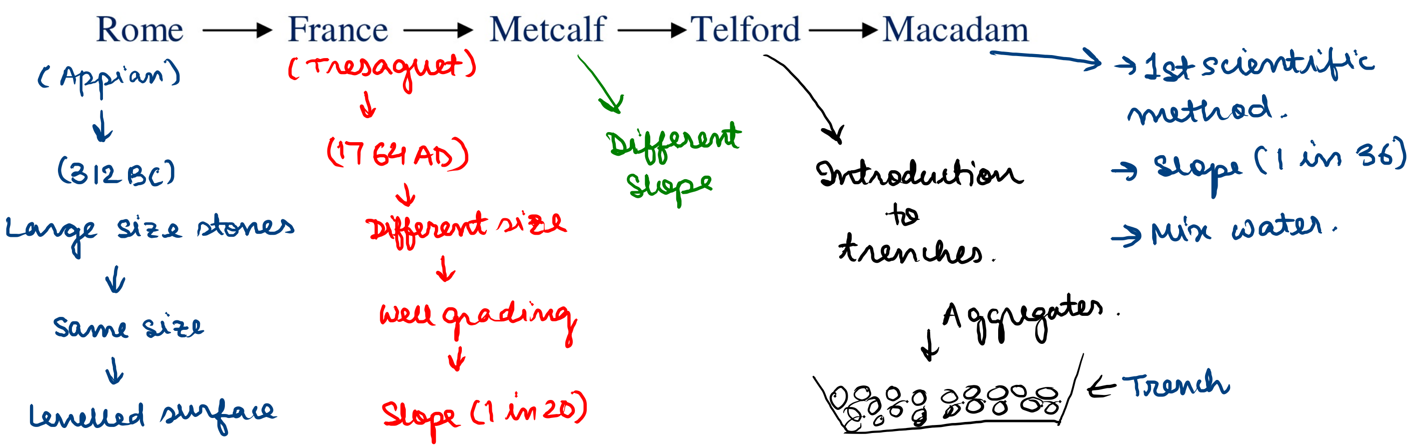
HIGHWAY ENGINEERING

World:



India (Jayakar Committee):

- Road Development should be considered as ' National Interest'.
- Road fund in 1929, tax should be taken from the users for development of roads.
- Semi – Official technical body should be formed named as Indian Roads Congress (IRC).
- Research Organization is formed in 1950 named as Central road research institute (CRRI).

ROAD DEVELOPMENT PLANS:

(i) Nagpur Road development plan (1943-1963)

- National Highway (NH), State Highway (SH), Major District Roads (MDR), Other District Road (ODR), Village Roads (VR). (No expressways are there in Nagpur Plan).
- Star & Grid road pattern is to be considered.
- 1532700 km length of road.
- Development rate = +15%.

(ii) Bombay Road plan (1961-1981)

- For every 100 km^2 there should be 32 km length road.
- Expressways were introduced.

- Development rate= +5%.

(iii) Lucknow Road plan (1981-2001)

- Target road length= 82km per 100 km^2.
- Primary= National highway, Expressways
- Secondary = State highway, Major district roads
- Tertiary = Other District road, Village Roads
- 66000 km of NH & 2000 km of Expressway
- NH= $\frac{A}{50}$ km ; SH = $\frac{A}{25}$ km ; MDR = $\frac{A}{12.5}$
- If there are 'n' towns, then SH = (62.5*n)

IMPORTANT POINTS:

- First longest road (Major road) was constructed during the time of Sher Shah Suri (1540- 1545 AD) from Calcutta to Lahore.
- The present Grand Trunk (GT) Road (NH 1) has been construction along this road.
- In 1865, during the period of Lord Dalhousie Central Public Works Department was formed.
- In 1927, Indian Roads & Transport Development Association (IRTDA) was setup with Head Office at Bombay to study the transport problems of the country.
- On recommendation of IRTDA, in 1928 Jayakar committee under the chairmanship of Mr. M.R. Jayakar was formed to look into the Road transport & road development problems in India.
- In 1930, the Central Road Organisation (CRO) was setup.
- In 1934, a semi – government body Indian Roads Congress (IRC) was setup at New Delhi.
- In 1939, Motor Vehicle Act was enacted for the administration of transport.
- In 1943, conference of all engineers was held at Nagpur plan.
- In 1956, National Highway Act was passed by the Parliament under which the central government took up complete financial responsibility of the National Highway.
- In 1960, Border Roads Development Board (BRDB) was established.

CLASSIFICATION OF ROADS: They are classified into two types:

(i) Urban roads: A road within a city or town is called an urban road.

Types of urban roads:

(a) Expressways : The central portion of a road for high speed vehicles is known as expressway or motorway. The expressways are to be provided with divided carriage way, controlled access, grade separators at roads.

(b) Arterial Street: The city roads which are meant for thorough traffic, usually on a continuous route, are called arterial streets.

(c) Sub – Arterial Street: The city roads which provide lower level of travel mobility than the arterial streets are called sub- arterial streets.

(d) Collector Street: The cities which are construction for collecting and distributing the traffic to and from local streets are called collector streets. These are located in residential, industrial and commercial areas.

(e) Local streets: The city roads which provide an access to residence, business and other buildings are called local streets.

(ii) Rural roads: A road outside the city or town is called rural road.

Types of rural roads:

(a) National Highway: The term highway is used for major or important roads of a country. The highways of national importance, connecting commercial or industrial centres with airports or sea- ports, state capitals and tourist centres. These are constructed and maintained by CPWD under Central Government.

(b) State Highway: The highways connecting district head quarters with state headquarters or highways of neighboring states are called state highways. These are constructed and maintained by PWD under the State Government.

(c) Major District Roads: The roads traversing each district serving areas of production and markets and connecting those with each other or with the National or State highways are called Major district roads. These are constructed and maintained by state government or the local district boards.

(d) Minor District Roads: These roads connects the important towns within the district to the district headquarters.

(e) Village Roads: The roads which connect village to adjoining village or group of villages with each other and to the nearest district road, are called village road. These are constructed and maintained by local district boards or blocks.

STRATEGY FOR DEVELOPMENT OF ROADS

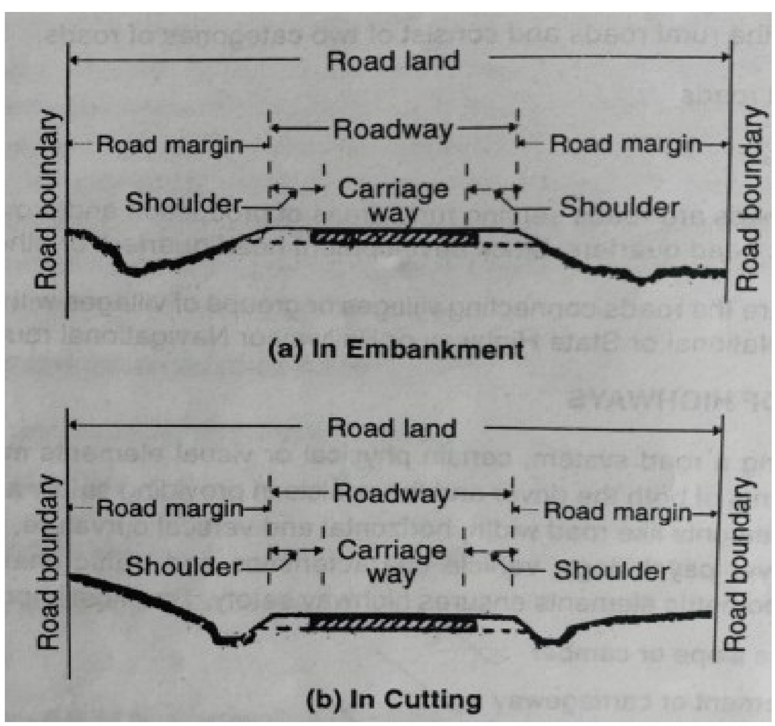
(i) Expressway: Traffic along some of the state highway is so high that it should be provided with expressed highway facilities.

(ii) Four Laning: The capacity of state highway on high density corridors, would be necessary to undertake four laning of existing roads. This would need to undertake strengthening of pavement, hard shoulders and by passes around conjusted towns.

- Golden Quadrilateral : Delhi, Mumbai, Chennai, Kolkata
- North – South corridor: Srinagar to Kanyakumari
- East – West corridor: Silchar to Porbander.

(iii) Two Laning: The major requirement in aspect of state highways is to bring the entire length of state highways to minimum two lane standards and with additional hard shoulders.

COMPONENTS OF A CITY ROAD



(i) Right of way: The area of land acquired for construction and future development of a road symmetrically about the central alignment is called right of way. The width of these acquired land is known as land width and it depends upon the importance of the road & possible future development.

(ii) Formation width: The top width of the highway embankment or the bottom width of highway cutting excluding the side drains is called formation width or road way. The formation width is the sum of widths of pavements or carriage way including the separators and width of the shoulders on either side of the carriage way.

(iii) Carriage way: The portion of the road surface which is used for vehicular traffic is known as carriage way or pavement. The width of carriage way depends upon the width and number of lanes. For single lane roads, the width of pavement is generally kept 3.75m.

(iv) Crown: The highest point on the road surface is called crown.

(v) Camber: Camber is the slope provided to the road surface in the transverse direction to drain off the rain water from road surface.

The values of camber recommended by IRC for different types of road surfaces are given in the following table

Type of Surface	Rainfall	
	Low	Heavy
1. Cement concrete and high type bituminous surface	1 in 60 (1.7%)	1 in 50 (2%)
2. Thin bituminous surface	1 in 50 (2%)	1 in 40 (2.5%)
3. Water Bound Macadam and gravel Pavement.	1 in 40 (2.5%)	1 in 33 (3%)
4. Earth surface	1 in 33 (3%)	1 in 25 (4%)

(vi) Separator or divider - The narrow continuous structure provided for dividing the two directions of the traffic flow, is known as separator or divider.

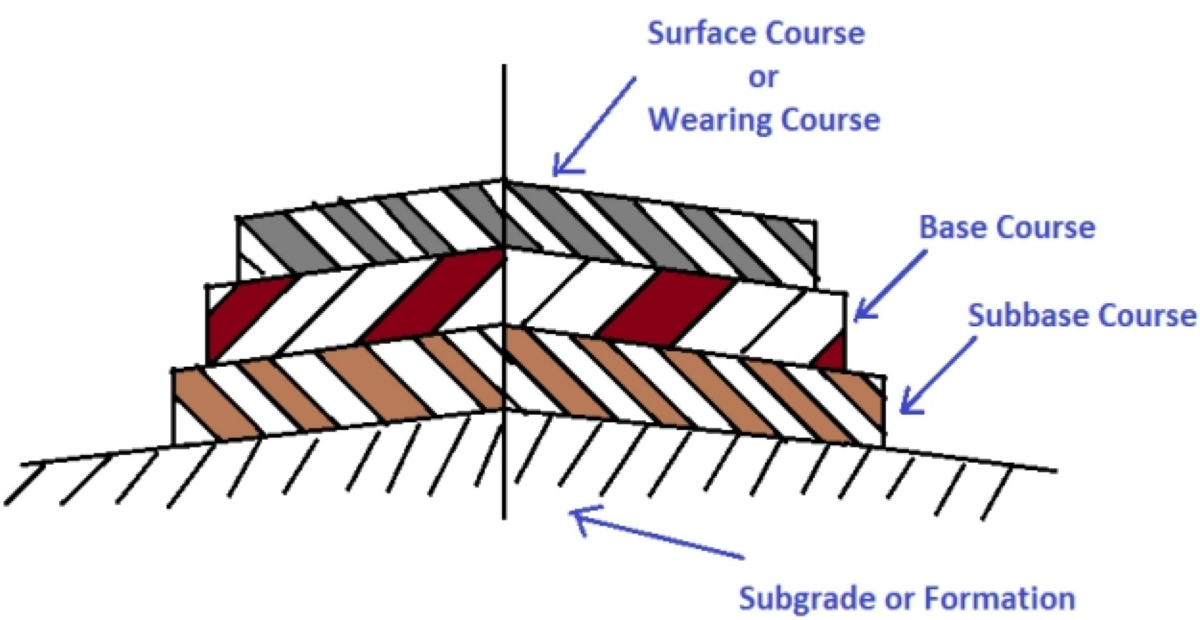
(vii) Shoulders:- The portions of the roadway between the outer edges of the carriage way and edges of the top surface of the embankment or inner edges of the side drains in cuttings of the roads, are called shoulders. The shoulders are generally in level with road surface, having a slope towards drain side. The minimum shoulder width recommended by IRC is 2.5m.

(viii) Kerbs- The boundaries between the pavement and shoulder of footpath are known as Kerbs.

(ix) Side slopes: The slopes of the sides of earthwork of embankments and cuttings to ensure their stability are called side slopes. The embankments are generally given a side slope of 1:1.5.

(x) Berms: The width of the land left in between the toes of the embankment and the inner edges of the borrow pits, is called berm.

VARIOUS COMPONENTS OF A ROAD SURFACE:



(i) Sub-grade: It is the soil foundation on which the road pavement rests and provides adequate and uniform support to the pavements.

(ii) Sub-base course: When the bearing capacity of the soil is poor & the intensity of traffic is high, an additional layer is provided between the soling and sub grade. This additional layer is called sub-base.

(iii) Base : The foundation of a road is also called soling or base. The thickness of base, in no case should be more than 30 cm. The base course receives the impact of the traffic though the wearing course. The load of the traffic is transferred to the sub- base and sub-grade through the base course.

(iv) Wearing course: It is the top most layer of a road pavement which is directly exposed to the traffic. The wearing course may be laid in one or two layers according to the total designed thickness and the thickness of each layer should not exceed 10cm. The thickness of the road surfacing depends upon the type of traffic, intensity of traffic and that of material.

WIDTH OF PAVEMENT:

- Single Lane = 3.75 m
- Two Lane without Kerb = 7m
- Two Lane with Kerb = 7.5m
- Intermediate Lane = 5.5m
- Multiple Lane = 3.5m per lane

WIDTH OF SHOULDER:

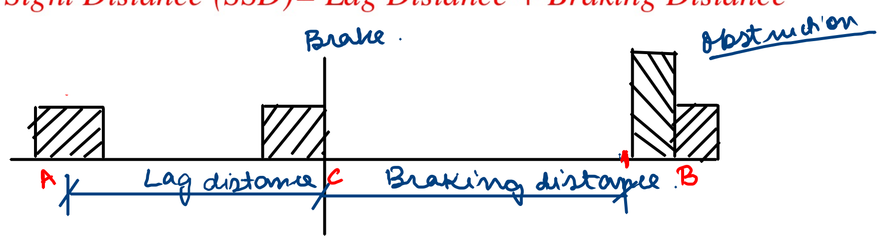
- Minimum width = 2.5m

GEOMETRIC DESIGN

SIGHT DISTANCE: The length of a road visible to a driver, clear of objects, while driving a vehicle is known as sight distance. It depends upon the height of the line of sight of the driver above the road surface when the vehicle is moving on a level stretch, on a horizontal curve or on a vertical curve. The standard height of the line of sight of the driver above the road surface is taken as 1.2m.

(i) STOPPING SIGHT DISTANCE(SSD): The minimum clear distance ahead required by the driver of a vehicle travelling at a given speed to bring his vehicle to a stop after an object on the carriage way becomes visible, thereby avoiding collision is called stopping sight distance. This is also called absolute minimum sight distance.

Stopping Sight Distance (SSD)= Lag Distance + Braking Distance



(a)Lag Distance: The distance travelled by the vehicle from the moment the driver sees the object till it applies the brake.

Lag distance= $\frac{1000}{3600} * V * t_R$

$V \rightarrow$ kmph

$\frac{1000}{3600}$ mps

$\Rightarrow$ Lag distance (m) = $0.278 V t_R$ (V → Kmph, t_R → sec)

(b)Braking Distance: It is the distance travelled by the vehicle after the application of brakes till it stops.

Braking Distance (m) = $\frac{V^2}{2g(f \pm n)} = \frac{V^2_{kmph}}{254(f \pm n)}$

→ n = positive for upward gradient
→ n = negative for downward gradient
→ n = 0 for flat surface.

Longitudinal friction = 0.35

Lateral friction = 0.15

<u>PIEV Theory:</u>

P = Perception

I = Intellection

E = Emotion

V = Volition

→ De-acceleration rate (a)

⇒ $f = \frac{a}{g}$

$$SSD_{(m)} = 0.278 V t_R + \frac{V^2}{254(f \pm n)}$$

→ For braking efficiency (b)

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

Notes: (a) Reaction Time, t_R

(i) For PIEV Theory = 0.5 to 4 sec

(ii) For calculation of SSD = 2.5 sec

(iii) For calculation of OSD = 2 sec

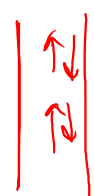
(b) Height of driver's eye = 1.2m

(c) Height of obstruction = 1.5m

(d) Minimum Sight Distances for different cases:

(i) For a single lane road, with 1 way traffic

Minimum sight distance = SSD



(ii)Single lane road, 2- way traffic

*Minimum sight distance = 2*SSD = ISD (Intermediate sight Distance)*

(iii) For 2 lane, 2 way traffic

Minimum sight distance = SSD

(e) Deceleration rate, 'a'

$f = a/g$

(ii) Overtaking sight distance (OSD): The minimum distance required for overtaking another vehicle safely and without interfering the speed of an opposing

Q. Calculate the reaction time for a vehicle moving at 90 Kmph, having a calculated SSD of 170 m.

Sol: SSD = Lag distance + Braking distance

$\Rightarrow \quad 170 = 0.278 * V * t_R + \frac{V^2}{254(f \pm n)}$

$\Rightarrow \quad 170 = 0.278 * 90 * t_R + \frac{90^2}{254 * 0.35}$

$\Rightarrow \quad t_R = 3.159 \simeq 3.16$ sec.

Q. A vehicle moving at 60 kmph on an ascending gradient of a highway has to come to stop position to avoid collision with a stationary object. The ratio of lag to brake distance is 6:5. Considering total reaction time of the driver as 2.5 seconds and the coefficient of longitudinal friction as 0.36, the value of ascending gradient in (%) is.

(A) 3.3 (B) 4.8 (C) 5.3 (D) 6.8

Sol: $\Rightarrow \frac{\text{Lag distance}}{\text{Braking distance}} = \frac{6}{5}$

$\Rightarrow \frac{0.278 * 60 * 2.5}{\frac{60^2}{254(0.36 + n)}} = \frac{6}{5}$

$\Rightarrow \frac{0.278 * 60 * 2.5 * 254 * (0.36 + n)}{60^2} = \frac{6}{5}$

$\Rightarrow \quad n = 4.8\%$

vehicle travelling at the design speed is called minimum overtaking or safe passing sight distance.

Case I: No opposing traffic (1 lane, 1 way traffic)

$OSD = d_1 + d_2$

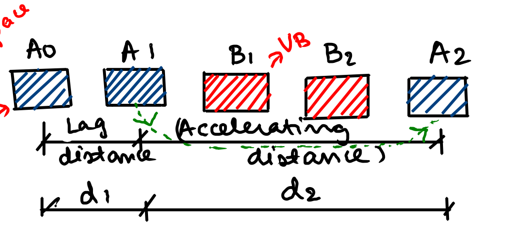
$d_1 = 0.278 * V_B * t_R$

$d_2 = 0.278 V_B T + \frac{1}{2} a T^2$

$T = \sqrt{\frac{4S}{a}} \Rightarrow S = 0.2 V_B + 6$ → length of the vehicle

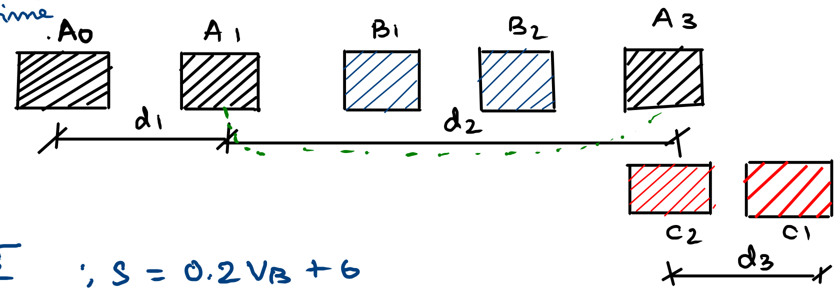
where, S = space headway (reaction time for space headway: 0.7 * 0.278 = 0.19 ≈ 0.2)

T = overtaking time



$OSD = 0.278 V_B t_R + V_B T + \frac{1}{2} a T^2$

Case II: Presence of opposing traffic: (1 way, 2 way traffic)



$OSD = d_1 + d_2 + d_3$

$d_1 = 0.278 V_B * t_R$

$d_2 = 0.278 V_B T + \frac{1}{2} a T^2 \Rightarrow T = \sqrt{\frac{4S}{a}}$; $S = 0.2 V_B + 6$

$d_3 = 0.278 * V_C * T$

$OSD = 0.278 V_B * t_R + 0.278 V_B T + \frac{1}{2} a T^2 + 0.278 * V_C T$

Overtaking = A

Overtaken = B

Notes: * Reaction time = 2 sec (IRC)

SP-I = overtaking zone begin

SP-II = End of overtaking zone

(i) *For one way road , OSD =* d_1+d_2

(ii) *Generally:* $V_A = V_C$

(iii) *As per IRC, if design speed = V kmph*

Then, $V_A=V_C$ *= V kmph;* V_B *= (V-16) kmph*

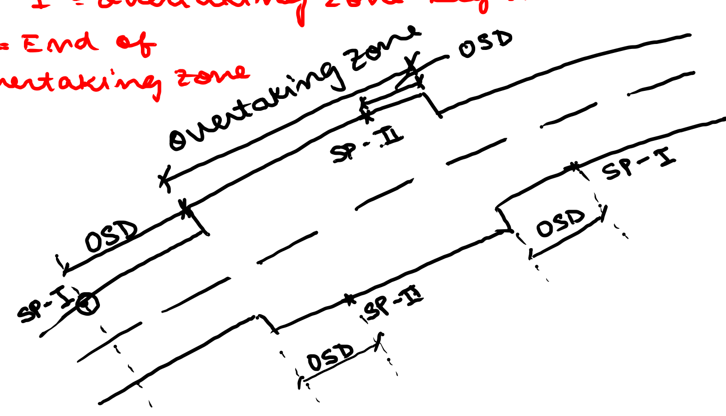
(iv) *Height of driver's eye = 1.2 m* } OSD

(v) *Height of obstruction= 1.2 m*

(vi) *Overtaking Zone*

(a) Minimum length = 3 times of OSD

(b) Maximum length = 5 times of OSD



(iii) Intermediate sight distance (ISD) - It is defined as twice the safe stopping sight distance and affords opportunity to the drivers to overtake with caution. ISD is provided when OSD can't be provided.

Q. On a two way traffic road, the speed of overtaking and overtaken vehicles are 100 kmph & 50 kmph respectively. If the average acceleration is 1 m/sec^2, determine the OSD.

Sol: Given, $V_A = 100$ kmph, $V_B = 50$ kmph, $V_C = 100$ kmph,
$a = 1$ m/sec^2, $t_R = 2$ sec.

$d_1 = 0.278 V_B * t_R = 0.278 * 50 * 2 = 27.8$ m

$d_2 = 0.278 V_B * T + \frac{1}{2} a T^2$

$S = 0.2 * V_B + 6 = 0.2 * 50 + 6 = 16$ m

$T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4*16}{1}} = 8$ sec

$d_2 = 0.278 * 50 * 8 + \frac{1}{2} * 1 * 8^2 = 143.2$ m

$d_3 = 0.278 * V_C * T = 0.278 * 100 * 8 = 222.4$ m

$OSD = d_1 + d_2 + d_3 = 27.8 + 143.2 + 222.4 = 393.4$ m

Q. On a two way traffic road, the speed of overtaking and overtaken vehicles are 100 and 50 Kmph. If the average acceleration is 1 m/s², determine the value of OSD.

$OSD = d_1 + d_2 + d_3$

$\Rightarrow d_1 = 0.278\, V_B * t_R = 0.278 * 50 * 2 = 27.8\ m$

$\Rightarrow d_2 = 0.278\, V_B * T + \frac{1}{2} a T^2 = 0.278 * 50 * 8 + \frac{1}{2} * 1 * 8^2 = 143.2\ m$

$\Rightarrow T = \sqrt{\frac{4S}{a}}$ $\Rightarrow S = 0.2 V_B + 6 = 0.2 * 50 + 6 = 16\ m$

$\Rightarrow T = \sqrt{\frac{4*16}{1}} = 8\ sec$

$\Rightarrow d_3 = 0.278\, V_C T = 0.278 * 100 * 8 = 222.4\ m$

$\therefore OSD = 27.8 + 143.2 + 222.4 = 393.4\ m$

ISD=2 SSD*

Therefore, SSD<ISD<OSD

SUPERELEVATION

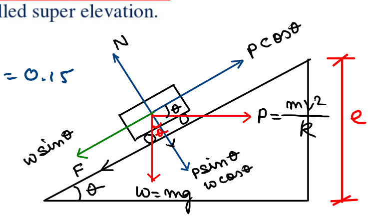
Raising of outer edge of the pavement with respect to inner edge throughout the length of the curve to counteract the centrifugal force and reduce the tendency of the vehicle to overturn is called super elevation.

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

$$\frac{e+f}{1-ef} = \frac{v^2}{127R}$$

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

$e = 0.05$, $f = 0.15$



DESIGN STEPS OF SUPER ELEVATION

STEP 1: (a) Calculation of the super elevation corresponding to 75% (3/4) of design speed and neglecting the role of friction.

(b) If e (calc) < e (max), then provide e= e (calc)

(c) If e (calc) > e (max), then provide e= e (max) and move to Step 2.

$$\Rightarrow e + f^{\to 0} = \frac{(0.75 v)^2}{127R}$$

$$\Rightarrow e_{calc} = \frac{v^2}{225R}$$

According to IRC, according to various terrain categories maximum super elevation values is as follows:

Terrain Categories	e_{max}
Plane	*0.07 = 7%*
Hilly	*0.1 = 10%*
Urban road, Built up area	*0.04= 4%*

STEP 2: (a) Provide $e = e_{max}$ and calculate f (coefficient of lateral friction)

(b) If $f_{calc} < f_{max}$, then provide $f = f_{calc.}$ and $e = e_{max}$

(c) If $f_{calc} > f_{max}$, then take $f = f_{max}$ and move to step 3.

$$\Rightarrow e_{max} + f_{calc} = \frac{V^2}{127R}$$

$$\Rightarrow f_{calc} = \frac{V^2}{127R} - e_{max} \quad [\because f_{max} = 0.15]$$

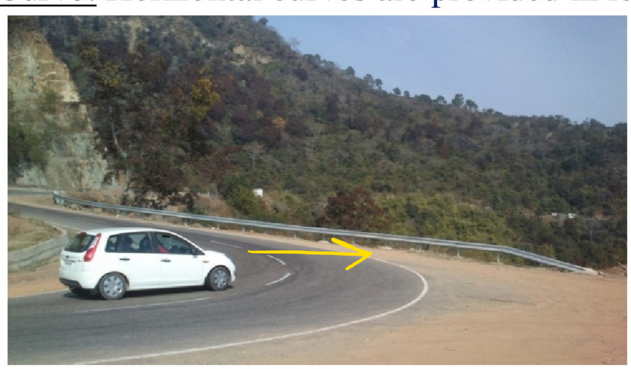
STEP 3: (a) Provide $e = e_{max}$ and $f = f_{max}$

(b) Redesign the design speed

$$\Rightarrow e_{max} + f_{max} = \frac{V^2}{127R}$$

$$\Rightarrow V_{kmph} = \sqrt{127R(e_{max} + f_{max})}$$

<u>Horizontal Curve:</u> Horizontal curves are provided in longitudinal direction.



Concepts:

1. When e is very high or speed is very high then $(1 - ef) \neq 1$.

$$\Rightarrow \frac{e+f}{1-ef} = \frac{V^2}{127R}$$

2. When pressure on both wheels are same then, lateral friction = 0

$$e_{equilibrium} = \frac{V^2}{127R}$$

3. Minimum value of superelevation

e_{min} = camber of Road.

Q1. The radius of a horizontal circular curve is 150m. The design speed is 60 Kmph and the design coefficient of lateral friction is 0.15. Calculate the super elevation required if full lateral friction is assumed to develop (%) ________.

(A) 1.9% (B) 2.9% (C) 3.9% ✓ (D) 4.9%

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

$$\Rightarrow e + 0.15 = \frac{60^2}{127 * 150} \Rightarrow e = 3.9\%$$

Q2. If the super elevation is to be designed for a design speed of 110 Kmph for a road in a plane area for curve of radius 420m. What would be the value of superelevation provided.

Sol: Step 1: $e_{calc} = \frac{V^2}{225R} = \frac{110^2}{225 * 420} = 0.128 > e_{max}$

$\therefore e = e_{max} = 0.07$

Step 2: $e_{max} + f_{calc} = \frac{V^2}{127R} \Rightarrow 0.07 + f_{cal} = \frac{110^2}{127 * 420}$

$\Rightarrow f_{cal} = 0.156 > 0.150$

Step 3: $e_{max} + f_{max} = \frac{V^2}{127R}$

$$\Rightarrow 0.07 + 0.150 = \frac{V^2}{127 * 420}$$

$$\Rightarrow V = 108.32 \text{ kmph}$$

Q3. For a road with camber of 3% and the design speed is 80 kmph, the minimum radius beyond which no superelevation is required is ______ m. (Ignore side friction).

$$\Rightarrow e_{min} + \cancel{f} \to 0 = \frac{V^2}{225 R}$$

$$\Rightarrow 0.03 = \frac{80^2}{225 * R}$$

$$\Rightarrow R = 948.14 \text{ m}$$

→ Skidding: Translational >> Rotational (wet pavement)

→ Pure Skid :- No Rotation only translation

→ Slipping: Rotational >> Translational (Muddy/ Sandy land)

→ Pure slip :- No translation only rotation.

- TERRAIN CLASSIFICATION

TERRAIN CLASSIFICATION	*CROSS SLOPE (%)*
Plain	*0-10*
Rolling	*10-25*
Mountainous	*25-60*
Steep	*>60*

- DESIGN SPEED: Design speed of roads depends upon class of road and type of terrain.

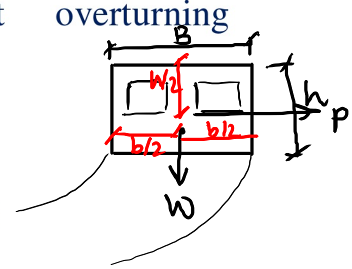
TYPE	*PLAIN*	*ROLLING*	*HILLY*	*STEEP*
NH & SH	*100-80*	*80-65*	*50-40*	*40-30*
MDR	*80-65*	*65-50*	*40-30*	*30-20*
ODR	*65-50*	*50-40*	*30-25*	*25-20*
VR	*50-40*	*40-35*	*25-20*	*25-20*

Expressways 120-100

- EFFECTS OF CENTRIFUGAL FORCE:

(i) Overturning of vehicle: For safety against overturning

$$\frac{P}{W} < \frac{B}{h}$$



(ii) Lateral skidding of vehicle: For safety against skidding

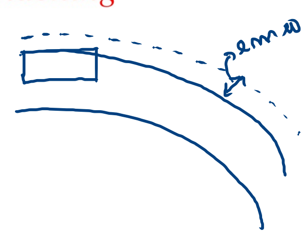
$$\frac{P}{W} < f$$

EXTRA WIDENING (E_w) : Additional width of carriageway that is required on horizontal curve is referred as extra widening.

Extra widening = Mechanical widening + Psychological widening

Mechanical widening:

$$e_{mw} = \frac{nl^2}{2R}$$



where, n = no. of lanes

l = length of vehicle

R = Radius of curve

Q. A 2 lane NH passing through a hilly terrain has a horizontal curve of radius 79 m. what is the width of the carriageway. Assume data as per IRC recommendations. V = 50 kmph

(A) 1.048 m (B) ✓ 8.048 m (c) 7.048 m

(D) 5.048 m

$$E_w = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} = \frac{2*6^2}{2*79} + \frac{50}{9.5\sqrt{79}} = 1.048\,m$$

∴ width of carriage way = 2*3.5 + 1.048
= 8.048 m

Q. While aligning a road of ruling gradient 6%, a horizontal curve of radius 60 m is encountered. Find the grade compensation & the compensated gradient.

Sol:- grade compensation = Min. $\left[\frac{30+R}{R}, \frac{75}{R}\right]$

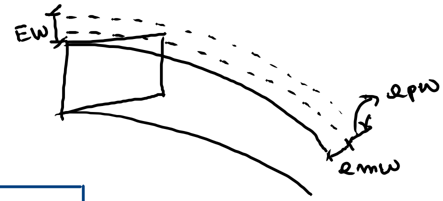
$$= \text{Min. of} \left[\frac{30+60}{60}, \frac{75}{60}\right]$$

= Min. of [1.5%; 1.25%]

⇒ grade compensation = 1.25%.

⇒ compensated gradient = Ruling gradient − grade compensation
= 6% − 1.25%
= 4.75%

Psychological Widening:



$$e_{pw} = \frac{V}{9.5\sqrt{R}}$$

$$\text{Extra widening} = \frac{n l^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

IRC recommendations

(i) When R>300m, No need to provide extra widening

(ii) When R< 50m, Provide extra widening at the inner edge.

(iii) When 50m≤ R ≤ 300m, Provide extra widening at both edges.

(iv) off - tracking => $OT = \frac{l^2}{2R}$

GRADIENT: Gradient is the longitudinal slope of the road. The slope of the road which is adopted in road design and calculations of cuts and fills is called 'Ruling gradient'. The gradient is decided in such a way that slow moving and fast moving, both types of traffic can easily negotiate over this slope. The different types of gradients are as follows:

(i) Limiting Gradient: This gradient is usually steeper than ruling gradient. Limiting gradient may be provided along the stretch of the road alignment if the topography compels, to avoid excess cost of cutting the steeper slopes. It is also known as maximum gradient.

(ii) Minimum Gradient: The gradient which is generally provided in the longitudinal direction of a road pavement to provide easy drainage of rain water is called minimum gradient.

(iii) Average Gradient: The total rise or fall between any two points chosen on the alignment divided by the horizontal distance between the two points is called average gradient.

(iv) Ruling Gradient: The suitable gradient which may be normally provided in the alignment of a road and in such a way that the vehicle may negotiate long stretched of the gradient without much fatigue is known as ruling gradient. It depends upon design speed and topography.

(v) Exceptional Gradient: The gradient less than the minimum gradient and more than the maximum gradient is called exceptional gradient. The maximum length of an exceptional gradient should not exceed 60m in one kilometer road length. The exceptional gradient becomes necessary to avoid deep cuttings. The stretches of exceptional gradient should be separated by a minimum length of 100m with limiting or flatter gradient.

The various gradients recommended by IRC are as follows:

Nature of terrain	*Ruling Gradient*	*Limiting Gradient*	*Exceptional Gradient*
Plains	*1 in 30 (3.3%)*	*1 in 20 (5%)*	*1 in 15 (6.7%)*
Hills	*1 in 20 (5%)*	*1 in 17 (6%)*	*1 in 14 (7%)*
Steep Terrain	*1 in 17 (6%)*	*1 in 14 (7%)*	*1 in 12.5 (8%)*

GRADE COMPENSATION: On sharp horizontal curves, the gradient should be decrease or compensated to decrease the tractive effort on the engine.

According to IRC, Grade compensation= Minimum of $\left(\frac{30+R}{R}, \frac{75}{R}\right)$ *%*

Compensated Gradient = Ruling Gradient – Grade compensation

When gradient ≤ 4%, then grade compensation is not required.

Compensated Gradient $\nless$ *4%*

TRAFFIC CAPACITY OF HIGHWAY:

(i) Traffic volume: The number of vehicles moving in a specified direction on a roadway that pass a given point during a specified unit of time, is called traffic volume. It is usually expressed as *vehicle per hour*.

(ii) Traffic density: The number of vehicles occupying a unit length of a roadway at a given instant, in called traffic density. It is usually expressed as *vehicles per kilometer*.

(iii) Traffic capacity: The maximum number of vehicles in a roadway that can pass a given point in unit time is called traffic capacity.

(iv) Basic capacity: The maximum number of passengers cars that can pass a given point on roadway during one hour under the most ideal road and traffic conditions, is called basic capacity. It is sometimes called theoretical capacity.

(v) Practical capacity. The maximum number of vehicles that can pass a given point on a roadway during one hour without imposing any restrictions to the driver's freedom for driving the vehicles, under prevailing roadway and traffic conditions is called practical capacity. It is sometimes called design capacity.

Determination of basic capacity: - The basic capacity of a single lane roadway may be determined from the formula,

$$C = \frac{1000\,V}{S}$$

Where, C = Capacity in Vehicles per hour

V = speed in kmph

S = Spacing of vehicle in meter

The value of S, the headway distance is determined from the consideration of perception brake reaction time and length of the vehicle.

S = Length of vehicle + Distance travelled in perception brake reaction time + Braking distance.

$$S = L + 0.278 * V * t + \frac{V^2}{254\,f}$$

Where, t= Perception brake reaction time

f= coefficient of friction

TYPES OF ROADS:

1. Earthen Roads: The centre line and road edges are marked on the ground along the alignment with the help of pegs. Then site is cleared by removing all the vegetables and the surface is brought to the required camber and gradient by depositing or excavating the earth. The surfaces is then rolled properly and watered.
2. Gravel Roads: It is a cheap type of road. Gravels are obtained from river beds and by crushing the stones. The size of gravel varies from 6mm to 35mm. This gravel is mixed with sand and clay, which acts as a binder. Sub-grade is prepared as per the required, gradient and camber after proper compaction.
3. Water Bound Macadam Road (WBM): It is used as village road or as a base for other important high cost roads. The road whose wearing course consists of clean crushed aggregates, mechanically interlocked by rolling and bound

together with filler material and water and laid on a well compacted base course is called WBM road. *Stone dust is used for binding the material*.

4. Bituminous road: The layer of bitumen surface dressing is provided to eliminate dust nuisance to increase life of the road and to make it impervious and smooth. *They are used because of their binding & water proofing properties.*
5. Cement concrete Road: On the base course a concrete slab is laid to a thickness of 5 to 8cm. This type is most expensive but very durable.

ROAD AGGREGATE TESTS:

NAME OF TEST	EQUIPMENT USED	SPECIFICATION	PROPERTY
Crushing test	Compression testing machine	Aggregate crushing value should be less than 45.	Strength
Abrasion test	Los Angles Abrasion testing machine	LA abrasion value should be less than 50.	Hardness
Impact test	Aggregate Impact testing machine	Aggregate impact value should not exceed 40%.	Toughness
Flakiness index test	Thickness Gauge and sieves	Flakiness index should not exceed 20%.	Shape
Elongation Index test	Length gauge and sieves,	Elongation index should not exceed 15%.	Shape
Angularity number test	Metallic scoop and cylinder and sieves	Angularity number should be up to 11.	Angularity of aggregate
Water absorption test	Dipping water bucket and balance	Absorption should be less than 0.6%	Porosity
Bitumen adhesion test	Static immersion test	Stripping value of aggregate should not exceed 25%	
Soundness test			Durability

CURVES: The curves are provided on highways to change the direction either in horizontal or vertical plane, in a gradual way. The curves are divided into two classes i.e., a horizontal curve and a vertical curve. A horizontal curve is provided to change the direction of the centre line of a road.

The types of horizontal curve are:

(i) Simple curve: A curve which consists of a single arc connecting two straights is called a simple circular curve.

(ii) Compound curve: A curve which consists of a series of two or more simple curves that turn in the same direction and join at the common tangent points is known as a compound curve.

(iii) Reverse curve: A curve which consists of two simple curves of opposite direction that join at the common tangent point, is known as a reverse curve.

(iv) Transition curve: A curve whose radius gradually changes from an infinite value to a finite value or vice versa for the purpose of giving easy change of direction of a road is called a transition or spiral or easement curve. The transition curves are of the following four types:

(a) True spiral: It is an ideal shape of a transition curve, in which the radius of curvature at any point is inversely proportional to the distance of the point from the beginning of the curve. The shift(s) of a transitions curve is given by,

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$$s = \frac{L^2}{24*R}$$

Where, L= Length of the transition curve

R= Radius of the circular curve

Length of Transition Curve:

- As per rate of change of centrifugal acceleration $(L_T) = \frac{V^3}{CR}$.
- As per rate of introduction of super elevation $(L_T) = eN(w+We)$
- As per minimum length of transition curve $(L_T) = 2.7*\frac{V^2}{R}$ *for Plain/ Rolling*

$(L_T) = \frac{V^2}{R}$ *for Mountainous/Steep*

(b) Cubic spiral: A cubic spiral is superior to cubic parabola as far as the degree of accuracy of a transition curve is concerned. The type of transition curve recommended by IRC for highway is *cubic spiral.*

(c) Cubic parabola: Though the cubic parabola is inferior to cubic spiral, yet it has been extensively used due to which it can be set out by rectangular coordinates.

(d) Bernoulli's lemniscates curve: This type of curve is mostly used in modern road construction as it is symmetrical and can be well adopted when the deflection angle between the tangents is large.

Vertical curves: A vertical curve is provided to change the gradient in vertical plane. The vertical curves are provided to get safety and adequate visibility. It also provides comport to the passengers.

The two types of vertical curves are as follows:

(i) Summit curve: A vertical curve with convexity upward is called a summit curve. The major factor in the design of a summit curve is the sight distance to be allowed on the highway since it is essential that an obstruction on the other side of the summit whether stationary or in motion must be visible to the driver on this side of the summit & vice versa.

The summit curves are required to be introduced at the situations where,

(a) A positive grade meets a negative grade.

(b) A positive grade meets another milder positive grade.

(c) A positive grade meets a level surface.

(d) A negative grade meets a steeper negative grade.

According to IRC, the minimum length of the curve adopted should not be less than one-half the design speed in kmph. It is assumed that the height of line of sight of the driver is 1.2m and height of the object is 10cm above the road surface.

(ii) Valley curve: A vertical curve with convexity downward is called a valley curve. The valley curves are required to be introduced at the situations where,

(a) A negative grade meets a positive grade.

(b) A negative grade meets another milder negative grade.
(c) A negative grade meets a level surface.
(d) A negative grade meets a steeper positive grade.

The length of the valley curve is designed on the basis of passenger's comport conditions and on the head light sight distance. In addition, the length of the curve should be such that it ensures satisfactory drainage at the lowest point.

<u>CONSTRUCTION MATERIALS IN HIGHWAY:</u>

Earth, sand, silt, clay, gravel, stone, cement, bitumen, tar, water, asphalt, brick etc.

SUMMIT CURVE: To determine the length of the summit curve.

(i) *For safe overtaking or passing sight distance (S)*

$L = \frac{NS^2}{9.6}$ *(when S<L)*

$L = 2S - \frac{9.6}{N}$ *(when S>L)*

(ii) *For stopping or non passing sight distance (S)*

$L = \frac{NS^2}{4.4}$ *(when S<L)*

$L = 2S - \frac{4.4}{N}$ *(when S>L)*

VALLEY CURVE: The length of valley curve (L) based on the comfort conditions is given by

=) *L = 2* Length of transition curve*

=) $L = 2*\{(\frac{GV^3}{C})\}^{(1/2)}$ *[Take c = 0.5 m/s]*

TYPES OF PAVEMENT:

(i) Flexible pavement: A pavement which consists of a mixture of asphaltic or bituminous material and aggregate placed on a good quality and compacted granular material is termed as flexible pavement. Example, Water Bound Macadam Road.

(ii) Rigid pavement: The pavement which is constructed from cement concrete or reinforced concrete slab is termed as rigid pavement.

(iii) Semi-Rigid Pavement: In this category, the wearing course of the pavement is constructed by spreading bricks or pre-cast rectangular cement concrete block or interlocking concrete block. The joints between them are filled with fine sand with standard sizes. The pieces of blocks act as a small rigid plate. Hence the wearing course constructed by these blocks is neither fully flexible not fully rigid layer. It pocesses dual properties and is suitable for low volume village roads, footpath or cycle tracks.

METHODS OF FLEXIBLE PAVEMENT DESIGN

1. Group Index Method
2. CBR Method
3. Triaxial Method
4. Mcleod Method
5. Burmister Method

FACTORS RELATED TO RIGID PANEMENT

1. Modulus of subgrade reaction (k)
2. Radius of Relative stiffness,
3. Westergards stress equation
4. Warping stresses
5. Frictional stress
6. Combination of stresses.

JOINTS IN CONCRETE PAVEMENT

(a) Longitudinal joint: The longitudinal joints in concrete pavement divide the pavement into lanes and serve to reduce transverse warping due to difference in temperature at the centre and the edge of the road. The joints also take care of the unequal settlement of the sub-grade and also of the expansion in transverse direction.

(b) Transverse joint: The transverse joint may be expansion joint, construction joint, warping joint and contraction joint. The expansion joint in the transverse direction prevents the development of excessive compressive stresses in the concrete pavements as a result of expansion caused by increase in temperature and moisture. The transverse joints are provided to permit the contraction of the slab. The transverse warping joints are provided to relieve tensile stresses included due to warping.

TRAFFIC ENGINEERING

The traffic engineering is that branch of engineering which deals with the improvement of traffic operation, design and application of control devices such as pavement marking, traffic markers, signs and traffic signal etc. and analysis of traffic characteristics. It also deals with the improvement of the existing road & street systems either by replanning and improving them or by controlling the use of the existing systems, by different types of users.

1. Traffic signs: The most common device for regulating, warning and guide drivers is the traffic signs. The signs should be placed such that the road user can see them easily and in time. These are generally installed at a height of 2.75m to 2.8 m above the ground level.

According to Indian Motor Vehicles Act, traffic signals are divided into the following three categories:-

(a) Regulatory or Mandatory signs: These are mandatory sign. It is used to inform road users of certain laws and regulations to provide safety and free flow of traffic. The violation of these signs is a legal offence. These signs include Stop and Give-way signs, Prohibitory signs like one way, overtaking prohibited, No parking, speed limits and vehicle control sign. Colors are red, green, yellow, black, blue and brown.

(b) Informatory sign: These signs are used to guide road users along routes, to inform them about destination and distance to identify points of geographical and historical interest and provide information that will make road travel easier, safe. Example parking zone etc.

(c) Warning or Cautionary sign: This signs are used to warn road users of the existence of certain hazardous conditions either on or adjacent to the road to warn the motorist to make caution to take desired action. The warning sign include schools, level crossing, narrow bridges, U-turns etc. The signs such as 'Road under repair' and 'speed breaker ahead' are also warning signs. These signs are painted on rectangular plates 40cm * 45 cm. An equilateral triangular plate of 45cm sides is provided 15 cm above each of these signs.

2. Traffic Signals: Traffic signals are controlled devices which have proved to be very effective systems of controlling and guiding the traffic. It is specially used on the intersection or road where there is heavy vehicular traffic.
3. Traffic Marking: These are special signs used to regulate the traffic. For example: Pavement marking-centre line marking, lane marking, Kerb marking- To separate the road and Kerb, Reflector unit marking- used for night road users for safe road driving.
4. Road Junctions - Road Junctions are places where two or more roads cross each others at different angles.

   Types:

   (a) Square Junction: At square junction, usually two roads of equal width of equal importance cross each other at right angles.

   (b) Acute angle junction: At such junction road crosses each other at angles other than 90°.

   (c) T-junction

   (d) Y-junction
5. Traffic Island: These are raised areas constructed within the roadway to establish physical channels though which the vehicular traffic is guided. They are divided into three groups:

   (a) Divisional Island: These types of islands are constructed to separate the traffic from opposite direction, eliminating head on collision.

   (b) Channelizing island: This type of Island is used to guide the traffic into proper channels through the intersection areas. The size and width of this island depend on the dimension of the intersection.

   (c) Rotary Island: These is an enlarge road intersection where all converging vehicles are forced to move round a large central island in one direction before they are allowed to move out of traffic flow into their respective lane radiating from the central island.