section : C

4.0 Transportation Engineering

4.1 Highway Engineering:

* Transportation:

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

↳ Movement of.....

- people → passanger transportation.
- goods → freight transportation.

Modes of transportation:

1. Primary modes ii. secondary mode.

1. Primary mode: 4-types:

a. landways:

i. Roadways : Roads, highways streets (Bus, car, Truck)

ii. Railways : Rail (Train, Wagon, container)

b. Water ways : lake, river, sea, ocean (Boat, ship)

c. Airways: Air-route (Aeroplane Helicopter Drone)

d. Spaceways: space-route (satellite, rocket)

ii. Secondary mode : 4-types.

a. Ropeways : cable (car, cabin, chair, gondola, lift)

b. Pipeline: Pipe (water, gas, sewer)

c. Canal: Irrigation canal (water)

d. Belt - conveyer: Belt (aggregates in crusher plant).

Advantages of road transport:

(i) It provides wide geographical coverage.
(ii) It provides door to door service.
(iii) It provides quick and assured deliveries of goods.
(iv) It provides highest employment potential.
(v) It influences the business activity.
(vi) It is flexible in using.
(vii) It is economical for short distance travel.
(viii) It is safer in comparision to other modes.

Disadvantages of road transport:

(i) It degrades the land.
(ii) It produces environment pollution.
(iii) It produces congestion.
(iv) It consumes large quantity of non-renewable sources.
(v) It produces effect on parking.
(vi) It is uneconomical for long distance travel.
(vii) Repeated number of accidents daily.

4.1.1 Highway planning and survey:

Necessities of highway planning:

i. To plan a road network for efficient and safe traffic operation.

ii. To set up priorities for road construction and maintenance.

iii. To set up requirements for road constructions and improvements in future.

iv. To know about the financing system.

Establishing economic and environment viability:

The different types of economic analysis are:

i. Payback period method
ii. Benefit cost ratio method
iii. IRR method, IRR > prevailing interest rate
iv. Net present value (NPV)
v. Present worth method (PWM)
v. 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 and fauna.
v. Biological effect.

Evaluation of alternatives:

steps:

i. setting of objectives.
ii. Developing the alternatives.
iii. ~~selecting the best~~
iv. selecting the best alternatives.
v. Formulation of real plan.

↳ After economic and environmental analysis, the project which provides maximum benefit will be selected.

↳ social analysis is also used during evaluation of alternatives.

classification of roads in Nepal: (6marks)

↳ As per NRS. 2070, road is classified into two categories:

a. Administrative classification.

b. Technical or functional classification:

a. Administrative classification:

↳ Administrative classification classifys road into four types:

1. National Highway: (राष्ट्रिय राजमार्ग)

↳ The road connecting along the length or across the width of the country is known as national highway.

↳ In Nepal there are 80s no. of highways.

↳ Highway are represented by capital letter 'H' followed by three digit number.

eg: H01 : Mahendra Highway (1027.67 km)
from Mechi bridge of Jhapa Border to Gaddhachowki Border Kanchanpur.

2. Feeder Road: (फिडर राजमार्ग)

↳ The road diparting from highway and connecting zonal headquarter, district headquarter, market centre, tourist area etc. is called feeder roads.

↳ In Nepal there are 208 nos of feeder roads.

↳ Feeder roads are represented by capital letter 'F' followed by 3-digit number.

Eg: F001 : Birtamod to Chandragadhi (12.58 km)

3. District Road:

↳ The roads within a district is known as district road.

↳ District roads are represented by capital letter 'DR'.

4. Urban Roads:

↳ The road within the metropolitian city, sub-metropolitan city, municipality, etc. is known as urban road.

↳ Urban road is also known as street.

6. Technical or Functional classification:

↳ Technical classification classifyes roads into 4-types:

1. class-I Roads: (Expressways)

↳ class-I roads are highest standard roads.

↳ Roads having ADT of 20000 PCU or more in 20 years perspective period.

↳ Design speed 120 kmph in plain terrain.

2. class-2 Roads: (Arterial roads)

↳ Roads having ADT of 5000-20000 PCU in 20 years perspective period

↳ Design speed 100 kmph in plain terrain.

3. Class-III Roads: (collector roads)

↳ Roads having ADT of 2000-5000 pcu in 20 years perspective period.

↳ Design speed 80 kmph.

4. Class-IV Roads: (local roads)

↳ Roads having ADT of less than 2000 pcu in 20 years perspective period.

↳ Design speed 60 kmph.

Relation between Administrative and 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:

↳ Degree of curve is the angle subtended by arc of 30 m length at centre.

Historical Development of Road construction in Nepal:-

1. During Rana Regime there were two office named "Batokaj Goswara" and "chhembhadel Adda" used for road construction in Nepal and other civil engineering works.

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

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

4. An army unit named "Samarjung" was established for the road maintenance work under "Purano Batokaj Goswara".

5. In 1950 AD an old office and new office was merged and an office named public work directives (PWD) was formed.

6. PWD has two units named as normal road and bridge work.

7. In 1970 AD. PWD was splitted into two departments named Department of Road and Department of Building

8. In 1958 AD, Tribhuvan Highway was constructed.
H02 (Tripureshwor to Birgunj)

9. In 1963 AD, Araniko Highway was constructed.
H03 (Kathmandu to Kodari)

10. In 1964 AD, Siddartha Highway was constructed.
H10 (Siddarthanagar to pokhara)

11. In 1974 AD, Prithvi Highway was constructed.
H04 (Naubise to prithvichowk)

12. In 1993 AD, six Regional office and 25 divisional office of DOR was created.

National Road Network of Nepal:

↳ As per the functional importance of road, road can be classified into four types:

a. Strategic Road Network.
b. District Road Network.
c. Urban Road Network.
d. Village Road Network.

Road survey and quantity calculation:

Road survey and its stages:

1. Map study
2. Reconnaissance survey
3. Preliminary survey
4. Detailed survey.

1. Map study:

↳ Also called as desk study.

↳ The different types of maps like topographical map, vegetative map, aerial photographs etc. are used during this stage of survey.

↳ Actual site is not visited in this stage.

↳ Tentative study of site is done during this stage.

2. Reconnaissance survey (Recci):

↳ In Reconnaissance survey different types of survey instruments like dumpy level, GPS, measuring tapes etc. are used.

↳ It is also known as walk over survey.

↳ Actual site is visited in this stage.

3. Preliminary survey:

↳ The different types of alignment with their tentative quantity calculation and cost estimation are done in this stage of survey.

↳ one final alignment is selected at this stage of survey.

4. Detailed survey:

↳ It is also known as final survey or location survey.

↳ In this stage of survey, the details parameter like catchment area, bearing capacity, rainfall intensity rainfall duration and frequency etc. are studied.

↳ Benchmarks are fixed in this stage of survey.

Highway alignment and controlling factor:

Alignment:

↳ Position or layout of centerline of the road on the ground is known as alignment.

Types of alignment:

oneway of expression:

a. Horizontal alignment
b. Vertical alignment

another way of expression:

a. Ridge alignment
b. valley alignment.

a. Horizontal alignment:

↳ In general horizontal alignment should be fluent and blend well with surrounding topography.

↳ A straight road alignment damages environment, destroys natural slope and disturbs plant growth.

consideration for horizontal alignment:

i. Avoid long tangent.
ii. Avoid sharp curve
iii. Proportionating of curve.
iv. co-ordination of horizontal alignments with other road alignments.
v. setting of bridge.
vi. Broken back curve should be avoided.

b. Vertical alignment:

↳ The vertical alignment should provide for a smooth longitudional profile consistent with category of the road layout & the terrain.

↳ Grade changes shouldnot be too frequent as to cause kinks and visual discontinuities.

Consideration for vertical alignment:

i. Avoid short valley curve.
ii. Avoid broken back gradeline.
iii. continuity in profile.
iv. Avoid saw-tooth of profile.

x: Basic requirements of road alignment:

↳ Basic requirements of road alignment are:

a. short.
b. Easy.
c. safe.
d. comfort.
e. Economical.
f. Useful.

a. short:

↳ Alignment should be as short as possible.

↳ If road constructed short, construction time, construction cost, vehicle operation cost, road maintenance cost etc. is reduced.

↳ probability of accidents also reduce in short road.

b. Easy:

↳ Road construction, vehicle operation and road maintenance should be easy.

c. Safe:

↳ Road construction, vehicle operation and road maintenance should be safe.

d. Comfort:

↳ Drivers should feel comfort while driving the vehicle.

↳ Passanger should feel comfort while travelling.

e. Economical:

↳ Road construction, vehicle operation and road maintenance should be economical in costs.

f. Useful:

↳ The constructed road should benefit to maximum number of users of the concerned locality.

Factors controlling highway alignment:

↳ Various factors controlling highway alignment are:

a. Obligatory point
   - Negative
   - Positive

b. Traffic

c. Geometric design parameter

d. Economy

e. Other consideration.

a. Obligatory points:

↳ Obligatory points are of two types:

i. Positive obligatory points:

↳ Points through which alignment should pass.

Eg: Hill side pass
Bridge site
Intermediate zone
Industrial estate etc.

ii. Negative obligatory points:

↳ Points through which alignment should not pass.

Eg: water logged area
Marshy land
Restricted zone
Religious sites
Border site.

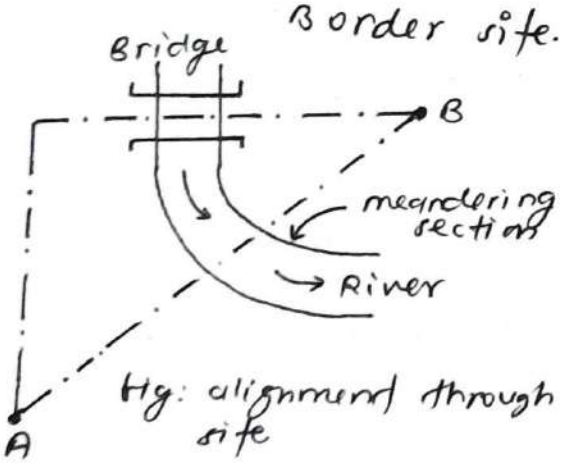


Fig: alignment through bridge site

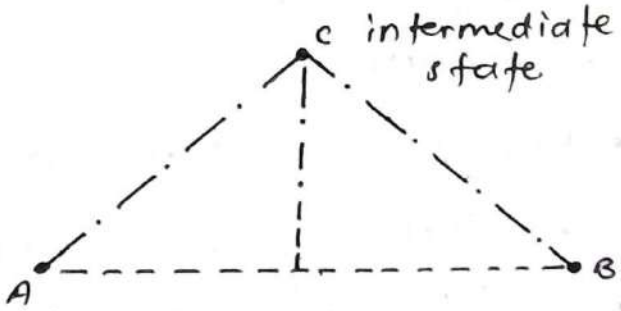


fig: alignment connecting intermediate state

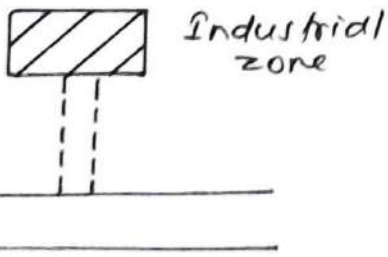


fig: Alignment connecting industrial zone.

fig: alignment avoiding lake (-ve obligatory point)

b. Traffic:

↳ Amount, volume of traffic control alignment. O and D study should be carried out.

↳ Alignment should benefit to maximum number of users.

c. Geometric design parameter:

↳ Different geometric design parameters such as camber, super-elevation, sight distance, transition curve etc. change the alignment of road.

d. Economy:

↳ alignment selected should be economical.

↳ required budget should be allocated by GoN.

e. Other consideration:

- Developmental, administrative and strategic need of the area.
- Geological location and geotechnical situation.
- Availability of construction material and labour.
- Political consideration and influence.
- Drainage and hydrological consideration.
- Environmental and social consideration.
- Topographical features of area.
- Monotony of straight roads.
- Existing right of way.

Factors controlling highway alignment on Hills roads:

or, Special considerations while aligning roads on hilly area:

a. Stability
b. Drainage
c. Geometric design standard of hill road.
d. Resisting length.

a. Stability:

↳ alignment should be stable.
↳ less prone to landslide.
↳ excerrive cutting and filling should be avoided.

b. Drainage:

↳ No. of drainage structures should be provided.
↳ Attempt should be made to make construction economical.

c. Geometric design standard of hill road:

↳ Different design standard should be considered.

eg: · hairpin bend
· gradient
· radius of curve (min^{m})
· super-elevation etc.

d. Resisting length:

↳ attempt should be made to make resisting length minimum

Asian Highway:

↳ Asian highway are also known as great asian highway. It is a co-operative project in the collaboration of Asian countries, European countries and United Nations Economic and social commission for Asia and pacific (ESCAP).

↳ 32 countries have signed the agreement to construct the roads towards Europe.

↳ countries like china, Japan, India, Pakistan, srilanka, Bangladesh etc have signed the agreement.

↳ Nepal has two Asian Highway (AH) i.e. AH2 and AH42

- AH2 : Bhadrapur to Kanchanpur (1027 km)
- AH42: Birgunj to Kodari (297 km)

↳ Total length of Asian Highway in Nepal is 1324 km.

↳ AH2 originates from Dhaka, Bangladesh and ends in New Delhi, India.

↳ AH42 originates from Barhi, India and ends in Lhasa, China.

Classification of Asian Highway:

↳ Asian highway is classified into four categories:

a. primary road
b. class-I road
c. class-II road
d. class-III road

a. Primary road:

↳ In this highway motorcycles, light weight vehicles and pedestrians are not allowed.

↳ Design speed (60-120) kmph.

↳ The road is of asphalt or cement concrete

b. class-I road:

↳ These type of road have four or more lane.

↳ Design speed (50-100) kmph.

↳ This type of road is of asphalt or cement concrete

c. class-II road:

↳ They are of 2 lane road.

↳ Design speed 80 kmph.

↳ The road is of asphalt or cement concrete.

d. class-III road:

↳ They are of 2 lane road.

↳ Design speed 60 kmph.

↳ They are laid with double bituminous surface treatment.

↳ They are of lowest standard road.

4.1.2 Geometric Design of Highway:

Introduction:

↳ Geometric design of highway deals with the dimensions and layout of visible features of highway such as alignment, sight distance and intersections.

↳ Geometric design of highway deals with following elements:

a. Cross-section Elements:

- carriageway
- shoulder
- Median strips
- Right of way
- super-elevation
- sight distance across land.
- Drainage structure
- Noise barrier.

b. Horizontal alignment details:

- straight portion.
- Transition curve.
- Horizontal curve.

c. Vertical alignment details:

- Grade.
- Vertical curve.

d. Sight distance consideration:

- stopping sight distance (SSD).
- overtaking sight distance (OSD).
- Intermediate sight distance (ISD).

e. Intersection elements:

Basic design and control criteria for highway geometric design:

1. Design speed
2. Design vehicle
3. Traffic volume and composition
4. Road user's Behaviour
5. Environmental factors.
6. Future requirements.
7. Topography.

1. Design speed:

↳ Design speed affects affects the geometric design of road.

↳ Higher design speed should have

- wider roads
- gentle radius of curve
- maintained sight distance.

↳ Design speed is taken as 98th percentile speed.

- It is the speed at which 98% of the vehicle moves below this speed. Also known as design speed.

As per 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

2. Design vehicle:

↳ As per NRS-2070, the design vehicle has,

length = 18 m

width = 2.5m

height = 4.57m.

3. Traffic volume and composition:

↳ The number of vehicles passing at a selected points in a unit of time is known as traffic volume.

↳ The type, number and nature of vehicles controls highway geometric design.

4. Road users Behaviour:

↳ Behaviours of road users affect the geometric design of highway.

5. Environmental factors:

↳ Factors like landscaping, air pollution, noise pollution, aesthetic conditions etc. affect geometric design of highway.

6. Future requirements of roads.:

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

7. Topography:

↳ The geometric design standard changes according to terrain to keep construction cost under control.

Cross-section Elements of highway:

↳ A typical cross-section of highway is shown below:

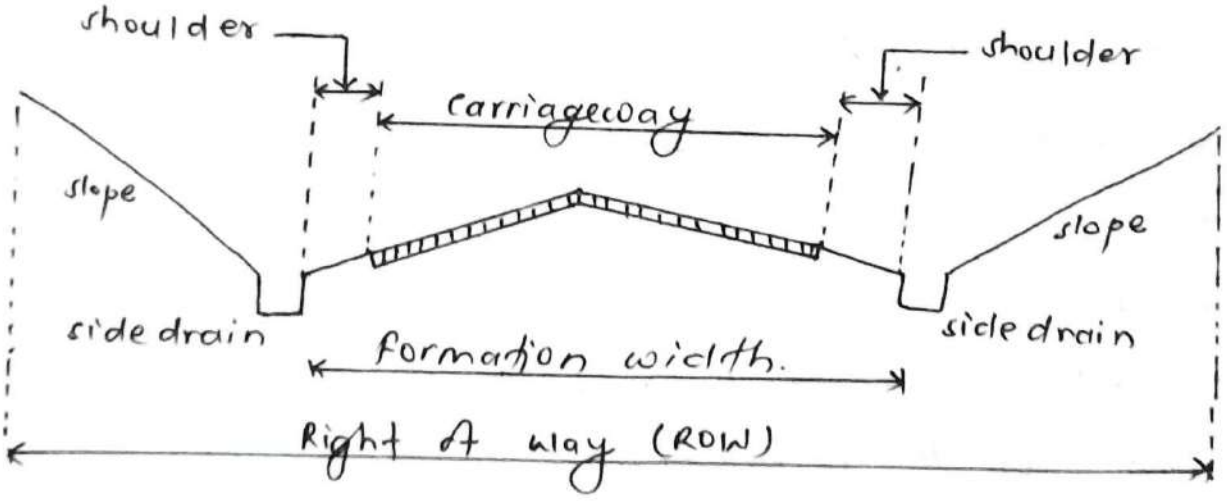


fig: typical cross-section of highway.

a. Right of way (ROW):

↳ Area reserved for future expansion is known as right of way.

↳ Right of way (ROW) is acquired before the tender stage.

As per NRS-2070:

Types of road	ROW.
Highway	50 m
Feeder roads	30 m
District roads	20m

b. Shoulder:

↳ The additional width provided on both sides of carriageway is known as shoulder.

↳ There are two types of shoulder:

i. Treated shoulder.

ii. Untreated shoulder.

Objectives of providing shoulder:

- In road having no footpath, it plays role of footpath.
- Repair and maintenance of vehicles can be done at shoulder.
- Emergency vehicles can be parked at shoulder.
- shoulder plays the factor of safety while overtaking the slow moving vehicles by fast moving vehicles.

As per NRS-2070:

Road class	class-I	class-II	class-III	class-IV
Minimum width of shoulder (both sides)	3.75m	2.5m	2.0m	1.5m. (Mcqs)

c. Carriageway:

↳ The portion of road that is used by vehicular traffic is known as carriageway.

As per NRS-2070:

- width of single lane road = 3.75 m
- multi-lane pavement width per lane = 3.5 m
- intermediate lane = 1.5 m.

d. Footpath:

↳ The portion of road that is used by pedestrian is known as footpath.

↳ Footpath is also known as footway or side walk.

As per NRS-2070:

Design hourly flow (Both ways) of 15 min. peak period survey.	Minimum footpath width (each side)
upto 500	1.5 m
500 - 1500	2 m
1500 - 2500	2.5 m
2500 - 3500	3 m.

Q. If the number 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

As per NRS-2070 codal provision for 500 - 1500 hourly volume (flow) width of footpath = 2 m

e. Camber:

↳ Convexity or cross slope provided on the cross section of a road is known as camber.

↳ Camber is also known as transverse slope or cross slope or gradient on either side of road.

↳ camber is represented by 'n' or x:y. i:e x in 100.

↳ The main function of camber is to drainoff rainfall.

↳ The highest point of camber is known as crown.

Types of camber:

i. straight line camber.

ii. Parabolic camber.

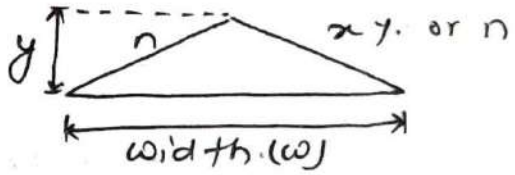
iii. Composite camber.

i. straight line camber:

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

↳ for straight line camber

$$y = nx.$$



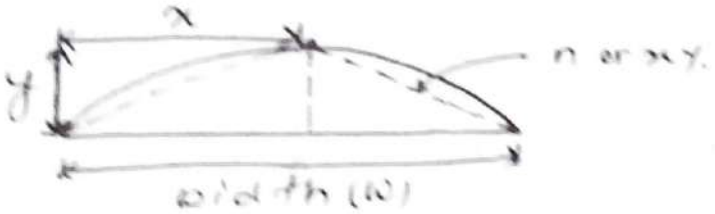
; where y = vertical height from edge to crown.

x = horizontal distance from crown toward edge

ii. Parabolic camber:

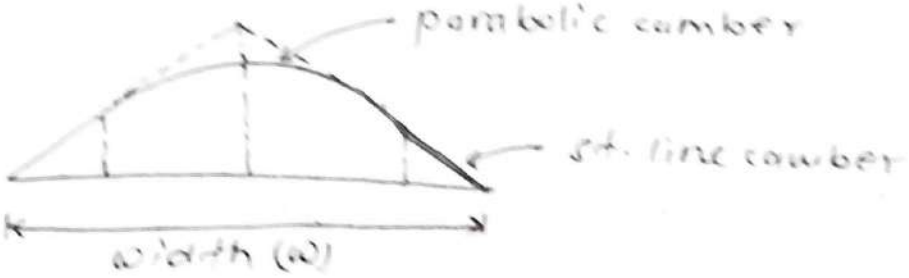
↳ Parabolic camber are adapted for very fast moving vehicles and generally with bituminous pavement.

↳ for parabolic camber $y = \frac{4n}{w} \times x^2$



iii. Composite camber:

↳ The combination of straight line camber at edge and parabolic camber at center is known as composite camber.



As per NRS-2070

Pavement	cement concrete	Bituminous road	Gravel road	Earthen road
camber %	1.5 to 2%	2.5%	4%	5%

Numerical:

Q. For a four lane bituminous road having the camber of 3% what would be the height of center w.r.to edge if provided width ....

a. straight line camber.

b. parabolic camber.

Solution:

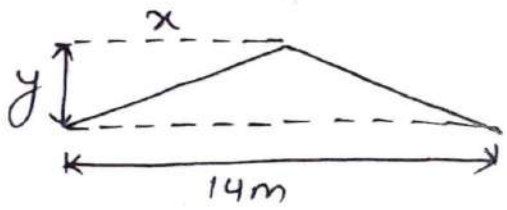
No. of lane : 4

Width of road (w) : 4 x 3.5 : 14 m.

camber (n) = 3% = 0.03

height of crown, y = ?

a. for straight line camber.



$y = nx$

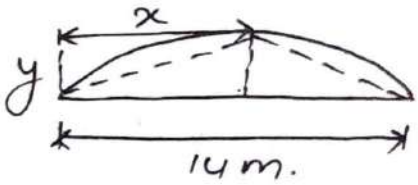
Here $x = \frac{14}{2} = 7m$

$y = 0.03 \times 7$

$y = 0.21\ m$

b. for parabolic camber.

$y = \frac{2n}{w} x^2$



Here $x = 7m$

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

$y = 0.21\ m.$

Q. If RL of a crown is 412.23 m and 2.5% slope for camber is provided, find the elevation of the edge of the pavement and elevation of the centre of lane of road for road width of 7.5m it provided with,

a. straight line camber.

b. parabolic camber.

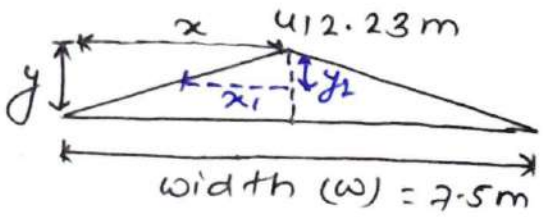
solution:

R.L of crown = 412.23 m

camber slope (n) = 2.5% = 0.025

width of road = 7.5

a. for straight line camber:



$y = nx$

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

$y = 0.094$ m.

∴ Elevation of edge of pavement = 412.23 − 0.094

= 412.130 m.

Height of crown w.r. to centerline $y_1 = nx_1$

$y_1 = 0.025 \times \left(\frac{7.5}{4}\right)$

$y_1 = 0.0467$ m

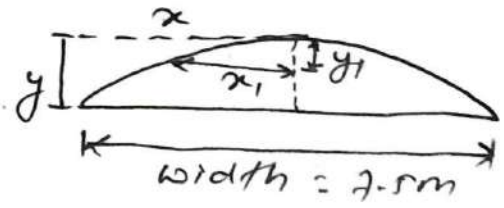
∴ Elevation of centre of lane = 412.23 − 0.047

= 412.183 m

b. For a parabolic camber:

Height of crown w.r. to edge, $y = \frac{2n}{w} \times x^2$

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



= 0.0938 m

∴ Elevation of edge of pavement = 412.23 − 0.0938

= 412.13 m

Height of crown w.r. to centre lane, $y_1 = \frac{2n}{w} x_1^2$

$$y_1 = \frac{2 \times 0.025}{7.5} \times \left(\frac{7.5}{4}\right)^2$$

$$y_1 = 0.0234 \text{ m.}$$

∴ Elevation of centre of lane = 412.23 − 0.0234

= 412.196 m

7. Super-elevation:

↳ Raising of outer edge of road w.r. to inner edge is known as super-elevation.

↳ Superelevation is also known as cant or banking.

↳ The main function of providing super-elevation is to counteract the centrifugal force.

Mathematically,

superelevation is expressed as,

$$e + f = \frac{V^2}{127R} \quad \text{or} \quad e = \frac{V^2}{127R} - f$$

; where

e = super-elevation

f = coeff. of lateral friction

V = design speed (kmph)

R = radius of curve (m).

for equilibrium superelevation, $f = 0$.

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

for mixed traffic condition, speed is designed for 75%.

$$e = \frac{(0.75V)^2}{127R}$$

$$e = \frac{V^2}{225R}$$

↳ The maximum value of super-elevation for plain, rolling, mountainous, steep terrain and snow bound areas
$= \frac{1}{15}$ or 1 in 15 or 1:15 or 0.67 or 6.7% or 7%.

↳ Maximum value of superelevation for hills road not bound by snow. (hair pin bend) = 0.10 or 10% or 1 in 10.

Numerical:

Q. The radius of the curve is 140m and the design speed of vehicle is 60 kmph. and the coefficient of lateral friction is 0.15 then calculate,

a. super elevation

b. coefficient of friction if no superelevation is provided.

c. equilibrium superelevation.

solution:

Radius of curve (R): 140m

Design speed (V): 60 kmph.

coeff. of friction (f): 0.15

a. super-elevation:

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

$$e = \frac{60^2}{127 \times 140} - 0.15$$

$$e = 0.052 < 0.07 \text{ (ok)}$$

b. coeff. of lateral friction if no super elevation is to be considered.

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

$$0 + f = \frac{60^2}{127 \times 140}$$

$$f = 0.202 > 0.15 \text{ (Not ok)}.$$

Thus provide $f = 0.15$ and change the design speed of vehicle for safe operation of vehicle. if no super elevation is to be provided.

c. Equilibrium super-elevation:

$$f = 0$$

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

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

$$e = 0.202 > 0.07 \text{ (Not ok)}$$

∴ Provide equilibrium super-elevation $e = 0.07$ and change the design speed of vehicle.

Q. 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) = 250m

Design speed (v) = 100 kmph

super elevation = ?

As national highway of Nepal is composed of mix traffic

$$e = \frac{v^2}{225R}$$

$$= \frac{100^2}{225 \times 250}$$

$$= 0.17 > 0.07 \text{ (Not ok)}$$

∴ Provide super elevation $e = 0.07$

and

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

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

$$f = 0.244 > 0.15 \text{ (Not ok)}$$

∴ Restriction in speed is needed.

Restricted permissible speed, $V = \sqrt{127R(e+f)}$

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

$V = 83.57$ kmph.

g. Kerbs / Curbs:

↳ It is the element which separate vehicular traffic and pedestrian traffic due to the physical barrier.

Types of Kerbs:

1. low or mountable kerbs
2. semi-barrier type kerbs
3. Barrier type kerbs

Functions of Kerbs:

1. To facilitate and control drainage.
2. To strengthen and protect pavement edge
3. To present more finished appearance
4. To assist in the orderly development of roadside
5. To segregate the traffic lanes.

h. Median strip:

↳ It is the raised strip within the roadway constructed to separate the traffic flowing in opposite direction

Functions of median strip:

i. To separate the opposite stream of traffic.
ii. To minimize head on collision.
iii. To minimize head light glare.
iv. To segregate traffic lane.

i. Guard rails:

↳ Guard rails are provided at edge of shoulder usually when road is on embankment.

↳ They serve to prevent the vehicle from running off the embankment.

Extra Note:

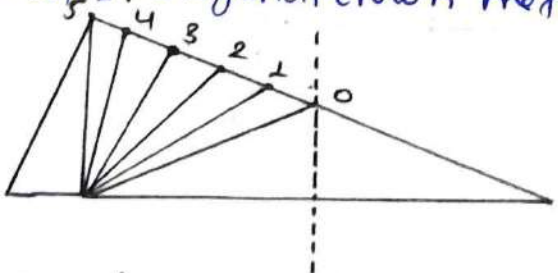
Methods of introducing super-elevation:

i. Elimination of the crown of the cambered section.
ii. Rotation of pavement to attain full super-elevation.

i. Elimination of the crown of the cambered section:

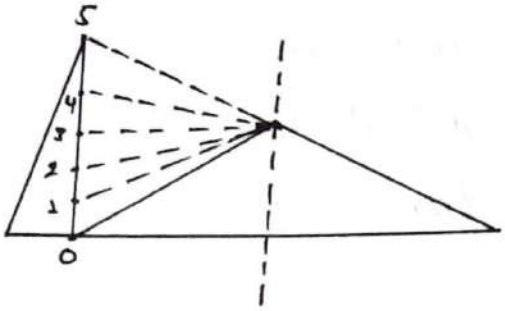
↳ This can be done by two methods:

Method-1: Diagonal crown method.



↳ Crown is progressively shifted outwards, thus increasing the width of inner half.

Method-2:



↳ 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 and elevation of the centerline is not altered.

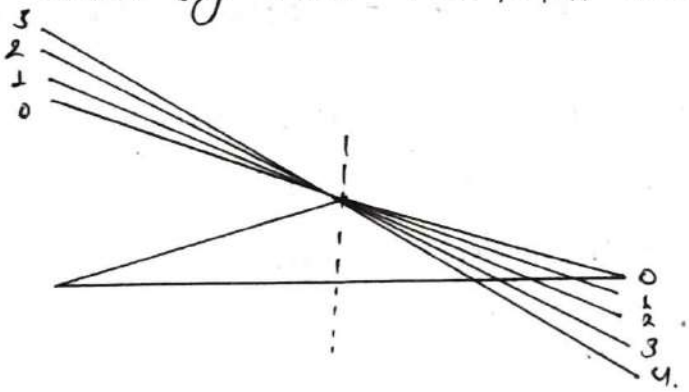
II Rotation of the pavement to attain full super-elevation:

↳ This can be done by two methods:

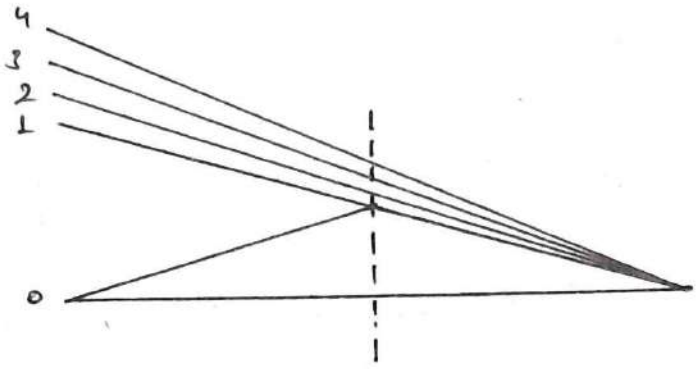
- By rotating pavement cross section about centerline:

↳ Depressing the inner edge and raising the outer edge each by half the total amount of super-elevati

i.e 4/2



- By rotating pavement cross section about inner edge:
  - ↳ Raising both the centre as well as outer edge of pavement such that the outer edge is raised by full amount of superelevation.(e).



Gradients and its types:

Gradient:

↳ Rate of rise or fall along the length of road w.r. to horizontal is called gradient.

↳ Gradient is represented by x %. or x in 100.

Factors affecting gradient:

I. Nature of traffic expected on road.

II. Physical factors associated with sites. such as.
- drainage
- appearance
- safety
- acces to adjacent property.

III. crossing (Road-Rail crossing, approach to bridge)

IV. Design speed.

V. Topography of the country.

Types of gradient:

a. Rolling gradient.
b. Limiting gradient.
c. Exceptional gradient.
d. Minimum gradient.

a. Rolling gradient:

↳ The gradient which the designer attempts to design is rolling gradient.

↳ Rolling gradient is known as design gradient or maximum gradient. (1:30 in plain)

As per NRS-2070:

Design speed (kmph)	20	30	40	60	80	100	120
Maximum gradient(%)	12%	10%	9%	7%	6%	5%	4%

b. Limiting gradient:

↳ The gradient steeper than the rolling gradient is known as limiting gradient.

↳ 1:20 in plain

↳ May be used in restricted length.

c. Exceptional gradient:

↳ The gradient in exceptional case i.e. above maximum or below minimum is called exceptional gradient.

↳ As per NRS-2070, the length of exceptional gradient should not be greater than 60 m in one kilometer road length.

↳ In case of successive exceptional gradient, there should be the provision of limiting gradient or flatter gradient of at least 100 m.

↳ 1:15 in plain.

d. Minimum gradient:

↳ The gradient provided at least to drain off rainfall is known as minimum gradient.

↳ Minimum longitudional gradient for drainage purpose is 0.5%. (NRS-2070).

NRS-2070 Recommendation for Gradient:

I. Vehicle operation cost is directly releated to longitudional gradient so it is recommended to adopt their value as small as possible.

II. Maximum gradient depends on the dynamic characteristics of commercial trucks, design speed and maximum allowable reduction in speed during climbing up the gradient.

III. Minimum grade on roads shall be 0.5% to facilitate better drainage.

IV. Good policy to design highways with gradient not exceeding 3%.

V. Gradients recommended are uppermost limiting value.

VI. Tendency should be to use lower values.

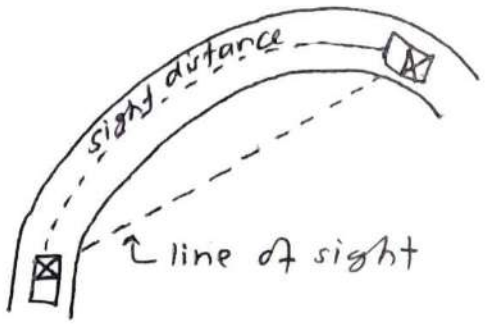
Sight Distance:

↳ The visible distance along the length of road is known as sight distance.

↳ The minimum sight available on a highway should be sufficient to stop vehicle without collision.

Types of sight distance:

i. Stopping sight Distance (SSD).
ii. Intermediate sight Distance (ISD).
iii. Overtaking sight Distance (OSD).



↳ sight distance is also the visible road ahead of driver.

1. Stopping sight Distance (SSD):

↳ The safe distance required to stop the vehicle is known as stopping sight distance.

↳ stopping sight distance is the summation of lag distance and brake distance.

$$\text{sight distance (SD)} = 0.278\, vt + \frac{v^2}{254(f \pm n)\eta}$$

; where v = design speed kmph.

t = reaction time of driver (2.5 sec)

f = coeff. of longitudional friction (0.35 to 0.40)

n = gradient +ve for ascending grade and -ve for descending gradle.

η = brake efficiency

- SSD for two way traffic in 2-lane road = S.D.
- SSD for two way traffic in single lane road = $\alpha \times$ S.D.

Factors affecting stopping sight distance: (PSC-079)

I. Speed of vehicle
II. reaction time of driver.
III. coeff. of longitudional friction.
IV. gradient along road
V. efficiency of brake.

I. Speed of the vehicle:

$SSD \propto V$

As $V \uparrow$, $SSD \uparrow$.

II. Total reaction time of driver:

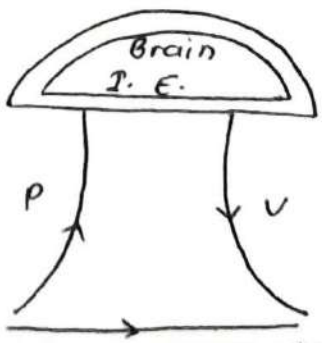
↳ Reaction time of driver is the time ~~taken~~ from the instant the object is visible to the driver to the instant brakes are effectively applied.

↳ Total reaction time depends on,

a. Perception time
b. Brake reaction time.

↳ Total reaction time of driver is best explained by: PIEV theory

- P = perception
- I = Intellectual
- E = Emotion
- V = Violation.



iii. coeff. of longitudional friction.

$SSD \propto \frac{1}{f}$

i.e. as coeff. of longitudional friction increases, SSD decreases and vice-versa.

iv. Gradient along road:

↳ for downward gradient more sight distance is required as compared to upward gradient.

v. Efficiency of brake:

↳ As efficiency decreases, SSD increases.

Numerical:

Q. Calculate the safe stopping sight distance for design speed of 80 kmph for the following:

a. two way traffic on a two lane road.

b. two way traffic on a single lane road.

Assume, $f = 0.37$ and $t = 2.5$ sec.

solution:

design speed (V) = 80 kmph.

reaction time of driver (t) = 2.5 sec

coeff. of longitudional friction (f) = 0.38

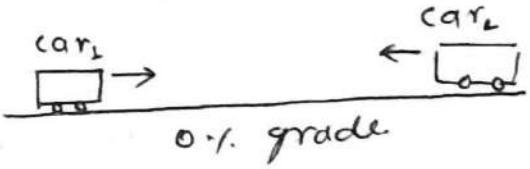
$$\text{sight distance (S.D)} = 0.278vt + \frac{v^2}{254(f \pm n)}$$

$$= 0.278 \times 50 \times 2.5 + \frac{50^2}{254(0.37 \pm 0) \times 1}$$

$$= 61.35 \text{ m.}$$

- SSD for two way traffic in two lane road = S.D. = 61.35 m.
- SSD for two way traffic in single lane road = 2 × S.D. = 2 × 61.35 = 122.7 m.

Q. Calculate the minimum stopping sight distance of two car approaching from opposite direction at the speed of 90 kmph and 50 kmph. The reaction time of the driver is 2.5 sec and the coeff. of longitudional friction is 0.40 and the brake efficiency is 50 % in either case.



solution:

speed of car_1 = 90 kmph.

speed of car_2 = 50 kmph.

reaction time of driver = 2.5 sec.

coeff. of longitudional friction = 0.40

brake efficiency (η) = 50 %.

then.

$$\text{SSD for } car_1 = 0.278Vt + \frac{V^2}{254(f \pm n)\eta}$$

$$= 0.278 \times 90 \times 2.5 + \frac{90^2}{254(0.40 \pm 0) \times 0.50}$$

$$= 222 \text{ m.}$$

SSD for car$_2$ $= 0.278 vt + \frac{v^2}{254(f \pm n)}$

$= 0.278 \times 90 \times 2.5 + \frac{90^2}{254(0.40 \pm 0) \times 0.50}$

$= 83.96$ m.

$\therefore$ Required stopping sight distance $= SSD_1 + SSD_2$

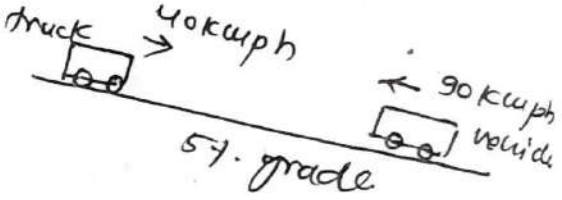
$= 222 + 83.96$

$= 305.96$ m.

$= 306$ m.

Q. Calculate the minimum sight distance required to avoid head on collision of truck speeding at 40 kmph. along certain 5% grade downward in road encounters with another vehicles comming towards it at a speed of 90 kmph. Assume coeff of friction 0.35.

solution:



speed of truck (V_t) = 40 kmph.

gradient for truck, $n = -0.05$

speed of vehicle (V_v) = 90 kmph.

gradient for vehicle, $n = +0.05$

coeff. of longitudinal friction (f) = 0.35

total reax^n time of driver (t) = 2.5 sec.

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

$= 48.79$ m.

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

$$= 142.27 \text{ m.}$$

∴ Required stopping sight distance $= SSD_{truck} + SSD_{vehicle}$

$= 48.79 + 142.27$

$= 191.07$ m Ans.

Extra:

↳ stopping sight distance is the summation of lag distance and brake distance.

- lag distance:
  - ↳ The distance travelled by vehicle during the perception time is known as lag distance.

$$\text{lag distance} = 0.278 Vt$$

where $t = 2.5$ sec (IRC recommendation)

- Brake distance:
  - ↳ The distance travelled by vehicle after the application of brake to dead stop is known as brake distance.

$$\text{Brake distance} = \frac{V^2}{254(f \pm n)\eta}$$

where, f = coeff. of long. friction (0.35 to 0.40)

SSD according to NRS-2070:

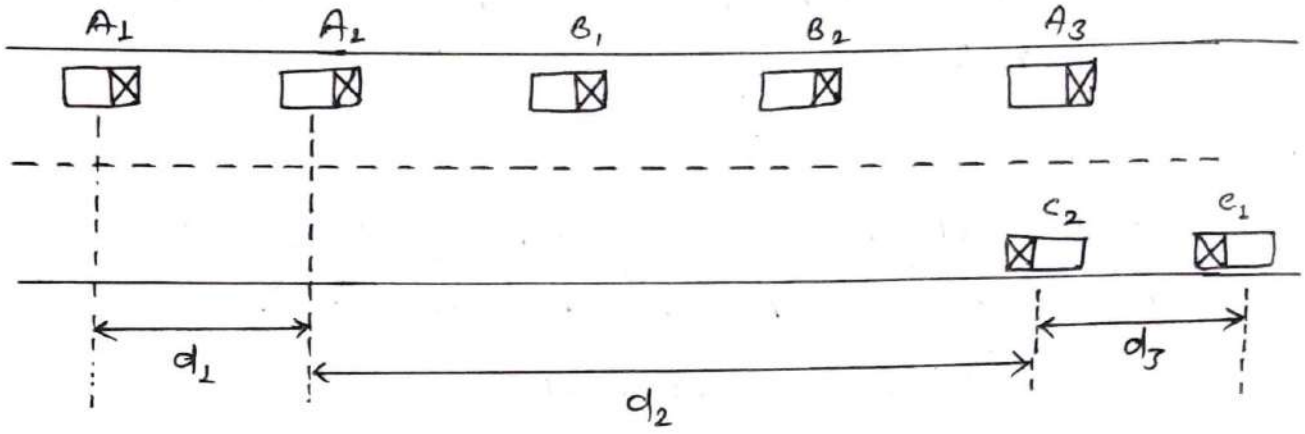
Speed (Kmph)	20	30	40	60	80	100	120
SSD (m)	20	30	50	80	130	190	260

11. Overtaking sight distance (OSD):

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

↳ On divided highway with 4 or more lane, there is no necessity to provide overtaking sight distance.

↳ The total reaction time for OSD is, t = 2 sec.



Here

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

↳ Vehicle B is overtaken vehicle and B_1, B_2 are its various positions.

↳ Vehicle C is the vehicle comming from opposite direction and C_1 and C_2 are its various positions.

Speed of overtaking vehicle = V

speed of overtaken vehicle = V_b.

If V_b is not given, then take $V_b = V - x$

where x ranges from (16-30) kmph

Reaction time of driver (t) = 2 sec.

thus,

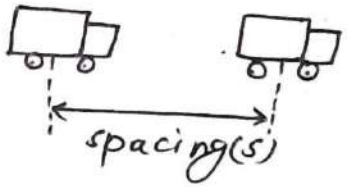
- distance (d_1) : $0.278\, V_b\, t$
- distance (d_2) : $0.278 V_b T + 2S$

where S = spacing $= 0.192 V_b + 6.1$

T = overtaking time $= \sqrt{\frac{14.4\,S}{A}}$ sec

A = acceleration of overtaking vehicle (kmph/sec).

- distance (d_3) : $0.278\, VT$



Therefore,

- OSD for two way traffic = $d_1 + d_2 + d_3$
- OSD for one way traffic = $d_1 + d_2$

Overtaking zone:

↳ Particular zone marked with wide roads for overtaking operation in the highway where it is not possible to provide overtaking sight distance throughout the length.

- Minimum length of overtaking zone = 3 x OSD.
- Desirable length of overtaking zone = 5 x OSD.

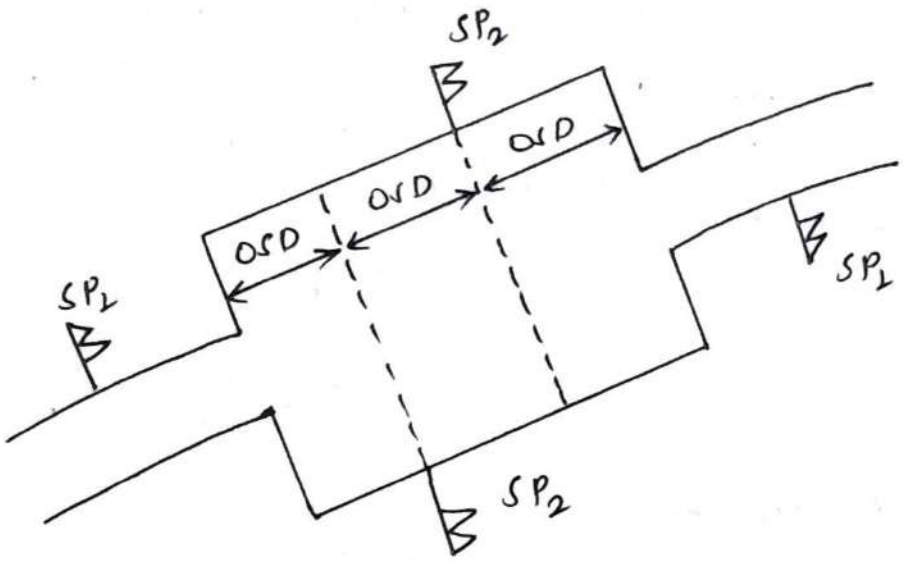


fig: overtaking zone.

SP_1 = sign post 1 (Beginning of overtaking zone)

SP_2 = sign post 2 (End of overtaking zone)

Numerical:

9. Calculate the overtaking sight distance for the vehicles where speed of overtaking vehicle is 90 kmph and speed of overtaken vehicle is 70 kmph. on a two way traffic road. The reaction time of driver is 2 sec. The acceleration of overtaking vehicle is 4 kmph/sec. Also calculate the minimum length of overtaking zone. Draw a neat sketch showing the position of sign post.

Solution:

Speed of overtaking vehicle (V) = 90 kmph.

Speed of overtaken vehicle (V_b) = 70 kmph.

Reaction time of driver (t) = 2 sec

Acceleration of overtaking vehicle (A) = 4 kmph/sec

OSD for two way traffic = ?

Minimum length of overtaking zone = ?

Desirable length of overtaking zone = ?

distance (d_1) = $0.278\, V_b\, t$

$= 0.278 \times 70 \times 2$

$= 38.92$ m

distance (d_2) = $0.278\, V_b\, T + 2S$

$S = 0.192\, V_b + 6.1$

$= 0.192 \times 70 + 6.1$

$= 19.54$ m

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

$d_2 = 0.278 V_b T + 2s$

$= 0.278 \times 70 \times 8.38 + 2 \times 19.54$

$= 202.15 m$

distance $(d_3) = 0.278 VT$

$= 0.278 \times 90 \times 8.38$

$= 209.66 m.$

Thus,

- OSD for two way traffic $= d_1 + d_2 + d_3$

  $= 38.92 + 202.15 + 209.66$

  $= 450.73 m.$

- Minimum length of overtaking zone $= 3 \times OSD$

  $= 3 \times 450.73$

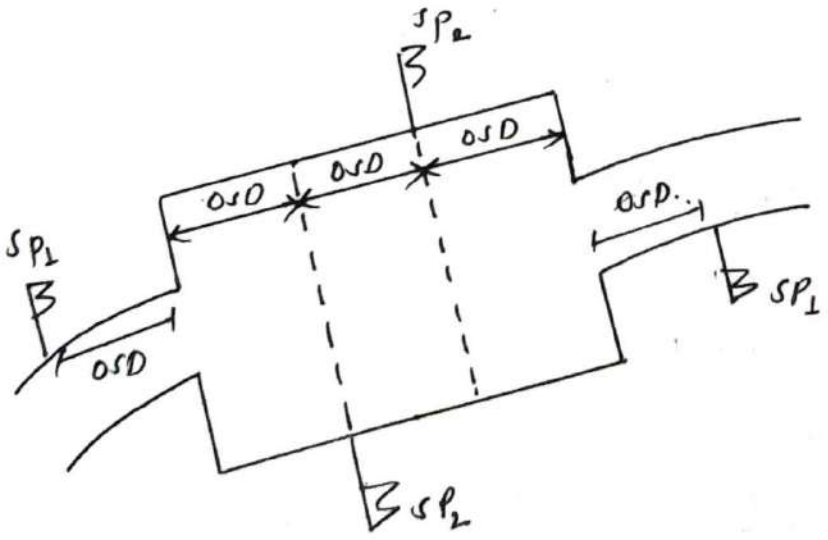
  $= 1352.19 m.$

- Desirable length of overtaking zone $= 5 \times OSD$

  $= 5 \times 450.73$

  $= 2253.65 m.$

- sketch and position of sign post:



Q. A vehicle is travelling at a speed 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.

The reaction time of driver is 2.5 sec and acceleration of overtaking vehicle is 2.5 kmph/sec.

solution:

speed of overtaking vehicle (V) = 90 kmph.

speed of overtaken vehicle (V_b) = V − 16 = 90 − 16 = 74 kmph.

Reaction time of driver (t) = 2.5 sec

Acceleration of overtaking vehicle (A) = 2.5 kmph/sec

then,

distance (d_1) = $0.278\, V_b\, t$

$= 0.278 \times 74 \times 2.5$

$= 51.43$ m.

spacing, $s = 0.192\, V_b + 6.1$

$= 0.192 \times 74 + 6.1$

$= 20.30$ m

overtaking time, $T = \sqrt{\frac{14.4\, s}{A}} = \sqrt{\frac{14.4 \times 20.30}{2.5}} = 10.81$ sec

distance (d_2) = $0.278\, V_b T + 2s$

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

$= 268$ m.

distance (d_3) = $0.278\ VT$

$= 0.278 \times 90 \times 10.81$

$= 270.46\ m.$

Thus.

- OSD for two lane road in two way traffic.

$= d_1 + d_2 + d_3$

$= 51.43 + 263 + 270.46$

$= 584.89\ m.$

- OSD for two lane road in one way traffic.

$= d_1 + d_2$

$= 51.43 + 263$

$= 314.43\ m.$

factor affecting overtaking sight distance:

I. speed of
   - overtaking vehicle
   - overtaken vehicle
   - vehicle comming from opposite direction.

II. Distance between overtaking and overtaken vehicle.

III. Acceleration of overtaken vehicle.

IV. Reaction time of driver.

V. Gradient of the road.

iii. Intermediate sight Distance:

↳ It is also known as headlight sight distance.

↳ It is defined as the twice the normal safe stopping distance.

$$ISD = 2 \times SD$$

↳ When OSD cannot be provided, intermediate sight distance is provided to give the limited overtaking opportunities for fast vehicles.

Curves:

↳ Curves are the geometric arcs provided at change in grade or alignment of the road.

Types of curves:

1. Horizontal curves:
   a. circular curve
   b. compound curve
   c. Reverse curve.
   d. Transition curve.
2. Vertical curve:
   a. summit curve.
   b. valley curve.

1. Horizontal curve:

↳ The curve provided to change the direction or alignment in horizontal plane is called horizontal curve.

↳ sharpness of horizontal curve increases as radius is decreased

Horizontal curve types:

a. **Circular curve:**

↳ An arc of some radius provided between two straight line.

↳ simple circular curve is generally used to introduce gradual change in direction, allowing vehicles to smoothly transition from one st. segment to another.

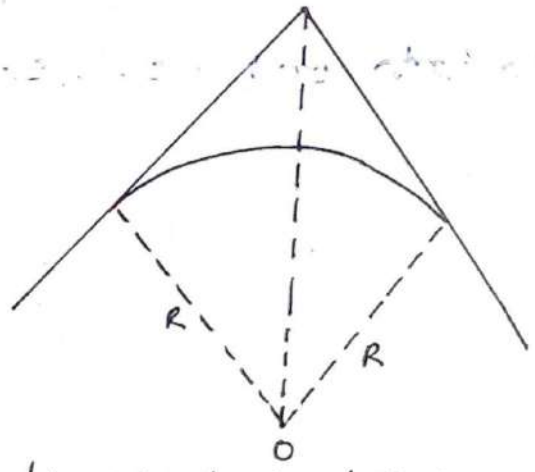


fig: simple circular curve

b. **compound curve:**

↳ Two simple circular curve of different radii combined together in same direction.

↳ It is useful in situations where space constraints or terrain require a more compact curve.

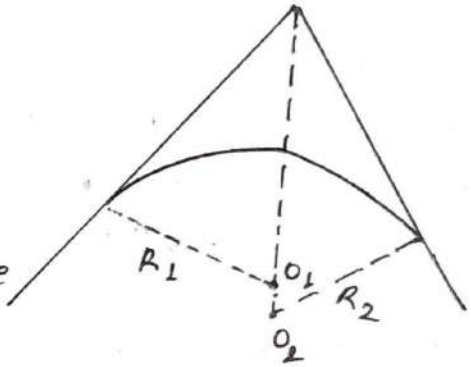


fig: compound curve

c. **Reverse curve:**

↳ Two simple circular curve combined together in opposite direction.

↳ It is useful in area with limited space or where road alignment needs to navigate around obstacles.

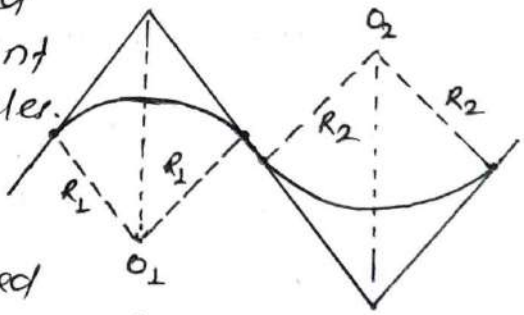


fig: Reverse curve

d. **Transition curve:**

↳ A curve of varying radius designed to provide a gradual transition between a straight road section and a curved road section.

↳ Usually used in highways, railways and other transportation system.

Types of transition curve:

i. spiral or clothoid spiral : ideal transition curve (MCQs)

ii. lemniscates

iii. cubic parabola.

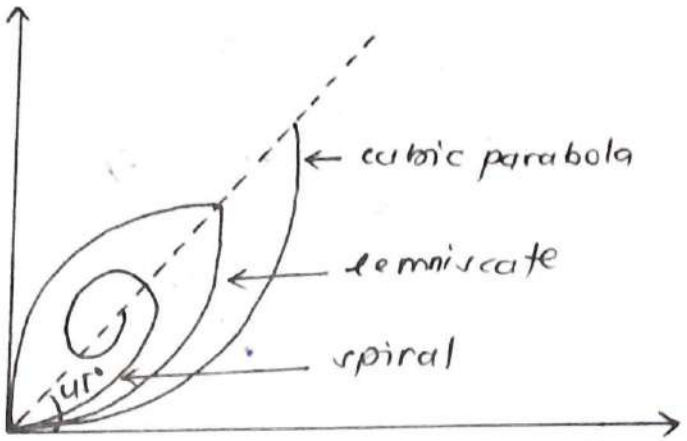


fig: transition curve.

Note:

- All these curves follow almost same path upto deflection angle of 4° and practically there is no significant difference between them upto 9°.
- In all these curves radius decreases as the length increases.

i. spiral or clothoid spiral.

↳ Ideal shape for transition curve.

↳ Rate of change of radial acceleration remains constant.

↳ Generally spiral curve is provided on hill road.

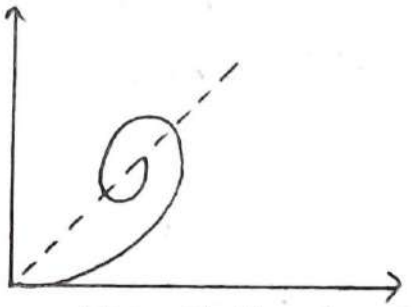


fig: clothoid spiral.

ii. lemniscates:

↳ Rate of change of radial acceleration is not constant.

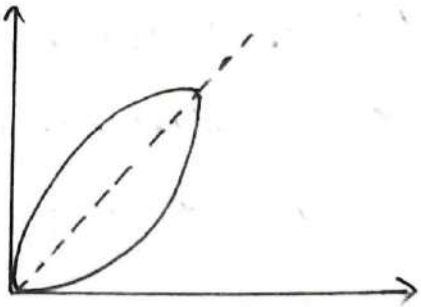


fig: lemniscate

iii. cubic parabola:

↳ Rate of change of radial acceleration is not constant.

↳ This shape curve is provided in railway.

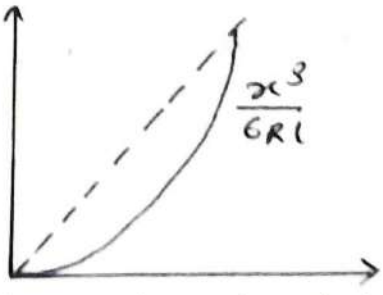
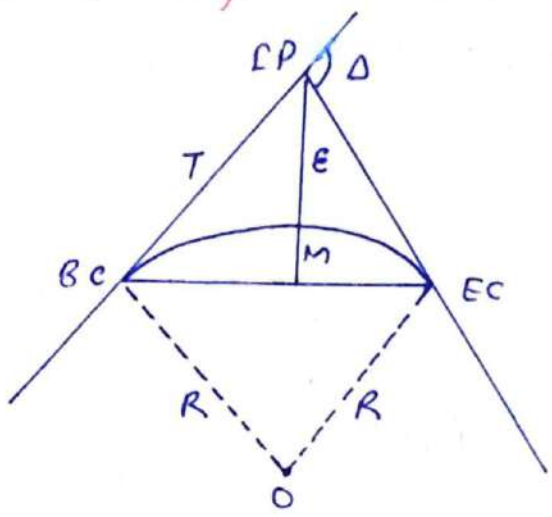


fig: cubic parabola.

Components of simple circular curve:



Here,

Δ = deflection angle

R = Radius of curve

BC = Beginning of curve

EC = End of curve

IP = Intersection point.

a. Tangent length (T) = $R \tan \Delta/2$

b. length of curve (L) = $\frac{\pi R \Delta}{180^\circ}$

c. Apex distance (E) = $R(\sec \Delta/2 - 1)$

d. Mid-ordinate (M) = $R(1 - \cos \Delta/2)$

e. length of long chord = $2R \sin \Delta/2$

f. chainage of beginning of curve = chainage of IP - tangent length.

g. chainage of end of curve = chainage of BC + length of curve

Grade compensation in horizontal curve:

↳ Reduction in gradient is known as grade compensation in horizontal curve.

- Grade compensation in % = $\frac{30+R}{R}$ %.

; where R = radius of curve.

↳ Maximum value of grade compensation = $\frac{75}{R}$ %.

↳ As per Indian Road Congress (IRC), grade compensation is not necessary for gradient flatter than 4%.

Numerical:

Q. While aligning a hill road having a gradient of 6%, a horizontal curve of radius 60 m is encountered, what will be the value of grade compensation and compensated gradient?

solution:

Rulling gradient = 6%

Radius of curve (R) = 60 m

then,

grade compensation = $\frac{30+R}{R}$ %.

= $\frac{30+60}{60}$ % = 1.5%

Maximum value of grade compensation = $\frac{75}{R}$ %.

= $\frac{75}{60}$ = 1.25%

∴ provide a grade compensation of 1.25%

and

compensated gradient = rulling gradient - grade compensation

= 6% - 1.25% = 4.75%

Design length of transition curve:

↳ Transition curve is designed based on:

i. Rate of change of centrifugal acceleration:

$$l_s = \frac{V^3}{46.5CR} \quad \text{or} \quad l_s = \frac{V^3}{47CR} \quad \text{or,} \quad l_s = \frac{0.0215V^3}{CR}$$

; where

l_s = length of transition curve

V = design speed (kmph)

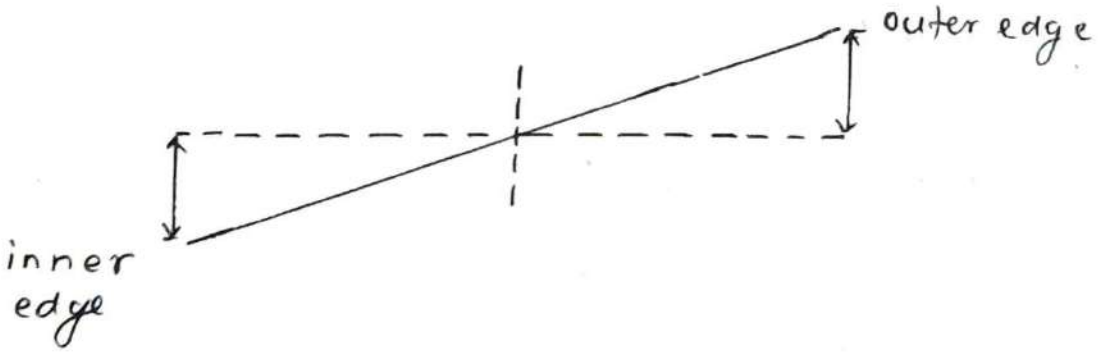
R = radius of curve (m)

c = rate of change of centrifugal acceleration m/s^3 or $m/s^2/s$.

$$c = \frac{80}{75+V}$$, the maximum value of c is 0.85 and that of minimum is 0.50.

ii. Rate of introduction of super-elevation:

a. when pavement is rotated about center-line:



length of transition curve

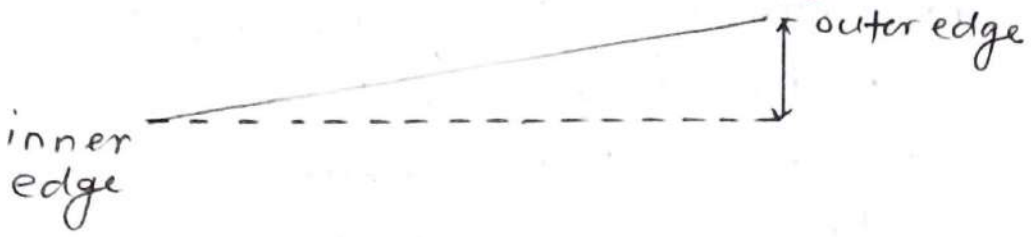
$$l_s = \frac{eN(w+w_e)}{2}$$; where e = super elevation

N = rate of introduction

w = width of road

w_e = extra widening

b. when pavement is rotated about inner edge:



$l_s = eN(w + w_e)$

where e = super elevation
N = rate of introduction of 'e'
w = width of road
w_e = extra-widening.

iii. By Empirical formula:

- For plain and rolling terrain, $l_s = \frac{2.7V^2}{R}$
- For mountainous and steep terrain, $l_s = \frac{V^2}{R}$

Hence,

- length of transition curve, l_s = maximum value of (i), (ii) and (iii).

Numerical:

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

solution.

Given,

Number of lane (n) = 2

∴ width of road = 3.5 × 2 = 7 m

Design speed (V) = 80 kmph.

Radius of curve (R) = 600m

Rate of introduction of 'e' = 1 in 80 i.e. N = 80.

Terrain type: plain terrain.

Extra-widening (W_e) = 0.5m

Transition curve is designes as,

1. By rate of introduction of 'e':

- since pavement is rotated about inner edge.

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

Here,

$$e = \frac{V^2}{225R} = \frac{80}{225 \times 600} = 0.047 \approx 0.07 \text{ (OK)}$$

$$l_s = 0.047 \times 80 \times (7 + 0.5)$$

$$= 28.4 \text{ m}$$

11. By rate of change of centrifugal acceleration:

$$l_s = \frac{V^3}{47cR} \quad ; \quad c = \frac{80}{75+V} = \frac{80}{75+80} = 0.516 \ (m/s^2/s)$$

so,

$$l_s = \frac{80^3}{47 \times 0.516 \times 600} = 35.18 \ m$$

111. By Empirical formula:

As the terrain is plain terrain,

$$l_s = \frac{2.7V^2}{R} = \frac{2.7 \times 80^2}{600} = 28.8 \ m.$$

Extra-widening (W_e):

↳ Extra widening is the additional width provided on the curved section of a carriageway

↳ Extra widening is the summation of mechanical widening and psychological widening.

$$W_e = W_{em} + W_{e,psy}$$

; where W_{em} = mechanical widening

$W_{e,psy}$ = psychological widening.

↳ Mechanical widening is provided on inner edge

↳ Psychological widening is provided on outer edge.

↳ On sharp curve, extra-widening is provided on inner edge only.

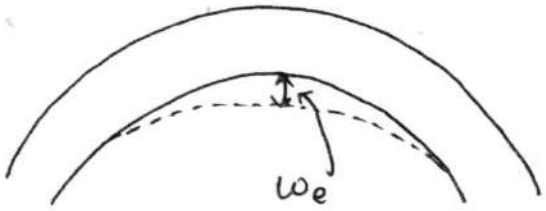
$$We = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

; where n = no. of lanes

l = length of wheel base. (6.1 m)

R = radius of curve (m)

V = design speed (kmph).



MCQs:

Q1. If the width of road is 10.5 m, then the amount of mechanical widening is...? (MSc, IOE)

a. $\frac{l}{R}$ b. $\frac{l^2}{2R}$ c. $\frac{2l^2}{R}$ d. $\frac{3l^2}{2R}$

for width = 10.5 m

no. of lanes, $n = 3$

Q2. If the width of the road is 14m, then amount of mechanical widening is.... ? (MSc, IOE)

a. $\frac{l}{R}$ b. $\frac{l^2}{2R}$ c. $\frac{2l^2}{R}$ d. none of above

for width = 14 m

no. of lane = 4

Numerical:

Q. Calculate the amount of extra-width for a two lane road having a radius of 300 m. The design speed of vehicle is 60 kmph. and the length of the wheel base of the vehicle is 6.1 m. [5 marks]

Solution:

no. of lane (n) = 2

radius of curve (R) = 300 m

design speed (V) = 60 kmph.

length of wheel base (ℓ) = 6.1 m.

we know,

$$\text{extra-widening } (W_e) = \frac{n\ell^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

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

$$= 0.488 \text{ m.}$$

II. Vertical curve:

↳ The curve provided to change the gradient or slope in vertical plane is called vertical curve.

↳ Vertical curves are provided for smooth travel along the road when two straight sections of a road meet at a point

Types of vertical curve:

1. Summit curve.
2. Valley curve.

1. Summit curve:

↳ A curve having convexity upward is called summit curve.

↳ Summit curve is provided when an ascending grade meets a descending grade.

↳ The summit curve allows a driver to maintain constant speed and provides adequate stopping sight distance at the highest point of curve.

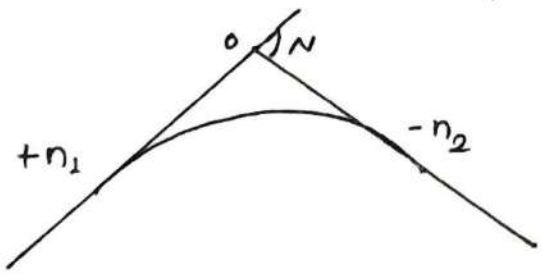


fig: summit curve.

Note:

↳ Ideal summit curve is circular.

Design length of summit curve:

↳ Generally simple parabolic curves are provided for design of summit curve.

↳ summit curve are designed based on:

i. stopping sight distance (SSD).

ii. Overtaking sight distance (OSD).

1. length of summit curve based on SSD:

case (a): when $L > SSD$.

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

; where N = deviation angle

S = SSD

H = height of eye level of driver above the pavement. (120 cm or 1.2 m)

h = height of obstace above the pavement (15 cm or 0.15 m)

Using these values of H and h.

$$L = \frac{NS^2}{(\sqrt{2\times1.2} + \sqrt{2\times0.15})^2}$$

$$L = \frac{NS^2}{4.4} \quad \therefore \quad L = \frac{NS^2}{4.4}$$

case (b): when $L < SSD$.

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

Using the value of H and h.

$$L = 2S - \frac{4.4}{N}$$

11. Length of summit curve based on OSD:

case(a): when $L > OSD$.

↳ for OSD, we put 'H' instead of 'h'.

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

$$= \frac{NS^2}{(2\sqrt{2H})^2}$$

$$= \frac{NS^2}{8H}$$

$$\therefore L = \frac{NS^2}{8H}$$

using $H = 1.2\,m$

$$L = \frac{NS^2}{9.6}$$

case(b): when $L < OSD$:

↳ for OSD we put 'H' instead of h.

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

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

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

using $H = 1.2\,m$

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

II. Valley curve:

↳ A curve having convexity downward is called. valley curve.

↳ Valley curve is provided when a descending grade meets an ascending grade.

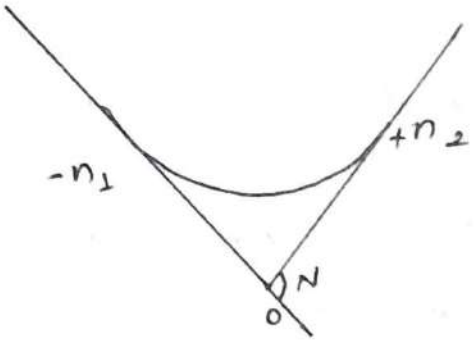


fig: valley curve.

Design length of valley curve:

↳ valley curves are designed based on:

1. Passanger comfort condition
2. Head light sight distance

1. length of valley curve based on passanger comfort condition

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

; where

L = length of valley curve

N = Deviation angle

V = design speed (kmph)

11. length of valley curve based on head light sight distance.

case (a): when $L > SSD$

$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha}$$

; where

N = deviation angle

S = SSD

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

α = inclination of rays of light (1°)

using $h_1 = 0.75m$ and $\alpha = 1°$

$$L = \frac{NS^2}{2 \times 0.75 + 2 \times S\tan 1°}$$

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

case (b): when $L < SSD$.

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

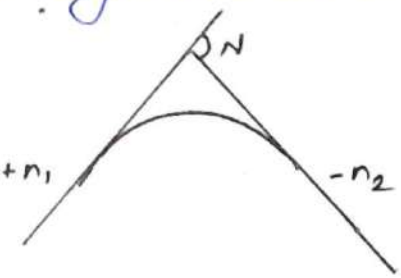
using $h_1 = 0.75m$ and $\alpha = 1°$

$$L = 2S - \frac{2 \times 0.75 + 2S\tan 1°}{N}$$

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

Numerical:

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



solution:

Here, $n_1 = +2.5\%$

$n_2 = -1.2\%$

OSD = 245 m

Height of driver's eye above pavement (H) = 1.22 m.

$N = n_1 - n_2$

$= +2.5\% - (-1.2\%)$

$= +3.7\%$

$= 0.037$

From the given grade, it forms the summit curve.

Since OSD is given, summit curve is designed based on OSD.

Case(a): When L > OSD:

$$L = \frac{NS^2}{8H}$$

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

$$= 227.5\ m > OSD = 245 \text{ (Not OK)}$$

Case(b): When L < OSD:

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

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

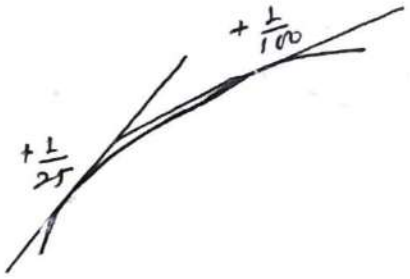
$$= 490 - \frac{8 \times 1.22}{0.037}$$

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

∴ length of summit curve formed = 226.216 m.

Q. A vertical summit curve is formed when an ascending gradient of 1 in 25 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 $(n_2) = +\frac{1}{100}$

$$N = n_1 - n_2$$

$$= +\frac{1}{25} - \left(+\frac{1}{100}\right)$$

$$= 0.03$$

Design speed (V) = 80 kmph.

then,

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

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

$$= 127.59 \text{ m}$$

case (a) when $L > SSD$.

$$L = \frac{NS^2}{4.4} = \frac{0.03 \times 127.6^2}{4.4} = 111.012\,m > SSD = 127.59\,m$$
(Not OK)

case (b): when $L < SSD$:

$$L = 2S - \frac{4.4}{N}$$

$$= 2 \times 127.6 - \frac{4.4}{0.03}$$

$$= 108.53\,m < 127.6\,m \text{ (OK)}$$

∴ length of summit curve is 108.53 m.

9. A valley curve is formed by a descending grade 1 in 25 meeting an ascending grade of 1 in 30. Design the length of valley curve if design speed is 80 kmph.

solution:

Given,

$n_1 = -1/25$

$n_2 = +1/30$

$V = 80$ kmph.

$N = n_1 - n_2$

$= -\frac{1}{25} - (+1/30)$

$= -0.073$

a. Based on passanger comfort criteria.

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

$$= 0.38 \times \{(-0.073) \times 80^3\}^{1/2}$$

$$= 73.46\,m$$

6. Based on head light sight distance:

Case(a) when $L > SSD$:

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

But

$$SSD = 0.278vt + \frac{v^2}{254f}$$

$$= 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.35}$$

($f = 0.35$ assumed)

$$= 127.59 \text{ m.}$$

$$L = \frac{0.078 \times 127.59^2}{1.5 + 0.035 \times 127.59} = 199.20 \text{ m} > SSD = 127.59 \text{ m}$$

(O/K)

∴ Provide length of valley curve as 199.20 m.

set-back distance:

↳ set back distance is the distance between the horizontal curve and the obstruction in a inside lane.

↳ set back distance is used to maintain the required sight distance.

↳ set back distance depends upon:

i. Required sight distance.
ii. Radius of curve
iii. length of curve.

Calculation of set-back distance:

case(a): When length of curve is greater than sight distance:
i.e. $L > S.D.$

(i) for single lane road:
set back distance from centreline of carriageway.

$$m = R - R\cos\alpha/2$$

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

(ii) For two or more than two lane road:

set back distance from centre of carriageway.

$$m = R - (R-d)\cos\alpha/2$$

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

d = distance between center-line of road and center line of inner-lane.

case(b): When length of curve is less than sight distance:
i.e. $L < S.D.$

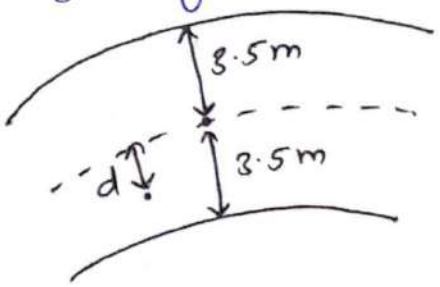
set back distance from centre of carriageway.

$$m = R-(R-d)\cos\alpha/2 + \left(\frac{S-Lc}{2}\right)\sin\alpha/2$$; where $\frac{\alpha}{2} = \frac{180\,Lc}{2\pi(R-d)}$

Numerical:

Q. The radius of circular curve is 300 m and sight distance required is 80 m. Assume length of curve greater than sight distance and the road is two lane. Calculate the set back distance from centre of carriageway.

solution:



Radius of curve (R) = 300 m

sight distance (S) = 80 m

No. of lane in road (n) = 2

Given, $L_c > S.D.$

so, set back distance from centre of carriageway:

$$m = R - (R-d)\cos\alpha/2$$

$$= 300 - (300 - 1.75)\cos\alpha/2$$

But

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

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

$$\alpha = 15.368°$$

so,

$$m = 300 - (300 - 1.75)\cos 15.368$$

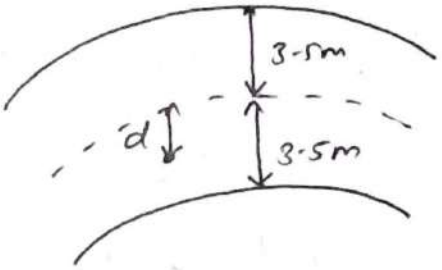
$$= 4.428 \text{ m.}$$

4. The radius of circular curve is ... and sight distance required is 400 m. The length of curve is 300m. Calculate the set back distance from,

a. centre of carriageway

b. Inner edge of carriageway.

Assume two-lane road:



Solution:

Radius of curve (R) = 650 m

length of circular curve (Lc) = 300 m

sight distance (S) = 400 m.

$$d = \frac{\text{width of one lane}}{2}$$

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

$$= 1.75 m.$$

Since $L_c < S$.

a. set-back distance from centre of carriageway.

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

Here,

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

$$\frac{\alpha}{2} = \frac{180 \times 300}{2\pi(650-1.75)}$$

$$\alpha = 13.25°$$

$$m = 650 - (650-1.75)\cos 13.25° + \left(\frac{400-300}{2}\right)\sin 13.25°$$

$$m = 30.46 m$$

b. set-back distance from inner edge of carriageway

m' = m - distance between inner edge and centre of road.

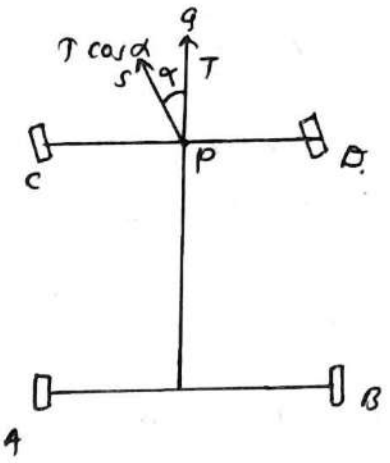
$$m' = 30.46 - \left(\frac{w}{2}\right)$$

$$m' = 30.46 - \left(\frac{7}{2}\right)$$

$$m' = 26.96 \text{ m.}$$ Ans.

Curve Resistance:

↳ When the automobile are steered by turning the front wheels, the rear wheels do not turns. When the vehicles moves on a horizontal curve, the direction of rotation of rear and front wheels are different, so there is some loss in tractive force. This loss of tractive force due to turning of a vehicle on a horizontal curve is called curve resistance.



Here.

- A and B are the rear driving wheel which will give a tractive force 'T' in the direction PQ.
- C and D are the front wheels, which gives tractive force T cos α in direction PS.

- loss of tractive force due to turning of vehicles on a horizontal curve which is termed as curve resistance will be equal to $(T - T\cos\alpha)$ or $T(1 - \cos\alpha)$.
- curve resistance depends upon the turning angle α.

4.1.3 sub-grade evaluation:

Sub-grade soil:

↳ soil is defined as the non-homogenous, porous, and unconsolidated materials which has different compositi and properties.

Functions of sub-grade soil:

i. To resist the ultimate load of pavement.
ii. To provide support to the pavement.

Desirable properties of sub-grade soil:

i. stability
ii. Incompressibility
iii. Permanency in strength.
iv. Minimum change in volume under the adverse condition of weather and water.
v. Good drainage.
vi. Ease of compaction.

common strength test for sub-grade evaluation:

i. California Bearing Ratio test (CBR test)
ii. California Resistance value test (CRV test)
iii. Triaxial compression test.
iv. Plate bearing test.

1. California Bearing Ratio test (CBR test):

↳ CBR test is a penetration test for pavement subgrade evaluation and design of flexible pavement.

↳ CBR test is carried out either in laboratory on prepared specimen or in field by taking in situ measurements.

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

II. California resistance value test (CRV test):

↳ Resistance value is found by using Hveem stabilometer.

↳ This test is used in an empirical method of flexible pavement design. based on soil strength.

III. Triaxial compression test:

↳ Most important soil strength test but not commonly used in structural design of pavements.

↳ Only few theoretical methods make use of this test.

IV. Plate bearing test:

↳ large diameter plate is used to evaluate load supporting capacity of pavement layers.

↳ plate bearing test is used for determining elastic modulus of sub-grade and other pavement layers.

↳ Also used for determination of modulus of sub-grade reaction 'k' in rigid pavement design.

↳ Different tests used for pavement subgrade evaluation and its design are:

1. CBR test.
2. Group index test.
3. plate bearing test. (Modulus of sub-grade reaction 'k')

1. California Bearing Ratio test: (CBR test):

↳ CBR test is a penetration test developed by california division of highway.

↳ CBR test is used to find the stability of soil-subgra and other flexible pavement material.

- Design of flexible pavements by CBR-method is done in two steps:

step-I. calculation of CBR-value.
step-II. calculation of thickness of pavement.

step-I: calculation of CBR-value:

$$CBR\ \% = \frac{\text{load sustained by specimen at penetration 2.5 or 5mm}}{\text{load sustained by standard specimen at corresponding penetration.}} \times 100$$

↳ The penetration value of 2.5mm is higher 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 then its value is taken.

↳ CBR test is done three times and its avg. value is taken

step-II: Calculation of thickness of pavement:

↳ Thickness of pavement by CBR-test is given by:

$$t = \left(\frac{1.75P}{CBR\%} - \frac{A}{\pi} \right)^{1/2}$$

; where t = thickness of pavement in cm.

P = wheel load (kg)

CBR % = calculated value

A = contact area (cm^2).

Note:

↳ CBR test gives overall thickness of pavement.

↳ Thickness of successive layer is calculated by subtracting corresponding thickness calculated from CBR test for each layer.

II. Group Index test:

↳ Group index is assigned to soil types having percent fines, liquid limit and plasticity index.

↳ Group index is found by equation:

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

; where

GI = group index number

a = % of soil passing through 0.075 mm sieve in excess of 35% but not exceeding 75%.

b = % of soil passing through 0.075 mm sieve in excess of 15% but not exceeding 55%.

c = liquid limit in excess of 40%.

d = plasticity index in excess of 10%.

Note:

GI should lies between 0 to 20.

↳ To design the thickness estimated traffic is calculated and assumed as light, medium and heavy.

Traffic type	No. of vehicles per day.
light	upto 50
Medium	50 to 300.
Heavy	greater than 300.

↳ From GI obtained and estimated traffic, appropriate chart is looked and the thickness of pavement is known from chart.

Limitations:

1. It only considers the physical properties of soil.
2. It doesnot show strength parameter.

III. Plate bearing test (Modulus of sub-grade reaction):

↳ plate bearing test is used in rigid pavement design by Westergaard method.

↳ It involves:

- calculation of sub-grade reaction 'k'.
- calculation of radius of relative stiffness. (ℓ).
- calculation of thickness of pavements.

• calculation of modulus of sub-grade reaction 'k'.

↳ Modulus of sub-grade reaction (k) is the reaction sustained by soil sample under rigid plate at standard diameter per unit of settlement.

↳ load sustained is directly proportional to deflection (Δ).

$$P \propto \Delta$$

$$P = k\Delta$$

$$\Rightarrow k = \frac{P}{\Delta} \text{ and permissible value of } \Delta = 0.125$$

$$\therefore k = \frac{P}{0.125}$$

where P = load sustained (kg/cm²)

$\Delta = 0.125$ cm.

• calculation of radius of relative stiffness (ℓ):

$$\ell = \left[\frac{Eh^3}{12k(1-\mu^2)} \right]^{1/4}$$

; k = modulus of sub-grade reax^n (kg/cm³)

; where ℓ = radius of relative stiffness (cm)

E = modulus of elasticity of cement concrete (kg/cm²)

μ = poisson's ratio of concrete

h = slab thickness.

- Calculation of thickness of slab (T):

a. According to older theory.

$$T = \sqrt{\frac{3W}{\sigma}}$$; where W = wheel load
σ = unit stress in tension.

b. According to sheet's formula:

$$T = \sqrt{\frac{2.4\,WC}{\sigma}}$$; where C = coefficient of sub-grade
W = wheel load
σ = unit stress in tension.

4.1.4 Hill Roads:

Hill road:

↳ Hill road is defined as the road passing through the terrain of 25% or more cross-slope.

↳ While designing hill road effort should be made to establish the shortest, most economical and safe route between ordinary points so that construction, O & M and vehicle operating costs will be minimum.

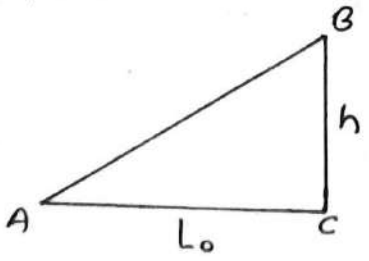
Factors affecting alignment selection of hill road:

↳ Various factors to be considered for alignment selection of hill road are:

i. Resisting length.
ii. Trace cut for hairpin bends.
iii. Geological consideration.
iv. Other consideration.

1. Resisting length:

↳ Resisting length of a road is its effective length taking into consideration the total work done against resistances.



Work done = $W \cdot f \cdot L_r$

; where L_r = resisting length = $L_o + h/f$
f = coeff. of friction
W = weight

↳ out of alternate alignments which fulfill the desir geometric standards, the one with minimum resisting length should be preferred.

ii. Trace cut for hair pin bends:

↳ Trace cut is a narrow track 0.6 to 1.0 m wide, prepare along the alignment of the hill road to enable acc for inspection during location of the route.

↳ out of several alternate alignments, one where trac cut for hair pin bend can be provided should be preferred.

iii. Geological consideration:

↳ Geological consideration should be taken into accounts such as,

- dip of strata should be as small as possible.
- bedding planes of rock should tend to dip away from cut.

iv. other considerations:

a. The alignment of the hill road should be on sound and stable area.

b. Deep cutting should be avoided as they are costly and difficult.

c. Rises and fall should be as easy as possible.

d. The road should be aligned in such a way that it faces sun for most of the time in winter. The heat of sun should easily melts the snow.

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

f. There should be provision of drainage of water from up-hill slopes.

g. For safety of traffic, there should be provision safety barrier at outer edge of curve of hill road.

h. Wider stretch of road should be provided at certain section for the provision of parking vehicles and overtaking the slow moving vehicles.

i. The radius of the bend should be enough to turn the longest vehicles expected to use on that section.

Types of hill road alignment:

↳ Generally two types of alignment are provided on hill roads.

a. River route.

b. Ridge route.

a. River route:

↳ It is located at river valley.

↳ It has numerous horizontal curves.

↳ It requires huge river training works.

↳ The road level should be located at a level higher than water level.

↳ The geological and hydrological structures should be looked after.

↳ Road alignment should cross the river at proper location

b. Ridge route:

↳ It consists of steeper slopes in comparision with river route.

↳ Rock cuttings are more in ridge route.

↳ It consists of numerous sharp curves including hairpin bends.

↳ Geological features should be known well.

Factors controlling alignment of hill road:

↳ Various factors controlling alignment of hill road are:

I. stability

II. Drainage

III. Geometric design standard
eg: hairpin bend,
gradient (limiting) etc.

IV. Resisting length.

I. stability:

↳ Hill alignment should be stable against landslides.

↳ cutting and filling should be stable.

II. Drainage:

↳ Adequate drainage facility should be provided.

↳ Attempt should be made to reduce the cross-drainage structure to minimum.

iii. Geometric design standards:

↳ Different sets of geometric design standards of hill road controls the hill road alignment selection.

eg: hairpin bends,
limiting gradient,
design speed,
horizontal curves etc.

iv. Resisting length:

↳ Resisting length of a road is its effective length taking into consideration the total work done against resistances.

↳ One with less resisting length is preferred.

Hairpin bend:

↳ A hairpin bend is a curve provided in hill road which have a large head in plan but narrow neck.

↳ A hairpin bend is a curve provided in hilly area due to abrupt elevation difference.

↳ In hill road, hair pin bend beromes necessary to attain height without substantial coverage of horizontal distance in two bends.

↳ The movement in sharp curve is brought into permissible limit by combining straight portion, reverse curve, straight portion and circular curve as shown in fig. below:

Design criteria of hairpin bend:

1. Design speed = 20 kmph.
2. Minimum radius of inner curve = 15m.
3. Minimum length of transition curve = 15m
4. Maximum super elevation = 10 %.
5. Maximum longitudional gradient = 4 %.
6. straight length between two successive hairpin bend should be at least equal to 60 m excluding the length of circular and transition curve.
7. At hairpin bend, it is preferrable to pave the road surface to the full width of roadway.
8. There should be good visibility for sight distance.
9. Approach gradient should not be steeper than 5% for 40m.

Types of hairpin bends:

i. Symmetrical hairpin bends.

ii. Unsymmetrical hairpin bends.

Derivation for length of hairpin bends:

Design consideration of hill road:

↳ Various design consideration of hill road are:

i. Rock cutting.
ii. Precipice work.
iii. Retaining wall.
iv. Revetment wall.
v. Foundation of retaining wall.
vi. Pavement types.

1. Rock cutting:

↳ Rock cutting should be carried out as per suitability and site condition.

- If rock strata slip downward into hill side, it is permitted to overhang road forming half tunn
- If rock strata is inclined towards hill side, cutting is continued until inner slope.

VI

ii. Precipice work:

↳ Where time available doesnot allow blasting and tunnel work, cliff galleries and cradles are resorted for the negotiation of cliffs and precipices.

↳ These are suitable for light vehicle only for short term use.

III. Retaining wall:

↳ Retaining wall in hill road construction provide adequate stability to raadway and to slope.

↳ constructed on valley side of roadway and cut hill side to prevent landslide towards roadway.

IV. Revetment wall:

↳ Embankment slope are normally protected with rough stone pitching about 30cm thick in order to avoid erosion due to flow of water. called revetment wall.

V. Foundation of retaining wall:

↳ should be taken upto bed rock.

↳ provided with dowel bar.

↳ provided with downward slope towards hill slope.

VI. Pavement types:

↳ Due to high rainfall intensity throughout the year, impermeable type of pavement should be provided.

↳ A flexible pavement with W.B.M base course and bituminous surfacing may be recommended for hill road.

Design parameter of hill road: (Geometric design)

1. Design speed:
   - same as NRS-2070.

2. sight distance:
   a. $SSD = 0.278Vt + \frac{V^2}{254(f \pm n)n}$ } same as plain road.
   b. $ISD = \alpha \times SD$.
   c. $OSD = 0.556V_b + 0.278V_bT + 0.278VT$

3. super-elevation (e):

$$e = \frac{V^2}{225R}$$

; where e = superelevation (mm).
V = design speed (kmph).
R = radius of curve (m).

4. camber:

Types of road	camber (%)
Earthen road	3 to 4 %
Gravel raad WBM	2.5 to 3 %
Thin bituminous surface	2 to 2.5 %
High type bituminous	1.7 to 2 %

5. Extra widening:

$$We = \frac{18n}{R} + \frac{V}{9.5\sqrt{R}}$$

; where n = number of lane.
R = radius of curve.
V = design speed. (kmph).

6. Minimum radius of horizontal curve:

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

; where f = coeff. of lateral friction.
V = design speed (kmph)
e = super-elevation.

8. Road width:

↳

9. Vertical clearance:

↳ Minimum vertical clearance = 5m.

10. lateral clearance:

↳ Minimum lateral clearance = shoulder width.

11. Gradient.

12. set back distance.

13. Transition curve.

14. Passing places

↳ 2 to 3 places on single lane. per km.

15. Hairpin bend.

Special structures of hill road:

↳ Various special structures of hill road are:

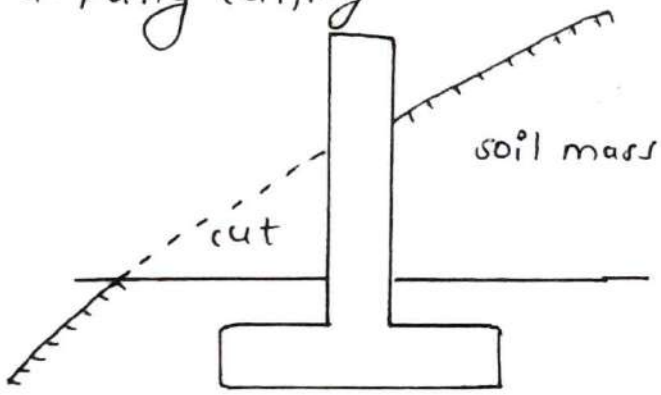
i. Retaining structure
ii. Drainage structure
iii. slope protection structure.

1. Retaining structure:

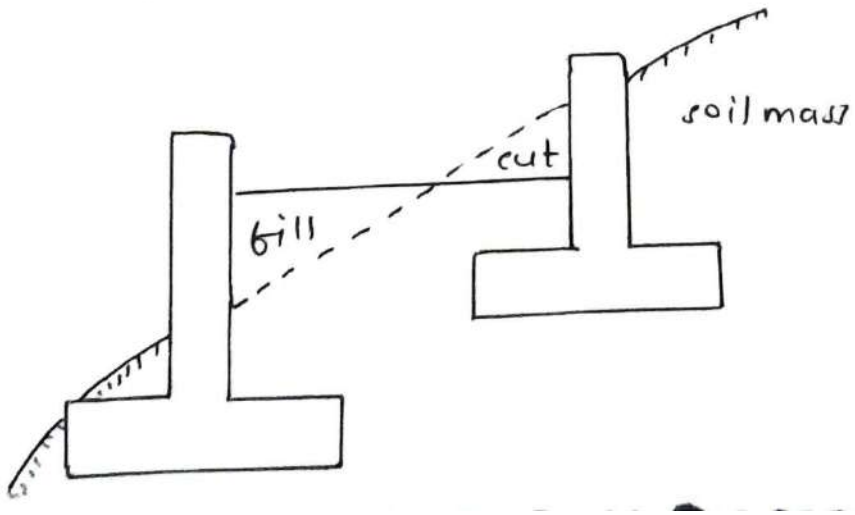
↳ Retaining wall is a wall which retains or sustains the vertical or nearly vertical soil mass.

↳ Various types of retaining structure are:

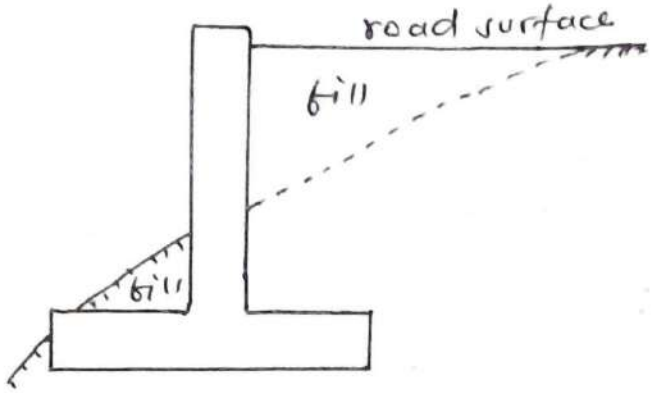
a. Fully cutting



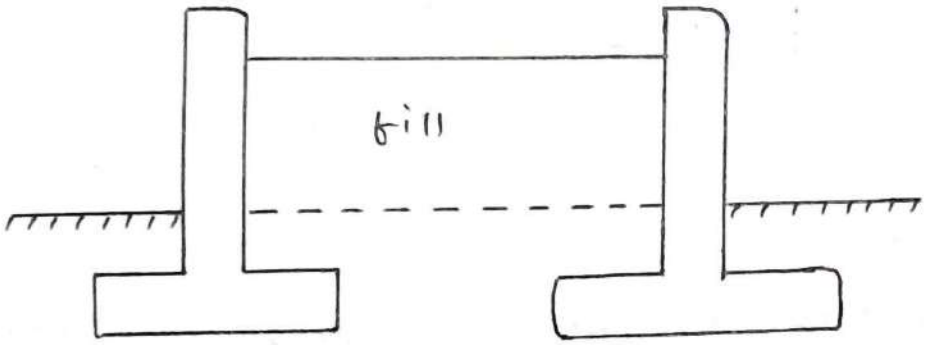
b. cutting and filling



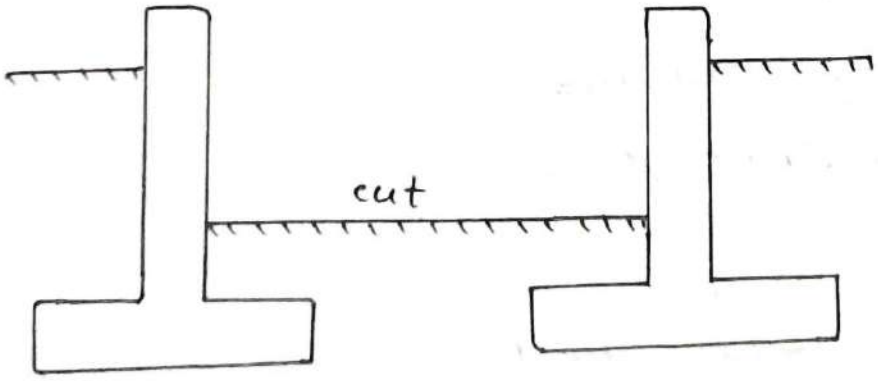
c. Fully filling



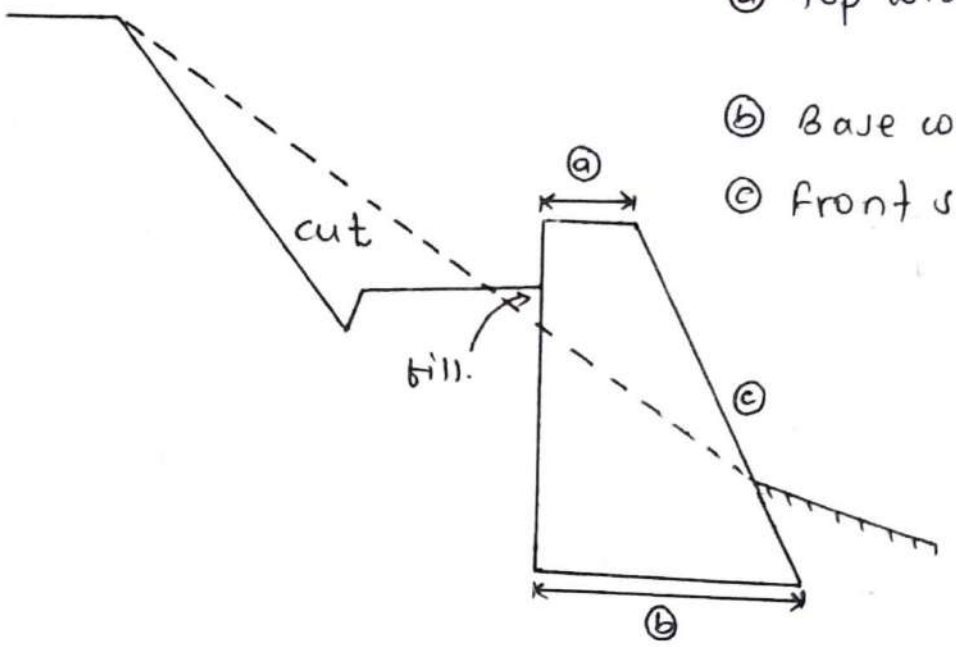
d. Fill with two retaining wall.



e. cut with two retaining wall.



Thumb rule for design of retaining wall:



@ Top width = 0.45 to 0.6m (0.5m)

ⓑ Base width = 0.5H

© Front side slope = 1:4

11. Drainage structure:

↳ various forms of drainage structure provided in hill roads are:

a. Hill side drain.

b. Road side drain.

c. cross drainage structure

d. sub-surface drainage structure

a. Hill side drain:

↳ Provided to intercept and divert water from hill slope.

↳ These structure run parallel to roadway

eg: catch drain

↳ Water from catch drain is diverted by sloping drains & carried across roads by mean of culverts.

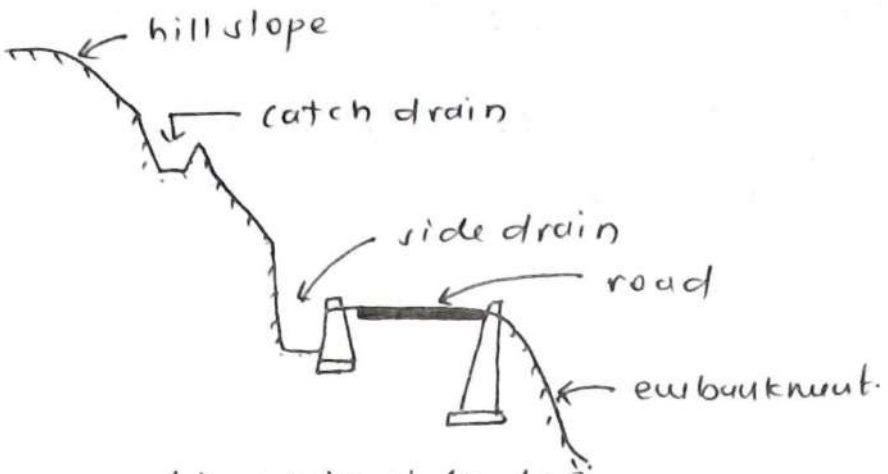
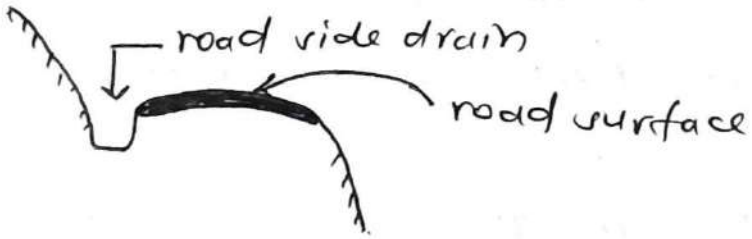


fig: Hill side drain.

b. Road side drain:

↳ Road side drain is provided parallel to road on hill side to intercept and divert water from road surface.

↳ Road side drain should be taken below the of road.



c. Cross-drainage structure:

↳ Cross-drainage structures are the structures constructed to allow rainwater cross across the roadway.

↳ Cross drainage structure are constructed under road and at right angle to it as far as possible.

↳ Different forms of cross drainage structure are:

- culverts
- causeways
- Aqueduct
- Inverted siph
- Bridge

d. Sub-surface drainage structure:

↳ sub-surface drainage structure are provided for intercepting and diverting seepage water on hill road

↳ seepage flow causes problem of stability of slopes as well as weakening of road bed.

Slope protection and Erosion control methods in hill road:

↳ In hill roads, landslides are very common due to steep slope.

↳ Various methods which can be used for slope protection and erosion control in hill roads are:

1. Vegetative covering
2. Bio-engineering
3. stone pitching, lining and protection walls.
4. Bank protection spurs and check dams.
5. Geotextiles
6. Bituminous treatments.

1. Vegetative covering:

↳ Vegetative covering controls erosion problem on hill slop

↳ Quick growing plants are selected for this purpose.

II. Bio-engineering:

↳ slope stabilization using vegetative system along with small civil-engineering structures is called bio-engineering.

III. Stone pitching; lining and protection walls:

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

IV. Bank protection spurs and checkdams:

↳ Spurs and checkdams may be provided for erosion control and slope protection in river routes.

V. Geotextiles:

↳ Geotextile is a permeable textiles used to increase soil stability, provide erosion control or aid in drainage.

↳ Used to improve soil characteristics.

VI. Bituminous treatments:

↳ It is used for erosion control in number of ways:

- Asphalt mulch treatment techniques.
- Laying and compacting asphalt mixing.

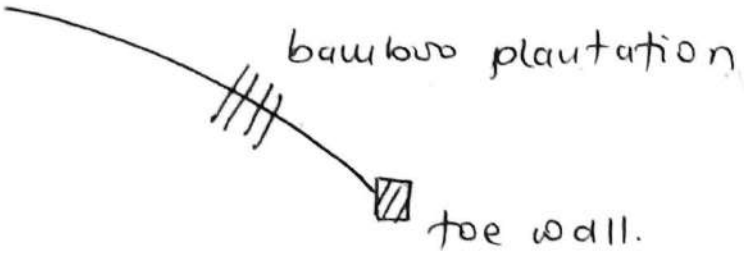
Slope-stabilization measures:

i. Turfing (vegetation)
ii. Terracing
iii. Jute netting
iv. Studding
v. Retaining structures
vi. Grouting and anchoring.
vii. Slope pitching
viii. Bio-engineering.

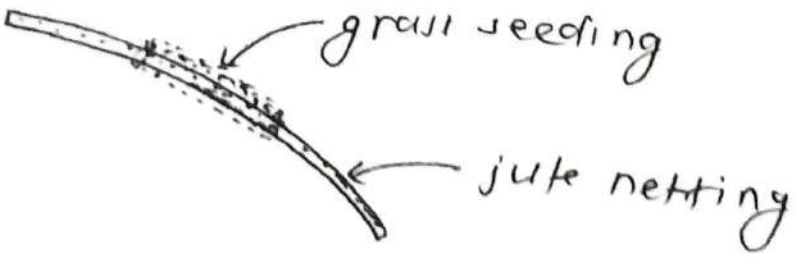
- **Bio-engineering:**

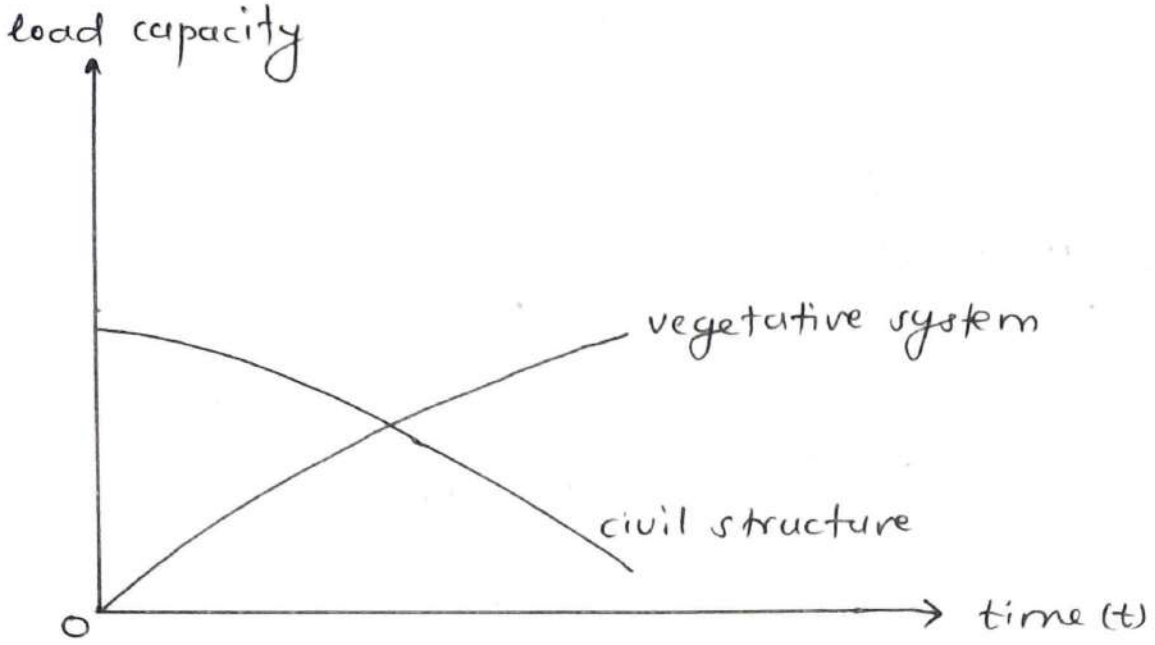
↳ slope stabilization using vegetative system along with small civil engineering structure is called bio-engineering.

Eg: ① toe wall + bamboo plantation.



② jute netting + grass seeding.



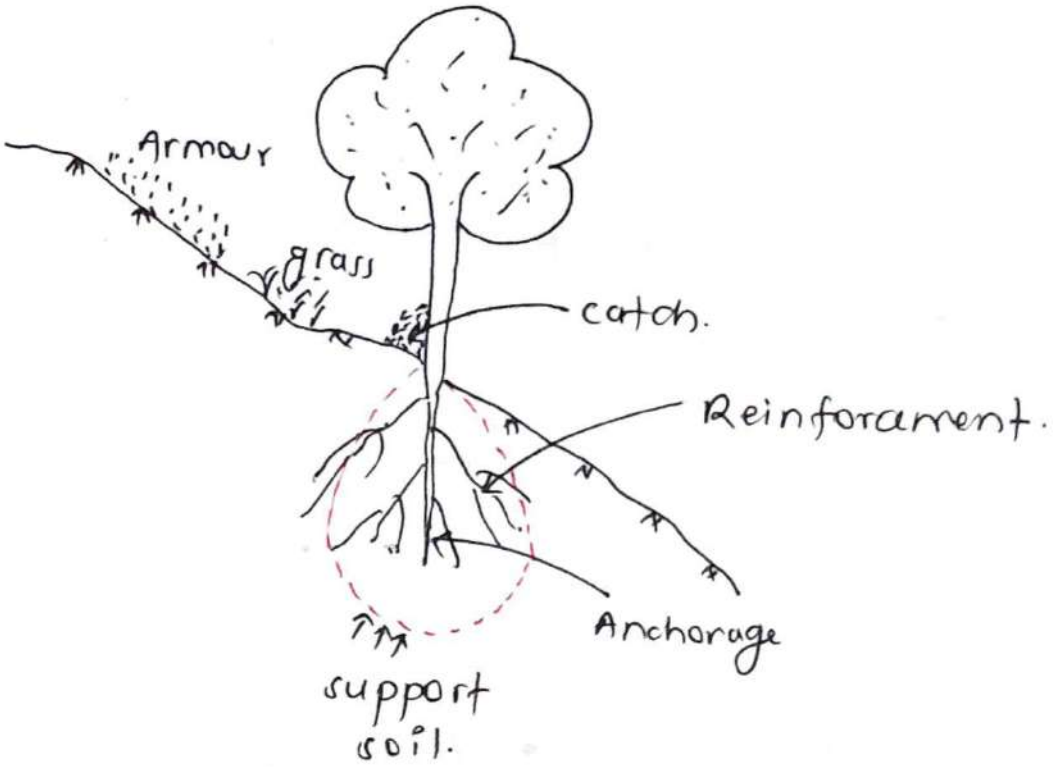


- civil engineering structure
  - toe wall.
  - brest wall.
  - detention wall.
  - bolster
  - checkdam
  - jute net
  - wire net
  - baffle fence

- Vegetative system.
  - grass plantation
  - shurbs / herbs
  - bamboo
  - tree
  - palisade
  - fascine

- Drainage structures:
  - cascade.
  - catch drain.
  - stone rip-rap.
  - French drain.

Hydrological function of vegetation:



i. Rainfall interception:

↳ vegetation prevents from soil erosion caused by spla of rain water.

ii. Retardation:

↳ speed of water reduces to $\frac{1}{4}^{th}$ and erosive action by $\frac{1}{16}^{th}$ with vegetative covering on steep slopes.

iii. Restraint:

↳ the roots physically binds the soil and prevents from soil erosion.

iv. Absorption:

↳ Roots absorb surface and underground water.

v. Evapo-transpiration:

↳ The water in the form of moisture evaporates from branches and leaves of trees.

vi. Stem-flow:

↳ A portion of water is received by trees and drops into the ground through branches and stem into lower velocity.

Advantages of bio-engineering:

i. Environment friendly.
ii. Do not require special design.
iii. No need of trained manpower (local people, local technology).
iv. Only one solution (may be ultimate solution)
v. long last solution.
vi. Economical way of stability (अर्नेची, bamboo etc. grow गर्ने भनिन्छ!)

Disadvantages of bio-engineering:

i. Do not function immediately.
ii. Not flexible in application among different people.

Typical cross-section of hill road:

↳ various configuration of hill road includes:

1. cut and fill.
2. Bench type.
3. Box cutting.
4. semi-tunnel.
5. Embankment with retaining wall.
6. semi-bridge.
7. Platform.

1. cut and fill:

↳ cut and fill is suitable for hill side slope greater than 2%.

↳ settlement of fill some-time causes appearance of cracks in pavements.

2. Bench type:

↳ Bench type is used when the road bed is stable but it includes huge earth-work.

3. Box cutting:

↳ Box cutting is preferred when the road bed is unstable but it involves huge earthwork.

4. Semi-tunnel:

↳ Semi-tunnel is preferred when there is rock face.

5. Embankment with retaining wall:

↳ Embankment with retaining wall is preferred for steeper slopes.

6. Semi- bridge:

↳ Semi-bridge is preferred in very steep slopes where retaining wall requires huge amount of earth-work.

7. Platforms:

↳ Platforms is preferred where natural ground has different level.

↳ The cantilevered portion is supported by inclined bracing.

Causes of moisture variation in sub-grade soil:

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

a. surface water (free water)

b. sub-surface water (ground water)

c. seepage flow.

a. surface water:

↳ surface water seeps into the subgrade soil through pavements and shoulders.

b. sub-surface water:

↳ Fluctuation of GWT

↳ Movement of capillary water.

↳ percolation of rain water.

c. seepage flow:

↳ seepage water from adjoining lands

control of sub-soil water:

i. Drainage of intiltered water
ii. control of seepage flow
iii. lowering of water table.
iv. control of capillary rise.

4.1.5 Highway drainage:

Highway drainage:

↳ The structures constructed for interception and removal of surface and sub-surface water is called highway drainage.

Importance of highway drainage:

1. Increase in moisture content causes decrease in strength and stability of many pavement materials like stabilized soil and WBM.
2. Variation in sub-grade clayey soil due to variation of moisture content.
3. Pavement failure by the formation of waves and corrugations in flexible pavements is due to poor drainag
4. Sustained contact of water with bituminous pavement causes failures due to stripping of bitumen from aggrega and formation of potholes.
5. Mud pumping in rigid pavement is due to presence of water in fine sub grade soil.
6. Excess moisture causes increase in weight and thus increa in stress, which leads the earth slopes and embankments foundation failure.

Requirements of highway drainage:

i. Surface should be impervious as far as possible.
ii. Side drain should be of sufficient capacity.
iii. Suitable measure of sub-surface drainage.
iv. Least amount of water from road side should be direct towards roads.
v. Highest level of GWT should be kept at least 1.2 m below sub-gr

Estimation of water quantity:

↳ Estimation of water quantity can be done by two ways:

i. Hydrological analysis.

ii. Hydraulic analysis.

i. Hydrological analysis:

↳ surface runoff is calculated as.

$$Q = \frac{C I A}{360}$$

; where Q = surface runoff (m^3/s)

C = Runoff coefficient

I = Intensity of rainfall (mm/hr)

A = catchment area. (ha)

- If the catchment area has different slopes and nature of land then average coefficient is taken.

$$C = \frac{C_1 A_1 + C_2 A_2 + \cdots + C_n A_n}{A_1 + A_2 + A_3 + \cdots + A_n}$$

Eg: $C = 0.8$ to 0.9 for bituminous & cement concrete road.

$C = 0.30$ to 0.70 for gravel and WBM road.

$C = 0.3$ to 0.55 for earthen road.

Intensity of rainfall:

- for storm duration 5 to 20 minutes.

$$I = \frac{760}{t+10}$$

; where I = intensity of rainfall (mm/hr)

t = duration of storm (minutes)

- for storm duration of 20 to 100 minutes.

$$I = \frac{1020}{t+20}$$

ii. Hydraulic analysis:

↳ surface runoff (φ) = A × V.

; where φ = surface runoff (m^3/s)
A = Area of drain (m^2)
V = velocity (m/s)

from manning's formula:

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

; where V = velocity (m/s)
n = manning's roughness coefficie
R = hydraulic mean depth.
S = bed slope.

Erosion control and Energy dissipation structure:

Factors affecting erosion are:

i. Intensity and duration of rainfall.
ii. Height and angle of slope.
iii. Type and condition of soil.
iv climatic conditions.

Erosion control measures are:

i. vegetative covering.
ii. Bio-engineering.
iii. Stone pitching, lining and protection walls.
iv. Bank protection spurs and checkdams.

v. Geotextiles.

vi. Bituminous treatments

vii. construction of drop and fall structures.

Energy dissipating structures:

↳ structures provided to dissipate energy of flowing water at high velocity.

↳ Different types of energy dissipating structures are:

a. Turfing (Turf)

b. lined canal, ditch, channel etc.

c. stone rip-rap.

d. Fall or drop structures

e. spur and checkdams

f. water cushion

g. cobbles, gravel at bed.

Types of Highway Drainage:

Highway Drainage

- Surface drainage system
  - ↳ Drainage structure provided on the ground.
  - Types:
    - a. Road side drain
    - b. cross drain
- Sub-surface drainage system.
  - ↳ Drainage structure provided below the ground.
  - Types:
    - a. Natural sub-surface drain.
    - b. Artificial sub-surface drain

Cross-drainage structure:

↳ Drainage structure provided to intercept and divert surface water across the road is called cross-drainage structure.

Different types of cross-drainage structures:

a. culvert
b. causeways
c. Aqueduct
d. Inverted siphon
e. Bridge.

a. culvert:

↳ A closed conduit placed under the embankment to cross the water across the roadway is known as culvert.

Types of culvert:

I. Pipe culvert
II. Box culvert
III. slab culvert
IV. Arch culvert

1. Pipe culvert.

↳ pipe culvert are suitable for stream having low discharge.

↳ There should be at least 50 cm of backfill so that traffic load will be transmitted with lower intensity of load.

↳ standard size of pipe culvert are 0.5m, 0.75m, 1m, 1.25m

↳ As per NRRS, minimum internal diameter of pipe culvert to be used in Nepal is 600 mm.

II. Box-culvert:

↳ culvert having box-shape is called box culvert.

↳ As per NRRS, minimum size of box culvert to be used in Nepal is 60cm x 60cm.

III. Slab culvert:

↳ In slab culvert, slab rests on abutments, made of stone masonary or RCC.

↳ Slab culverts are preferred for movement of gravel ~~with~~ debris.

IV. Arch culvert:

↳ Arch culvert are suitable where huge filling are required and traffic having higher intensity of loads.

6. causeways:

Types of causeways:

i. low level causeways.

ii. High level causeways.

1. low level causeways:

↳ A causeway provided to pass water at bed level is known as low level causeway.

↳ Maximum depth of water ≤ 15 cm for max^m time in a year.

↳ Bed slope of causeway ≤ 4%.

↳ Total period of interruption

- ≯ 10 days in district roads
- ≯ 15 days in village roads.

fig

ii. High level causeway:

↳ A causeway having vents to pass normal water and flash flood to pass both through vents and road as well is called high level causeways.

↳ Total period of interruption

- ≯ 3 days in district road
- ≯ 15 days in village road

fig

↳ Flood design period is taken as 10 years.

c. Aqueduct:

↳ An open or closed conduit provided to pass the water above the road is called aqueduct.

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

↳ Aqueduct are preferred when culvert cannot be provided.

d. Inverted siphon:

↳ A structure provided below road to pass water from one side to another is called inverted siphon.

↳ Inverted siphon are preferred when aqueduct and culvert are not feasible.

e. Bridge:

↳ A bridge is a cross drainage structure provided to pass over an obstacle.

↳ As per NRS-2070 and NBS-2067, cross drainage structure having span length less than 6m is culvert and having span length greater than 6m is bridge.

Major provision of Nepal Bridge standard - 2067:

↳ Major provision of Nepal Bridge standard - 2067 are:

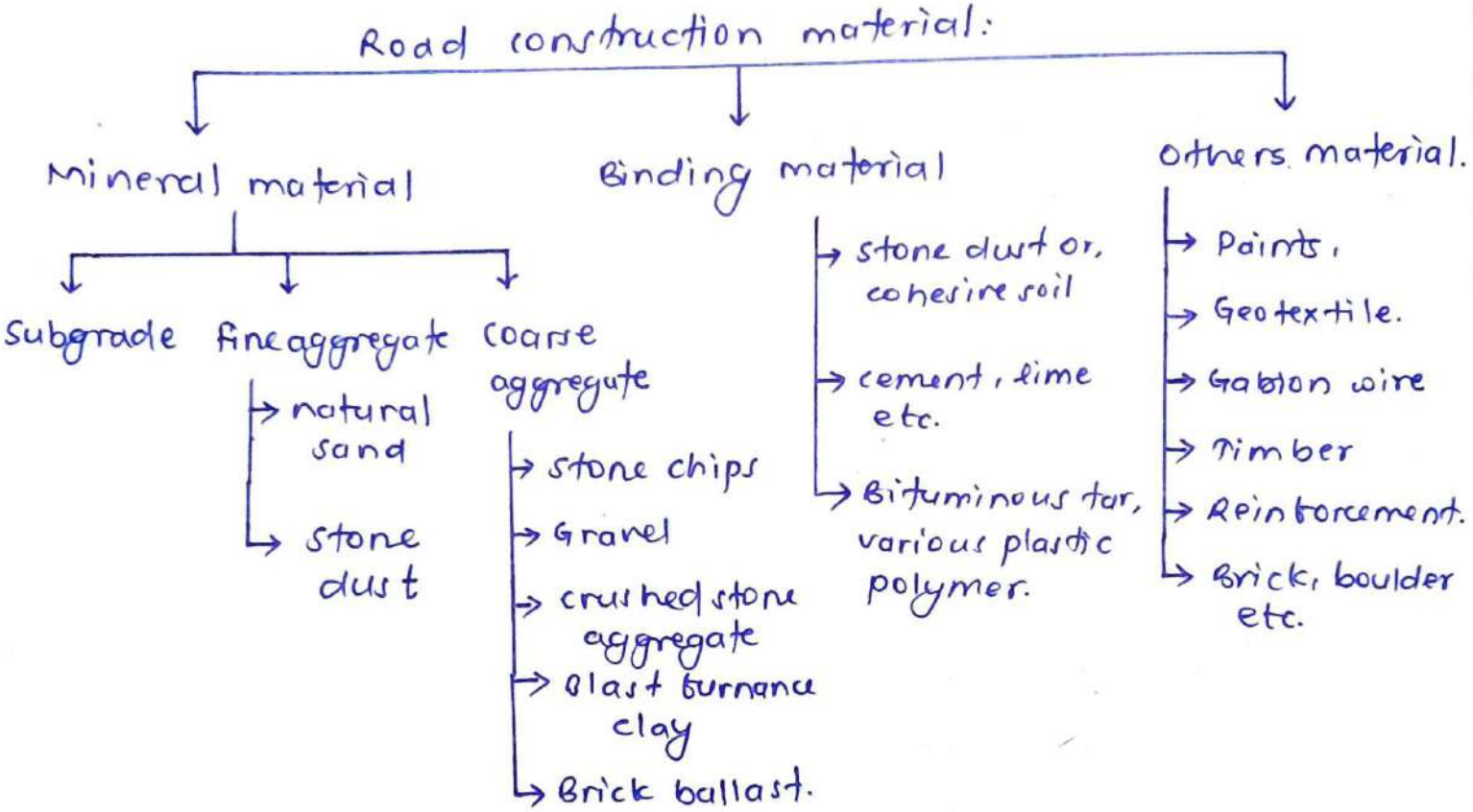
1. Design life = 50 years.
2. Future anticipated traffic = 30 years.
3. Flood return period = 100 years.
4. Min^{m} height of railing = 1m from top of footpath or te
5. Minimum height of raised kerb = 200 mm.
6. Minimum width of raised kerb = 450mm.
7. Minimum freeboard = 1m
8. All permanent bridge in Nepal shall be designed as per LRC or AASTHO loading.
9. All bridges in highways and urban roads shall be designed with minimum carriageway width of 7.5m and that of feeder road is 6m.
10.

: HIGHWAY MATERIALS:

Highway materials:

↳ The material used for the construction of highway is termed as highway materials.

↳ The nature, quality and some other properties of highway materials are different from building materials.



*: Road aggregate:

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

Classification of road aggregate:

a. Based on size:

1. Coarse aggregate: pass through 75mm sieve & entirely retain on 4.75mm sieve.

II. Fine aggregate: Pass through 4.75 mm IS sieve and entirely retain on 600μ sieve.

III. All in aggregate: Mixture of fine and coarse aggregate.

b. Based on types of rock:

I. Aggregate obtained from igneous rock.
II. Aggregate obtained from sedimentary rock.
III. Aggregate obtained from metamorphic rock.

c. Based on surface texture:

I. Glossy aggregate
II. Smooth aggregate.
III. Granular aggregate.
IV. Rough aggregate.
V. Crystalline aggregate.
VI. Honey combed aggregate.
VII. Porous aggregate.

d. Based on strength:

I. Hard aggregate.
II. Soft aggregate.

e. Based on shape:

I. Rounded aggregate (% void = 33%)
II. Irregular aggregate (% void = 35 to 37%)
III. Flaky aggregate (least dimension is less than $\frac{3}{5}$th of its mean dimension).
IV. Angular aggregate (% void = 38 to 45%)
V. Elongated aggregate (greatest dimension is greater than $\frac{9}{5}$th of its mean dimension

f. Based on surface moisture:

i. Very-very dry aggregate
ii. Dry aggregate
iii. Saturated surface dry aggregate.
iv. 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 know their properties:

a. Strength: should be sufficiently strong to withstand the stress due to traffic wheel load.

b. Hardness: should be hard enough to resist the wear due to abbrasive action of traffic.

c. Toughness: It is defined as the resistance to impact. severe hammer is quite common when heavily loaded steel tyred vehicles move on water bound macadam & adequate impact resistance aggregate to be used.

d. Durability:

↳ Durability is the resistance to weather or ability to remain strong even over long period.

↳ The stone used in pavement should be durable.

e. shape and size: It is well known that flaky and elongated aggregate have less strength and durability when compared with cubical, angular or rounded particle

f. Adherion with bitumen: The aggregate used in bituminous pavement should have more adherive property with bitumen.

g. Cementation: Aggregate must poses good cumentation property in presence of moisture, specially used in WBM road.

*: Tests of aggregates:

↳ Various tests of aggregates are:

① Abrassion test.
② crushing test.
③ Impact test.
④ soundness test.
⑤ shape test.
⑥ sp. gravity and water absorption test.
⑦ Gradation test.
⑧ Bituminous adhesion test. or stripping test.

1. Abrasion test:

Principle:

- To find out the abrassion resistance of aggregates.

Use:

- To select the aggregate type for road construction.

Apparatus and materials required:

- los angeles abrassion testing machine.
  - ↳ hollow cylinder of length = 500 mm and diameter = 700 mm.
  - ↳ CI spheres having diameter = 48mm. and weight = 390-445 gm.
- Aggregates.
  - ↳ weight of sample = 5-10 kg.

Procedure:

↳ place the sample (W_1 kg) in testing machine.

↳ Rotater the machine @ (30-33) rpm and total required revolution is (500-1000) depending upon grading.

Obervation:

Initial wt. of sample = W_1

wt. retained on 1.7mm sieve = W_2

loss of weight = $W_1 - W_2$

$$\% \text{ wear} = \frac{W_1 - W_2}{W_1} \times 100\%$$

Test is done three times and avg. value is taken.

Specification:

- for cement concrete pavement, % wear ≤ 16 %.
- for bituminous surface, % wear ≤ 30%.
- for bituminous base course, % wear ≤ 50 %.

Note:

↳ Abrassion test is of three types:

a. los angles abrassion test.
b. Dory abrassion test.
c. Deval abrassion test.

↳ Above discussed is the los angles abrassion test.

11. Crushing test:

Principle:

- To find out the compressive resistance of aggregates.

Use:

- To select the aggregate type for road construction

Apparatus and materials required:

- cylindrical mould having diameter = 11.5cm and height = 18 cm
- Tamping rod having diameter = 16cm and length = 45cm.
- Aggregates sized 10 - 12.5 mm

Procedure:

↳ heat the aggregates at 100 - 110°C for ≤ 4 hrs and allow to cool at room temperature.

↳ Place the aggregates in a cylindrical mould.

- At first $\frac{1}{3}^{rd}$ of height is filled and a gentle blow of 25 times is given by tamping rod.
- Repeat the same process for next two layers.

↳ Apply compressive load of 40 tonner @ 4 tons per minute

Observation:

Initial wt. of sample = W_1

Wt. passing through 2.36 mm sieve = W_2

crushing value = $\frac{W_2}{W_1} \times 100\%$

↳ Repeat the test three times and their average value is taken.

Specification:

- for surface course, crushing value ≤ 30%.
- for base course, crushing value ≤ 45%.

III. Impact test:

Principle:

- To evaluate the toughness of aggregates to impact loading.

Use: To select the aggregate type for road construction.

Apparatus and materials required:

- cylindrical mould having internal diameter = 10.5cm and height = 5cm.
- Metal hammer of weight = 13.5 to 14 kg having free fall height = 38 ± 0.5 cm.
- Tamping rod having diameter = 10 cm and length = 23 cm.
- Aggregate sized 10 - 12.5 cm.

Procedure:

↳ heat the aggregate at 100°c to 110°c for ≤ 4 hrs and cool at room temperature

↳ Place the aggregates in a cylindrical mould

- At first $\frac{1}{3}$rd of height is filled and a gentle blow of 25 times is given by tamping rod.
- Repeat the same process for next two layers.

↳ Apply the impact load by a hammer of 13.5 to 14 kg weight from a free fall height of 380 ± 5mm.

↳ Apply impact load for 15 number of times.

Observation:

Initial wt. of sample = W_1

Wt. passing through 2.36mm sieve = W_2

Impact value = $\frac{W_2}{W_1} \times 100$ %.

Test is done three times and their avg. value is taken.

Specification:

Impact value	Characteristics:
< 10 %.	exceptionally strong
10 - 20 %.	strong
20 - 30 %.	satisfactory
> 30 %.	poor.

iv. Soundness test:

Principle:

- To find out the weathering resistance of aggregates. i.e. alternate cycle of wet and dry condition.

Use:

- To select the type of aggregate for road construction.

Apparatus and materials required:

- Sodium sulphate and magnesium sulphate solution.
- Aggregate sample.

Procedure:

↳ certain wt. of dry aggregates of specified size is taken.

↳ Immerse the aggregate in sodium and magnesium sulphate solution for (16-18) hrs. at 20°c.

↳ After then oven dry the sample at 105 to 110°c and allow to cool at room temperature.

↳ This completes one cycle.

↳ conduct 10 complete cycle in the same way.

Observation:

Initial wt. of sample = W_1

wt. after 10 complete cycle = W_2

% loss in weight = $\frac{W_1 - W_2}{W_1} \times 100\%$

specification:

- for sodium sulphate solution, % loss in weight ≤ 12%
- for magnesium sulphate solution, % loss in weight ≤ 18%

V. Gradation test:

Principle:

- To find out the different size of aggregates in a sample.

Use:

- for gradation of aggregates using graphical method.

Materials required:

- Aggregates sample.

Procedure:

↳ Pass the aggregates through a number of sieve from top to bottom arranged according to size.

↳ calculate the weight retained of each sieve.

↳ Calculate % passing or % retained on each sieve

VI. Water absorption-test:

Principle:

- To determine water absorption value of aggregates.

Use:

- To select appropriate type of aggregate for road construction.

Materials required:

- Aggregates sample : about 2 kg
- Water

Procedure:

↳ place the aggregates sample in water for 24 hrs.

↳ dry the aggregates in oven for 24 hrs at 100°C to 500°C.

Observation:

↳ wt. of moist aggregate = W_1

↳ wt. of dry aggregate = W_2

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

Specification:

- For good stone, water absorption capacity < 5%.
- stone is rejected if water absorption capacity > 10%.

Binder (Bituminous road binder): [PSC-079 5marks]

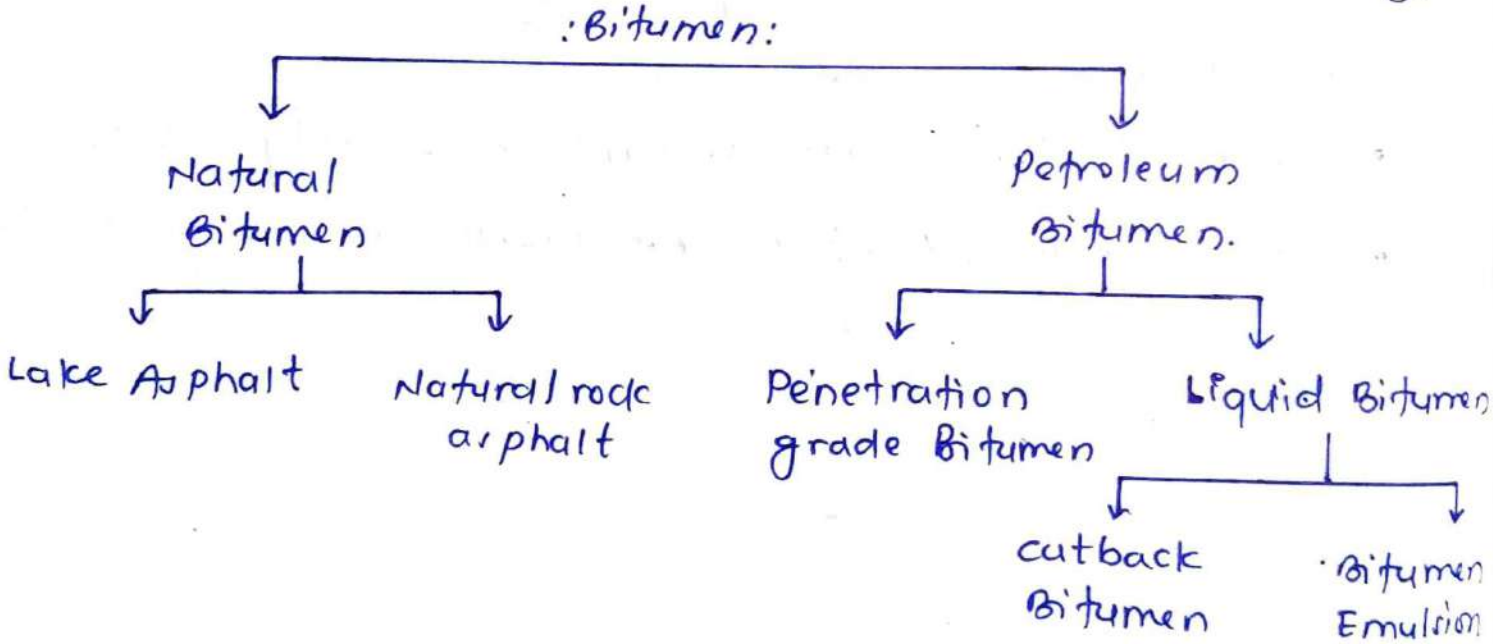
↳ Bitumen is a non-crystalline, viscous or solid materials having adhesive properties consisting essentially of hydro carbons.

↳ It is a byproduct obtained by distillation of petroleum crude.

↳ It is black or brown in colour.

↳ Bitumen is main binder used in road construction obtained from petroleum.

↳ According to source of origin, bitumen are of two types:



Natural Bitumen:

↳ Bitumen found in nature directly.

↳ doesnot require distillation process.

↳ not found in pure state, i.e. combined with impurities called asphalt.

Two types:

a. lake asphalt.

b. Natural rock asphalt.

Petroleum bitumen:

↳ obtained from fractional distillation of crude oil.

↳ quality of petroleum bitumen depends on quality of crude oil. (Also called as residual asphalt)

(mcqs - ppsc-gandaki)

Two types:

a. Penetration grade bitumen

↳ bitumen manufactured at different viscosity.

↳ penetration grade range from 15 to 450, but comm-only used range is 85 to 200.

b. Liquid bitumen:

↳ It is a by product of bitumen obtained by mixing bitumen with other liquid.

Types of liquid bitumen:

① cutback bitumen

② Bitumen emulsion.

① cut-back bitumen:

↳ solution of bitumen in a volatile or partly volatile solvents such as kerosene, creosote, naptha, etc

↳ Addition of volatile solution decreases the viscosity of bitumen.

↳ Generally used as prime coat and tack coat.

② Bitumen Emulsion:

↳ Bitumen emulsion is a mixture of water, bitumen and emulsifying agent.

↳ It is used in road as a seal coat and during road maintenance.

Types of emulsion:

(i) Rapid setting
(ii) Medium setting
(iii) slow setting.

Advantages of emulsion:

(i) Do not require petroleum solvent to make it liquid.
(ii) can be used without heating in most cases.
(iii) It contributes to energy conservation.
(iv) It can be used in wet condition.
(v) More environ friendly than cut-back bitumen.

Desirable properties of Bitumen:

a. should have adequate viscosity.
b. should not be highly susceptible to temperature.
c. bitumen should not strip off from road aggregate in presence of water.
d. adequate affinity and adherion between bitumen and aggreg

*: Application of bitumen:

(i) surface treatment
(ii) Recycling
(iii) Road construction
(iv) soil stabilization
(v) Patch repair work on bituminous road.
(vi) As a prime or tack coat
(vii) Embankment protection.
(viii) Reservoir linning
(ix) Water proofing etc.

*: Test of bitumen: [Psc-079] [5 marks]

① Penetration test
② Ductility test.
③ Viscosity test
④ Float test
⑤ softening point test
⑥ Flash and fire point test
⑦ sp. gravity test
⑧ solubility test.
⑨ spot test
⑩ loss on heating test.
⑪ water content test

1. Penetration test:

Principle:

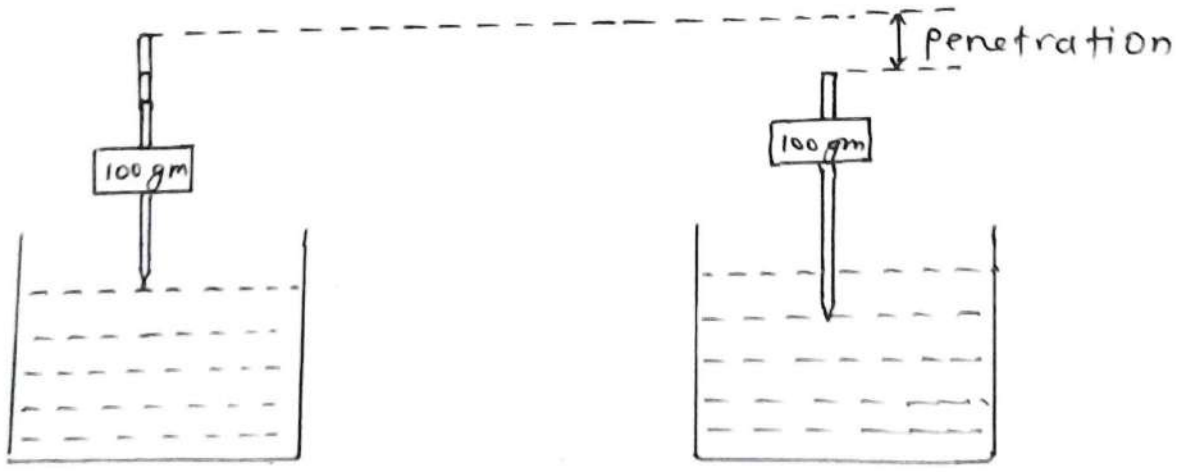
↳ To determine consistency of bitumen material. (hardness).

Use:

↳ For bitumen grading and selecting suitable grade of bitumen for specific weather condition.

Procedure:

↳ pour the bitumen in container.
↳ apply a needle with 100g load for 5 second on bitumen.
↳ The penetration of bitumen is reported in 0.1 mm.
eg: if



Start. After 5 sec

fig: penetration setup.

II. Ductility test:

Principle:

↳ To determine ability of bitumen being stretched.

Use:

↳ To indicate how well bitumen can tolerate temperature changes and traffic load.

Procedure:

↳ Heat the bitumen and place in a contained named Briquettee.

↳ put the sample in water bath for 95 minutes.

↳ stretch the sample at a speed of 50mm per minute

↳ Ductility value is the length before sample is torn.

III. Softening point test:

Principle:

↳ To determine the temperature at which bitumen begins to melt and soften.

Use:

↳ To know the temperature upto which a bituminous binder should be heated for various road use application

Procedure:

↳ Place two steel ball on bitumen sample.

↳ Put the assembly in water bath

↳ heat the water at the rate of 5°C per minute.

↳ softening point value is the temperature at which steel ball drops from a height of 2.5cm and hits the bottom of beaker.

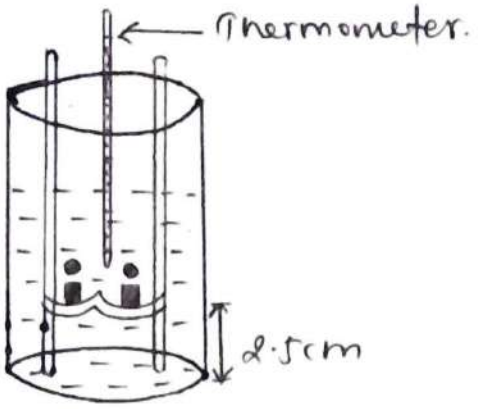


fig: apparatus setup for ductility test.

iv. Viscosity test:

Principle:

↳ To determine the viscosity of bitumen.

Use:

↳ for grading of bitumen.

↳ for know the viscosity required during asphalt concreting.

Procedure:

↳ place a sample in a viscometer

↳ measure the flow out time in seconds to fill 50 ml of bitumen through a nozzle of 10mm diameter.

viscosity = calibration coefficient x time.

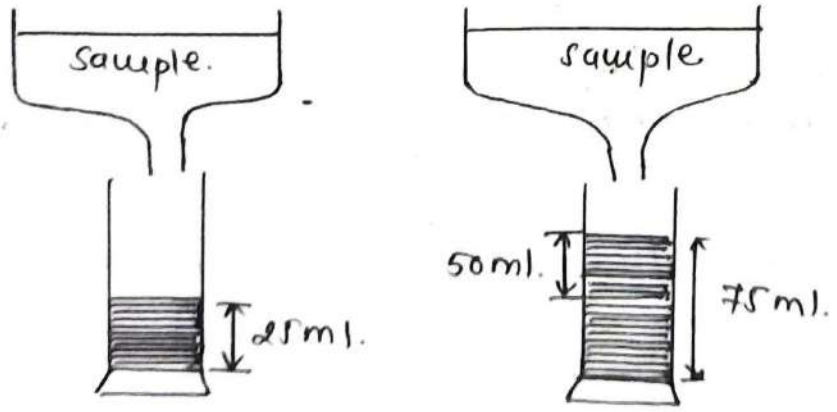


fig: viscosity test apparatus setup.

v. Float test:

Principle:

↳ To measure the consistency of highly viscous bitumen sample.

Use:

↳ for bitumen grading

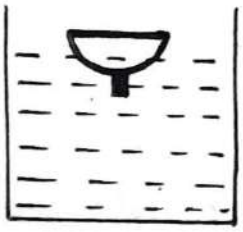
↳ selecting suitable bitumen for road construction.

Procedure:

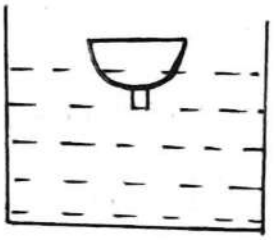
↳ place a sample in collar and put it in a water bath at 5°c.

↳ Then transfer it to water bath at 50°c,

↳ Note the time in second until bitumen burst out from collar.



water at 5°c



water at 50°c.

vi. Fire and flash point test:

Principle:

↳ To determine the burning temperature of bitume

Use:

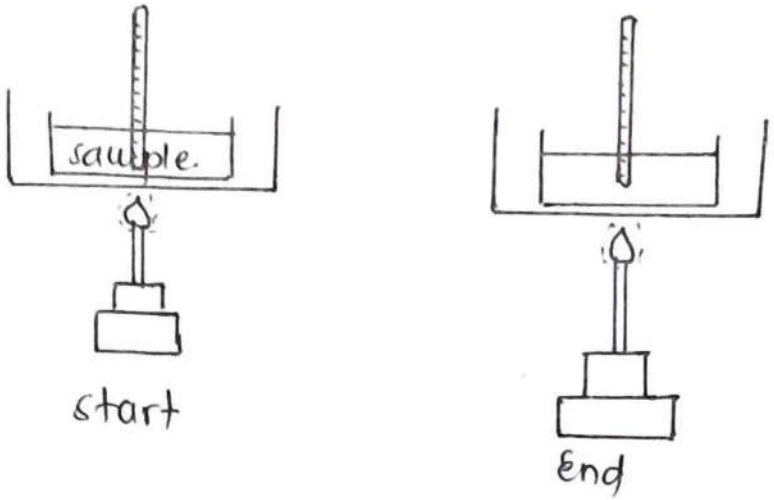
↳ to determine the safety of heating and transporting bitumen.

Procedure:

↳ Heat the bitumen filled test cup @ 5°c per minute.

↳ Note the temperature at which bitumen flashes for a while known as flash point.

↳ Note the temperature at which bitumen ignites fire for at least 5 seconds known as fire point.



VII. solubility test:

Principle:

↳ To measure inorganic content of bitumen.

Use:

↳ for detecting contamination in asphalt concrete.

Procedure:

↳ Dissolve 2gm of bitumen sample in 125ml of trichloro-ethylene.

↳ Weigh the solution, filter it and wash the insoluble matter

↳ Dry it and weigh it again.

*: Bituminous Mixes:

↳ The composition of aggregates (fine & coarse) with bitumen and other bituminous materials is called bituminous mixes.

↳ Bituminous mixes are used for road pavement construction.

*: Desirable properties of bituminous mixes are: (PPSC-P2, 2019/A) (5 marks)

① Stability
② Durability
③ Workability
④ Flexibility
⑤ Skid resistance

*: Types of bituminous mixes:

↳ various bituminous mixes are:

① surface dressing
② Premix carpet
③ otta-seal
④ Bituminous macadam
⑤ Bituminous concrete
⑥ Asphalt concrete
⑦ mixed seal surfacing
⑧ stone mixed-asphalt
⑨ cold mixes and hot mixes
⑩ Dense bituminous macadam (DBM).

1. Surface Dressing:

↳ surface dressing is a mixture of polymer modified bitumen emulsion and a layer of chippings.

↳ It will seal the surface, improve the surface texture and prolong the life of road by many years.

↳ It is the speedy efficient and economic method of prerentive maintenance and carrying out the minor re-profilling of carriageway surface.

Functions:

① improves the skid resistance which makes the road safer.

② helps to make a road waterproof.

③ protects the road against frost and water damage.

↳ surface dressing is carried out from late may to early august.

Laying process:

↳ spray the road with bitumen binder, followed by a layer of stone chippings. The chippings are pressed

↳ The chippings are pressed into the surface by a roller.

↳ To ensure the uniform coating of emulsion, more chipping are deliberately applied to the surface than actually required to complete the dressing process.

↳ Before road is open to traffic, it is swept to remove around 90% excess chippings.

↳ The road then further receives sweeps to remove any loose chippings.

II. Premix carpet:

↳ Premix carpet is laid as a wearing course with a thickness of 20 mm.

↳ The mix is composed of two single sized aggregates.

- first: passing 22.5mm and retained on 11.2 mm
- second: passing 13.2 mm and retained on 5.6 mm.

↳ viscosity grade bitumen are applied according to climatic condition.

III. Otta-seal:

↳ It is a particular type of bituminous surface treatment which was originally developed by Norwegian Road Research laboratory (NRRL).

↳ Used as a temporary surfacing on a newly constructed road initially, but because of its good performance it is now adopted as permanent single or double seal.

↳ construction of ottaseal is similar to that of convectional bituminous surface treatment.

↳ ottaseal is essentially a 16-32 mm thick bituminous surfacing constituted of an admixture of graded aggregates, ranging from natural gravel to crushed rock, in combination with relatively low viscosity binder.

iv. Bituminous macadam:

↳ A pavement constructed by spreading two or more layers of crushed stone on a suitable base and pouring a bituminous binder.

↳ It is open graded macadam and highly permeable in nature.

↳ void content is 20-30% higher than dense grade bitumen macadam.

v. Bituminous concrete:/ Asphalt concrete:

↳ Bituminous concrete is a composite material consisting of aggregates (such as crushed stone, gravel or sand) and asphalt binder.

↳ It is durable and versatile material used in variety of applications.

Uses of bituminous concrete:

① surfacing roads, airports and other public space

② used to paving the expressways, fast tracks etc.

Application of bituminous concrete:

① Road construction.: make surface of roads

② Roofing: roofing materials such as shingles and tiles.

③ Paving: used to make side walks, driveways, playground surface etc.

*Note:

↳ Dense graded mix consists of naturally occuring gravels which are graded from relatively coarse to fine sizes.

↳ Open graded mixes consists of aggregates of uniform size.

Classification of bituminous mixes:

a. Dense graded bitumen mixes:
   i. Dense bitumen macadam (DBM)
   ii. Bitumen concrete (BC)

b. semi-dense graded bitumen mixes:
   i. semi-dense bitumen concrete (SDBC)
   ii. Mixed seal surfacing (MSS)

c. Open graded bitumen mixes:
   i. Asphalt treated permeable base (ATPB)
   ii. Bituminous macadam (BM)
   iii. Built up spray grout (BUSG)

d. Gap graded bituminous mixes
   i. Stone Matrix Asphalt (SMA).

Design procedure of bituminous mixes:

↳ steps to be followed for design of bituminous mixes:

(i) selection of aggregate
(ii) selection of aggregate grading
(iii) determination of specific gravity of aggregates.
(iv) Proportioning of aggregates.
(v) Preparation of specimen.
(vi) Determination of specific gravity of compacted specim
(vii) stability test on compacted specimen.
(viii) selection of optimum bitumen content.

*: Road Tar:

↳ Road tar is a viscous liquid, black in colour having adhesive properties obtained by fractional distillation of crude tar.

↳ Tar contains 45 to 95% bituminous contents.

↳ contains more carbon than asphalt.

*: Crude tar is obtained by destructive distillation of organic materials like coal, wood, shale etc in absence of air.

Types of road tar:

(i) coal tar
(ii) wood tar
(iii) mineral tar.

Q. Differentiate between bitumen and tar:

S.N	Bitumen	S.N	Tar:
(i)	Bitumen is obtained from fractional distillation of crude oil.	(i)	Tar is obtained from destructive distillation of wood or coal tar.
(ii)	It contains less free carbon	(ii)	It contains more free carbon.
(iii)	Bitumen is soluble in carbon disulphide and ccl4.	(iii)	Tar is soluble in toulene.
(iv)	occurs as a solid at normal state.	(iv)	occurs in viscous liquid state.
(v)	It has better weather resisting property.	(v)	It has poor weather resisting property.
(vi)	It is less susceptible to temperature.	(vi)	It is more susceptible to temperature.

Asphalt concrete (AC):

↳ Asphalt concrete is a dense graded premix bituminous mix which is well compacted to form high quality pavement surface course.

↳ The asphalt concrete consists of well maintained gradation of coarse aggregates, fine aggregate, mineral filler and bitumen.

↳ It is designed by Marshal Methods to fulfill the requirements of stability, density, flexibility and voids.

Advantages:

(i) Durable
(ii) Impervious
(iii) Better skid resistance
(iv) Better load spreading property

Disadvantages:

(i) costly construction
(ii) Need of sophisticated machinery
(iii) Very high bitumen content.

Q. Differentiate between bitumen, tar and asphalt: [5 mark]

Ans: Difference between bitumen, tar and asphalt is presented below:

Parameters	Bitumen	Tar	Asphalt.
Definition	• Bitumen is non-crystalline viscous or solid material having adhesive property.	• Tar is is viscous black liquid having adhesive property.	• Asphalt is a mixture of bitumen and aggregates (coarse, fine & sand)
source	• Bitumen is obtained by fractional distillation of crude oil.	• Tar is obtained by destructive distillation of wood or coal tar.	• Asphalt is obtained by mixing bitumen and aggregates.
state	• Bitumen occurs in solid state generally.	• Tar occurs in viscous liquid state generally.	• Asphalt in solid or semi-solid state.
Use	• Bitumen is used for binding other materials.	• Tar is used for water proofing and sealing purpose.	• Asphalt is used for road construction.
Durability	• Bitumen is highly durable.	• Tar is less durable	• Asphalt concrete is medium durable.
Effect on heating.	• On heating bitumen melts.	• On heating tar becomes fluid	• Burns with smoke on heating.
solubility	• soluble in carbon disulphide and ccly.	• soluble in toulene.	• Asphalt is soluble in oil and waxes.
carbon content	• Bitumen has more carbon content.	• Tar has most carbon content	• Asphalt has less carbon content
Resistant to acid and water.	• Bitumen has good resistance to acid and water.	• Tar has less resistance to acid and water.	• Asphalt has good resistance to acid and water.

Design procedure of bitumen mixes:

↳ Design process of bituminous mix consists of three steps:

(i) selection of aggregates
(ii) selection of binder
(iii) Determination of optimum binder content (OBC).

1. selection of aggregates:

↳ Aggregates having sufficient strength, hardness and soundness are choosen.

↳ In base course maximum aggregates size of 2.5cm are used where surface course of 1.25 to 1.87 cm are used in the mix.

Aggregates test	Maximum percentage:
i. los angles abrassion test	30%.
ii. water absorption test	2%.
iii. soundness test (5 cycle)	
iv. Loss with sodium sulphate	12%.
v. Loss with magnesium sulphate	18%.

ii. selection of binder:

↳ selection of binder depends upon the nature of traffic and climatic condition.

↳ Penetration grade bitumen is considered suitable.

iii. Determination of optimum binder content:

↳ Determination of optimum binder content is done by....

① surface area concept.

② void concept method.

↳ Binder must be enough to form film around the mineral particles.

↳ stability of bitumen mixes is obtained by interlocking of particles.

↳ Excess of bitumen causes flow of mix and various surface distortion.

↳ void must be minimized to improve the stability of the selection of appropriate well graded materials.

↳ Minimum voids are filled with binders.