

LEARNING MATERIAL

SEMESTER & BRANCH: 4TH SEMESTER CIVIL ENGINEERING

THEORY SUBJECT: HIGHWAY ENGINEERING (TH-4)

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Highway : The road of national or state importance in a country is known as highway.

Highway engineering :- It is the branch of engineering science which deals with the study of planning, designing, construction and maintenance of the road depending upon nature and volume of traffic.

Importance of highway engineering :-

Highway transportation plays vital role for the country's industrial economic and cultural progress as well as in the defence of our country.

The following points indicate the importance of highway transportation.

- (1) The highway helps in the overall development of a country in the field of industry and culture.
- (2) The highway play an important role in the defence and military transportation.
- (3) The highway help in maintaining law and order of various states within the country.
- (4) The highway help in the movement of traffic from one place to another.

(5) The highway help in increasing the trade relations and increasing the economic activities.

(6) The highway transportation is cheap and convenient mode of transportation in most of the cases.

(7) The highway transportation provide goods commercial links between various villages, towns and cities.

(8) The highways serve as feeder lines for airways, railways and waterways.

(9) The highways are the only source of transporting goods and passengers where other mode of transportation are not available.

Important organization promoting road development:-

(i) Indian road congress (I.R.C)

(ii) Ministry of surface transportation (MORTH)

(iii) Central road research institute (CRRI)

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(i) Indian road congress (I.R.C)

* The Indian road congress was established by central government in 1934 as per recommendation of Jayakar Committee.

* The IRC was constituted to provide a forum for regular pooling of views and ideas on all matters.

affecting the construction and maintenance of road in India.

- + Presently the Indian road congress has become the active body to recommend specifications regarding design and construction of roads and bridges.
- + The IRC works in close collaboration with road wings of ministry of surface transportation Govt of India.
- + IRC publishes journals standard specifications and guidelines on various aspects of highway engineering.
- + The technical activities of the IRC are carried out by experts in each subject.

Imp Functions of Indian road congress :-

The IRC is a body of professional highway engineers having the following functions :-

- + To provide forum of expression of collective opinion of its members for all matters affecting the construction and maintenance of roads in India.
- + To promote the use of standard specifications and practices.
- + To suggest improved method of planning, designing, construction and maintenance of road.
- + To conduct periodical meeting to discuss technical questions regarding road.

- To make laws for the development, improvement, and protection of road.

Central road research Institute (C.R.R.I)

- In 1950, The central road research institute was started at delhi for road research work in the country.
- This is one of the chain of national laboratories under council of scientific and industrial in India.
- The institute has the following objective
 - (i) To carry out the basic and applied research for design, construction and maintenance of various road.
 - (ii) To carry out research on traffic safety and transport economics.

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- (iii) To research on economical utilization of locally available materials for construction and maintenance of road.
- (iv) To develop new machinery, tool equipment and instrument for high way engineering.
- (v) To provide technical advice and consultation.
- (vi) To provide library and documentation services.

(vii) The institute is headed by a director :
and has following wing .

- (i) General project
- (ii) Documentation
- (iii) Soil and Geotechnical engg .
- (iv) Flexible pavement
- (v) Rigid pavement
- (vi) Extension
- (vii) Traffic and transportation
- (viii) Workshop
- (ix) Electrical instrumentation
- (x) Environmental safety

Ministry of road transport and highways
(MORTH)

(i) Morth is an organisation of central government .

(ii) It is formed with the task to formulate
in consultation with other department .
of central and state government , polices
of road transport . National highways
and transport research with a view
to increasing the mobility and efficiency
of road transport system in the country .

→ It has two wings

- (i) Road wing
- (ii) transport wing

Road wing :—

Road wings deals with development and maintenance of national ways in the country.

Transport wings :—

Transport wing deals with matter relating to road transport.

Main responsibilities of road wings :—

- planning development, and maintenance of national highway in the country.
- Extends technical and financial support to state governments for the develop of state roads and the road inter-state connectivity and economic importance.
- Develops standard specification for roads and bridges in the country.
- Serves as a store of technical knowledge on roads and bridges.

Main responsibilities of transport wing :—

- Making Laws of motor vehicle.
- Administration of motor vehicle act 1988.
- Taxation Administration of the road transport corporation act 1950.
- Taxation of motor vehicle.

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- Compulsory insurance of motor vehicle.
- Develop road safety standards in the form of national policy on road safety.
- Preparing and implementing the annual road safety plan.
- Maintaining road accident statistics and takes steps for developing a road safety culture.

Classification of road :-

Road are classified into following two broad categories.

(i) Urban road,

(ii) Non-urban road / Rural Road.

Urban road

- urban are those which fall within the jurisdiction of municipalities and Cantonment boards.

- urban roads are classified as follows :-

- (i) Express way
- (ii) Arterial streets
- (iii) Sub-Arterial streets
- (iv) Collector streets
- (v) Local streets

Non-urban road :-

- Non-urban roads are those located in the areas other than urban areas. They are also known as rural roads.

- The non-urban roads are classified into five categories:

I.M.P. - This classification is popularly known as I.R.C. classification of road.

- (I) National highway (N.H)
- (II) State highway (S.H)
- (III) Major district road (M.D.R)
- (IV) Other district road (O.D.R)
- (V) Village road (V.R)

(1) Express ways :-

- These are divided arterial highways for motor traffic and provided generally with grade separation at intersection.
- The main function of express way is to provide for movement of heavy traffic at high speed.

(2) Arterial streets :-

- Arterial streets primarily meant for through traffic usually on a continuous route.
- Arterial streets along with express ways serve as the principal network for through traffic flow.
- A properly developed and designated arterial streets system would help to identify residential.

neighbourhoods, Industrial areas and commercial areas.

- These streets are spaced generally at less than 1.5 km in central business area and at 8 km or more in develop urban.

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(3) Sub-arterial Streets :-

- These are streets of some what lower level of mobility than arterial streets.
- These are spaced at 0.5 km in the central business area and 3 to 5 km in sub-urban areas.

(4) Collector Streets :-

- These are intended for collecting and distributing the traffic to and from local street.
- it also provide access to arterial streets.

(5) Local streets :-

- These are primarily intended for access for residence business and other abutting property.
- These street do not large volume of traffic.

classification of rural roads as per IRC classification.

(1) National highway (NH)

→ The main highways running through the length and breadth of the country connecting state capitals, port foreign highways, large town etc are known as national highways.

→ These are of national importance for strategic, administrative and other purpose.

→ All the national high ways are assigned the respective number.

→ The highway connecting Amritsar - Ambala - Delhi is denoted as NH-1, NH 100 is Channa - Hazaribag - Bogudare and NH-953 Vyara - Nalang - Rajpipla Badeli.

→ The total length of national highway is 76818 Km.

(2) State highway :-

→ The high ways district head quarters and important cities with in state or connecting them, with national highway of other state are known as state highways.

→ These highway serve as main arteries of traffic to and from district roads.

③) Major district road (M.D.R) :-

- The important road with the district serving areas of production and market and connecting these with each other or with the highways are known as major district roads.
- The road have roughly the same specification as the state highways.

④) Other district Road (O.D.R) :-

- O.D.R are the road serving rural areas of production and providing them with outlet to tehsil head quarters, market centre etc.
- These roads have some-what lower specification than major district roads.

⑤) Village Road (V.R) :-

- village road some road connecting villages or group of villages, with each other or with nearest district road main highway, railways etc.
- The road are very important from the point of view of rural areas development.
- The construction and maintenance of these road are responsibility of local district authority.

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Importance of geometric design —

- The geometric design of a highway deals with the dimension and layout of visible features of the high way such as alignment sight distances and intersection etc.
- The geometrics of highway should be designed to provide optimum efficiency in traffic operations with maximum safety at reasonable cost.
- The designer may be exposed to either planning of a new highway network or improvement of existing highway to meet the requirements of existing road.
- It is possible to design and construct the pavement of the road in stages but it is very expensive and rather difficult to improve the geometric element of the road in stages at a later date.
- Therefore it is important to plan and design the geometrical features of the road during the initial alignment itself taking into consideration the future growth of traffic flow and possibility of road being upgraded to a higher category or to a higher category design speed standard at a later stage.

→ Geometric design of highway deals with the following elements.

- (i) Cross-section elements
- (ii) Sight distance considerations.
- (iii) Horizontal alignment details.
- (iv) Vertical alignment details.
- (v) Intersections elements.

(i) Cross-section elements:-

→ The considerations for the width of the pavement, formation and land surface characteristics and cross-slope of pavement are included.

(ii) Sight distance considerations:-

→ The clear visible distance ahead a driver on a horizontal and vertical curves and at intersection govern the safe movement of vehicles.

(iii) Horizontal alignment details:-

→ The change in the road direction are made possible by introducing horizontal curves.

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Design controls and criteria:-

- * Design speed
- * Topography
- * Traffic factors
- * Design hourly volume and capacity.

Design speed :-

- In India different speed standards have been assigned for different class of road.

Ex: Express ways - speed $\rightarrow$ 120 km/h

N.H speed $\rightarrow$ 100 km/h

S.H speed $\rightarrow$ 80 km/h

- Design speed may be modified depending upon terrain condition.

Topography :-

classification based on the general slope of the country.

- (i) Plane terrain $< 10\%$.
- (ii) Rolling terrain $10\% - 25\%$.
- (iii) Mountainous terrain $25\% - 60\%$.
- (iv) Steep terrain $> 60\%$.

Traffic factor :-

- vehicular characteristics and human characteristics road user.
- Different vehicle classes have different speed and acceleration characteristics, different dimension and weight.
- Human factor includes the physical, mental and psychological characteristics of driver and pedestrian.

Design hourly volume and capacity :-

- Traffic flow fluctuating with time.
- Low value during off peak hours to the highest value during peak hours.
- So it is uneconomical to design the road way for peak traffic flow.

Environmental and other factors :-

- * Aesthetics
- * Landscaping
- * Air pollution
- * Noise pollution

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Pavement surface characteristics :-

Pavement surface depend on the type of pavement which is decided base on.

- (i) Availability of material
- (ii) Volume and composition of traffic
- (iii) Soil sub grade
- (iv) climatic condition.
- (v) construction facility.
- (vi) cost consideration.

Important surface characteristics :-

The important surface characteristics are

- (i) Friction
- (ii) pavement evenness
- (iii) Light reflecting characteristics
- (iv) Drainage of surface water.

(1) Friction :-

skidding $\rightarrow$ when the path travel along the road surface is more than the circumferential moment of the wheel due to rotation is called as skidding ($L > R$)

slipping - ($R > L$)

$\Rightarrow$ When wheel revolves more than the corresponding longitudinal movement along the road.

Factors affecting the friction :-

(i) Type of pavement surface

(ii) Roughness of pavement

(iii) Condition of pavement

(iv) Type and condition of tyre.

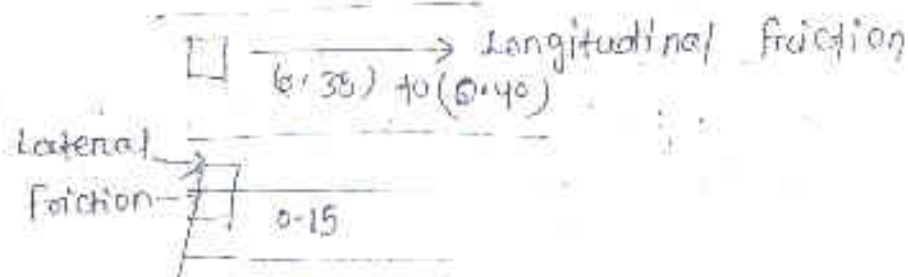
(v) Speed of the vehicle

(vi) Brakes efficiency

(vii) Load and tyre pressure.

(viii) Temperature of tyre and pavement.

$\rightarrow$ The smooth and worned tyre offer least friction factor on dry pavement. but new tyre with treads gives higher friction factor on wet pavement.



→ IRC recommended the longitudinal coefficient of friction varies from 0.35 - 0.40 and coefficient of lateral friction of 0.15.

(ii) unevenness of pavement surface :-

The unevenness of pavement material surface cause by

- (i) use of inferior pavement material
- (ii) poor maintenance
- (iii) Improper construction equipment / machinery.
- (iv) Improper surface and subsurface drainage.
- (v) In adequate compaction of the fill subgrade and pavement layers.

→ un-scientific construction practices including the use of boulder stones and bricks as silling course over loose sub-grade soil.

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Pavement unevenness

→ Higher operating speed are possible on even surface than uneven surface.

→ It affects vehicle operation cost, comfort and safety, fuel consumption, wear and tear of tyres and other moving parts.

→ It is commonly measured by an equipment called Bump Integrator.

> Bump integrator is the cumulative measure of vertical undulation of the pavement surface recorded per ^{unit} horizontal length.

> 250 cm/km for speed of 100 km/h and more than 350 cm/km considered very unsatisfactory even at speed of 50 km/h.

Light reflecting characteristics:-

> Night visibility very much depends upon the light reflecting characteristics of the pavement.

> The glare caused by the reflection of head light is high on wet pavement surface than on dry pavement surface.

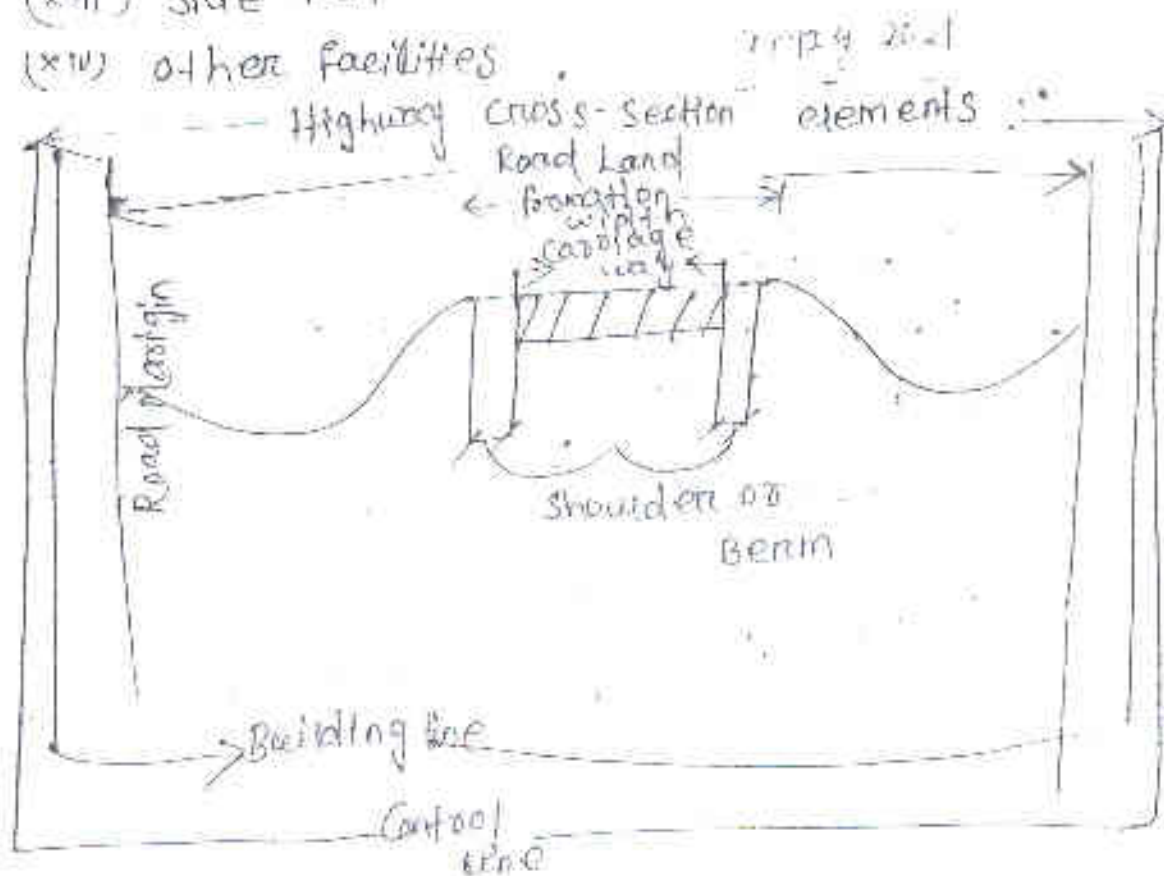
> Light coloured or white pavement or rigid pavement surface give good visibility at night particularly during rain.

Seepage of surface water:-

> The pavement surface should be absolutely impervious to prevent the entry of seepage water into the pavement layer.

Highway cross-section elements:→

- (i) Carriage way
- (ii) Shoulder
- (iii) Road width
- (iv) Right of way
- (v) Building line
- (vi) Control line
- (vii) Median
- (viii) Camber
- (ix) Crown
- (x) Side slope
- (xi) Kerb
- (xii) Gained rail
- (xiii) Side rail
- (xiv) other facilities



Building Line -

In order to reserve sufficient space for further development of roads. It is desirable to control the building activities on either side of the road bounded beyond the lane width acquired for the land.

Control Line :-

In addition to building line it is desirable to control the nature of building up to future set back distance.

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Camber :-

→ It is the slope provided to the road surface in the transverse direction to drainout the water from the pavement.

→ Objective of Camber -

* To prevent the entry of surface water into the subgrade through pavement.

* To prevent the entry of water into the bituminous pavement layer.

* To remove the rain water from the pavement surface as quick as possible and to allow the pavement to get dry soon after the rain.

* It is expressed as a percentage or IN/H

* It depends on the pavement surface of rainfall.

shape of the camber

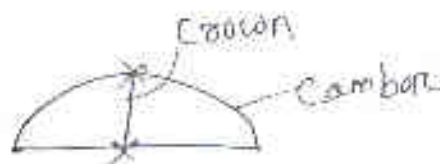
* parabolic shape
(fast moving vehicle)



* straight line shape



* Combination of straight and parabolic



Recommended values of camber for different type of road surface.

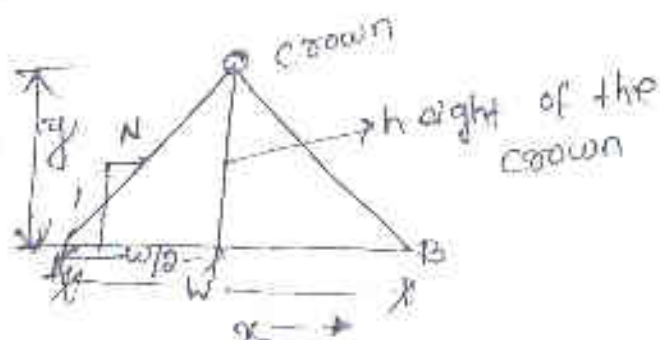
Sl. No.	Types of road surface	Range of camber in areas rain fall range	
		heavy	Light
1	cement concrete and high type bituminous surface	1 in 50 (2%)	1 in 60 (1.7%)
2	Thin bituminous surface	1 in 40 (2.5%)	1 in 50 (2%)
3	W.B.M and gravel pavement	1 in 33 (3%)	1 in 40 (2.5%)
4	Earth	1 in 25 (4%)	1 in 33 (3%)

Example - 1

In a district where rain fall is heavy. M&R of W.B.M pavement 3.8 m. wide and a state highway of bituminous concrete pavement 7.0 m wide are to be constructed. what should be

number

Q.2 straight line crown

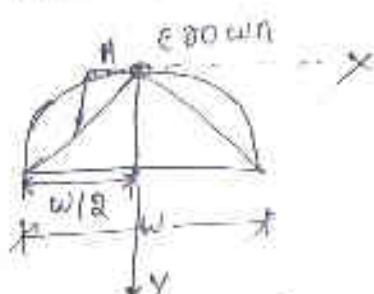


$$\tan \theta = \frac{y}{w/2}$$

$$\rightarrow \frac{1}{N} = \frac{y}{w/2}$$

$$\Rightarrow \boxed{y = \frac{w}{2N}}$$

Q.3 parabolic crown



$$y = 0 \quad x = 0$$

$$y = y \quad \text{when } x = w/2$$

$$y = ax^2 \Rightarrow y = a(w/2)^2$$

$$\Rightarrow a = \frac{2y}{w}$$

$$\boxed{y = \frac{2x^2}{Nw}}$$

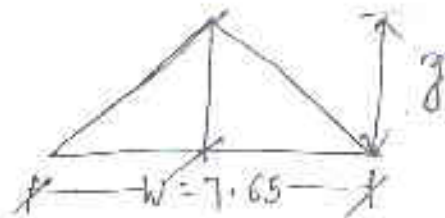
Combining straight parabolic crown



$$\boxed{y = y_1 + y_2}$$

Q A 2 lane NH passing through a heavy rainfall
 fall area made up of cement cement
 concrete surface what will be the crown
 height?

Soln A square camber is straight line.



Heavy rainfall area $\frac{1}{N} = 2\% = \frac{2}{100} = \frac{1}{50}$

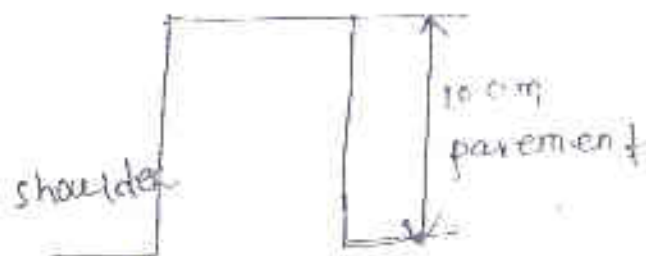
$$g = \frac{W}{2N} = \frac{W}{2} \times \frac{1}{N}$$

$$= \frac{7.00}{2} \times \frac{1}{50} = 0.07 \text{ m.}$$

Kerb

- > It indicates the boundary betⁿ pavement and shoulder.
 - > It is desirable to provide kerbs in urban areas.
 - > It is of three type.
 - ① Low or mountable type
 - ② semi-barrier type.
 - ③ barrier type.
- Low or mountable Kerb :-

- > It is rectangular in shape
- > It allows the driver to enter the shoulder area with little difficulty.
- > The height of this type of shoulder kerb is about 10 cm. above the pavement edge. with slope to help the vehicle climb the kerb easily.

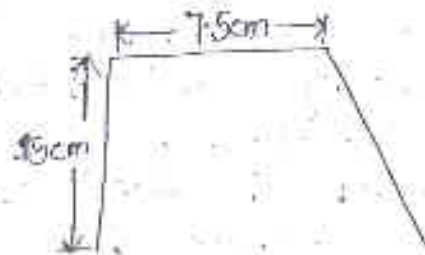


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Semiboulder Kurb :-

- (i) It is trapezoidal in shape.
- (ii) It is provided on the periphery of a road way where the pedestrian traffic is high.
- (iii) Height above 15 cm above the pavement edge with batter of 1:1 on the top 7.5 cm.



- (iv) It prevents parking the vehicle but during emergency it is difficult to drive over this kurb with some difficulty.

Boulder type kurb :-

- (i) It is trapezoidal in shape.
- (ii) It is provided in built-up area adjacent to the footpath with considerable pedestrian traffic.

The height of the kurb is about 20 cm above the pavement edge with a steeper batter 1v:0.25 h.

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Right of way :-

- It is the area of land acquired for the road along its alignment. The width of this acquired land is known as land width.
- Land width depends on the importance of the road and possible future development.
- The land width is governed by the following factors.
 - (i) Width of the formation depending on the category of highway and width of road way and road margin.
 - (ii) Height of embankment or depth of cutting, which is governed by the topography and the vertical alignment.
 - (iii) Side slope of embankment or cutting which depend on the height of slope soil type.

Guard rails :-

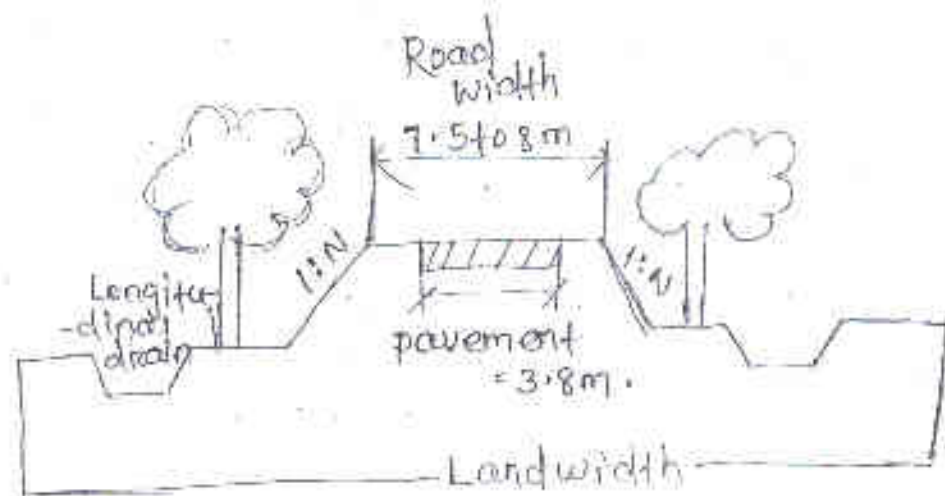
- These are provided at the edge of the shoulder when the road is constructed so that vehicles are prevented from running off the embankment.
- When the height of the fill exceeds 3m Guard rails are provided.

Footpath :- These are provided in urban areas when the vehicular as well as pedestrian traffic are heavy.

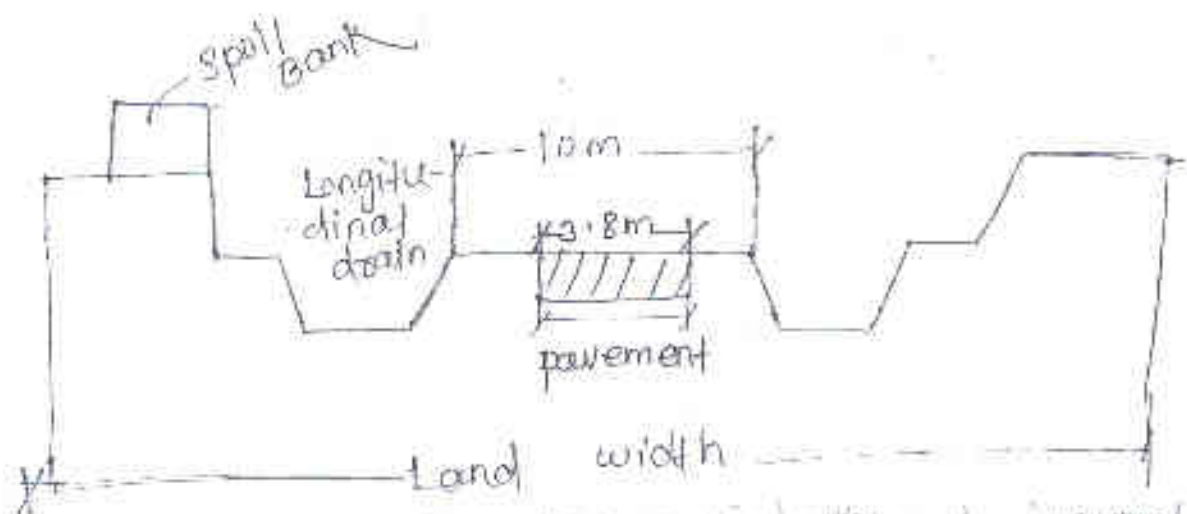
- To provide protection to pedestrian and to decrease accidents.

- The minimum width of footpath is 1.5 m.

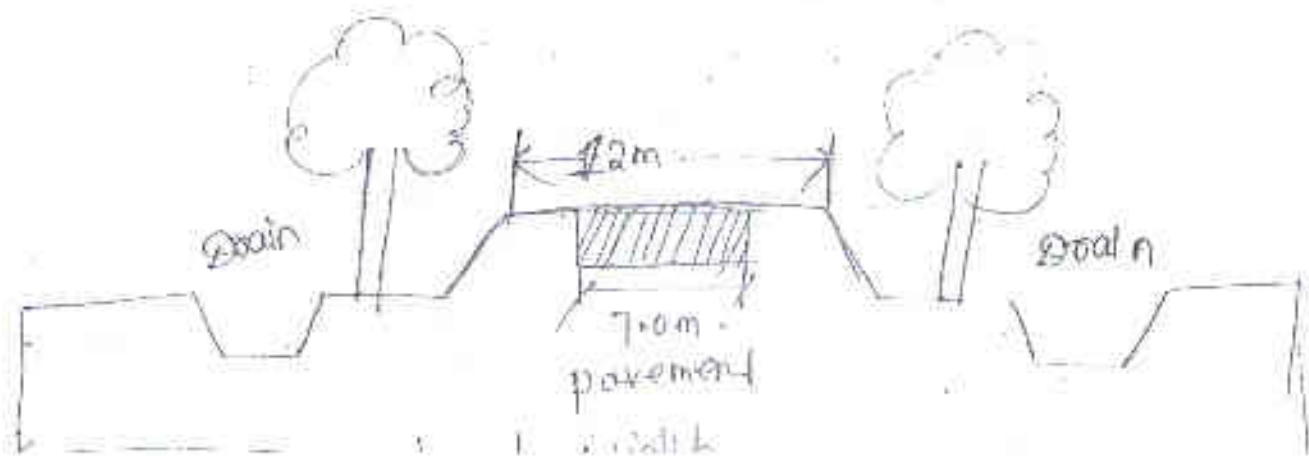
Typical cross-section of road



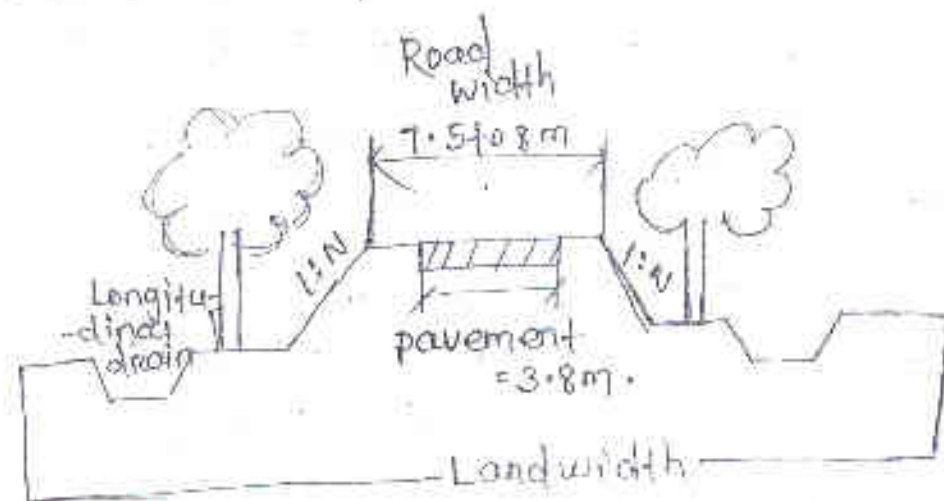
V.R or ODR in Embankment in rural area.
Cross-section of MCR including in rural area.



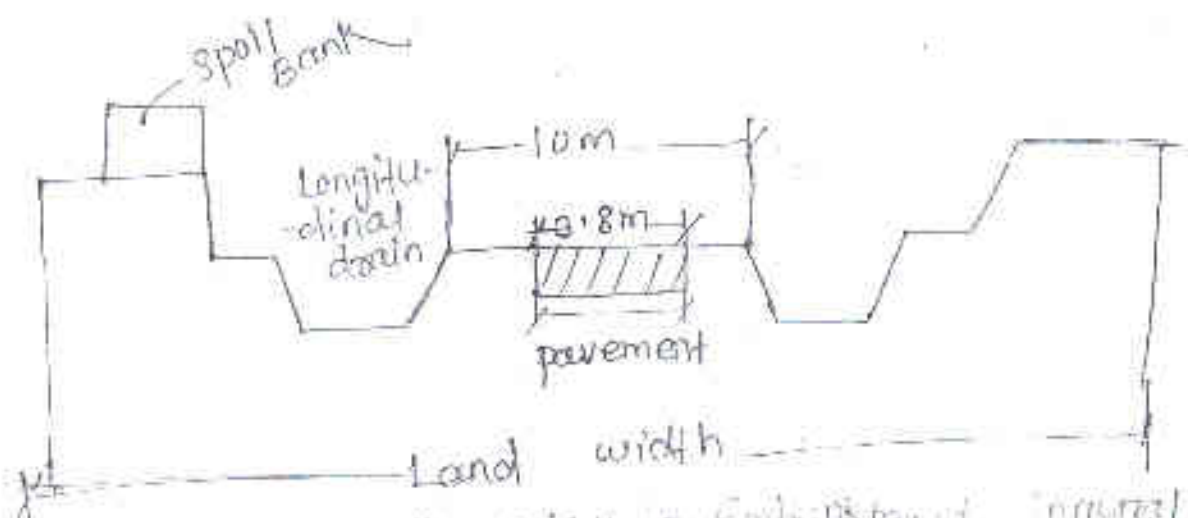
Cross-section of R.H. in Embankment in rural area.



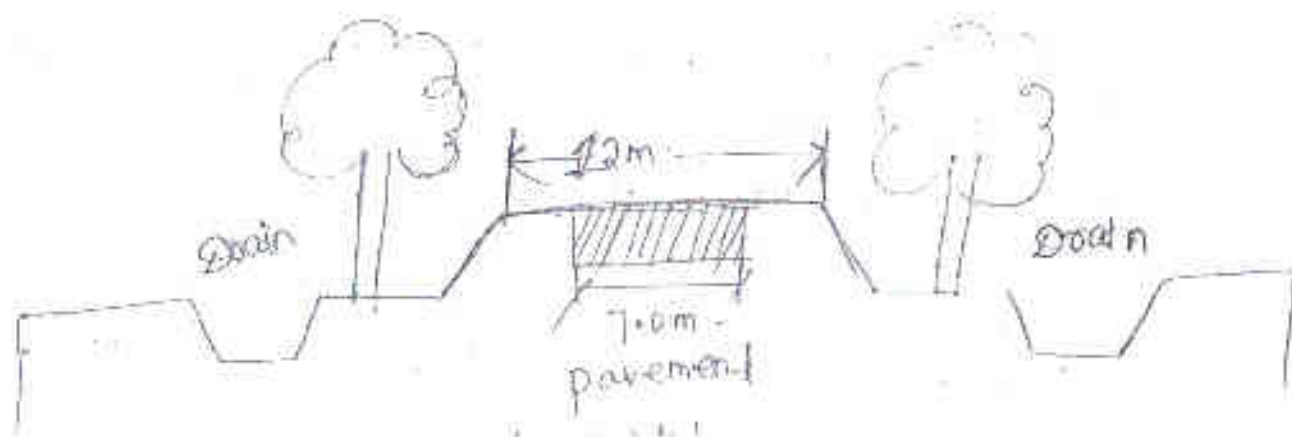
7 typical cross-section of road :-



V.R or ODR in Embankment in rural area.
 Cross-section of MRR in cutting in rural areas



Cross-section of NH/SH in Embankment in rural areas



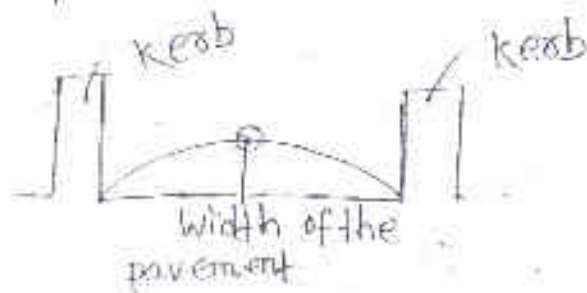
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Traffic Separators or median :-

- > The function is to prevent head on collision betⁿ the vehicle moving in opposite direction.
- > segregate slow traffic and to protect the pedestrians.
- > IRC recommends a min^m desirable width of 5m and may be reduced to 3m. where land is restricted.

Crown :-

The highest point on the road surface is called crown



Driveway :-

- > It connects the highway with commercial establishment like fuel station, service station etc.
- > It should be located away from the intersection.

Cycle track :-

- > It is provided in urban areas where the volume of cycle traffic on the road is high.

Traffic on the road is high

- A minimum width of 2m is provided for cycle track.

Footpath :-

- These are provided in urban areas when the vehicular as well as pedestrian traffic is heavy.
- To protect the pedestrian and decrease accident.
- Minimum width of 1.5 m is provided.

Sight distance considerations :-

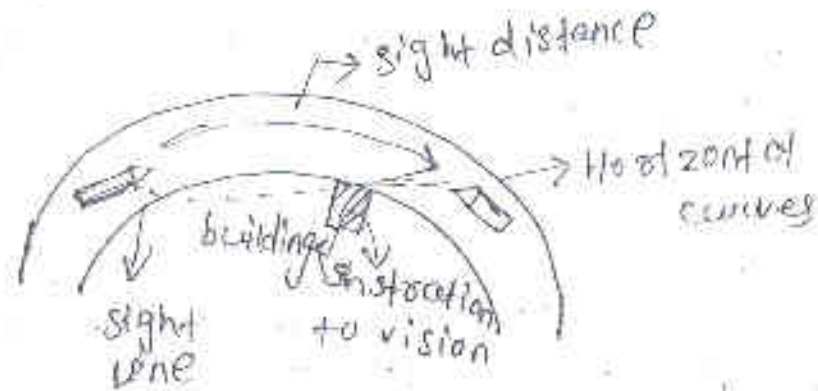
Sight distance :-

- It is the length of road visible ahead to the driver at any instance.
- Sight distance is the actual distance visible from driver's eye level (1.2m) at a specific height of obstruction (0.15m) on the road surface ahead.
- Sight distance is very important for safe operation of vehicles.

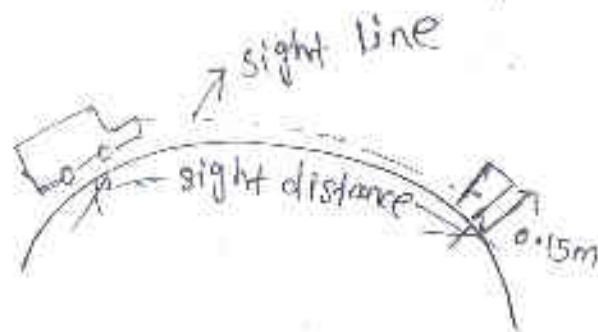
Restrictions to sight distance :-

- ① At horizontal curves
- ② At vertical curves
- ③ At intersection

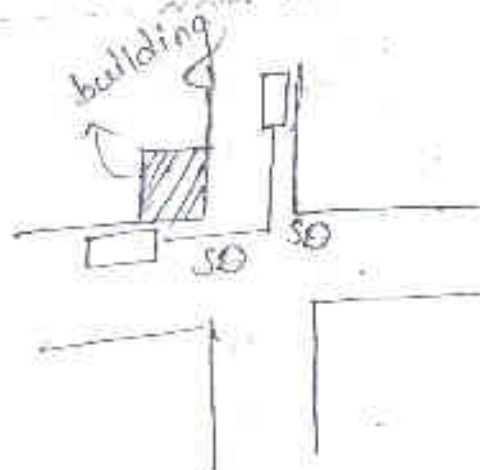
sight distance at horizontal curve:-



sight distance at vertical curve:-



sight distance at intersection:-



Types of sight distance:-

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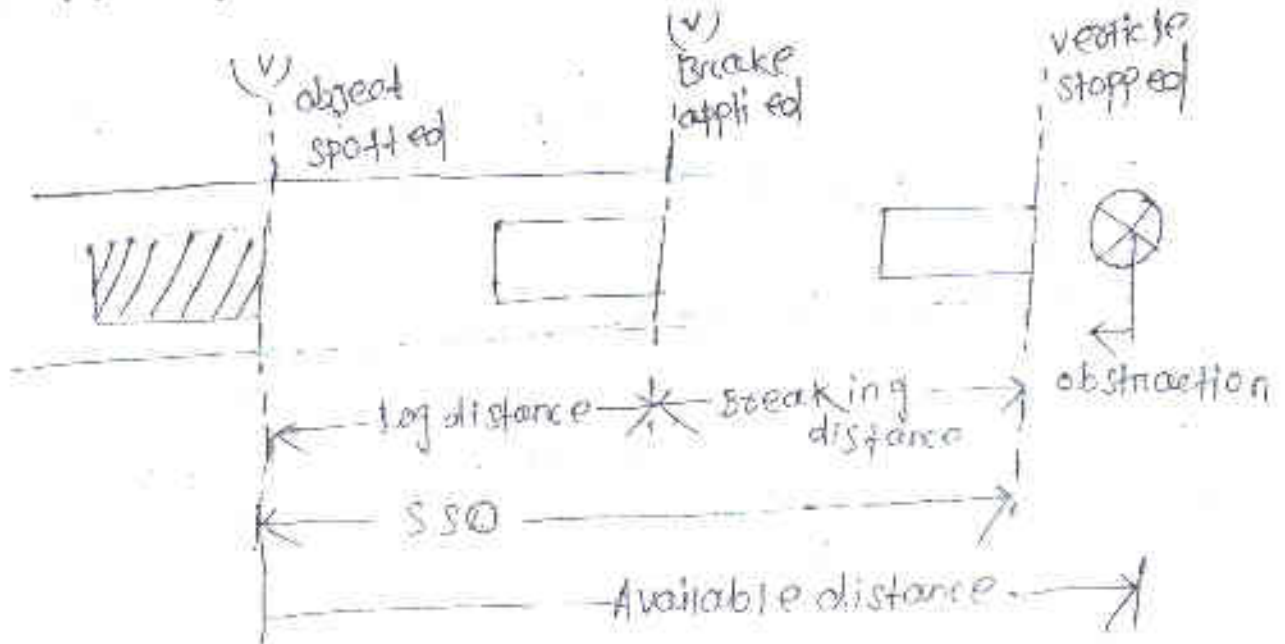
- ① $SSD \Rightarrow$ stopping sight distance / Absolute min^m sight distance.
- ② overtaking sight distance / passing sight distance (OSD)

(iii) safe sight distance for entering an unsignalized intersection.

Apparent from these above '3' situations. IRC provides more two situation.

Sloping sight distance (SSD)

It is the length of the road visible ahead to the driver from specified height above the carries way of any instant of time to safely stop the vehicle before collision.



$SSD = \text{Log distance} + \text{Braking distance}$

$\downarrow$
Reaction time

$\downarrow$
After application
of Brakes

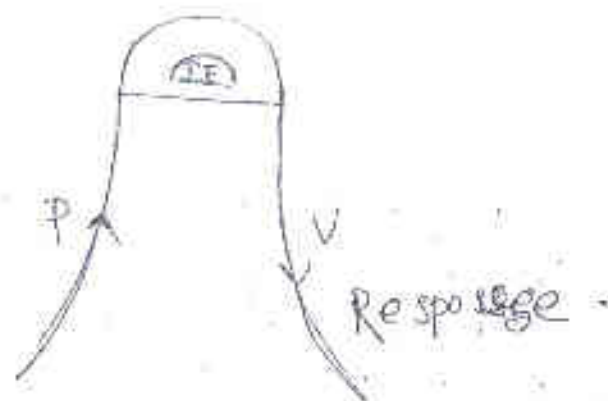
$$SSD \leq \text{Available distance}$$

Lag distance = $\frac{\text{distance travelled}}{\text{time}}$ in reaction

Lag distance $= v \cdot t_R \rightarrow \text{sec}$
 $\downarrow$
 m/sec

As per IRC : Total reaction time (t_R)
 $= 2.5 \text{ sec}$

t_R consists of PIEV Theory :—



$P \rightarrow$ perception time :—

It is the time required to perceive any object.

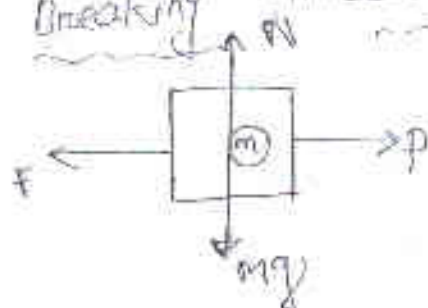
$I \rightarrow$ Intellection time :—

It is the time required for understanding and comparing different situation.

$E \rightarrow$ Emotion time :— It is the time lost in emotional sensation like angry fear

$V \rightarrow$ volition time :— It is the time required

In the application of brakes.
 Breaking distance :— (s)



$$N = mg \quad \text{--- (1)}$$

$$P = F$$

$$= N$$

$$P = Nmg$$

$F = \mu N = \mu v$
 Loss in kinetic energy = work done against friction

$$\Rightarrow \left(\frac{1}{2} mv^2 - 0 \right) = F \cdot S$$

$$\Rightarrow \frac{1}{2} mv^2 = \mu N S$$

$$\Rightarrow \frac{1}{2} mv^2 = \mu mg S$$

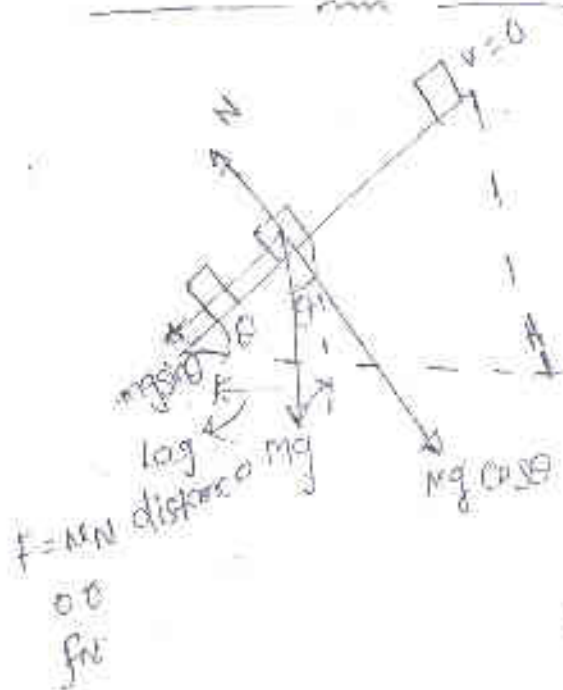
$$\Rightarrow S = \frac{v^2}{2g\mu}$$

$$SSD = V + R + \frac{v^2}{2g\mu}$$

effective

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Effect of gradient



Loss in K.E = work done friction

$$\Rightarrow \frac{1}{2} mv^2 = (F + mg \sin \theta) S$$

$$\Rightarrow \frac{1}{2} mv^2 = \left(\mu mg \cos \theta + mg \sin \theta \right) S$$

$$\Rightarrow \frac{v^2}{2} = g \cos \theta \left(\mu + \frac{\sin \theta}{\cos \theta} \right) S$$

$$\Rightarrow \frac{v^2}{2} = g \cos \theta (\mu + \tan \theta) S$$

$$S = \frac{v^2}{2g \cos \theta (\mu + \tan \theta)}$$

θ is very small

$$\cos \theta = 1$$

$$\sin \theta = \tan \theta = \theta = \alpha$$

$$S = \frac{v^2}{2g(\mu + \alpha)} \quad \text{---> upward gradient}$$

$$S = \frac{v^2}{2g(\mu - \alpha)} \quad \text{---> Downward gradient}$$

$$SSD = v t_R + \frac{v^2}{2g(f \pm \alpha)b}$$

$b \rightarrow$ braking efficiency (100% $\neq 1$)

plane terrain $\alpha = 0$, $b = 1$

$$SSD = v t_R + \frac{v^2}{2gf}$$

SSD

① Two lane Two way  $SSD = SSD$

② Two lane one way  $SSD = SSD$

③ one lane Two way  $SSD = SSD_1 + SSD_2$

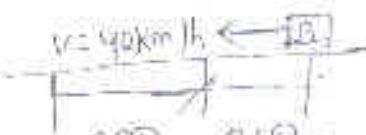
④ one lane one way  $SSD = SSD$

Q Two vehicles travelling in opposite direction with 65 km/h and 40 km/h. find the min distance to avoid head on collision. $f = 0.35$

Soln

$$\text{[A]} \rightarrow v = 65 \text{ km/h}$$

$$v = 40 \text{ km/h} \leftarrow \text{[B]}$$



To avoid head on collision (same lane in opposite direction)

$$SSD = SSD_1 + SSD_2$$

$$V_1 = 65 \times \frac{5}{18} / 65/36$$

$$= 18.05$$

$$SSD_1 = V_1 t_R + \frac{V_1^2}{2g(f \pm a)b}$$

$$V_2 = 40/36$$

$$= 11.11 \text{ m/sec}$$

$$\text{So } a = 0, b = 1$$

$$SSD_1 = V_1 t_R + \frac{V_1^2}{2gf}$$

$$t_R = 2.5 \text{ sec}$$

$$V_1 = 18.05 \text{ m/sec}$$

$$= 18.05 \times 2.5 + \frac{(18.05)^2}{2 \times 9.81 \times 0.35}$$

$$= 92.56 \text{ m.}$$

$$SSD_2 = V_2 t_R + \frac{V_2^2}{2gf}$$

$$V_2 = 11.11 \text{ m/sec}$$

$$SSD_2 = 11.11 \times 2.5 + \frac{(11.11)^2}{2 \times 9.81 \times 0.35}$$

$$= 45.75 \text{ m.}$$

$$SSD = SSD_1 + SSD_2$$

$$= 92.56 \text{ m} + 45.75 \text{ m.}$$

$$= 138.31 \text{ m.}$$

20 Calculate the stopping distance on a high way at a descending gradient of 2%. for a design speed of 80 kmph. (Assume other data as per IRC)

Soln

$$SSD = V t_R + \frac{V^2}{2g(f \pm a)b}$$

$$b = 1 \quad \text{gradient} = -ve$$

$$SSD = v t_R + \frac{v^2}{2g(f - \alpha)}$$

$$V = 80 \text{ kmph} = 80 \times \frac{5}{18} \\ = 22.22 \text{ m/sec}$$

$$t_R = 2.5 \text{ sec}, f = 0.35$$

$$\alpha = 2\% = \frac{2}{100} = \frac{1}{50} = 0.02$$

$$= 22.22 \times 2.5 + \frac{(22.22)^2}{2 \times 9.81 (0.35 - 0.02)}$$

$$= 131.80 \text{ m.}$$

18 may 2021

3Q The design speed for a road is 65 km/h longitudinal Co-efficient of friction is 0.36 and reaction time of driver is 2.5 sec. calculate (i) Head light sight distance (ii) Intermediate sight distance.

$$HSD = SSD$$

Data given :-

$$\text{Design speed (v)} = 65 \text{ km/h} \\ = \frac{65}{3.6} = 18.05 \text{ m/s}$$

$$\text{Coefficient friction (f)} = 0.36$$

$$\text{Reaction time (t}_R\text{)} = 2.5 \text{ sec}$$

$$SSD = v t_R + \frac{v^2}{2g(f - \alpha)}$$

$$SSD = vR + \frac{v^2}{2gf} = 18.05 \times 2.5 + \frac{(18.05)^2}{2 \times 9.81 \times 0.35}$$

$$= 92.56 \text{ m.}$$

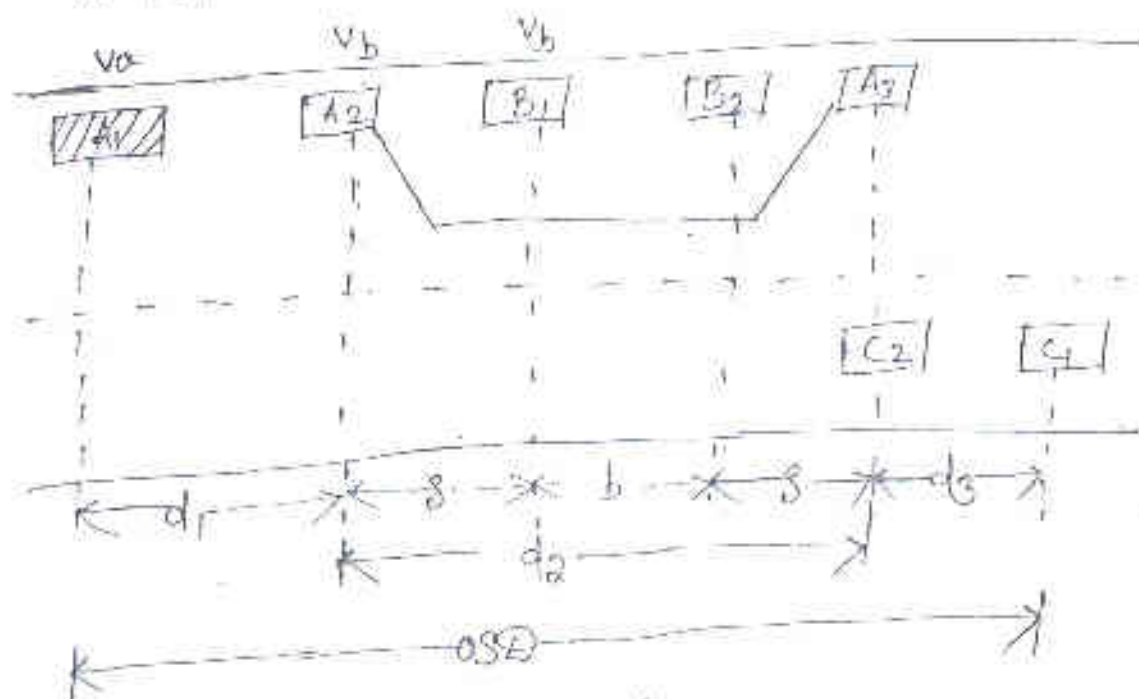
$$HSD = SSD = 92.56 \text{ m.}$$

$$ISD = 2 \times SSD$$

$$= 2 \times 92.56 = 185.12 \text{ m.}$$

OSO

> It is the min^m distance available to driver of vehicle trying to overtake slow vehicle ahead with safety against traffic direction.



$$OSO = d_1 + d_2 + d_3$$

$d_1 \rightarrow$ distance travelled by overtaking vehicle in reaction time.

(In this time the vehicle 'A' is forced to move with slower speed i.e. v_b .)

$$d_1 = v_b \times t_R \quad (\text{As per IRC } t_R = 2 \text{ sec})$$

$d_2 \rightarrow$ distance travelled by overtaking vehicle while accelerating

$$d_2 = v_b \cdot T + \frac{1}{2} a T^2 \quad \text{--- eqn (i)}$$

$$d_2 = b T^2$$

$b \rightarrow$ distance travelled by overtaken vehicle.

$$d_2 = v_b T + a T^2 \quad \text{--- (ii) eqn}$$

Equating eqn (i) and eqn (ii)

$$v_b T + \frac{1}{2} a T^2 = v_b T + a T^2$$

$$T = \sqrt{\frac{4b}{a}}$$

s : min^m space interval betⁿ two vehicles.

$s = 0.2 \quad v_b (\text{km/h}) + 6$
$s = 0.7 v_b (\text{m/s}) + 6$

$d_3 \rightarrow$ distance travelled by vehicle C_1 to C_2 in opposite direction.

$$d_3 = v \cdot T$$

17 May 2021

Key points to remember :-

> speed of overtaking vehicle at the time of overtaking = speed of slower vehicle.

> If speed of slow moving vehicle is not given. take it as = speed of overtaking vehicle in km/h - 10 km/h

> If minimum spacing is not given take it as $= 0.7 V_b \text{ (m/s)} + \text{Avg length of wheel base (6m)}$

$$= 0.7 V_b \text{ (m/s)} + 6$$

$$= 0.2 V_b \text{ (km/h)} + 6$$

> If overtaking time is not given. Take

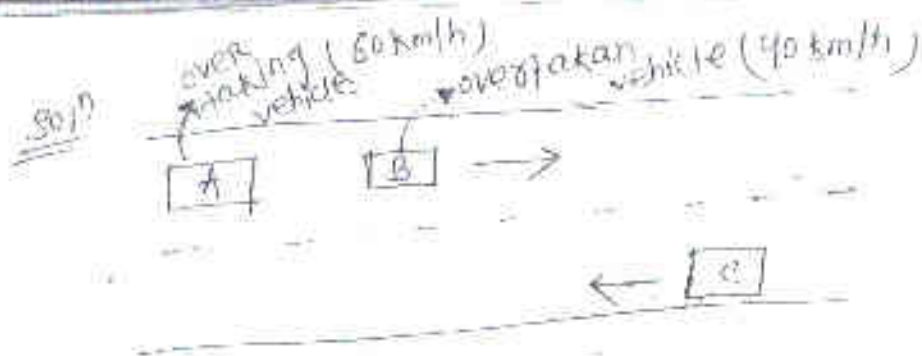
$$t \text{ as } T = \sqrt{\frac{4S}{a}}$$

$$T = \sqrt{\frac{2S_1 + S_2}{a}}$$

> If the speed of opposite moving vehicle is not given Take $V_c = V_A$

> for one way traffic $d_3 = 0$

Q. on a two way traffic road speed of overtaking and overtaken vehicle are 55 km/h and 40 km/h respectively. If avg. acceleration is 0.90 m/s^2 . Find the ASE?



$$OSD = d_1 + d_2 + d_3$$

$$d_1 = V_b t_r$$

$$= \frac{40}{3.6} \times 2 = 22.22 \text{ m}.$$

$$d_2 = V_b T + 2S$$

$$T = \sqrt{\frac{4S}{a}}$$

$$S = 0.2 V_b + 6$$

$$= 0.2 \times 40 + 6 = 14 \text{ m}.$$

$$T = \sqrt{\frac{4 \times 14}{0.92}}$$

$$= 7.80 \text{ sec}$$

$$d_2 = V_b T + 2S$$

$$= 11.11 \times 7.80 + 2 \times 14 = 114.65 \text{ m}.$$

$$d_3 = V_c T \quad V_A = V_c$$

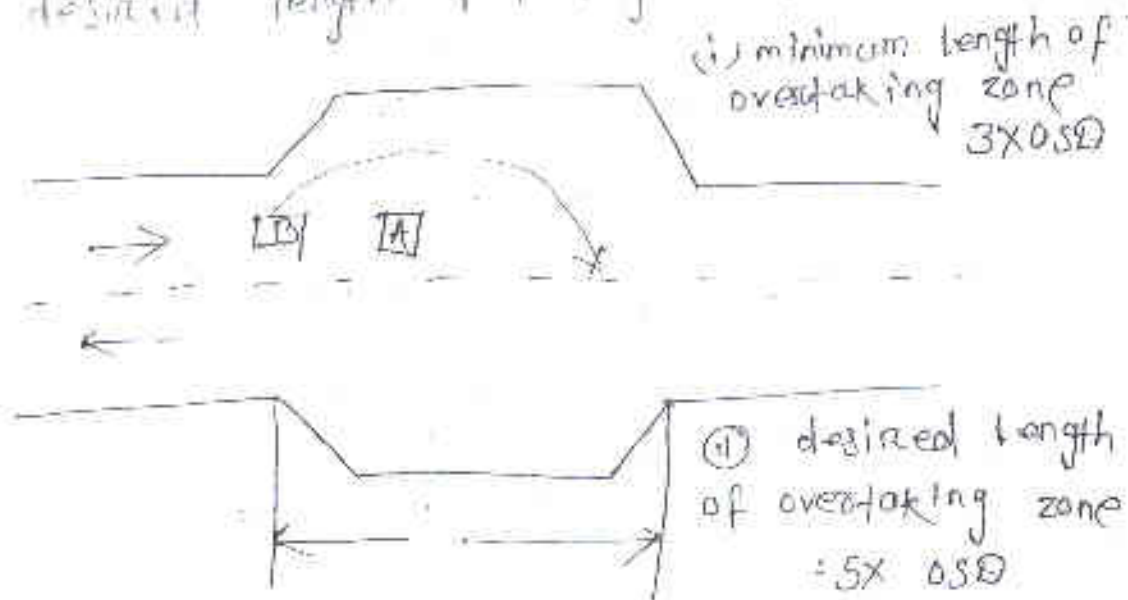
$$= \frac{65}{3.6} \times 7.80$$

$$= 140.83 \text{ m}.$$

$$OSD = d_1 + d_2 + d_3$$

$$= 22.22 + 114.65 + 140.83 = 277.7 \text{ m}.$$

Q. On a two way traffic road speed of overtaking and overtaken vehicle are 50 kmph and 60 kmph respectively if the avg acceleration is 3 m/s^2 find OSD ?
 (i) min length of overtaking zone & desired length of taking zone.



$$\text{OSD} = d_1 + d_2 + d_3$$

$$d_1 = V_b t$$

$$= \left(\frac{50}{3.6} \right) \times 2$$

$$= 27.77 \text{ m}$$

$$d_2 = V_b T + 2S$$

$$T = \sqrt{\frac{4S}{a}}$$

$$S = 0.2 \times 50 + 6$$

$$= 16 \text{ m}$$

$$T = \sqrt{\frac{4 \times 16}{3}}$$

$$T = 8 \text{ sec}$$

$$d_2 = \left(\frac{50}{3.6} \right) \times 8 + 2 \times 16 = 143.11 \text{ m}$$

$$d_3 = V_o T = \left(\frac{60}{3.6} \right) \times 8 = 133.33 \text{ m}$$

$$OSD = d_1 + d_2 + d_3$$

$$= 27.77 + 143.11 + 133.33$$

$$= 304.21 \text{ m}$$

Min^m length of overtaking zone

$$3 \times OSD = 3 \times 304.21$$

$$= 912.63 \text{ m}$$

desired length of overtaking zone

$$5 \times OSD = 5 \times 304.21$$

$$= 1521.05 \text{ m} \text{ : Ans}$$

20 May 2021

36. Calculate the shape safe overtaking sight distance for a design speed of 96 km/h. Assume all other data suitable.

Solⁿ

$$OSD = d_1 + d_2 \text{ for one way traffic}$$

$$OSD = d_1 + d_2 + d_3 \text{ for two way traffic}$$

speed of overtaking vehicle

$$V_a = 96 \text{ km/h}$$

speed of overtaken vehicle

$$V_b = V_a - 16 \text{ km/h}$$

$$= 96 - 16 \text{ km/h}$$

$$= 80 \text{ km/h}$$

$$d_1 = V_b t_R$$

$$= \left(\frac{80}{3.6} \right) \times 2 = 44.44 \text{ m.}$$

$$d_2 = V_b T + 2S$$

$$S = 0.2 + V_b + 6$$

$$= 0.2 + 80 + 6 = 86.2 \text{ m.}$$

$$a = 1 \text{ m/sec}^2$$

$$T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 86.2}{1}} = 18.74 \text{ sec}$$

$$d_2 = V_b T + 2S = \left(\frac{80}{3.6} \right) \times 18.74 + 2 \times 86.2 = 444.44 \text{ m.}$$

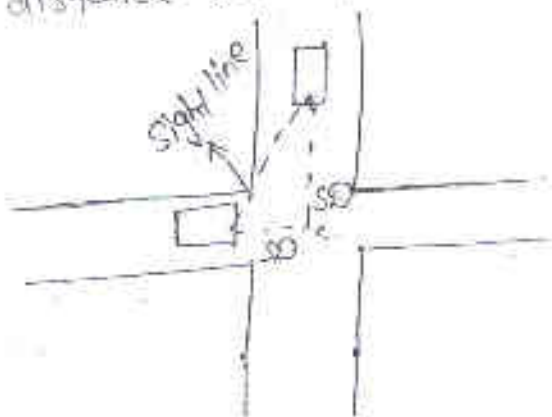
$$d_3 = V_c T = \left(\frac{96}{3.6} \right) \times 18.74 = 496.88 \text{ m.}$$

$$\text{OSD on one way traffic road} = d_1 + d_2 = 44.44 + 444.44 = 488.88 \text{ m.}$$

$$\text{OSD on two way traffic road} = d_1 + d_2 + d_3 = 44.44 + 444.44 + 496.88 = 985.76 \text{ m.}$$

(3) safe sight distance on uncontrolled intersection: ————

> The sight distance needed by the driver of a vehicle to see another vehicle approaching the intersection reacts and applying the breaks to bring his vehicle to stop at the intersection without any collision or accident is called as safe sight distance at intersection.



> The sight distance at intersection should be sufficient to satisfy the following conditions.

(i) To enable vehicle to change its speed.

(ii) To enable vehicle to stop.

(iii) To enable stopped vehicle to cross a main road.

(1) Enabling the approaching vehicle to change speed: ————— o o o o o o ————— o o o o —————

> The sight distance should be sufficient to enable either one or both the approaching vehicles to change the speed to avoid collision.

> The vehicle approaching from the minor road should slow down.

> The total reaction time required for the driver to decide to change speed may be assumed as two seconds & at least one more sec. will be needed for making the change in speed.

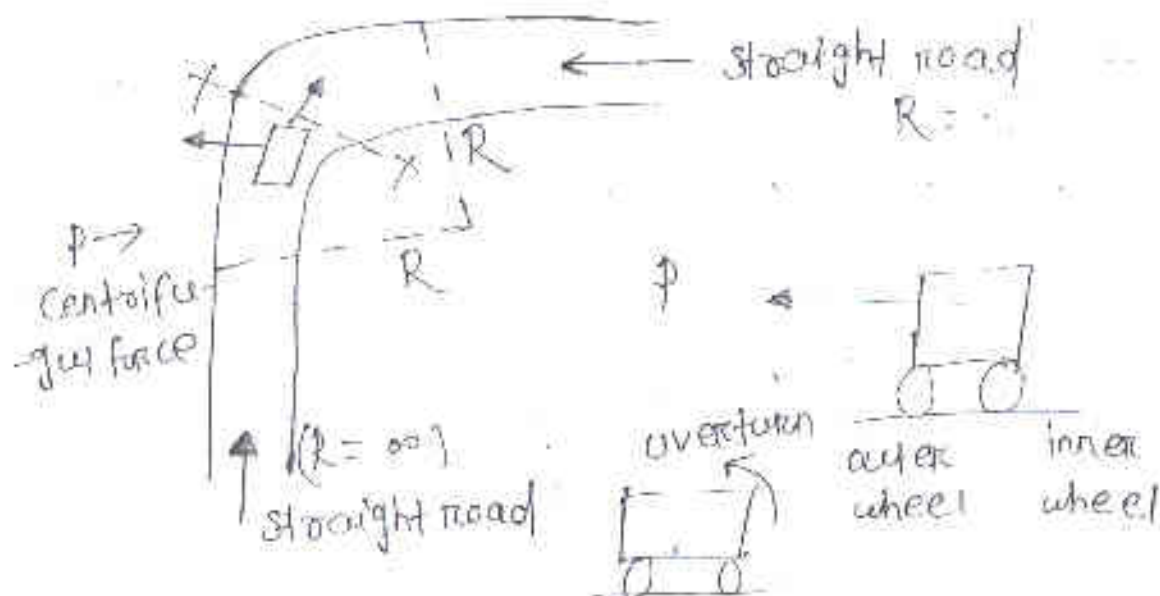
Horizontal alignment details: ————— 21 May 21

Horizontal curve: ————— o o o o o o —————

When a vehicle moves in horizontal curve. Centrifugal force act horizontally outwards through C.G of the vehicle, which cause two effects.

(i) Overturning the vehicle about outer wheel

(ii) Skid the vehicle laterally outward.



Centrifugal force

$$p = \frac{mv^2}{R}$$

$$\Rightarrow p = \frac{wv^2}{gR}$$

$$\Rightarrow \frac{p}{w} = \frac{v^2}{gR}$$

$$\begin{cases} w = mg \\ m = \frac{w}{g} \end{cases}$$

$\frac{p}{w} \rightarrow$ centrifugal reaction / impact factor.

Road $\rightarrow \frac{p}{w} = \frac{1}{4}$, Railway $\rightarrow \frac{1}{8}$

$$p = \frac{mv^2}{R}$$

$$p \propto \frac{1}{R}$$

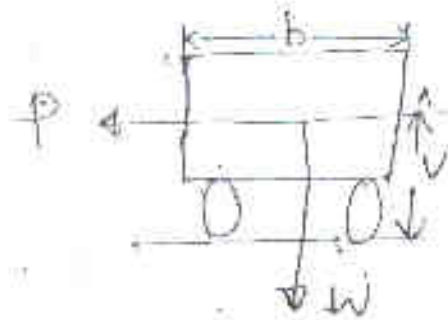
$R \rightarrow$ more $\rightarrow$ wide curve
(p-less)

$R \rightarrow$ less $\rightarrow$ sharp curve
(p-more)



overturning effect -

Taking moment of force with respect to outer wheel when vehicle is just about to overturn.



$\frac{P}{W} \rightarrow$ centrifugal ratio / impact factor

Road $\rightarrow \frac{P}{W} = \frac{1}{4}$, Railway $\rightarrow \frac{1}{8}$

$$P = \frac{mv^2}{R}$$

$$P \propto \frac{1}{R}$$

$R \rightarrow$ more $\rightarrow$

Taking moment of forces about outer wheel

$P \times h = W \times \frac{b}{2} \rightarrow$ Resisting moment.
overturning moment

$$\Rightarrow \frac{P}{W} = \frac{b}{2h}$$

$$\Rightarrow \frac{P}{W} = \frac{v^2}{gR} = \frac{b}{2h}$$

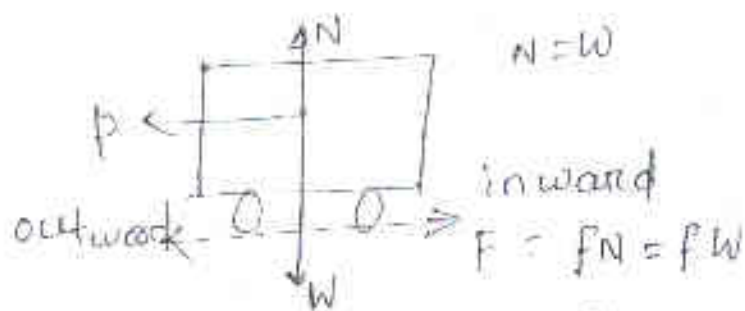
Hence for vehicle to be safe in overturning

$$\left(\frac{P}{W} = \frac{v^2}{gR} \right) \leq \frac{b}{2h}$$

$b \rightarrow$ gap betⁿ inner and outer wheel.

$h \rightarrow$ height of C.G. of the vehicle.

Lateral skidding :-



So lateral force (outward) is balanced
by friction force (inward) to avoid
skidding $p = F$
 $p = fW$

$$\Rightarrow \frac{p}{W} = f$$

$$\Rightarrow \frac{p}{W} = \frac{v^2}{gR} = f$$

to be safe in lateral skidding,

$$\left(\frac{p}{W} = \frac{v^2}{gR} \right) \leq f \rightarrow \text{Co-efficient of Lateral friction.}$$

(3) To be safe in overturning and skidding too

$$\left(\frac{p}{W} = \frac{v^2}{2g} \right) \leq \frac{b}{2h} \cdot 2f$$

1Q Braking distance of a vehicle is thrice when it travels down gradient on the same road as compared to up gradient find gradient (if $f = 0.4$)

$$+ \rightarrow \text{up gradient } s = \frac{v^2}{2g(f+r)}$$

$$- \rightarrow \text{down gradient } s = \frac{v^2}{2g(f-r)}$$

$$\frac{3v^2}{2g(f+x)} = \frac{v^2}{2g(f-x)}$$

$$\Rightarrow \frac{3}{f+x} = \frac{1}{f-x}$$

$$\Rightarrow 3(f-x) = f+x$$

$$\Rightarrow 3f - 3x = f + x$$

$$\Rightarrow 2f = 4x$$

$$\Rightarrow 4x = 2f$$

$$\Rightarrow x = \frac{f}{2} = \frac{0.4}{2} = 0.2$$

12 May 2021

Q3 The driver of a vehicle traveling at mph up gradient requires 9m less as compared to down gradient up the same road after he applies brakes which is gradient of 1

+ve $\rightarrow$ up gradient $\frac{v^2}{2g(f+x)}$ - braking distance

-ve $\rightarrow$ down $\frac{v^2}{2g(f-x)}$

$$\frac{v^2}{2g(f+x)} + 9 = \frac{v^2}{2g(f-x)}$$

$$\Rightarrow \frac{v^2}{2g(f+x)} - \frac{v^2}{2g(f-x)} = -9$$

$$\Rightarrow \frac{v^2}{2g} \left(\frac{1}{f+x} - \frac{1}{f-x} \right) = -9$$

$$\Rightarrow \frac{(60/36)^2}{2 \times 9.81} \times \left(\frac{1}{0.4+x} - \frac{1}{0.4-x} \right) = -9$$

$$\Rightarrow 14.15 \left(\frac{0.4-x-0.4-x}{(0.4+x)(0.4-x)} \right) = -9$$

$$\Rightarrow 14.15 \left(\frac{0.4-x-0.4-x}{0.4^2-x^2} \right) = -9$$

$$\Rightarrow \frac{-2x}{0.16-x^2} = \frac{-9}{14.15} = +0.63$$

$$\Rightarrow -2x = -0.63(0.16-x^2)$$

$$\Rightarrow 2x = 0.63(0.16-x^2)$$

$$\Rightarrow 2x = 0.10 - 0.16x^2$$

$$\Rightarrow +0.63x^2 + 2x - 0.10 = 0$$

$$\Rightarrow 0.63(x^2 + 3.17x - 0.15) = 0$$

$$\Rightarrow x^2 + 3.17x - 0.15 = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$x = 1 \quad b = 3.17 \quad c = -0.15$$

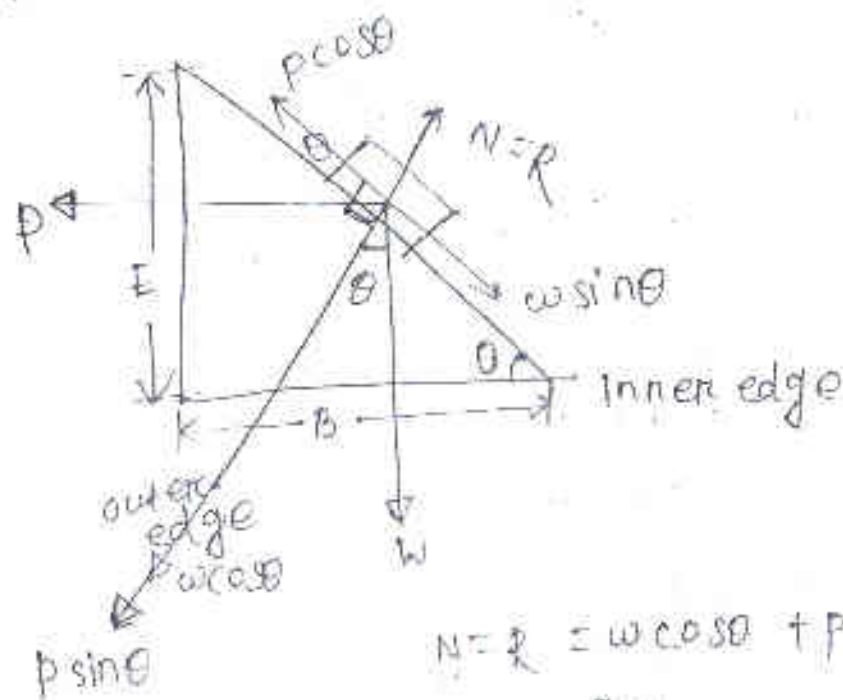
$$x_1 = \frac{-3.17 + \sqrt{3.17^2 - 4 \times 1 \times (-0.15)}}{2 \times 1}$$

$$= 0.04$$

$$\text{gradient} = 4 >$$

Analysis of Super elevation

Then a vehicle moves under a circular curve. A force is acting on the C.G. of vehicle i.e. centrifugal force. In order to reduce the effect of centrifugal force and to reduce the tendency of the vehicle of overturn or skid. The outer edge of the pavement is raised w.r.t. inner edges through out the curve. is called as super elevation.



$$N = R = W \cos \theta + P \sin \theta$$

$$F = \mu N$$

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

$$P \cos \theta = W \sin \theta + F$$

$$\Rightarrow P \cos \theta = W \sin \theta + \mu N$$

$$\Rightarrow P \cos \theta = W \sin \theta + \mu (W \cos \theta + P \sin \theta)$$

$$\Rightarrow P \cos \theta = W \sin \theta + \mu W \cos \theta + \mu P \sin \theta$$

$$\Rightarrow P \cos \theta - \mu P \sin \theta = W \sin \theta + \mu W \cos \theta$$

$$\Rightarrow P \cos \theta (1 - \mu \tan \theta) = W (\sin \theta + \mu \cos \theta)$$

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

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

Dividing by $\cos\theta$

$$\frac{P}{W} = \frac{\tan\theta + f}{1 - f \tan\theta}$$

$$\Rightarrow \boxed{\frac{P}{W} = \frac{v^2}{gR} = \frac{\tan\theta + f}{1 - f \tan\theta}}$$

use when θ has some significant value.

$$\frac{v^2}{gR} = \frac{\tan\theta + f}{1 - f \tan\theta} \quad (f = 0.15)$$

when θ is very very small

$$\tan\theta = \sin\theta = \cos\theta = \theta = e$$

e - (super elevation)

$$\frac{v^2}{gR} = \frac{e + f}{1 - fe}$$

$$f = 0.15$$

$$e = 7\% = 0.07$$

$$fe = 0.01$$

$$\frac{v^2}{gR} = e + f \quad \boxed{e + f = \frac{v^2}{gR}}$$

21 May 2021

where $e \rightarrow$ super elevation

$f \rightarrow$ co-efficient of lateral friction

$v \rightarrow$ speed of vehicle (m/sec) ^(0.15)

$g \rightarrow 9.81 \text{ m/sec}^2$

$R \rightarrow$ Radius of curve (m)

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

where $e = 0$

$$f = \frac{v^2}{gR}$$

$$v = \sqrt{f g R}$$

m/sec

$$(\text{kmph}) = \sqrt{f \cdot (187)^2 R}$$

max^m and min^m super elevation:—

① plane terrain / rolling terrain $\rightarrow 7\%$

② hilly terrain $\rightarrow 10\% = 0.10$

③ urban area / building area $\rightarrow 4\%$

Min^m super elevation:—

$$e_{\min} = \text{cantor}$$

superelevation design:-

(IRC - 38 - 1988)

In a mixed traffic flow, the different vehicle will move with different speed. providing high value of 'e' is uncomfortable for slower vehicle and provided less value of 'e' is uncomfortable for faster moving vehicle. ϕ

Design procedure of superelevation as IRC

Step-1

e is calculated on 75% of design speed.

$$e_{\text{design}} = \frac{0.7V^3}{gR} = \frac{V^3}{225R}$$

$$e_{\text{design}} \leq e_{\text{max}} \rightarrow 0.10 \geq 7\%$$

If design 'e' is less than max^m 'e' (7%)

then stop calculation

e_{design} be the superelevation

If e_{design} value is greater than

e_{max}^m (7%) then provide $e = e_{\text{max}}$ and go to 2nd step.

Step-2 check for friction:

use $e = e_{\text{max}}$ and calculate 'f'

$$e_{\text{max}} + f = \frac{V^3}{225R} = \frac{V^3}{127R}$$

If $f \leq 0.15$, safe and stop design procedure.

If $f > 0.15$, no of safe and go to step-3

step-3 Restrict the speed (by putting $= 7\% \& f = 0.15$)

$$e_{\max} + f = \frac{v^2}{gR} = \frac{v^2}{127R}$$

v is calculated

note:- based on this calculated speed we calculate super elevation 'e' from the eqⁿ $e_{\text{design}} = \frac{v^2}{225R}$

10 The radius of a horizontal circular curve is 100m. the design speed is 50 km/h and design co-efficient of lateral friction > 0.15

(a) Calculate the super elevation if full lateral friction is assumed to develop

(b) calculate the co-efficient of friction needed if no superelevation is provided.

$$\text{Sol}^n \quad e + f = \frac{v^2}{127R}$$

$$\Rightarrow e + 0.15 = \frac{50^2}{127R}$$

$$\Rightarrow e = \frac{50^2}{127 \times 100} - 0.15 = 0.046$$

$$= \frac{1}{21.73}$$

$$= 1 \text{ in } 21.73$$

When $e = 0$

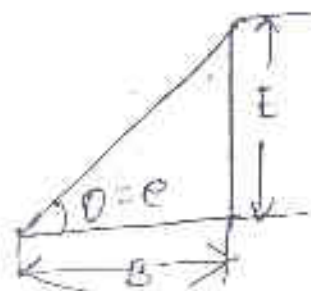
$$e + f = \frac{v^2}{127R} \Rightarrow f = \frac{v^2}{127R}$$

1 June 2021

Q20 A two lane road with design speed 80 km/h has $R = 480 \text{ m}$. Design 'e' for mixed traffic of width of the pavement at horizontal curve is 7.5m. How much should be the outer edge of pavement raised.

$$e = \frac{E}{B}$$

$$E = e \times B$$



Sol

$$e_{\text{design}} = \frac{v^2}{225R}$$

$$= \frac{80^2}{225 \times 480}$$

$$= 0.05$$

$$e_{\text{max}} = 7\% = 0.07$$

$$e_{\text{design}} < e_{\text{max}}$$

$$(0.05) \quad (0.07)$$

$$e_{\text{design}} = 0.05$$

$$\begin{aligned}
 E &= e \times B \\
 &= 0.05 \times 7.5 \\
 &= 0.375 \text{ m.}
 \end{aligned}$$

20 Design the rate of superelevation for a horizontal highway curve $R=500 \text{ m.}$ and speed $= 100 \text{ km/h.}$

Solⁿ step-1

$$e_{\text{design}} = \frac{v^2}{225R} = \frac{100^2}{225 \times 500} = 0.08$$

$$e_{\text{max}} = 7\% = 0.07$$

$$e_{\text{design}} > e_{\text{max}}$$

step-2

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

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

$$e \Rightarrow e_{\text{max}}$$

$$f = \frac{100^2}{127 \times 500} - 0.07$$

$$f = 0.08$$

$$\left[\because f = 0.15 \right]$$

$$f = 0.08 < f = 0.15$$

$$e = e_{\text{max}} \quad f = 0.08 \quad \text{Ans}$$

36 Design speed (v) = 80 km/h

Radius (R) = 200 m (certain locality)

$$f = 0.15$$

(a) calculate e to maintain the speed.

(*) If $e \neq 0.07$ calculate (v_a) as it is not possible to increase the radius.

Step 1

$$e_{\text{design}} = \frac{v^2}{225R}$$
$$= \frac{80^2}{225 \times 200} = 0.14$$

$$e_{\text{max}} = 0.07$$

$$e_{\text{design}} > e_{\text{max}}$$

Step 2

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

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

$$\Rightarrow f = \frac{80^2}{127 \times 200} - 0.07$$

$$\Rightarrow 0.18$$

$$f_{\text{max}} = 0.15$$

$$f_{\text{design}} > f_{\text{max}}$$

Step-3

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

$$\Rightarrow 0.07 + 0.15 = \frac{va^2}{127R}$$

$$\Rightarrow 0.22 \times 127R = va^2 \Rightarrow 27.94R = va^2$$

$$\Rightarrow va = \sqrt{27.94R}$$

$$\Rightarrow va = \sqrt{27.94 \times 200}$$
$$= 074.75 \text{ km/h}$$

$$\boxed{va = 074.75}$$

2 June 2021

extra - widening :-

The object of providing extra widening of pavements on horizontal curves are due to the following two sources :-

- (i) To avoid off tracking: due to rigidity of wheel base.
- (ii) At speed higher than design speed to encounter transverse skidding.
- (iii) To increase the visibility of curve.

$\Rightarrow$ To encounter the psychological overtaking.

Analysis of extra widening on curve:-

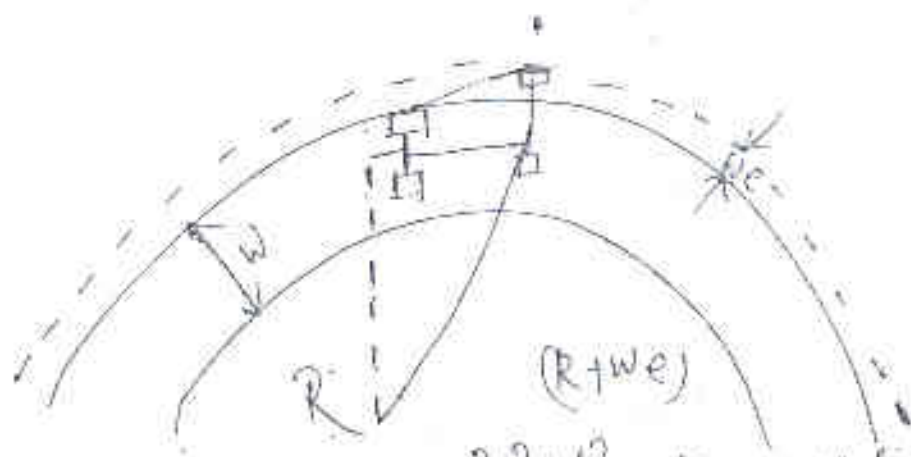
The extra widening of pavement on horizontal curves is divided into two parts.

- (i) Mechanical widening (W_m)
- (ii) Psychological widening (W_p)

$$W_e = W_m + W_p$$

Mechanical widening (W_m) :-

The widening required to account for the offtracking due to the offtracking due to the rigidity of wheel base is called as mechanical widening (W_m).



$$L^2 = 2RW_e$$

$$W_e = \frac{L^2}{2R}$$

↓
offtracking

$$W_e = \frac{L^2}{2R}$$

$$R^2 + L^2 = (R + W_e)^2$$

$$\Rightarrow R^2 + L^2 = R^2 + W_e^2 + 2R \times W_e$$

$W_e \rightarrow$ is very small.

$W_e^2 \rightarrow$ is very small

n = no of between lanes

Δ = length of arc of the vehicle = 5m

R = Radius of curve

w_m = mechanical widening.

Psychological widening :-

$$w_p = \frac{V}{9.5R}$$

V $\rightarrow$ speed in km/h

R $\rightarrow$ Radius in m

$$w_e = \frac{n\Delta^2}{2R} + \frac{V}{9.5R}$$

NOTE :-

(i) If only mechanical widening is given asking total extra widening.

Equation $\frac{\Delta^2}{2R}$ = mechanical widening

R = calculate

$$w_e = \frac{n\Delta^2}{2R} + \frac{V}{9.5R}$$

(ii) Generally provide $\left(\frac{w_e}{2}\right)$ on both side equally $50m \leq R \leq 300m$.

(iii) If $R < 50m$ (sharp bend) total extra widening is only on inner side.

(iv) If $R > 300m \rightarrow$ Then extra widening may be omitted.

⑥ on a single lane road only mechanical extra widening is provided.

10 Calculate the extra widening required for a pavement of width 7m on horizontal curve of radius 250m. if the longest wheel base of vehicle expected on the road is 7.0m design speed is 70 km/h compare the value obtained with IRC recommendation.

Soln External widening required.

$$W_e = W_m \cdot \tau \cdot W_p \cdot S$$

$$= \frac{nL^2}{2R} + \frac{V}{9.5VR}$$

$n = 2$ (two lanes for pavement width 7.0m)

$$R = 250$$

$$V = 70 \text{ km/h}$$

$$L = 7.0 \text{ m}$$

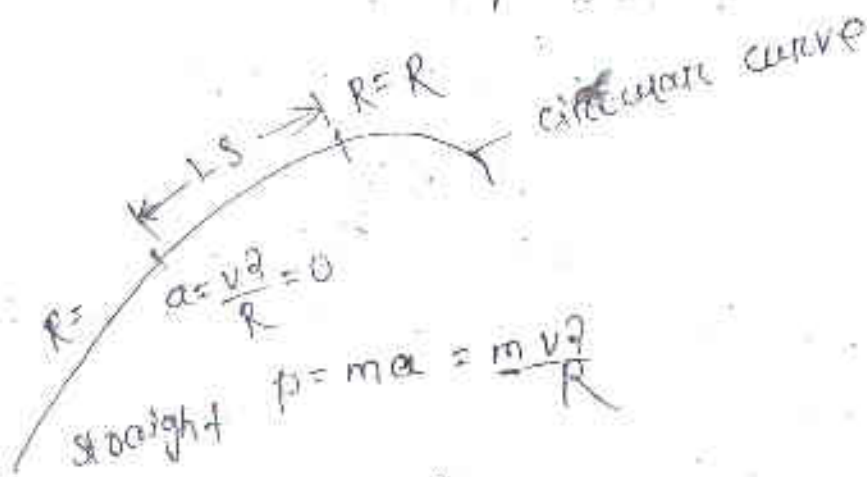
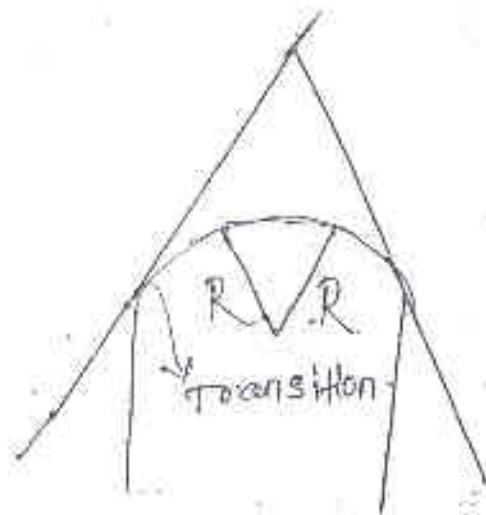
$$W_e = \frac{nL^2}{2R} + \frac{V}{9.5VR} = \frac{2 \times 7^2}{2 \times 250} + \frac{70}{9.5 \times 250}$$

$$\text{IRC } W_e = 0.6$$

$$= 0.66 \text{ m}$$

Radius of curve	up to 200	20 to 400	41 to 600	61 to 1000	100 to 3000	above 3000
extra width in m.						
Two lane	1.5	1.5	1.2	0.9	0.6	NIL
Single lane	0.9	0.6	0.6	NIL	NIL	NIL

Transition curve diagram



$$R \rightarrow \infty \rightarrow a = 0$$

$$R \rightarrow R \rightarrow a = \frac{v^2}{R}$$

Rate of change of radial acceleration:-

$$(C) = \frac{d\vec{a}}{dt} = \frac{d}{dt} \left(\frac{v^2}{R} - 0 \right)$$

$$Jerk = \frac{\left(\frac{v^2}{R} - 0 \right)}{LS/v}$$

$$C = \frac{v^3}{LSR} \Rightarrow LS = \frac{v^3}{CR} \cdot \frac{m/sec}{m}$$

$$0.5 \leq C \leq 0.8$$

$$C = \frac{80}{m/sec^3 \cdot 10 + V_{kmph}}$$

Transition curve :-

- A curve having varying radius is known as transition curve.
- It is curve of radius of changes gradually from m to R .
- It is provided between straight and circular curve for the following objects :-

- (i) To gradually introduce centrifugal force to avoid jerk.
- (ii) Comfort and security of driver.
- (iii) For gradual introduction of super elevation and extra widening.
- (iv) To improve aesthetic appearance.

Calculation of length of transition curve :-

- (i) Based on the change of radial acceleration.

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- (ii) As per rate of change of super elevation
Length of transition curve.

(a) $L_s = 150x \rightarrow$ Plain / Rolling terrain.

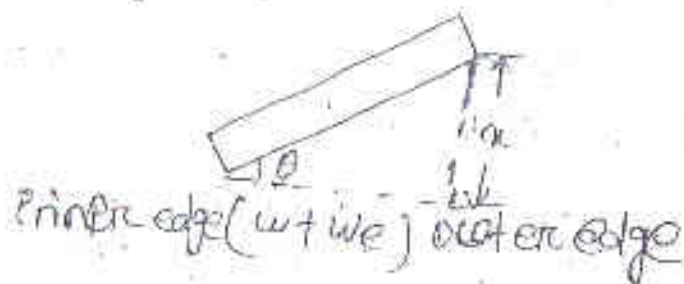
(b) $L_s = 100x \rightarrow$ Building area.

(c) $L_s = 60x \rightarrow$ Hilly Area.

$x \rightarrow$ rate of outer edge.

Case - I

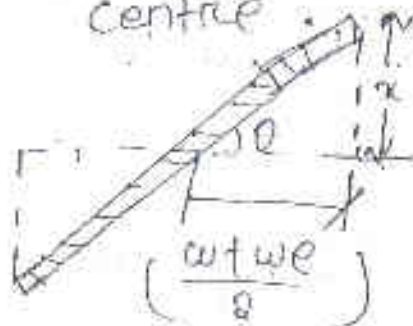
When pavement is rotated about edge e .



$$e = \tan \theta = \frac{x}{(w + we)}$$

$$\Rightarrow x = e (w + we)$$

Case - II when pavement rotated about centre



$$e = \tan \theta = \frac{x}{\left(\frac{w + we}{2}\right)} \Rightarrow x = e \left(\frac{w + we}{2}\right)$$

As per empirical formula:—

$$L_s \text{ (m)} = 2.7 \frac{v^3}{R} \text{ (Plain / Rolling terrain)}$$

$$L_s \text{ (m)} = \frac{v^3}{R} \text{ (Hilly terrain)}$$

$$\left\{ \begin{array}{l} v \rightarrow \text{km/h} \\ R \rightarrow \text{m} \end{array} \right\}$$

NOTE

Max^m of above three criteria should be at least provided as a length of transition curve.

Idea form of transition curve - spiral

Q1 Find the length of transition curve and extra widening required on a horizontal curve of radius 300m of two lane High way passing through rolling terrain for design speed of 80 km/h.
(Assume pavement is rotated about inner edge)

Solⁿ Data given:-

Design speed (V) = 80 km/h

Radius of curve (R) = 300m

two lane highway (n) = 2

length of wheel base of the vehicle (L) = 6m.

Width of road = 7m.

For rolling terrain $e = 7\% = 0.07$

$$W_e = W_m + W_p$$

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

$$W_e = \frac{2 \times 6^2}{2 \times 300} + \frac{80}{9.5\sqrt{300}}$$

$$= 0.6m$$

Length of transition curve:-

(1) Based on rate of change radial acceleration.

$$C = \frac{80}{75+V} = \frac{80}{75+80} = 0.516 \text{ m/sec}^3$$

$$0.5 \leq C \leq 0.8$$

$$L_s = \frac{V^3}{CR} \rightarrow \text{m/sec}$$

$$= \frac{\left(\frac{80}{3.6}\right)^3}{0.516 \times 300} = 70.8 \text{ m.}$$

(ii) Based on superelevation:-
 ----- o o o o o -----

Length of transition curve

$$L_s = 156 \times$$

pavement rotated about inner edge

$$e = e(w + w_e) = 0.07(7 + 0.6)$$

$$= 0.532 \text{ m.}$$

put the value of 'e' in the equation

$$L_s = 156 \times e$$

$$= 156 \times 0.532$$

$$= 79.8 \text{ m.}$$

(iii) Based on empirical formula

$$L_s = 2.7 \frac{V^3}{R}$$

$$= 2.7 \times \frac{80^3}{300} = 57.6 \text{ m.}$$

$$L_s = \begin{cases} 70.89 \text{ m.} \\ 79.80 \text{ m.} \\ 57.60 \text{ m.} \end{cases}$$

So the length of transition curve
 = 79.80 m.

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Shift of Curve :-

When there is no transition curve in b/w straight and circular portion. Then circular curve has to be shift below to introduce transition in between circular curve and straight path.

→ shift is denoted by S

$$S = \frac{L_s^2}{24R}$$

where $L_s \rightarrow$ length of transition curve in m.

$R \rightarrow$ Radius of curve in m.

Q

$$S = \frac{L_s^2}{24R} = \frac{79.80^2}{24 \times 300} = 0.88 \text{ m.}$$

10 calculate the length of transition curve and shift using the following data.

Design speed = 65 km/h

Radius of curve = 220 m.

pavement rotated about centre line
= 1 in 156

pavement including extra widening
= 7.5 m.

Solⁿ

Step-1

$$C = \frac{80}{75 + V} = \frac{80}{75 + 65} = 0.57 \text{ m/sec}^2$$

The value of C lies between 0.5 to 0.8 so C is accepted.

$$L_s = \frac{V^3}{CR} = \frac{\left(\frac{65}{3.6}\right)^3}{0.57 \times 220} = 46.93 \text{ m.}$$

Step 2

super elevation rate

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

$$= \frac{65^2}{225 \times 220} = 0.085$$

$$e_{\text{cal}} > e_{\text{allowable}}, \text{ so } e = 0.07$$

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

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

$$\Rightarrow f = \frac{65^2}{127 \times 220} - 0.07 = 0.08 < 0.15$$

$$f = 0.08, e = 0.07, V = 65 \text{ km/h}$$

$$B = 7.5 \text{ m (w.t.w.e)}$$

$$x = \left(\frac{w + w_e}{2}\right)e = \frac{7.5}{2} \times 0.07$$

$$= 0.26$$

Rate of introduction of super elevation

$$1 \text{ in } 150 = 150 \times x$$

$$L_s = 150 \times 0.26 = 39 \text{ m.}$$

Step-3

$$L_s = \frac{2.7 v^2}{R}$$
$$= \frac{2.7 \times 65^2}{220} = 51.85 \text{ m.}$$

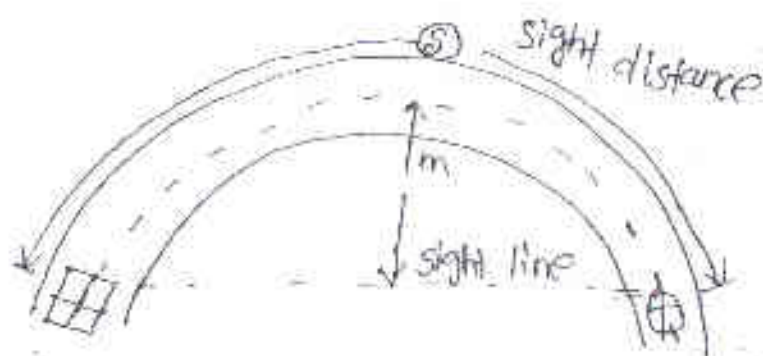
So length of transition curve

$$\therefore L_s = 51.85 \text{ m.}$$

Step-4

$$\text{Shift (S)} = \frac{L_s^2}{24R} = \frac{51.85^2}{24 \times 220} = 0.50 \text{ m.}$$

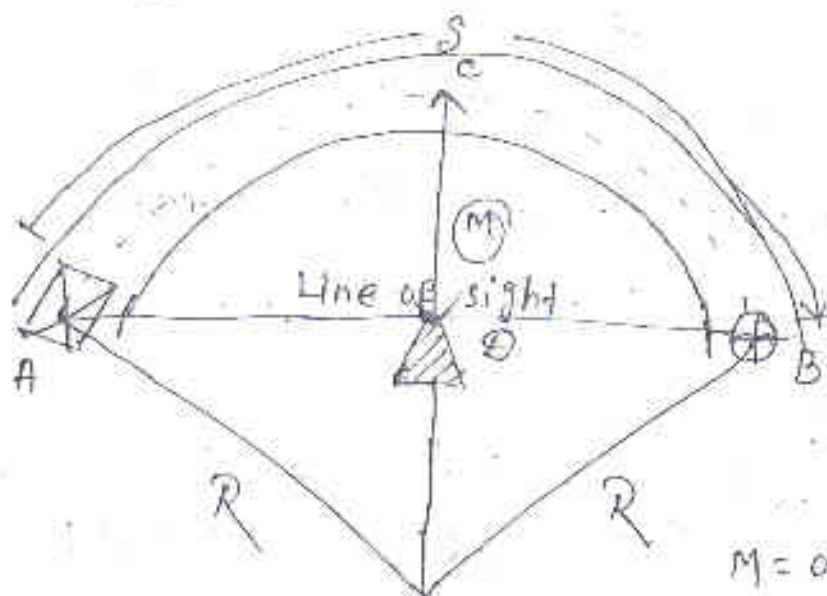
Set back distance on horizontal curve (clearance)



→ maximum distance to be maintained from centre of the road to any obstruction on inner side. So that visible distance shouldn't be less than sight distance for which set back is to be designed.

→ Set back is always measured from centre of the road.

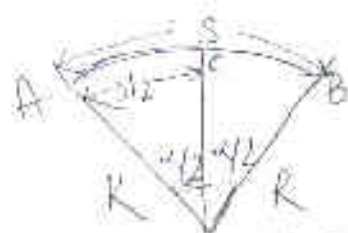
Case-1 (single lane road $L_c > S$)



Setback $e\theta(M)$ =

Formula

$$\begin{aligned} M &= OC - OD \\ &= R - R \cos \frac{\alpha}{2} \\ &= R \left(1 - \cos \frac{\alpha}{2} \right) \end{aligned}$$



$$R \frac{\alpha}{2} = \frac{S}{2}$$

$$\Rightarrow \frac{\alpha}{2} = \frac{S}{2R} \text{ radian}$$

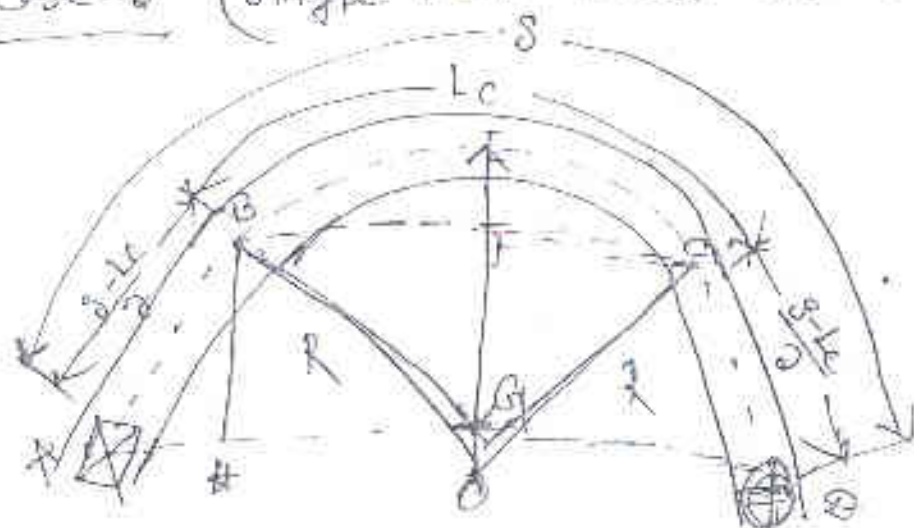
$$\Rightarrow \frac{\alpha}{2} = \frac{S}{2R} \times \frac{180^\circ}{\pi}$$

single lane $L_c > S$

$$\text{Setback}(M) = R \left(1 - \cos \frac{\alpha}{2} \right)$$

$$\frac{\alpha}{2} = \frac{S}{2R} \times \frac{180}{\pi}$$

Case-2 (single lane road $L_c < S$)



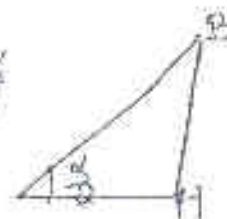
$$EG = EP + FG$$

$$= (OE - OF) + FG$$

$$= (OE - OF) + BH$$

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

$$M = R \left(1 - \cos \frac{\alpha}{2} \right) + \left(\frac{S - Lc}{2} \right) \sin \frac{\alpha}{2}$$



$$BH = \left(\frac{S - Lc}{2} \right) \times \sin \frac{\alpha}{2}$$

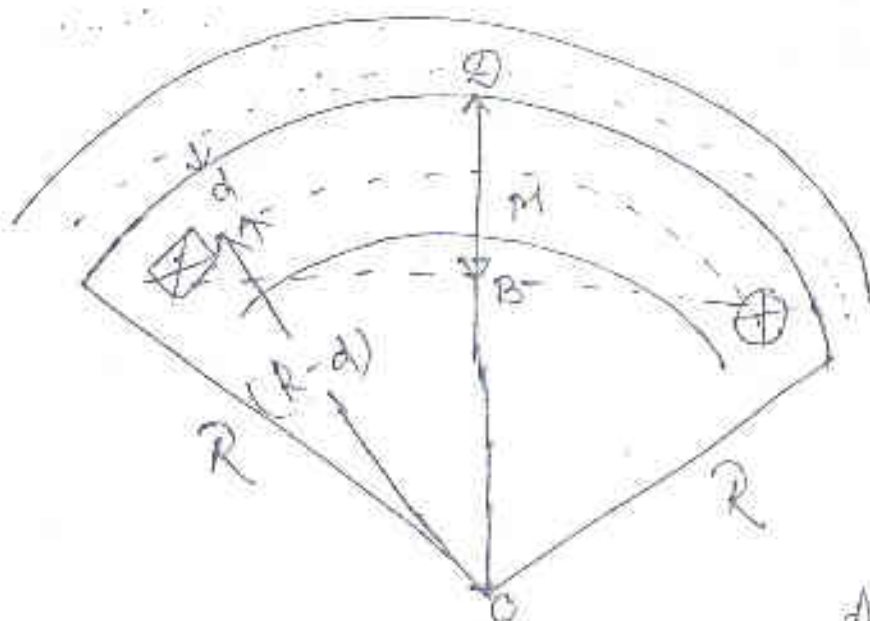
To calculate 'α'

$$R \cdot \frac{\alpha}{2} = \frac{Lc}{2}$$

$$\frac{\alpha}{2} = \frac{Lc}{2R} \text{ radian}$$

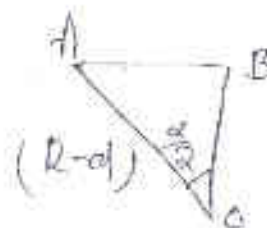
$$\Rightarrow \frac{\alpha}{2} = \frac{Lc}{2R} \times \frac{180^\circ}{\pi}$$

Case-3 (Double Lane Road $Lc > S$)



$$BD = OD - OB$$

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



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Set back from centre inner lane

$$EB = BD - ED$$

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

Set back $BD = OD - OB$

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

from centre of road.

$$\Rightarrow EB = BD - ED$$

Case - iv

double lane road ($L < S$)

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

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

Ex If a vehicle is running on a 2 lane highway of 7.5m on a 300m curve, if SSD is 80m and length of curve is 300m. Find set back distance.

Solⁿ Given data:-

Length of curve (L) = 300m.

SSD = 80m.

Width of the road = 7.5m.

Radius of curve (R) = 300m.

$L < S$

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

$$= \frac{7.5}{2} = \frac{S}{2(R-d)} \times \frac{180^\circ}{\pi}$$

$$= 1.88^{\circ}$$

width of the road is given $d = \frac{w}{4} = \frac{7.5}{4} = 1.875$

width of the road is not given

$$d = \left(\frac{w + 100}{4} \right)$$

$$M = 300 - (300 + 1.875) \cos 7.68^{\circ}$$

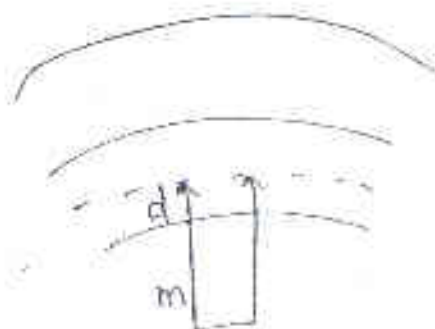
$$= 4.95 \text{ m.}$$

Q2

There is a horizontal highway curve of radius 400m and length 800m. On this highway, compute the set back distance required from the centre line on the inner side of the curve so as to provide for safe overtaking sight distance of 300m.

The distance betⁿ the centre line of the road and the inner lane = 1.9m.

Soln



Given data:-

$$OSD = 300 \text{ m}$$

$$d = 1.9 \text{ m}$$

$$L_c = 200 \text{ m}$$

$$L_c < S$$

$$L_c < S$$

$$S = 300 \text{ (transition curve OSD)}$$

$$L_c > S$$

$$\Rightarrow p = (R - 1)$$

$$m = R - (R-d) \cos \frac{\alpha}{2} + S - \frac{Lc}{2} \sin \frac{\alpha}{2}$$

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

$$= \frac{\alpha}{2} = \frac{200}{2(400-1.9)} \times \frac{180}{\pi}$$

$$\Rightarrow 14.39^\circ \approx 14.4^\circ$$

$$m = 400 - (400 - 1.9) \cos(14.4^\circ) + \frac{(300-200)}{2}$$

$$\sin(14.4^\circ)$$

$$= 26.84 \text{ m}$$

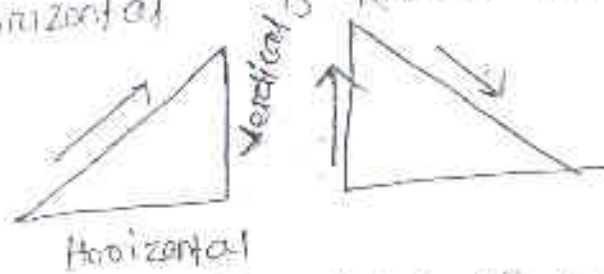
O.S.M
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Vertical curve :-

As we know that the nature of the ground may not be uniform and may consist of different gradient (for instance the rising gradient may be followed by falling gradient and vice-versa). In such cases a parabolic path is provided in vertical plain in order to connect the gradient for easy movement of vehicle.

→ It should be safe and comfortable in operation, pleasing in appearance and adequate in drainage.

Gradient :- The rise or fall along the length of road with respect to horizontal is known as gradient.



There are four type of gradient.

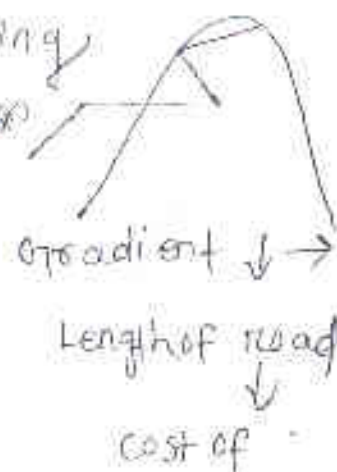
① Falling gradient :- It is the maximum gradient within which designer attempt to design the vertical profile of the road.

~~Ruling gradient~~

(ii) Limiting gradient :-

~~~~~ o o o ~~~~~

- > It is used when ruling gradient results in increase in cost of construction
- > It is steeper than ruling gradient.



Exmp.

(iii) Exceptional gradient

----- o o o -----

- > It is steeper than above two
- > It is provided when situation is unavoidable
- > It will not be provided more than 100m.

(iv) Minimum gradient :- It is provided from

point of view of drainage system.

Concrete surface  $\rightarrow \frac{1}{500}$

Earthen surface  $\rightarrow \frac{1}{200}$

|                                                      | Existing gradient | Minimum gradient | Maximum gradient |
|------------------------------------------------------|-------------------|------------------|------------------|
| ① Plain or rolling terrain - air                     | 3.3%              | 5%               | 6.1%             |
| ② Hilly terrain elevation more than 3m above MSL     | 5%                | 6%               | 7%               |
| ③ Hilly terrain elevation not more than 3m above MSL | 6%                | 7%               | 8%               |

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Grade Compensation:

When sharp horizontal curve is introduced on the road which has already permissible gradient. Then gradient should be decreased for the loss of tractive force due to curve.

→ Grade compensation is required for grade flatter than 4%.

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

→ Maximum compensation allowed =  $\frac{75}{R} \%$

where  $R \rightarrow$  Radius of curve in m.

> Compensated grade = Grade - Grade compensation

> If compensated grade is less than 4%.

take 4% as compensated grade.

Q If ruling gradient is  $\frac{1}{20}$ , what will be the grade compensation and compensated grade for a curve of radius 120m.

Sol into given:-

Radius of curve  $R = 120\text{m}$ .

$$\text{Grade} = \frac{1}{20} = \frac{1}{20} \times 100 = 5\%$$

$$\begin{aligned}\text{Grade Compensation} &= \frac{30 + R}{R} \\ &= \frac{30 + 120}{120} \\ &= 1.25\%\end{aligned}$$

$$\text{Max}^m \text{ Compensation allowed} = \frac{75}{R} = \frac{75}{120} = 0.625\%$$

$$\text{Compensated grade} = \text{Grade} - \text{Max}^m \text{ Grade Compensation}$$

$$5\% - 0.625\% = 4.375\% > 4\%$$

Type of vertical curve (i) Summit curve (ii) valley curve

### Summit curve

- ① Summit curve with convexity upward (∩) may be formed by when intersection lies above the curve

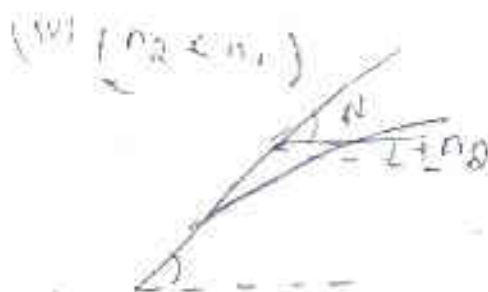


Deviation angle (N)

$$\begin{aligned} & |n_1 - n_2| \\ &= |n_1 - (-n_2)| \\ &= |n_1 + n_2| \end{aligned}$$



$$\begin{aligned} N &= |n_1 - 0| \\ &= n_1 \end{aligned}$$



### valley curve

- ① valley curve with concavity upward (∪) may be formed when intersection lies below the curve.

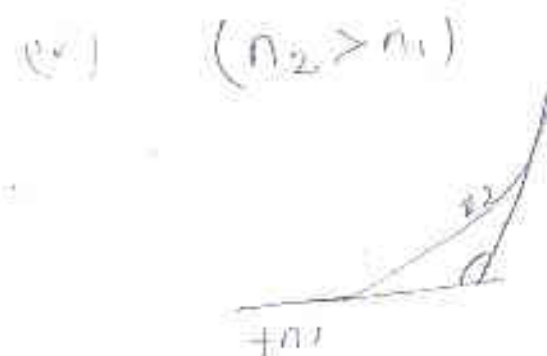


Deviation angle (N)

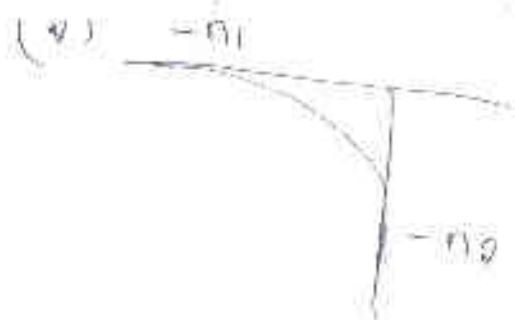
$$\begin{aligned} & |-n_1 - n_2| \\ &= |-n_1 - n_2| \\ &= |-(n_1 + n_2)| \\ &= n_1 + n_2 \end{aligned}$$



$$\begin{aligned} N &= |-n_1 - 0| \\ &= |-n_1| = n_1 \end{aligned}$$

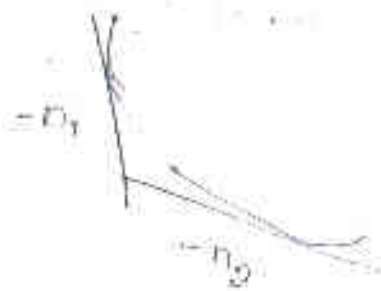


steep of gradient decreases.

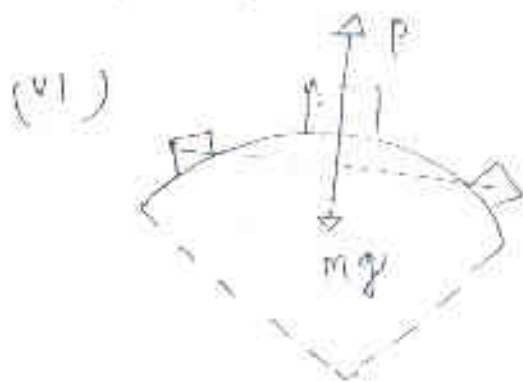


steepness of downward gradient increases.

steeper up gradient



steepness of downward gradient, decreases.



(vii)  $\rightarrow$  No problem of discomfort as weight of vehicle is balance by centrifugal force.

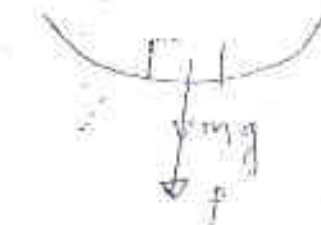
(viii)  $\rightarrow$  No drainage problem

(ix)  $\rightarrow$  Problem of sight distance

(x)  $\rightarrow$  parabolic curve is provided (square parabola)

(xi)  $\rightarrow$  Length of summit curve:-

$$L = \frac{N S^2}{(\sqrt{2h_1} + \sqrt{2h_2})^2}$$



$\rightarrow$  problem of discomfort

$\rightarrow$  drainage problem

$\rightarrow$  No problem of sight distance (only driving night time problem)

$\rightarrow$  Transition curve is provided (cubic parabola)

$\rightarrow$  Length of valley curve:-

$$y = b x^3$$

$$b = \frac{2}{3} \text{ of } \frac{N}{L^2}$$

$$(vi) y = ax^2$$

$$a = \frac{N}{2L}$$

$$N = (n_0 - n_1)$$

$L$  = Length of curve.

Length of <sup>summit</sup> curve

Case - I ( $L > S$ ) (Length of

curve is greater than sight distance)

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

$N$  → deviation angle

$S$  → sight distance

(SSD / OSD / ISD)

$H$  → Height of the drivers eye

$h$  → Height of the object or obstruction

$$(a) \text{ SSD} = S \rightarrow H = 1.2 \text{ m} \quad h = 0.15 \text{ m}$$

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

$$(b) \text{ ISD / OSD} = S \rightarrow H = 1.2 \text{ m} \quad h = 1.2 \text{ m}$$

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

Case - II

Length of curve  $<$  sight distance

( $L < S$ )

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

$$(a) \quad SSD = S \rightarrow H = 1.2m \quad h = 0.15m$$

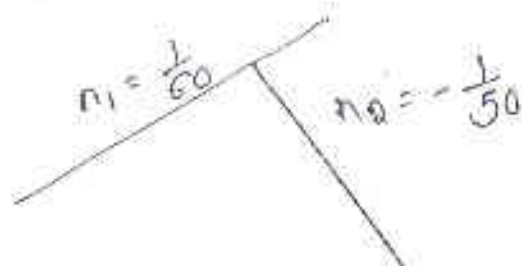
$$L = 2S = \frac{4.4}{N}$$

$$(b) \quad OSD / SSD = S \rightarrow H = 1.2m \quad h = 1.2m$$

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

22 Jun 2021

Q1 An ascending gradient of  $\frac{1}{60}$  meets with descending gradient of  $\frac{1}{50}$ . Find the length of summit curve for SSD of 180 m.



Soln

given data :-

Ascending gradient  $(+n_1) = \frac{1}{60}$

Descending gradient  $(-n_2) = \frac{1}{50}$

stopping sight distance  $(S) = 180m$

$$\text{Deviation angle } (N) = \left| \frac{1}{60} - \left(-\frac{1}{50}\right) \right|$$

$$= \frac{11}{300}$$

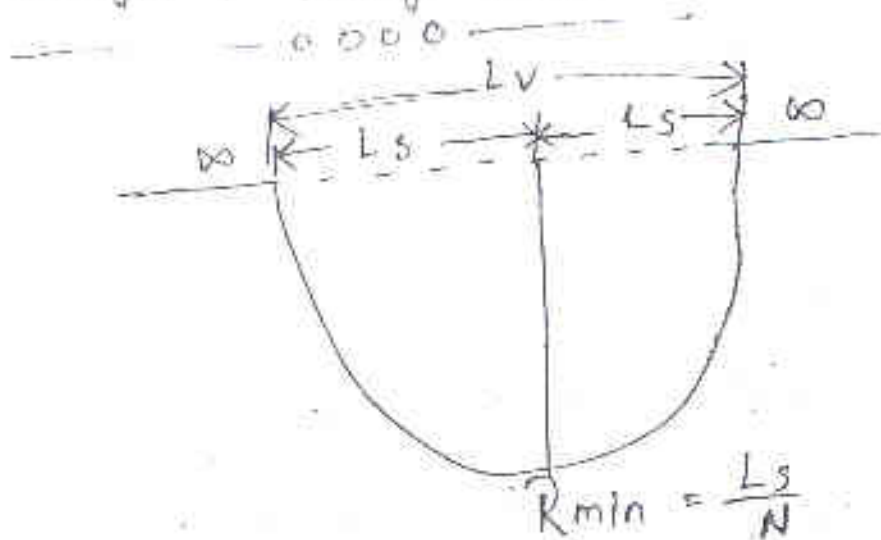
Assume the length of curve is greater than sight distance ( $L > S$ )

$$L = \frac{N S^2}{4.4} = \frac{\frac{11}{300} \times 180^2}{4.4} = 270m$$

$$270 \text{ m} > 180 \text{ m}.$$

Assumption is correct. Length of summit curve 270 m.

Length of valley curve:-



Comfort condition:- Two transition curve is joined back to back to form a valley.

$$L_s = \frac{v^3}{cR} = \frac{v^3}{c(\frac{L_s}{N})}$$

$$\Rightarrow c\left(\frac{L_s}{N}\right)L_s = v^3$$

$$\Rightarrow \frac{cL_s^2}{N} = v^3$$

$$\Rightarrow L_s^2 = \frac{Nv^3}{c}$$

$$\Rightarrow L_s = \sqrt{\frac{Nv^3}{c}}$$

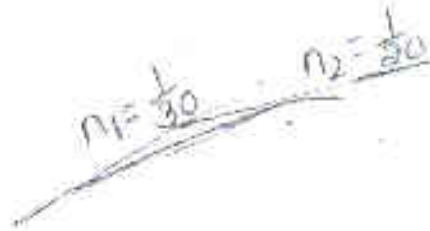
$$L_v = 2L_s = 2\sqrt{\frac{Nv^3}{c}} \text{ m/sec}$$

$N \rightarrow$  deviation angle

$v \rightarrow$  speed of the vehicle in m/sec

c  $\rightarrow$  Rate of change of acceleration (0.6)

Q An ascending gradient of  $\frac{1}{30}$  meets with  
~~an~~ ascending gradient of  $\frac{1}{20}$ . Find the  
length of summit curve for OSD of  
90 m.



Sol Data given:—

$$\text{Ascending gradient } (+n_1) = \frac{1}{30}$$

$$\text{Ascending gradient } (+n_2) = \frac{1}{20}$$

Deviation angle  $\angle \theta(n)$

$$= (+n_1 - (+n_2)) = \left| \frac{1}{30} - \frac{1}{20} \right|$$

$$= 0.16$$

Length of curve is greater than sight  
distance condition:— OSD = S = 90 m.

$$L = \frac{Ns^2}{9.6} = \frac{0.16(90)^2}{9.6} = 135 \text{ m} > 90 \text{ m}$$

Assumption is correct. length of  
summit curve = 135 m. Ans

23 Jun 2021

DIMY SAI RAM

UNIT - 3

Highway materials

Sub-grade (soil as subgrade)

- (i) Subgrade is the layer of pavement whose main function is to support the upper layers of the pavement. and to provide good drainage facility to the infiltrating the rain water.
- (ii) It has to act as a single structure along with other layers of the pavement.
- (iii) Soil is compacted to its max dry density which can be achieved by using the optimum moisture content and the methods of compactions control strength has to be ensured which is required for the given design thickness of the pavement.
- (iv) Strength analysis and the thickness of the pavement are inter-linked because more thickness of the pavement is needed if the soil is weak. but if soil process a good strength, then less thickness is needed.
- (v) This is ensured by using the CBR test. which is produced by the California state highway department.

$$(3) \text{ C.B.R value}(\%) = \frac{\text{Load required for soil sample}}{\text{standard load value for standard aggregate}}$$

$$\text{C.B.R value at 2.5mm} = \frac{\text{load reqd for 2.5mm penetrated} \times 100}{1350 \text{ kg}}$$

$$\text{C.B.R value at 5mm} = \frac{\text{Load required for 5mm penetration}}{2055 \text{ kg}} \times 100$$

> C.B.R value is used for flexural pavement.

> Generally 2.5mm CBR value is more than 5mm C.B.R value. But if 5mm CBR value is more 2.5mm CBR value. Then the test is conducted again and whichever value Combs. Max<sup>m</sup> will be taken as C.B.R.

> C.B.R value is avg of max<sup>m</sup> of C.B.R value 3 specimen.

California bearing ratio test - (CBR test)

> This is a penetration test developed by the California division of highway as a method for evaluating the stability of soil subgrade and other flexible pavement materials.

→ The test results have been corrected with flexible pavement thickness requirement for highway and air fields

25 June 2021

→ The CBR test may be conducted in the Laboratory on a prepared specimen in a both mould or in-situ in the field.

→ The Laboratory CBR apparatus consists of a mould 150mm diameter with a base plate and a collar.

→ A loading frame with the cylindrical plunger of 50mm dia and dial gauges for measuring the expansion on soaking and the penetration value

→ The penetration consists of causing a cylinder plunger of 50mm diameter to penetrate a pavement component material 1.25 mm/min.

→ The load values to cause 2.5mm and 5 mm penetration are recorded.

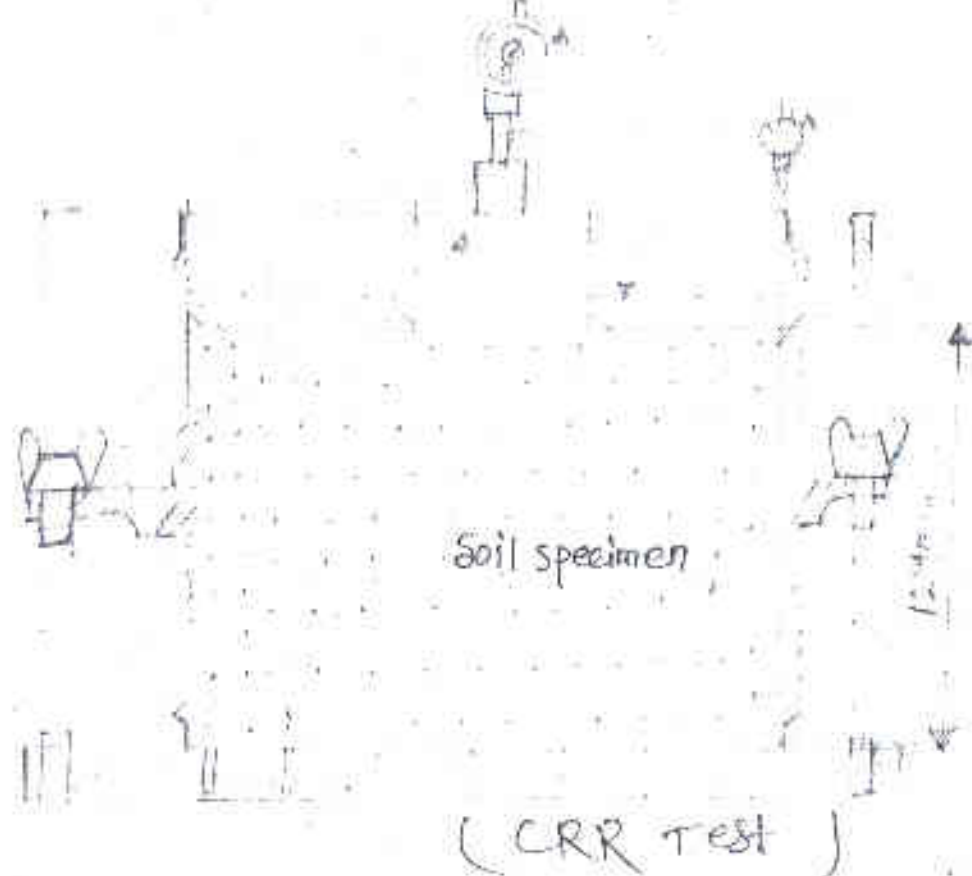
→ These loads are expressed as percentage of standard load values at respective deformation level to obtained CBR value.

→ The standard load values obtained from the from avg. of a large number of tests on crushed stones are 1370 kg and 2055 kg respectively at 2.5 and

## Penetration - Test

The mould containing the specimen, with the base plate in position but the top face exposed, shall be placed on the lower plate of the testing machine. Surcharge weights, sufficient to produce an intensity of loading equal to the weight of the base materials and pavement shall be placed on the specimen. If the specimen has been soaked previously, the surcharge shall be equal to that used during the soaking period. To prevent upheaval of soil into the hole of the surcharge weight 2.5 kg annular weight shall be placed on the soil surface prior to seating the penetration plunger after which the remainder of the surcharge weight shall be placed. The plunger shall be seated under a load of 4 kg so that full contact is established between the surface of the specimen and the plunger. The load and deformation gauges shall then be set to zero (in other words, the initial load applied to the plunger shall be considered as zero when determining the load penetration relation). Load shall be applied to the plunger into the soil at the rate of 1.25 mm per minute. Reading of the shall be taken at penetration of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0 and 12.5 mm (The maximum load and penetration shall be recorded if it occurs for a penetration of ~~less~~ less than 12.5 mm). The plunger shall be raised and the mould detached from the loading equipment. About

20 to 50 g. of soil shall be collected from the top 30 mm layer of the specimen and the water content determined according to IS: 2720 - 1973. If the average water content of the whole specimen is desired, water content sample shall be taken from the entire of the specimen.



Load penetration curve: -

The load penetration curve shall be plotted. This curve is usually convex upwards although the initial portion of the curve may be convex downwards due to surface irregularities. A correction shall then be applied by drawing a tangent to the point of greatest slope and then transposing the

axis of the load so that zero penetration is taken as the point where the tangent cuts the axis of penetration. The corrected load-penetration curve would then consist of the tangent from the new origin to the point of tangency on the re-sited curve and then the curve itself, as illustrated.

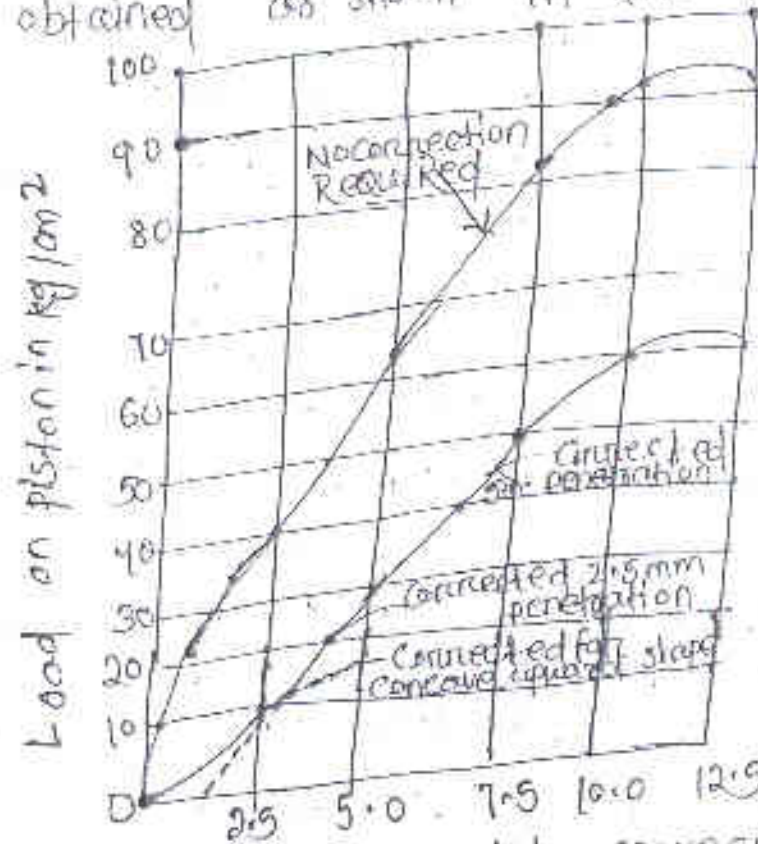
California Bearing ratio :- The CBR values are usually calculated for penetrations of 2.5 and 5 mm corresponding to the penetration value at which the CBR values is desired. connected load value shall be taken from the load penetration curve and the CBR calculated as following California Bearing Ratio

$$= \frac{P_1}{P_3} \times 100$$

26 June 2021

- 26 June 2021
- PS
- The specimen in the mould is subjected to force during soaking and swelling and water absorption values are noted.
- The surcharge weight is placed on the top of the specimen in the mould and the speedily is placed under the prong of the load.
- The load values are noted (corresponding) to the penetration values of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, ... (2.5 mm).

→ The load penetration graph is plotted. Two typical types of curves may be obtained as shown in the fig.



PENETRATION IN MM

→ The curve is with convexity upwards as for specimen - 1 and the load corresponding to 2.5 and 5.0 mm penetration values are noted.

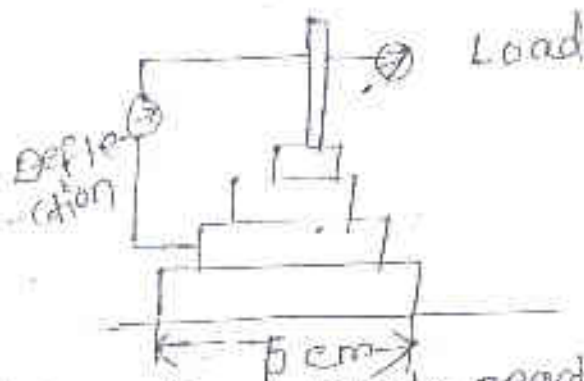
→ The CBR value is calculated as per

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

Load sustained by standard aggregates at the corresponding penetration level

## Plate Bearing Test :-

→ It is carried out on subgrade soil in the field with load bearing area to find power of subgrade and it is represented by modulus of subgrade reaction.



Modulus of subgrade reaction (K)

$$K = \frac{P}{\Delta} = \frac{P}{0.125 \text{ m}} = \text{kg/cm}^3$$

→ standard size of plate = 75 cm  
→ data is used in both flexible and rigid pavement.

Empirical formula to find  $\Delta$  :-

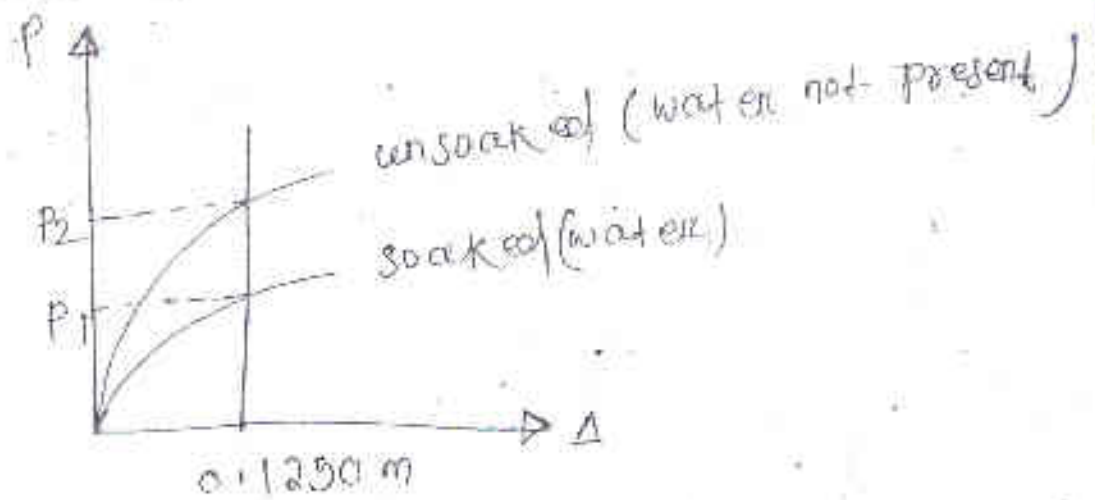
$$\Delta = \frac{1.18 P}{E_s} \rightarrow \text{Rigid plate / plate load test}$$

$$\Delta = \frac{1.5 P A}{E_s} \rightarrow \text{Flexible plate / wheel load test}$$

$a$  → contact radius

$E_s$  → modulus of elasticity of soil subgrade

## Correction to moisture :-



$$k = \frac{P}{\Delta}$$

$$\Rightarrow \Delta = \frac{P}{k} = \text{constant}$$

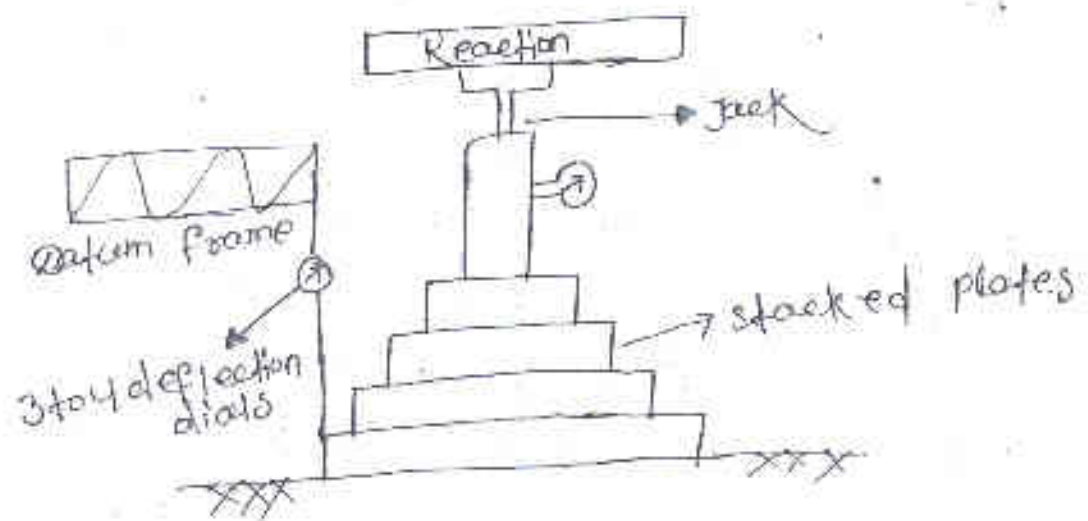
$$\frac{P_v}{k_v} = \frac{P_s}{k_s}$$

## Plate bearing test :- 5 July 2021

- The plate bearing test is used to evaluate the supporting power of subgrade for use in pavement design by using relatively large diameter of plate.
- The plate bearing test is carried out to find out the modulus of subgrade reaction in the westergaard's Analysis for wheel load stresses in cement concrete pavement.
- The test set up consists of a set of plates of diameter 75, 150, 300 and 450 mm. A loading device consisting of

jack and proving ring arrangement and a reaction frame, against which the jack can give a thrust to the plate.

→ A datum frame resting far from the loaded area and dial gauges from this frame are used to measure the settlement of the loaded plate.



Modulus of subgrade reaction :-

Modulus of subgrade reaction ( $K$ ) may be defined as the pressure sustained per unit deformation of subgrade at specified deformation using specified plate.

→ The standard plate size for finding  $K$ -value is 75cm diameter.

→ The test site is levelled and the plate is properly seated on the prepared surface.

→ The stiffening plates of decreasing diameters are placed and the jack and proving ring assembly are fitted to provide reaction against the frame.

→ Three or four dial gauges are fixed on the periphery of the plate from independent datum frame for measuring settlements.

6 July 2021

→ The test site is levelled and the plate is properly seated on the prepared surface. and the jack and proving ring assembly are fitted to provide reaction against the frame.

→ Three or four dial gauge are fixed on the periphery of the plate from the independent datum frame for measuring settlements.

→ A seating load of  $0.07 \text{ kg/cm}^2$  ( $320 \text{ kg}$  for  $750 \text{ mm}$ ) plate is applied and released after a few settling.

→ A load sufficient to cause approximately  $0.25 \text{ mm}$  settlement is applied and when there is no increase in settlement or when the rate of settlement is less than  $0.25 \text{ mm}$ . The reading of settlement is found out and the load is noted from the proving ring dial reading.

$$K = \frac{P}{0.125} \text{ kg/cm}^2$$

## Stone aggregates :-

- Aggregates form the major portion of pavement structure and they form the prime materials used in pavement construction.
- Aggregates have to bear stresses occurring due to the wheel loads on the pavement and on the surface course. They also have to resist wear due to abrasive action of traffic.
- These are used in pavement construction in cement concrete, bituminous concrete and other bituminous constructions.
- Most of the road aggregates are prepared from natural rock. Gravel aggregate are small rounded stones of different sizes which are generally obtained as such from some river beds.
- Sand is fine aggregate from which weathering of rock. The properties of rock from which the aggregates are formed depend on the properties of constituent materials and the nature of bond bet<sup>n</sup> them.
- Based on the origin of rock, are classified as Igneous, sedimentary, metamorphic.
- The aggregate are specified based on their grain size, shape, texture and its gradations.

→ Aggregate size is as contained by sieving through square sieves of successively decreasing sizes.

→ The required aggregate sizes are chosen to fulfill the desired gradation. The grading of different road making purposes have been specified by various agencies like A.S.T.M, B.S.I, I.S.I and the IRC.

Desirable properties of road aggregate.

- (i) Strength
- (ii) Hardness
- (iii) Toughness
- (iv) Durability
- (v) Shape of Aggregates
- (vi) Adhesion with bitumen

1 July 2021

(i) Strength :- The aggregates to be used in road construction should be sufficiently strong to withstand the stresses due to traffic wheel load.

→ The aggregates which are to be used in the top ~~per~~ layer of the pavements particularly in the wearing course have to be capable of withstanding high.

stresses in addition to wear and tear they should possess sufficient strength resistance to crushing.

## (2) Hardness :-

→ The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. So they should be hard enough to resist the wear due to abrasive action of traffic.

→ Abrasive action may be increased due to presence of abrasive material like sand between the tyres of moving vehicles and the aggregates exposed at the top surface.

→ The mutual rubbing of stones is called attrition.

(3) Toughness :- Aggregates in the pavements are also subjected to impact due to moving wheel loads. Sever impact LKp hammering is quite common when heavily loaded steel tyred vehicles move on water bound macadam roads.

→ Jumping of the steel tyred wheels from one stone to another at different level causes severe impact on the stones.

→ The magnitude of impact would increase with the toughness of the road surface.

• vehicular characteristics.

→ The resistance to the impact is another desirable properties of aggregates.

(4) Durability :-

→ The stone used in the pavement construction should be durable and should resist disintegration due to the action of weather.

→ The property of the stones to withstand the adverse action of weather may be called as soundness.

→ The aggregates are subjected to the physical and chemical action of rain ground water etc. Hence it is desirable that the road stones used in the construction should sound enough to withstand the weathering.

(5) Shape of Aggregates :- The size of the aggregates is first qualified by the size of square sieve opening through which an aggregate may pass and not by shape.

→ Aggregates which happen to fall in a size range may have particular shape of particles. rounded, cubical, Angular flaky or elongated shape.

8 July 2021

## Tests for road aggregate :-

The following tests are carried out for road aggregate.

- (i) crushing test
- (ii) Abrasion test
- (iii) Impact test
- (iv) Soundness
- (v) shape test
- (vi) specific gravity and water absorption test.
- (vii) Bitumen adhesion test

### Aggregate crushing test :-

→ The strength of coarse aggregate is determined by aggregate crushing test.

→ The apparatus for standard test consist of a steel cylinder 15.2 cm dia. with a base plate and a plunger, compressive testing machines, cylindrical measure of diameter 11.5 cm and height 18 cm tamping rod and sieves.

→ Dry aggregate passing 12.5 mm sieve and retained on 10 mm sieve is filled in the cylindrical measure in three equal layers.

→ Each layer is tamped with 25 blows. Then the test sample is weighed (w<sub>g</sub>) and placed in the test cylinder in three equal layers tamping each layers 25 times.

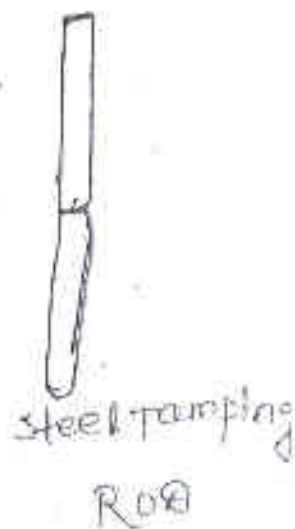
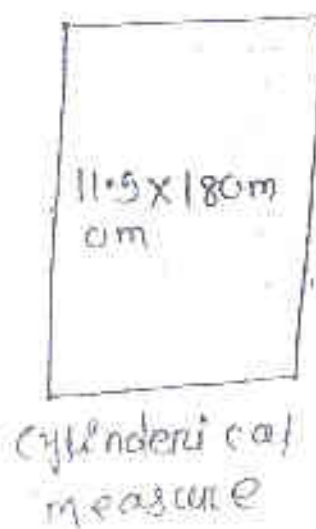
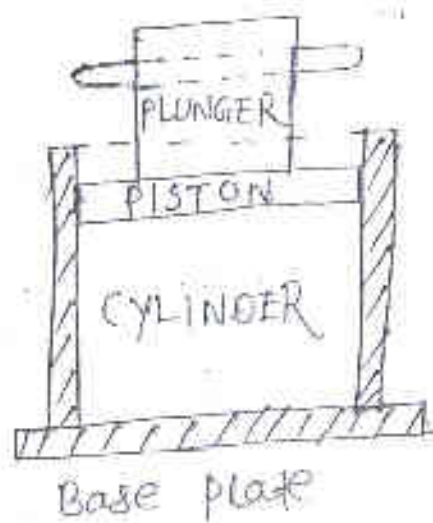
→ The plunger is placed on the top of specimen and a load of 40 tonnes is applied at a rate of 4 tonnes per min by the compression machine.

→ The crushed aggregate is removed and sieved on 2.36 mm sieve. The crushed material which passes this sieve is weighted equal to  $w_2$ .

→ The aggregate crushing value is the % of the crushed material passing 2.36 mm sieve in terms of original weight of the specimen.

$$\text{Aggregate crushing value} = \frac{w_1}{w_2} \times 100$$

→ strong aggregates given low crushing value. the aggregate crushing value for good quality aggregate to be used in the base course shall not be exceed 45% and value for surface course shall be less than 30%.



10 July 2021

### Abrasion tests:-

- Due to the movements of traffic, the road stones used in the surface course are subjected to wearing action at the top.
- Hence road stones should be hard enough to resist the abrasion due to traffic. Abrasion tests are carried out ~~out~~ to check the hardness property of the stone.
- The abrasion test may be carried out any one of the following three tests.

- (i) Los angles abrasion test.
- (ii) Deval abrasion test
- (iii) Dorry abrasion test

### Los angles abrasion tests :-

13 July 2021

- (i) The principle of Los angle abrasion is to find the percentage of wear due to relative rubbing action bet<sup>n</sup> the aggregate and steel balanced as abrasive charge.
- (ii) The Los angles machine consists of a hollow cylinder closed at both ends having inside dia 70 cm and length 50 cm and mounted so as to rotate about its horizontal axis as shown in the fig.
- (iii) The abrasive charge consists of cast iron spheres of approximate diameter of 4.8 cm and each of weights

340 to 410 gm.

(iv) The number of spheres to be used as abrasive charge and their total weight have been specified on the grading of the aggregate sample.

(v) The specified <sup>weight</sup> of aggregate specimen (5 to 10 kg) depending on gradation) is placed on the machine along with the abrasive charge.

(vi) The machine is rotated at a speed of 30 to 33 rpm for the specified number of revolutions.

(vii) The abraded aggregate is then sieved on 1.7mm sieve and the weight of powdered aggregate passing this sieve is found.

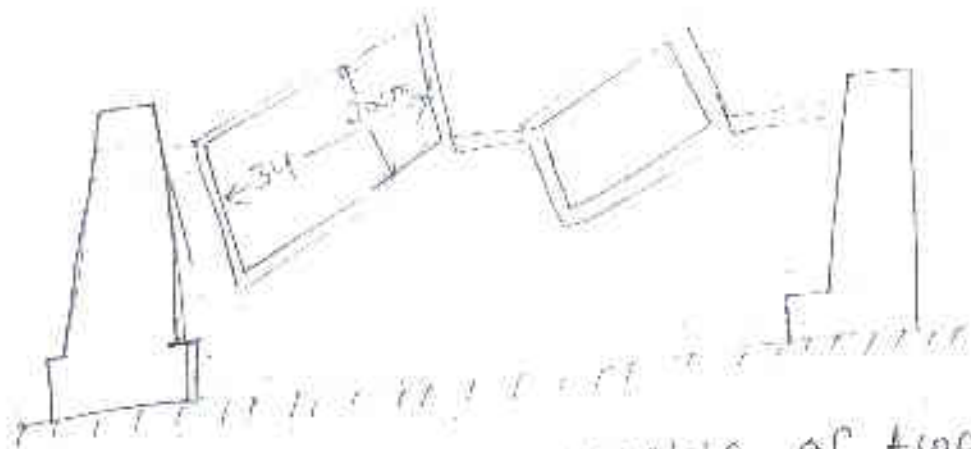
$$\text{Abrasive value} = \frac{\text{weight of aggregate passed on 1.7mm sieve}}{\text{original wt of the sample}} \times 100$$

(viii) The Los angle abrasion value of good aggregates acceptable for cement concrete, bituminous concrete & other high quality pavement materials should be less than 30%.

(ix) values up to 50% are allowed in base course like water bound macadam and bituminous macadam.

14 July 2021

## 2. Deval abrasion test :-



- (i) The Deval machine consists of two hollow cylinders of diameter 30 cm and length 34 cm mounted in such a way that the cylinders rotate about a horizontal axis but the axis of the cylinders make  $30^\circ$  angle with horizontal.
- (ii) Specified quantity of dry aggregate specimen (4 kg to 5 kg) of any one of the specified gradings is placed in the cylinder.
- (iii) The abrasive charge consists of 6 cast iron or steel spheres of about 4.8 cm diameter and total weight 2500 g is placed.
- (iv) Two tests may be carried out simultaneously using both the cylinders. The machine is rotated at a speed of 30 to 33 rpm. After 10,000 revolutions the material is sieved on 17 mm IS sieve. The material passing this sieve is expressed as the percentage of the original wt. of the sample and is reported as abrasion value.

(V) when the test is carried out by Deval machine without using abrasive charges the test is known as Deval abrasion test.

#### (vi) Quarry abrasion test :-

> The abrasion value of aggregate is also determined using quarry abrasion testing machine. This is a British method.

> The machine consists of a flat circular iron disc of 600 mm diameter which is rotated in a horizontal plane at 28 to 30 rpm.

> Two rectangular trays are kept 26 mm from the centre of the disc to hold the aggregate sample in specified manner.

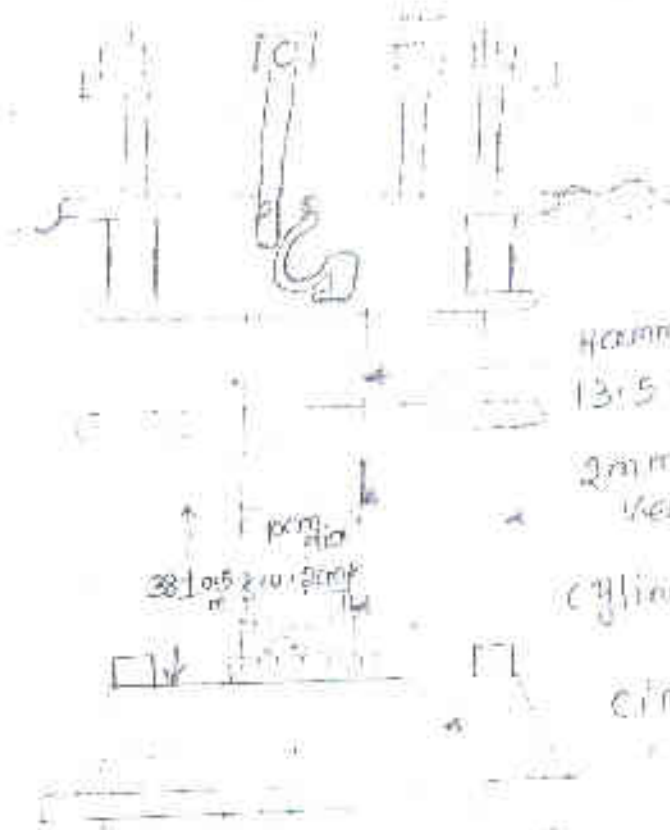
Abrasive sand is fed through the funnel and the disc is subjected to 500 revolutions.

15 July 2021

#### Impact test :-

> A test designed to evaluate the toughness of stone or the resistance of aggregates to fracture under repeated impact is called impact test.

> The aggregate impact test is commonly carried out to evaluate the resistance to impact of aggregates.



Hammer of weight  
13.5 to 14 kg  
2mm chamfer  
vertical guide bar  
cylindrical cup  
circular base

- The aggregate impact testing machine consists of a metallic steel base and cylindrical steel cup of dia 10.2cm and depth 5cm in which the aggregate specimen is placed.
- A metallic hammer of wt of 13.5 - 14kg having a free fall from a height 38cm is arranged to drop the vertical guides.
- Aggregate specimen passing 4.75mm sieve and retained on 10mm sieve is filled in the cylindrical measured in 3 layers by tamping, is layer by 25 blows.
- The sample is transformed from the measured in the cup of the aggregate impact testing machine and tamped compacted by tamping 25 times.
- The hammer is raised to a height of 38cm above the upper surface of the aggregate cup and is allowed to fall freely on the

⇒ After subjecting the test specimen to 15 blows, the crushed aggregate is sieved on 2.36 mm sieve. The impact value is expressed as the percentage fine formed in terms of total aggregate of sample.

⇒ The aggregate impact value for wearing course the pavement should not exceed 30%.

17 July 2021

### Soundness Test :-

⇒ This test is carried out to study the resistance of aggregates to weathering action.

⇒ The resistance to disintegration of aggregate is determined by using saturated solution of sodium sulphate or magnesium sulphate.

Procedure :- Take individual samples in a wire mesh basket and immerse it in the solution of sodium sulphate or magnesium sulphate for not less than 16 hours nor more than 18 hours. In such a manner that the solution covers them to a depth of at least 15 mm.

⇒ After completion of the immersion period remove the samples from solution and allow it to drain for 15 minutes and pre it in drying oven.

→ Dry the sample until it attains a constant mass and then remove it from solution and allow it to drain for  $\downarrow$  and cool it to room temperature.

→ After cooling again immerse it in the solution as described in step-1.

→ The process of alternate immersion and drying is repeated until the specified number of cycles as agreed between the purchaser and the vendor is obtained.

→ After completion of the first cycle and after the sample has been cooled, wash it to free from sodium sulphate or magnesium sulphate solution. This may be determined when there is no reaction of the wash water with barium chloride.

→ Then dry each fraction of the sample to constant temp of  $105$  to  $110^{\circ}\text{C}$  and weight it.

→ Sieve the fine aggregates over the same sieve on which it was retained before test.

→ Sieve the coarse aggregate over the sieve shown below for the appropriate size of particles.

20 July 2021

Specific gravity and water absorption test:-

→ The specific gravity of an aggregate is considered to a measure of the quality or strength of the materials.

→ Stones having low specific gravity values are generally weaker than those having higher values.

### Procedure :-

- A box 2 kg of dry aggregate sample is placed in wire basket and immersed in water for 24 hours.
- Then the sample is weighed in water and the buoyant weight is found.
- The aggregate are then taken out weighed after drying the surface. Then the aggregates are dried in an oven for 24 hours at a temp.  $100-110^{\circ}\text{C}$ .
- Then the dry weight is determined.
- Specific gravity is calculated by dividing the dry weight of aggregate by weight of equal volume of water.
- The water absorption is expressed as the percentage of water absorbed in terms of over dried weight of the aggregate.
- The specific gravity of rocks vary from 2.6 to 2.9 where as the water absorption is not acceptable more than 0.6 percent.

### Bituminous Materials :-

- Bituminous binders used in pavement construction and tar works include both bitumen.
- Bitumen is a petroleum product obtained by the distillation of petroleum.
- where as road tar is obtained by the destructive distillation of coal or wood.

- > Both bitumen and tar have similar appearance black in colour but they have different characteristics.

22 July 2021

Bitumen Bitumen is a petroleum by product obtained by the distillation of petroleum crude oil.

- > It is a black or brown mixture of hydrocarbon.

- > It is insoluble in water.

- > Bitumen contains:-

i) Carbon (87%)

ii) Hydrogen (11%)

iii) Oxygen (2%)

- > S.G. gravity of bitumen  $\rightarrow 0.97$  to  $1.03$

- > Bituminous materials or asphalts are used for road way construction primarily because of their excellent binding characteristics and water proofing properties and relatively low cost.

- > When the bitumen contains some inert material or mineral. Sometimes called asphalt.

- > In India good bitumen suitable for road work is obtained from assam petroleum.

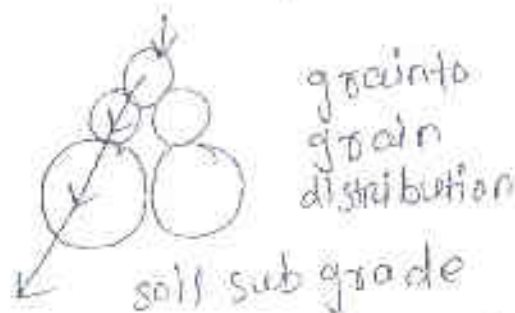
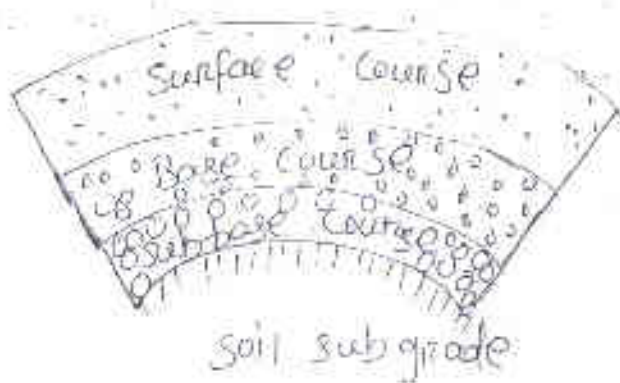
Pavements are generally classified into two categories ① Flexible pavement

② Rigid pavement

23 July 2021

### Flexible pavement

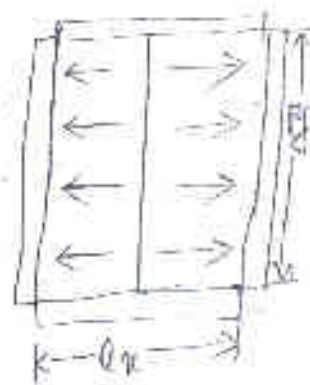
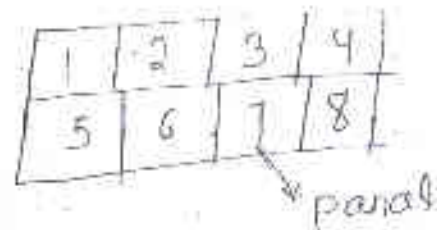
- (i) The life span is 15 yrs.
- (ii) Bitumen is used as binding material.
- (iii) The load is transferred through grain to grain distribution



- (iv) Initial cost is less but maintenance cost is high.
- (v) It takes less load.
- (vi) Thickness more

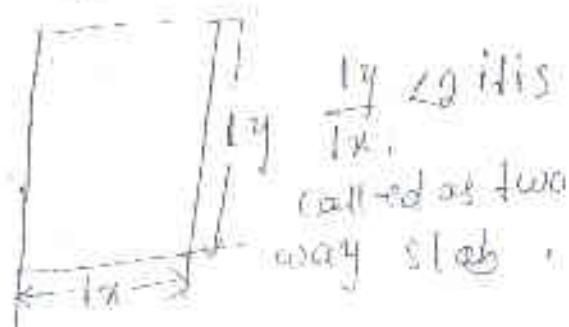
### Rigid pavement

- (i) The life span is 30 yrs.
- (ii) Concrete is used as binding material.
- (iii) Slab action takes place.

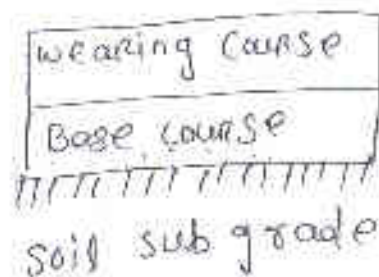


$\frac{l_y}{l_x} > 2 =$  one way slab

$l_y \rightarrow$  longer span  
 $l_x \rightarrow$  shorter span



- (ii) Joints are not required.
- (iv) Initial cost is high but maintenance cost is less.
- (v) It takes more load.
- (vi) Thickness is less.
- (vii) Joint are required.



### Flexible pavements :-

- (i) Flexible pavements are those which on the whole have low flexural strength.
- (ii) The flexible pavement layer reflect the deformation of the lower layers on the surface of the layer.
- (iii) A typical flexible pavement consists of four components.

- (i) soil sub grade
- (ii) base course
- (iii) sub-base course
- (iv) surface course

### Typical cross-section of flexible pavement :-



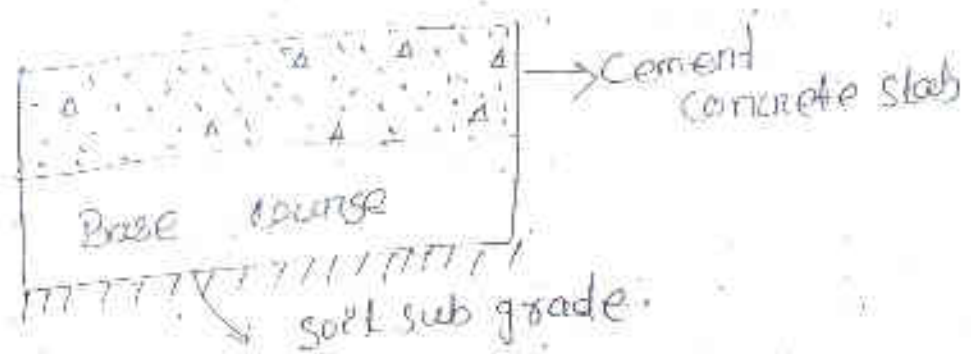
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- The flexible pavement layers transmit the vertical or compressive stresses to the lower layers by grain to grain transfer through the point of contact of granular structure.
- A well compacted granular structure consisting of strong graded aggregate can transfer the compressive stresses through a wider area and form a good flexible pavement layer.
- The load spreading ability of this layer depends on the type of materials and the mix design factors.
- The vertical compressive stress is max<sup>m</sup> on the pavement surface directly under wheel load and is equal to the contact pressure under the contact pressure under the wheel.

### Rigid pavement:-

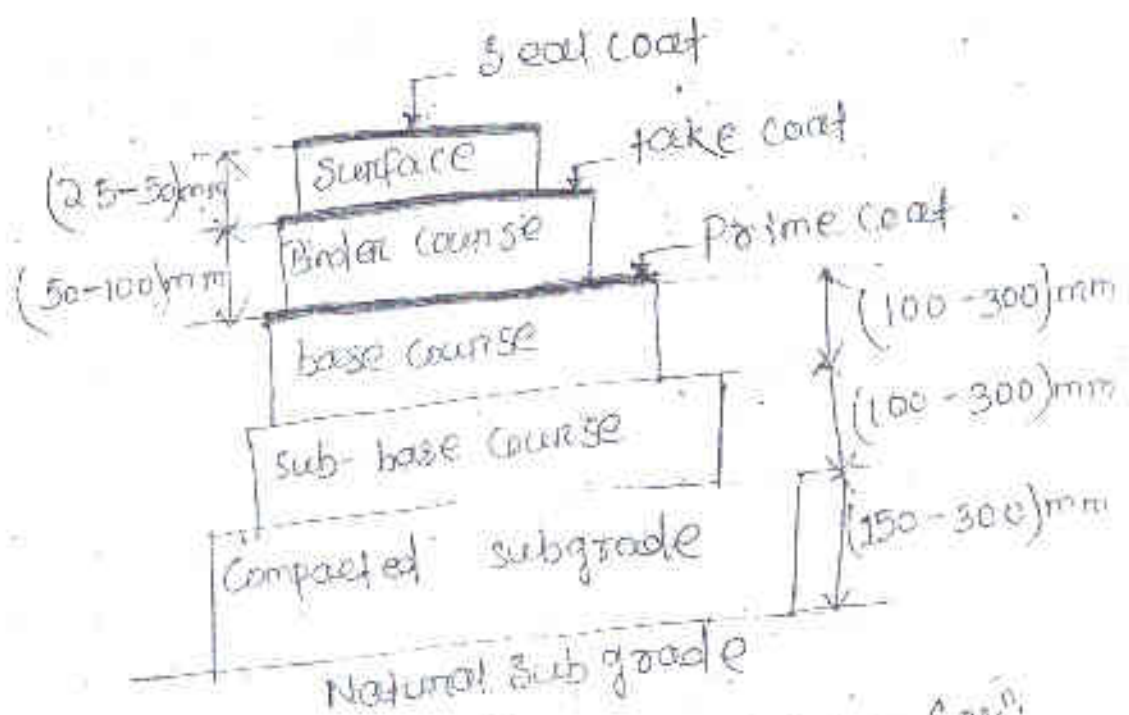
- Rigid pavements are those, which possess worthy flexural strength.
- The loads are transferred by slab action.
- The rigid pavements are made of portland cement concrete, either plain ~~reinforced~~ or prestressed concrete.
- The plain cement concrete slabs are expected to take up about  $40 \text{ kg/cm}^2$  flexurable stress.
- The rigid pavement has the slab action and is capable of transmitting the wheel load stresses through a wider area below.

# Typical cross-section of rigid pavement :-



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## Functions of pavement Component



G.S.S. - Granular Subbase (mm)

W.B.M. - Water bound Macadam

- (1) sub-grade :- The sub-grade is the layer that forms the pavement system. It is the compacted soil of the pavement system.

- Subgrade soils are subjected to lower stresses than the surface, base and sub-base courses, since load stresses decreased with depth. The controlling subgrade stress usually lies the top of the subgrade.
- It acts as bedding layer.

## (2) Sub-base course :-

- The sub-base course serves as the principal structural component of the flexible pavement.
- It distributes the imposed wheel load to the pavement foundation the subgrade.
- It generally contains GSB (Granular sub base) layer and act as a drainage layer also and providing support to base and surface course.

## (3) Base course :-

- The base course is the layer of material immediately beneath the surface of binder course.
- It provides additional load distribution and contributes to the sub-surface drainage.
- It generally contains WBM / WMM.

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## Surface course :-

layer directly in contact with traffic loads.

surface course is the layer in contact with traffic loads.

→ They are usually constructed with dense graded bituminous concrete.

→ It provides characteristics such as friction smoothness drainage, prevent the entrance of excessive quantities of surface water into the underlying base, sub base and subgrade.

→ It must be tough to resist the distortion under traffic and provide smooth and skid resistant riding surface.

→ It contains bituminous layer.

Flexible pavement subgrade preparation:-

→ The preparation of subgrades site clearance grading (embankment and cutting) and compaction.

→ The subgrade may be situated on embankment or excavation or on the existing ground surface. In all the cases, the site should be cleared off and the top soil consists of grass, roots nettist and other organic matter are to be removed.

→ The gradient operation is started so as to bring the critical profile of the subgrade to designed grade and embankment.

→ Bull dozers scrapers

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## Soil compaction

By compaction of soil, the particles are mechanically constrained to be packed more closely by expelling part of the air void.

→ Compaction increases the density of and stability, reduces settlement and lowers the effect of moisture.

→ Hence proper compaction of fills, subgrade, sub base and base course are considered essential for proper highway construction.

→ The various factors influencing soil compaction include the moisture content, type of soil and stone content.

→ It is a well known fact that there is an optimum moisture content (OMC) for a soil which would give maximum dry density for a particular type and amount of compaction. Hence it is always desirable to compact the soil at the OMC after determining the compaction equipment.

Compacting equipment :- Compaction is achieved in the field either by rolling, ramming or by vibration. So the compacting equipment may also be classified as rollers, rammers, and vibrators. Compaction of sands are also achieved by watering, ponding and jetting.

Rollers :- The principle of roller is the application of pressure which is slowly increased or decreased.

→ The various type of the rollers are used for compaction are smooth wheel rollers, pneumatic tyred roller, sheep foot rollers.

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Smooth wheeled roller :-

→ There are two types of smooth wheeled rollers

① Mecadam rollers.

② Tandem rollers

→ The ~~net~~ gross or total wt of the mecadam roller varies between 4 to 18 tonnes, where as the tandem roller with two axles varies between 1 to 49 tonne.

→ The  $\downarrow$  efficiency of the smooth wheeled   
 Compacting

roller depends on wt, width and diameter of each roller.

→ The smooth wheeled rollers are suitable to roll a wide range of soils, granular soils and pavement materials for various layers.

## Pneumatic typed roller :-

→ In this type number of pneumatic wheels are mounted on two or more axis under a loading platform.

→ These rollers are pulled by tractors.

→ This type of roller are suitable to compact nonplastic silt and fine sands.

Sheep's foot roller :- This type of roller consists of hollow steel cylinder with projecting feet.

→ The wt of this type roller can be increased by filling the drum with wet soil.

→ The wt diameter and width of the roller may be varied and also the shape and size of the feet.

→ These may be pulled by tractors. The compaction effectings of this type of roller depends on the wt of roller and number of feet in contact with the ground at a time.

→ This type of roller are suitable to compact clayey soil. During rolling operations. The projecting feet get compacted.

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→ The thickness of compacting layer is kept about 50 cm more than the length of each foot.

→ About 24 or more number of passes of the roller may be necessary to obtained adequate compaction.

→

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U.S.M

## Rammers

→ Rammers are useful to compact relatively small areas and where rollers can't operate such as compaction of trenches foundations and slopes. The output of rammer is much lower than that of roller.

## Vibrators

→ Vibrators are most suited for compacting dry cohesion less granular material.

→ There are also vibrator mounted roller to give the combined effect of rolling & vibration.

→ vibratory are used in compacting a wide range of material.

## Watering (Jetting & ponding) :-

→ It is considered to be an efficient method of compacting cohesionless sands, watering heavily and rolling by smooth wheel of pneumatic tyred roller may also give adequate compaction of cohesionless sand.

## Field control for compaction :-

→ For adequate quality control in construction it is essential to have proper field control in compaction. The two field tests needed are

- ① Measurement of moisture content.

⑦ measurement of dry density.

The moisture content

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Excavation :-

- (1) It is the process of cutting or removing and loosening earth, including rock from its original position, transporting and dumping it as a fill or spoil bank.
- (2) The excavation or cutting may be needed in soil soft rock or even in hard rock before preparing subgrade. The selection of excavation equipment and the cost analysis is made based on the stiffness of the materials to be excavated.
- (3) Earth excavation work may be divided as excavation or cutting, grading and compaction.
- (4) The depth of excavation directly depends on the vertical profile of the road requirement.
- (5) The slope to be provided is governed by the type of including stratification.

Embankment :- when it is need to raise the grade line of a highway above the existing ground level it becomes necessary to construct embankment.

- The grade line may be raised due to any of the following reasons
- (i) To keep the subgrade above the high ground water table.
  - (ii) To prevent damage to pavement due to surface water and capillary water.
  - (iii) To maintain the design standard of the highway with vertical alignment.

The design elements in highway embankment :-

(i) height

(ii) fill material

(iii) settlement

(iv) stability of foundation

(v) stability of slopes

Height The height of the embankment depends on the desired one of the highway and soil profile.

> Also the height of the fill is some times governed by stability of foundation particularly when the foundation soil is weak.

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(ii) fill material :-

> Granular soil is generally preferred as highway embankment material.

> clay sand silts are considered less desirable.

> organic soils particularly peat are unsuitable.

> The best of the soils available locally is selected with a view to keep the load and self wt as low as possible at times light wt. fill material like cinder may be used to reduce the wt when soil is weak.

(iii) settlement The embankment may settle after completion of construction either due to consolidation and settlement of the foundation or due to settlement of the embankment itself or due to both.