing of forms:

→ Steel or wooden forms are used for the purpose. The depth of the forms should be equal to the thickness of pavements. The forms are jointed neatly and are set with exactness to the required grade & alignment.

(III) Batching of material & Mixing:

→ After determining the proportion of ingredients for the field mix, the materials are mixed in batch mixer which will ensure a uniform distribution of materials throughout the mass, so that the mix is uniform in colour & is homogeneous.

(IV) Transporting & placing of concrete:

→ The mixed cement concrete is deposited on the soil subgrade or sub base to the required depth & width of the pavement section within the formwork in continuous operation. Care should be taken to ensure that no segregation of materials is resulted while the concrete is being transported from the mixer to its placement. The spreading is done uniformly.

(V) Compacting & finishing:

→ The surface of the pavement is compacted either by means of a power driven finishing machine or by a vibrating hand screed. The slab surface is tested for its grade & level with straight edge.

⑥ Curing of cement concrete:

→ The entire pavement surface is cured as follows:

ⓐ Initial curing in which the surface is entirely covered with jute mats saturated with water

ⓑ final curing, done either by wet soil which is kept thoroughly saturated with water for 14 days or using an impervious membrane.

⑦ Opening to traffic:

→ When the concrete attains the required strength or after 28 days of curing the concrete road is opened to the traffic.

⑧ Construction of joints:

→ Joints are provided in cement concrete pavement for expansion, contraction, and warping of the slabs due to the variation in the temp^{r} of slabs.

→ The main fuction of these joints are to minimise the temp^{r} stress induced in the pavement slab.

→ Expansion joints are provided to allow for expansion of the slabs due to rise in temp^{r} above the construction temp^{r} of cement concrete. They are provided at interval of 50 to 60 m for smooth interface laid in winter and 90 to 120m for smooth interface laid in summer.

→ Contraction joints are provided to permit the contraction of the slab. These are spaced closer than expansion joints.
The max^{m} spacing of contraction joints in reinforced cement concrete slabs is 4.5m and in reinforced slab of thickness 20cm is 14m.

→ Longitudinal joints are provided to allow differential shrinkage and swelling due to rapid change in subgrade moisture.

→ Longitudinal joints are provided in cement concrete roads which have width over 4.5m.

(#) Bituminous Concrete:

- It is the highest quality of construction in the group of black top surface. It consist of carefully proportioned dense grading of coarse aggregate, fine aggregate & mineral filler coated with bitumen binder. This kind of surfacing is more durable, have better riding quality, more load carrying capacity.

Materials:

Bitumen – 30/40, 60/70, 80/100

Aggregate – specified gradation

LAA ≤ 40%

Impact ≤ 30%

flakiness Index ≤ 25%.

water absorption ≤ 1%.

Plants and equipment:

Hot mix plant : Mechanical finisher

Rollers

Construction steps:

1. Preparation of existing base layer
2. Removal of pot holes or ruts if any
3. The surface shall be thoroughly swept & scraped clean, free of dust and other foreign matter.
4. Irregularities are filled in with premix chippings at least a week before laying surface course.
5. If existing surface is extremely wavy, a bituminous leveling Coarse of adequate thickness is provided.
6. Application of tack coat : a tack coat of bitumen is applied at 6 to 7.5 kg per $10m^2$ just ahead of Oncoming bituminous construction.

(7) Production of mix from hot mix plant.

(8) Placing of premix

(9) Rolling & compaction: The mix placed over the base course is thoroughly rolled at a speed not more than 5 km per hour & compaction are of great significance in strength of the resulting pavement structure.

(#) Bituminous Bound Macadam:

→ It consists of one or more course of compacted crushed aggregate premixed with bituminous binder and laid immediately after mixing & the compacted. This is used primarily for use as a base course.
When this layer is exposed as a surface course, at least a seal coat is necessary.

Materials:

Bitumen of grade - 30/40, 60/70, 80/100 penetration
Tar - RT-4
Cutback & emulsion may be used in cold mix construction technique.
Coarse aggregate - specified gradation
LAA ≤ 50%
Aggregate Impact value ≤ 35%
Flakiness Index ≤ 15%
Loss with Na_2SO_4 for 5 cycles ≤ 12%

Plants & equipment:

(a) Bitumen heating device, hot mix plant; sprayer, mechanical mix or improvised hand mixer.
spreader - Mechanical paver or finisher grader

Construction procedure:

(a) Preparation of underlying layer:

→ The existing layer is prepared to a proper profile. The surface is properly cleaned after patching the pot holes & making even the irregularities.

(b) Application of tack coat or prime coat:

→ 4-7.5 kg/10m² for black top layer & 7.5-10 kg/10 m² for untreated WBM layer.

The tack coat shall be applied just ahead of the spreading of premixed macadam.

(c) Premix preparation:

↳ The binder and aggregates to be used are separately heated to a specified temperature & then mixed properly. The mix is then carried to the site for the placement through a transporters or a wheel barrow.

(d) Placement:

↳ The transported mix is immediately placed on the desired location & spread to predetermined thickness. The camber profile is checked with a template.

(e) Rolling & finishing (8-10 tonnes tandem roller): The rolling is commenced from the edges of the pavement construction towards the center & uniform overlapping is provided.

(f) Application of seal coat :- The seal coat (bitumen) is applied & again rolled.

(g) Opening to traffic:

→ The finished surface shall be opened to traffic preferably after minimum period of 24 hours.

(11) Grouted or penetration Macadam:

↳ Bituminous penetration macadam shall consist of the construction of one or more courses of compacted crushed aggregate bonded or keyed by alternate application of bituminous materials & filling aggregate & the application of a seal coat, when specified. The thickness of an individual course shall not exceed 75mm.

Materials:

- Bitumen of grade 30/40, 60/70, 80/100 or fare RT-4 & RT-5 may be used.
- Coarse aggregate – hard, strong, durable, clean
  - LAA value – ≤ 40%
  - AIV value – ≤ 30%
  - flakiness index – ≤ 25%
  - stripping at 40°C – ≤ 25%
  - Loss with Na_2SO_4 for 5 cycles – ≤ 12%
- Seal coat: Chipping 9mm size
  - 0.09 to 0.11 M^3 per 10 M^2
- Binder: Straight run bitumen 9.8 kg to 12 kg per 10 M^2

Plants & equipment

- Bitumen heating device
- Bitumen distributor
- Aggregate spreader
- Rollers

Construction procedure:

→ Preparation of existing surface:

↳ The existing layer is prepared to a proper profile. The surface is properly cleaned after patching the pot holes & making even the irregularities. Prime coat may be applied on porous surface.

② Spreading the coarse aggregate:

↳ The coarse aggregates are spread either by mechanical spreader or by hand. The spreading shall be carried out no further in advance that can be completed in one average day's work. The camber profile is checked with a template.

③ Rolling (dry rolled with Lot Rollers):

↳ Rolling is commenced from the sides & proceeded towards the center the overlap recommended being 30cm.

④ Bitumen application (50 to 67 kg for 5 and 7.5cm thick for $10M^2$)

↳ The bitumen is applied over the dry & compacted aggregates with pressure distributor or mechanical sprayer.

⑤ Spreading of key aggregate:

↳ The key aggregates are spread & rolled after the application of bitumen.

⑥ Seal coat (Premixed sand bitumen):

↳ The seal coat is applied if another surfacing course is not constructed immediately & traffic is to be allowed.

⑦ Finishing:

↳ The constructed pavement section is checked for its cross profile with template & Longitudinal profile by straight edge.

⑧ Opening to traffic:

↳ The finished surface shall be opened to traffic preferably after minimum period of 24 hours.

(#) Soil stabilization:

↳ soil stabilization is the process of improving the bearing capacity of the soil by proportioning & controlled compaction with suitable admixture or binder.

→ If the stability of local soil is not adequate for supporting wheel loads, the properties are improved by soil stabilization techniques.

Purpose of soil stabilization:

1. To increase the strength of sub-bases, base course etc.
2. To bring about economy in the cost of a road.
3. To reduce frost susceptibility.
4. To reduce compressibility & thereby settlements.
5. To improve permeability characteristics.

Techniques of soil stabilization:-

(a) **Proper proportioning** → various locally available soils and aggregates are mixed in suitable proportions & compacted to serve the desired objectives. The stability of fine grained soil can be improved by addition of gravel & sand components in suitable proportions. Likewise the stability of a cohesionless sand may be improved by the addition of some cohesive soil.

(b) **Cementing agent** → The strength of stabilized soil can considerably be increased by the addition of cementing agent like portland cement, lime mortar etc.

(c) **Modifying agent** → when small amount of modifier is added to the soil to be stabilized, it brings a lot of improvement in the performance of soil. The common modifier used in the case of highly plastic soil is lime.

④ Water proofing & water repelling agent:

→ Water proofing agents are provided to prevent loss of strength properties of soil while it comes in contact with water. Bituminous material is mostly used for water proofing.
Almost same function as water proofing agent may be performed by some water repelling agent like vinyl resins other resinous materials.

⑤ Water retaining agent:

→ Some non cohesive soil maintain sufficient stability & strength when their layers posses certain minimum amount of moisture but soil may become loose & less stable when complete dry.
Calcium chloride if added to the stabilized soil will continue to absorb moisture from atmosphere & thus retain its stability.

⑥ Heat treatment:

↳ Thermal stabilization is useful for clayey soil for reducing swelling properties.

⑦ Chemical stabilization:

↳ There are several chemicals which when added single or in combination even in trace quantities (less than 0.5% by weight of soil) may impart useful changes in certain types of soil.

Soil stabilization methods:

① Mechanical soil stabilization (Granular stabilization)
② Soil lime stabilization
③ Soil cement stabilization
④ Soil bitumen stabilization

(#) stabilization of black cotton soil :-

→ Black cotton soil are highly clayey soil, grayish to blackish in colour. It shows excessive variation in vol^{m} due to change in moisture content. The expansive characteristics of black cotton soil is found due to presence of Montmorillonite clay mineral. Therefore stabilization of black cotton soil is not so simple.

→ followings are the main problems observed in black cotton soil for stabilization;

(a) It is very difficult to pulverize since dry soil has high dry strength & wet is too sticky & unmanageable.

(b) There is excessive variation in vol^{m} & stability with variation in water content.

(c) There is max^{m} possibilities of formation of cracks due to shrinkage & swelling.

(d) It exerts high swelling pressure.

↳ To minimize the above problems, the stabilization of black cotton soil can be done either with cement or lime. The use of cement is very costly since large vol^{m} of cements are needed. So stabilization of black cotton soil is done by lime. By addition of suitable proportion of lime to the black cotton soil and allowing it to react for few day, modification in the properties takes place.

Some predominant modification are as follows :-

(i) Plasticity index decreases to about zero & the soil behaves like non-plastic soil.

(ii) The affinity with water decreases & there are less changes in volume.

(iii) shrinkage limit is increased & there is less shrinkage after compaction.

After certain modifications in the properties of black cotton soil, it is used for sub-grade, sub-base & base course. The following are the recommendation for satisfactory stabilization of black cotton soils for road construction.

(I) The soil subgrade may be treated with a small proportion of lime upto the desired depth.

(II) Sub base may be constructed with a layer of well compacted soil-lime.

(III) Base course may be prepared by using soil lime plus some additive.

(IV) Bituminous surface course, preferably a superior type should be used as a wearing course.

(#) Construction of Asphalt Concrete layers including prime coat, Tack coat & Seal coat:

→ The surface of existing pavement layer is to be cleaned to remove dust & dirt and a thin layer of bituminous binder is to be sprayed before the construction of any types of bituminous layer over this surface. This treatment with bituminous material is called Interface treatment.
Interface treatment may either be a prime coat, tack coat or seal coat.

(a) Prime coat:-

↳ Prime coat is the first application of low viscosity liquid bituminous material over an existing porous pavement surface like WBM roads.

→ The bituminous primer is sprayed uniformly using a mechanical sprayer at a rate of 7.30 to 14.60 kg per 10 m^2 area.

The function of prime coat are;

(a) Develops adhesion or bond between the base & the wearing surface.

(b) Seals the pores and capillary voids thus making it water proofing.

(c) Binds together any loose aggregates on the existing surface.

(b) Tack coat :-

→ It is a single initial application of bituminous material on existing pavement surface which is relatively impervious such as existing bituminous, cement concrete or a pervious surface like WBM which has already been treated by a prime coat. Tack coat is usually applied by spraying bituminous material of higher viscosity like the hot bitumen at the rate of 4.9 - 9.8 kg/10m^2 area depending upon the type of the surface.

→ The difference between a tack coat & a prime coat is that unlike the latter, the binder does not penetrate into the layer receiving the new application. Tack coat remains at the interface between the old surface & new application and promotes necessary bonds between two.

(c) Seal coat :

→ Seal coat may be defined as a very thin surface treatment or single coat surface dressing which is either applied as final step in the construction of certain bituminous surface or to existing surfaces, which have cracked or worn out.

It consists of aggregate or binder.

The qty. of binder & aggregate can be as follows :-

Binder : 9.8 - 12 kg/10m^2

Aggregates : 0.09 cu.m / 10m^2

The main function of seal coat are;

(1) To seal the surface against the ingress of water
(2) To develop skid resistant texture.
(3) To increase the strength & bearing capacity of the existing surfaces.

Otta seal:

=) Otta seal is the bituminous surfacing consisting of graded aggregates ranging from natural gravel to crushed rock in combination with relatively soft (low viscosity) binders, with or without sand cover seal.

Types of Otta seal;

(1) Single ottaseal with or without sand cover seal with aggregate grading "open", "medium" or "dense".

(2) Double Otta seal with or without sand cover seal with aggregate grading "open", "medium" or "dense"

Materials:

Bitumen: MC 3000 or MC 800 cut back

Aggregate: clean, strong, hard & durable with the following properties

LAA value – 40% (max)

AIV value – 30% (max)

flakiness index(FI) – 30% (max)

Plasticity index – < 5 preferable NP

Coarse sand: clean, hard and durable with following properties

plasticity index – NP

Gradation all passes from 6.7mm

Equipment requirement:

- storage tank with Bitumen heating device
- Mechanical Broom or Hand Brushes
- Air Compressor
- Bitumen Distributor
- Aggregate spreader
- Pneumatic Rollers

Construction steps:

- Preparation & intensive cleaning of existing surface by mechanical broom or hand brushes & air compressor.
- Application of the prime coat at specified rate if necessitate in design.
- Spreading of binder as per specified rate of application.
- Spreading of aggregate of specified grading as per specified rate of application.
- Rolling by two pneumatic rollers of a minimum weight of 12 tons or more at the day of construction.
- A minimum of 15 passes with a pneumatic roller is reqd over the entire surface area.
- After initial rolling, one pass with 10-12 tons static steel roller to improve the embedment of the larger aggregate.
- Daily a minimum of 15 passes with pneumatic roller shall be applied covering the entire surfaced area.
- Aggregates dislodged by traffic during the immediate post construction period shall be broom back in the wheel tracks during first 2-3 weeks, so that aggregate particles are embedded into the binder.
- Spreading of binder as per specified rate of application.
- Spreading of sand as per specified rate of application.
- Rolling with pneumatic roller & curing the surface till four weeks.
- After 8-12 weeks second coat is executed following the above mentioned construction steps.

4.1.10 Highway Maintenance, Repair and Rehabilitation

⇒ Highway maintenance is concerned with the task of preserving, repairing & restoring a system of roadways with its elements to keep the serviceable conditions of highway as normal as possible and as best as practicable.

→ The maintenance activities include identification of defects & the possible causes thereof, determination of appropriate remedial measures, implementation of these in the field & monitoring of the results.

⇒ Highway maintenance can be broadly divided into two parts viz;

- Road maintenance – Concerns with all the maintenance works on the road way (carriageway and shoulder) and on all structures within & immediately adjacent to the roadway such as side ditches, culverts, causeways, bridges etc.

- Roadside maintenance – All maintenance works on structures & surface above & below the road having direct active and/or passive influence on the road come under roadside maintenance which includes culvert protection works, retaining walls, area drain, cut slopes, fill slopes, river protection works etc.

(#) General Causes of pavement failure

↳ The general causes of pavement failure needing maintenance are;

(a) Defects in the quality of the material used.
(b) Defects in the construction method & improper quality control during construction.
(c) Inadequate surface or subsurface drainage of the road resulting in the stagnation of water in the subgrade or in any of the pavement layers.
(d) Increase in the magnitude of wheel load & the no. of load repetitions due to increase in traffic volume.
(e) settlement of foundation of embankment of fill materials.
(f) Environmental factors like heavy rainfall, soil erosion, high watertable, snowfall, frost action etc.
(g) Inadequate pavement thickness.
(h) Inadequate subgrade support & poor subgrade soil.

(#) Need for Maintenance

(1) To preserve the road asset and to deliver the designated level of service to the road users.
2) Rs. one investment in maintenance saves Rs. 3 to 6 required later for rehabilitation & reconstruction.

(#) Purpose of Maintenance

(I) Reducing deterioration & extending the service life of road.
(II) Lowering vehicle operating costs
(III) keeping the road open
(IV) Safety
(V) Environmental issues.

Depending upon the various types of failure & remedial maintenance operations highway maintenance can be classified as;

(a) Routine maintenance:

↳ These are maintenance works of localized nature required continually on any road whatever its engineering characteristics & traffic volume.

↳ These works are generally carried out by forced Labour or petti contractor.

→ It covers following activities;

1) Grass & bush cutting, grading & reshaping of unpaved surfaces.
2) cleansing of carriageways, ditches, drains, signs & signals etc.
3) Replacement of ancillary furniture & equipment that has been damaged e.g. Signing, barrier, road marking etc.
4) Repair of minor damage to carriage ways, slopes, culverts, signals & sign post barriers etc.
5) clearing & cleaning of ditches & culverts.

(b) Recurrent maintenance:

↳ These are maintenance works of localized nature and of limited extent carried out at more or less regular intervals of six to 2 years with a frequency that depends on the traffic volume. These works need to be done by the use of minor equipment.

→ ~~It covers the renewal of wearing surface, repairing the damaged portions of side drains~~

↳ It cover the activities like pot hole patching, edge repair, holes and ruts, repair of depression, local reconstruction, crack sealing, repair of road furniture etc.

(c) Periodic Maintenance:

↳ These are maintenance operations of large extent required at intervals of several years (generally at interval of 6 years in case of black top & 4 years in case of gravel road depending upon the volume of traffic)

→ It covers renewal of wearing course of pavement surface, resealing/surface dressing of the paved roads, restoration of road marking, culverts & ancillary items, repairing of metal bridge etc.

(d) Special Maintenance:

↳ Special maintenance operations may be needed for special problems, which if not identified in time, may cause pavement failure. These repairs include strengthening of pavement structure by overlay or reconstruction of pavement, widening of roads, repair of damages caused by floods, providing additional safety measures like traffic sign, traffic islands, rotaries etc.

(e) Preventive maintenance:

↳ It describes actions taken to prevent premature deterioration and/or to retard the progression of deficiencies so as to reduce the rate of deterioration & effectively increase the useful life of the pavement.

↳ It includes -

(a) Slope stabilization works
(b) Toe protection
(c) Horizontal drilling for taking water out
(d) Catch/intercepting drains
(e) Checkdams, catchpits, drainage cascades etc.

● Corrective maintenance:

↳ It is also known as remedial / curative maintenance includes maintenance actions taken to correct deficiencies which are potentially hazardous e.g; to repair defects which seriously affect a pavement's operation so as to keep the highway within a tolerable limit of serviceability.

Difference between maintenance and Rehabilitation:

● Maintenance

↳ It is the works performed to upkeep a pavement in its as-constructed conditions.

Rehabilitation

↳ It is the measures employed in improving the structural strength of the pavement.
Like overlay of greater thickness, replacement of surfacing & base course, full construction etc.

Planning of maintenance operation:

→ The factors to be considered in the planning of maintenance system are;

(1) Minimum acceptable serviceability standard for the maintenance of different categories of roads.
(2) field survey for the evaluation of maintenance requirements
(3) various factors influencing the maintenance needs such as sub-grade soil, drainage, climate, traffic etc.
(4) Estimation of rate of deterioration of the pavement under the prevailing set of condition.
(5) Type & extent of maintenance requirements
(6) Availability of funds.
(7) Maintenance cost, availability of materials, manpower & equipment etc.
(8) Need based allocation for optimum utilization of inputs & fixing maintenance priorities.

(#) Evaluation of Pavement Distress & Pavement Condition:

→ Pavement evaluation is a technique of assessing the existing condition of pavement & make decisions to what extent the pavement fulfils the intended requirements so that the maintenance & strengthening job can be planned in appropriate time.

→ It covers a thorough study of various factors such as

(1) subgrade support
(2) Pavement composition & its thickness
(3) Traffic loading
(4) Environmental condition etc.

→ There are mainly two methods of pavement evaluation;

(a) <u>structural evaluation:</u>

→ This may be carried out be plate bearing test.

→ The structural capacity of pavement may be assessed by load carried out at a specified deflection or by amount of deflection at a specified load.

→ Performance of flexible pavement is directly related with elastic deformation of pavements.

→ Bankelman beam is most commonly used equipment for the assessment of flexible pavement overlay thickness requirement.

(b) <u>Evaluation of pavement surface condition:-</u>

→ The pavement condition of flexible pavement is evaluated by unevenness, ruts, patches & cracks.

→ The pavement condition of rigid pavement is assessed by cracks developed & by faulty joints affecting the riding quality of the pavement.

→ The pavement unevenness may be measured using unevenness index, profilograph, profilometer etc.

→ Unevenness index is defined as the cumulative uneven of surface in cm/km.

→ It is measured by the equipment named Bump Integrator.

Typical flexible pavement failure;

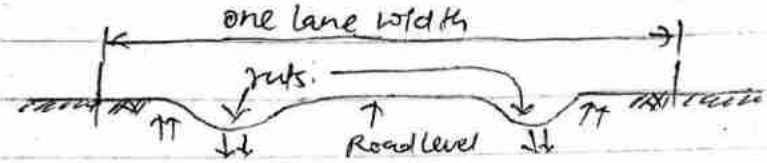
fig: alligator cracking

(1) Alligator (or map cracking)

→ Much common type of flexible pavement failure.
→ Occurs due to relative movement of pavement layers materials.
→ Localized weakness & moisture variation in the underlying base course may also cause this type of failure.

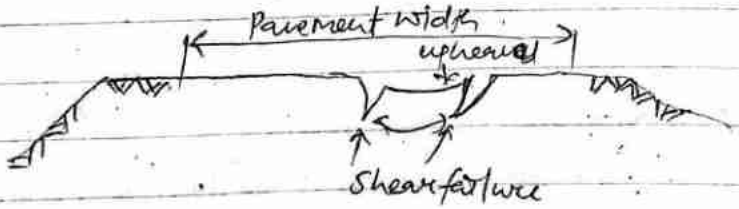
(2) Consolidation of pavement layers:

→ Repeated application of loads along the same wheel paths cause cumulative deformation resulting in consolidation deformation or longitudinal ruts.



(3) Shear failure & Cracking:

→ This is mainly due to inherent weakness of pavement mix, low shearing resistance due to inadequate stability or excessively heavy loading.

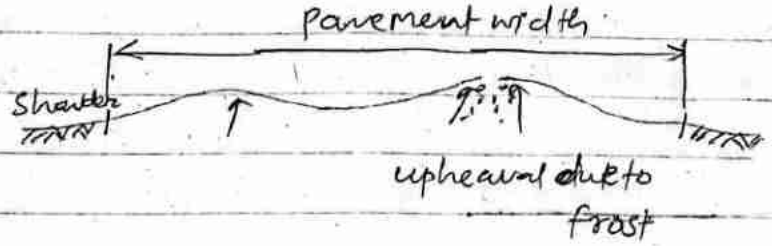


(4) Longitudinal cracking:

→ These are mainly due to frost action & differential volume change in subgrade.
→ settlement of fill & sliding of side slopes would also cause this type of failure.

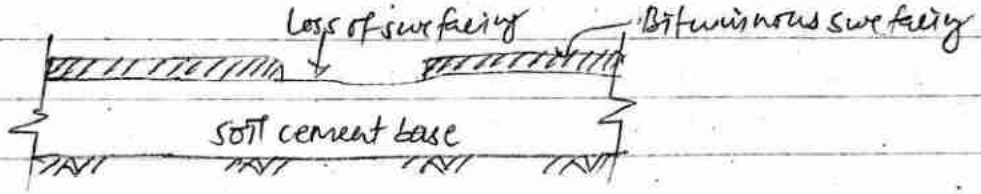
⑤ frost heaving :

→ It is due to frost melting or thaw and alternate cycles of freezing & thawing.



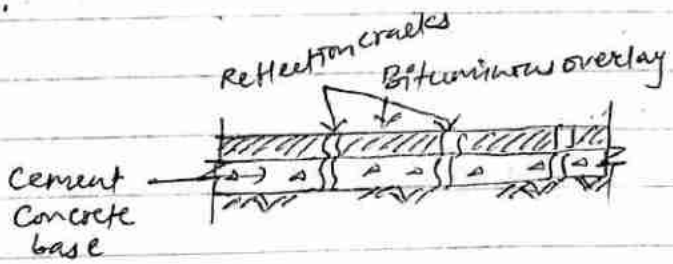
⑥ Lack of binding with lower Layers :-

→ slipping occurs when the surface course is not bound with the underlying layer. This is more pronounced when there is lack of prime / tack coat between the layers.



⑦ Reflection cracking :

→ Reflection cracking is observed in bituminous overlays provided over existing cement concrete pavements. The crack pattern as existing in cement concrete pavements are mostly reflected on bituminous surfacing in the same pattern.



⑧ formation of waves & corrugation :-

→ This maybe due to defective rolling, poor sub grade condition, poor soil or inadequate stability, poor gradation of mix etc.

→ formation of structural cracks are the main causes of failure of cement concrete pavements.
The failure may be mainly due to two factors.

① Deficiency of pavement materials
- Soft aggregate
- Poor workmanship
- Poor joint filler & sealer materials
- Poor surface finish
- Improper & insufficient curing
- Ingress of surface water through cracks makes further progressive failures.

② Structural inadequacy of pavement system
- Inadequate subgrade support & poor subgrade soil
- Incorrect spacing of joints
- Inadequate pavement thickness

The various defects that occur in due to above are;
① Cracking of slab corners
② Cracking of pavements longitudinally
③ settlements of slab
④ Widening of joints
⑤ Mud pumping etc.

Typical Rigid pavement failures:

(1) Scaling of cement concrete:

→ This is mainly due deficiency in the mix or presence of chemical impurities which damage the mix.

(2) shrinkage cracks:

→ Due to curing operation of cement concrete pavements immediately after construction, the shrinkage cracks normally develop.

(3) Spalling of joints:

→ Spalling of joints is due to faulty alignment of the filler material.

(4) Warping cracks:

→ Warping crack is found due to improper design of joints to accomodate the warping of slabs at edges in an irregular pattern.

(5) Mud pumping:

→ Soil slurry ejects out through the joints & cracks during the downward Movement of slab under heavy wheel loads.

⊕ Viability Gap funding (VGF):

→ The main constraints in Nepal's infrastructure sector like hydropower, highway etc. is the lack of source for finance. More than the overall difficulty of securing funds, some projects may not be financially viable though they are economically justified & necessary. This is the nature of several infrastructural projects which are long term & development oriented. for the successful completion of such projects, the government should design viability Gap funding (VGF).

→ Viability Gap funding (VGF) means a grant one-time or deferred, provided to support infrastructure projects that are economically justified but fall short of financial viability.

→ The scheme should be designed as a plan scheme to be administered by the ministry of finance & amount in the budget are made on a year to year for main National project.
Such a grant under VGF is provided as a capital subsidy to attract the private sector to participate in PPP projects that are otherwise financially unviable.