HIGHWAY ENGINEERING

GEOMETRIC DESIGN OF HIGHWAYS

Highway cross-section elements:

(a) Pavement Surface Characteristics:

(i) Friction (Skid resistance):

- It is used to calculate design speed, radius of curves, super elevation, sight distances, etc.
- Two phenomena occurring due to friction are skid and slip. Skid occurs when wheel moves without rotating. Slip occurs when wheel rotates more than its corresponding longitudinal distance.
- Frictional resistance along the direction of movement of wheel is called longitudinal frictional resistance and perpendicular to it is known as lateral frictional resistance.
- IRC recommends coeff. of longitudinal friction as 0.35 to 0.40 and coeff. of lateral friction as 0.15.
- Frictional resistance decreases with temperature, wear and tear of tyre, tyre pressure, load, smoothness of pavement and wetness of pavement.

Variation of longitudinal coeff. of friction (f) with speed

Speed (empty)	f
20-30	0.4
40	0.38
50	0.37
60	0.36
80-100	0.35

(ii) Pavement unevenness:

- It is the cumulative measure of vertical unduraturn of pavement surface recorded per unit horizontal distance of road.
- It is measured by bump indicator or rougho meter and is expressed in terms of unevenness index and unit is usually cm/km.
- Lesser the value, better the pavement.
- For good pavements, it should be 150 cm/km and 250 cm/km is considered satisfactory.

(b) Camber or Cross-slope:

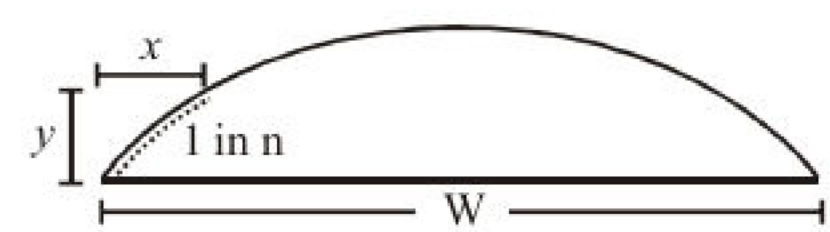
It is the slope provided along transverse direction for drainage of rain water from road surface and preventing from seepage to layers below surface and water logging.

- It is expressed as 1 in n or as percentage.
- Depending on shape it can be parabolic, elliptic, straight line or combination of straight line and parabolic.

1. Parabolic/elliptic camber:

Equation of design: $y = \dfrac{2x^2}{nw}$

- most preferred
- good for fast-moving traffic

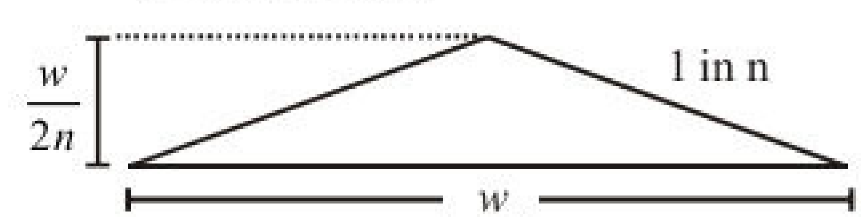


(1 in n means 1 V : nH)

2. Straight line camber:

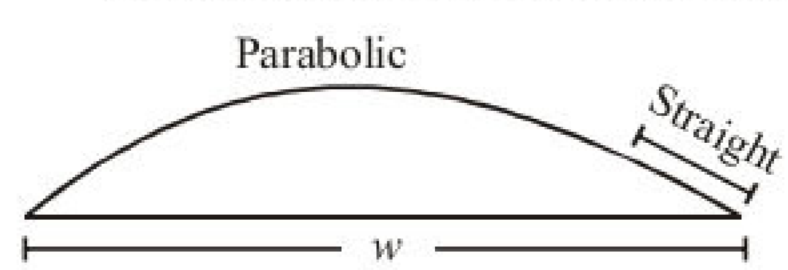
Height at centre $= \dfrac{w}{2n}$

- preferred for cement concrete pavement.
- used when divider is there at the centre of road or on curved road.



3. Combination of straight and parabolic shape:

- has advantages of both parabolic and straight roads.
- useful to increase contact area of wheel.
- parabolic at centre and straight at both sides.



(c) Width of pavement or carriage way:

- Width of pavement depends on width of each lane and number of lanes.
- Number of lanes depends on predicted traffic volume and capacity of each lane.
- Maximum width of vehicles as per IRC is 2.44 m.

(d) Road margins:

Various elements of margins are:

(i) **Shoulders:** Provided to serve as an emergency lane. Minimum width recommended is 2.5 m.

(ii) Frontage roads

(iii) Drive ways

(iv) Parking lane

(v) Footpath

(vi) Guard rail etc.

(e) Width of road way or formation:

Formation width = carriage way width including separations, if any + shoulder.

Type of road	Plain and rolling terrain	Mountain or steep terrain
• NH and SH		
– Single lane	12 m	6.25 m
– Double lane	12 m	8.80 m
• Major District Road (MDR)		
– Single & double lane	9 m	4.75 m
• Other District Road (ODR)		
– Single lane	7.5 m	4.75 m
– Double lane	9 m	
• Village road/Single lane	7.5 m	4m
• Single lane bridge	4.25 m	–

(f) Right of way:

Area acquired for road, along its alignment. It depends on the number of lanes, importance of road and future development.

Right of way = Formation width + Road margins.

- **NH and SH :**
  Normal width = 45 m
  Maximum width = 60 m
- **Distance between :**
  Building line = 80 m
  Control line = 150 m

SIGHT DISTANCES

It is the length of road visible ahead to the driver of a moving vehicle at various instances. There are mainly five sight distances considered.

(1) Stopping Sight Distance (SSD):

It is the minimum sight distance visible to a driver at any instance, that has sufficient length to stop the vehicle travelling at design speed without any chances of collision.

- SSD is given by:
  SSD = Lag distance (L) + Breaking distance (B)
- Lag distance = reaction time × design speed = $t \times v$

Breaking distance, $B = \dfrac{v^2}{2gf}$

$v \rightarrow$ velocity in m/s

$f \rightarrow$ longitudinal coeff. of friction

$$\therefore \quad \text{SSD} = vt + \frac{v^2}{2gf}$$

V in m/s

SSD at sloping road:

$$\text{SSD} = vt + \frac{v^2}{2g(f \pm 0.01n)} \ (v \text{ in m/s})$$

$$\text{or} \quad \text{SSD} = 0.278Vt + \frac{V^2}{254(f \pm 0.01n)} \ (\text{V in km/h})$$

'+' for ascending slope and '–' for descending slope. 'n' is gradient percentage.

SSD at level surface with braking efficiency, η:

$$\text{SSD} = Vt + \frac{V^2}{2gf\eta} \text{ or } 0.278Vt + \frac{V^2}{254f\eta}$$

Points to be noted

- For sloping ground replace 'f' by $(f \pm 0.01n)$ and for braking efficiency, η multiply 'f' with 'η'.
- In case of sloping ground and braking efficiencies, denominator becomes $2g(f \pm 0.01n) \times \eta$.
- SSD for single lane 1-way traffic = minimum SSD (found out by above equation)
- SSD for single lane 2-way traffic
  $= \dfrac{1}{3} \times$ minimum SSD
- SSD for two lane 2-way traffic = minimum SSD.

2. Overtaking Sight Distance (OSD):

It is the minimum sight distance visible to a driver intending to overtake a slow moving vehicle with safety against collision with traffic from opposite direction.

A $\rightarrow$ Overtaking vehicle
B $\rightarrow$ Overtaken vehicle
C $\rightarrow$ Oncoming vehicle
$d_1 \rightarrow$ distance travelled by A during reaction time
$d_2 \rightarrow$ distance travelled by A during overtaking
$d_3 \rightarrow$ distance travelled by C during overtaking

$d_1 = v_B t$

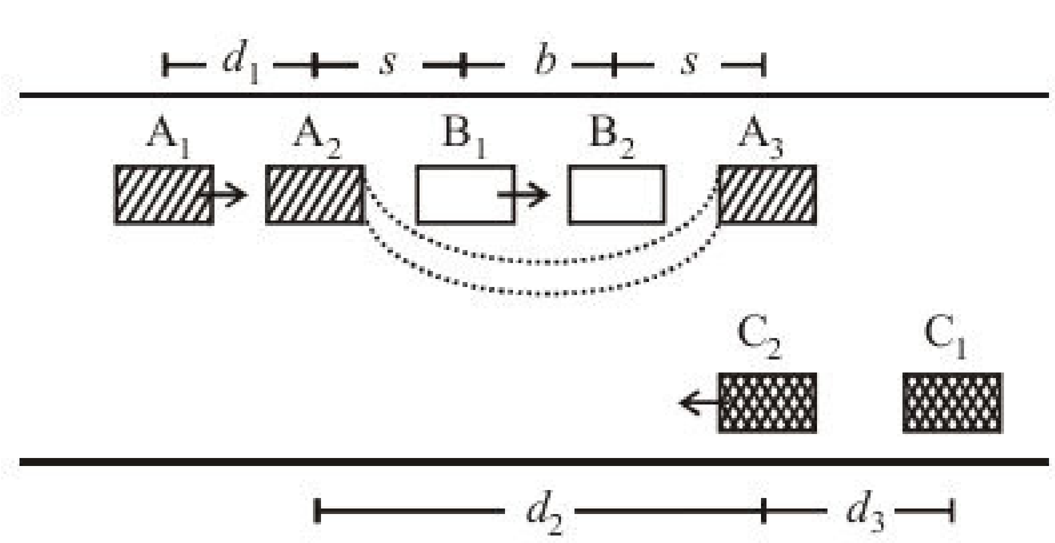
$t \rightarrow$ reaction time (2.5 seconds)

$d_2 = b + 2s = v_B T + 2s$

$T \rightarrow$ time for overtaking

$d_3 = vT. \quad T = \sqrt{\dfrac{4s}{a}}$ sec ($a \rightarrow$ acceleration in m/s)

OSD = $d_1 + d_2 + d_3$



3. **Sight Distance at Intersections:**

   At uncontrolled intersections, there should be sufficient visibility at least equal to SSD of the roads.

   IRC recommended sight distances at intersections:

Velocity (kmph)	Minor roads	60	65	80	100
Sight distance (m)	15	110	145	180	220

4. **Intermediate Sight Distance (ISD):**

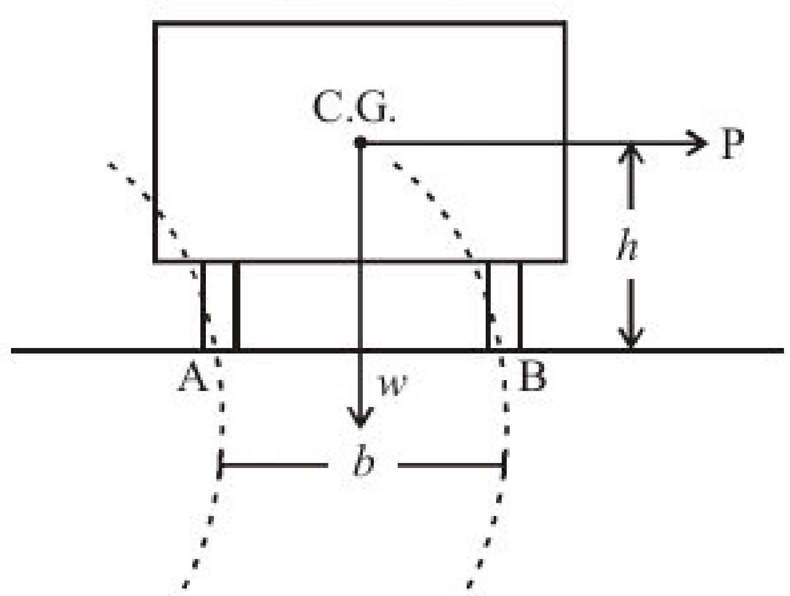
   In cases where OSD cannot be given, ISD is provided to give limited overtaking opportunities to fast-moving vehicles.

5. **Head Light Sight Distance:**

   It is the sight distance visible to a driver during night under illumination of front head lamps. This is critical at gradients.

HORIZONTAL CURVES

Consider a vehicle moving on a flat road without any super elevation while negotiating a curve,



C.G. : Centre of gravity of vehicle

Centrifugal force acting on the vehicle,

$$P = \frac{mV^2}{R} = \frac{w}{g}\frac{v^2}{R}$$

where, m = mass of vehicle

w = weight of vehicle

R = radius of curve (m)

v = velocity of vehicle (m/s)

$$\therefore \quad \frac{P}{w} = \frac{V^2}{gR}$$

Rates $\frac{P}{w}$ is called centrifugal ratio or impact factor.

A vehicle negotiating a horizontal curve has two effects based on the centrifugal force. Either the vehicle has the tendency to overturn about the outer wheel (here wheel B) or it has the tendency to skid laterally outwards the road surface (in direction AB)

At equilibrium,

$$Ph = w.\frac{b}{z} \Rightarrow \frac{P}{w} = \frac{b}{2h}$$

(i) **Tendency to overturn:**

At this condition, wheel A just lifts from the surface, i.e., pressure at A = 0

To avoid overturning, centrifugal ratio should be less than

$$\frac{b}{2h} \text{ i.e., } \frac{P}{w} \text{ or } \frac{v^2}{2g} < \frac{b}{2h}$$

Note: To reduce tendency to overturn, while designing a vehicle 'b' should be more and 'h' should be less, i.e., the vehicle should be broader with lesser height. You might have seen that some of the sports cars are designed so.

(ii) **Tendency to lateral skidding:**

Centrifugal force, $P = f \times w$

where, f = coeff. of lateral friction. (≈ 0.15)

To avoid lateral skid, centrifugal ratio should be less than 'f'

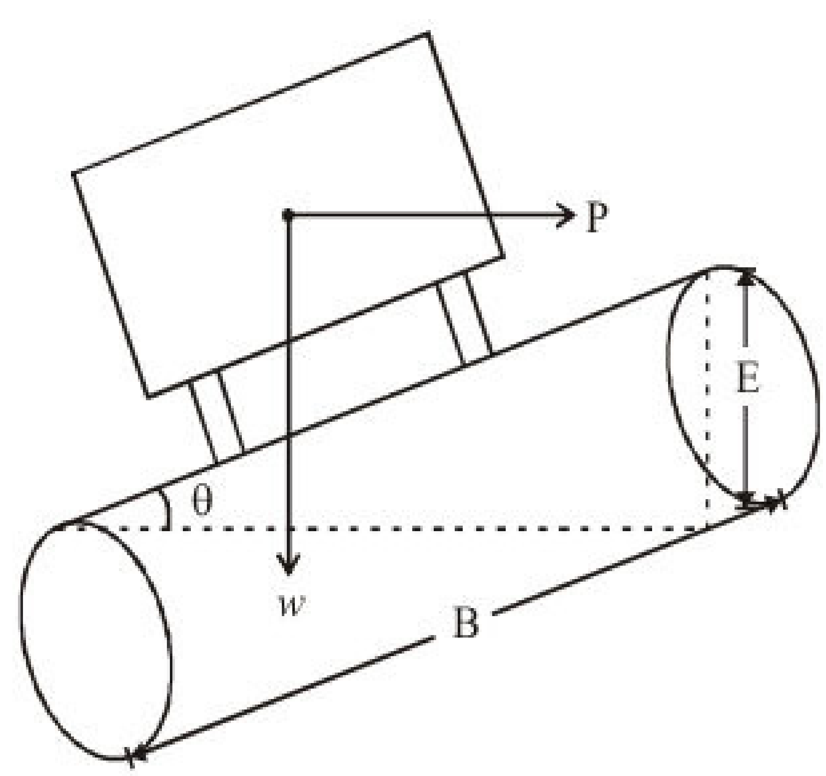
$$\text{i.e., } \frac{P}{w} \text{ or } \frac{v^2}{2g} < f$$

Points to be noted

- If $f < b/2h$, the vehicle skids before it overturns.
- If $f > b/2h$, the vehicle overturns before it skids.
- To avoid both skidding and overturning, the centrifugal ratio should be less than both $\left(\frac{b}{2h}\right)$ and 'f'.

SUPER ELEVATION:

We have already discussed that in order to avoid of skidding and overturning, $\frac{p}{w}$ should be less than $\left(\frac{b}{2h}\right)$ and f. To reduce the value of centrifugal ratio $\left(\frac{p}{w}\right)$, we have to reduce the value of centrifugal force, p. This can be done by raising the outer edge of the road with respect to the inner edge. This transverse slope is called super elevation or banking or cant.



Rate of super elevation,

$$e = \tan\theta \approx \sin\theta = \frac{E}{B} \qquad (\because \theta \text{ is small, } \tan\theta \approx \sin\theta)$$

Total height to be elevated,

$E = e \,.\, B$

General equation of super elevation is :

$$e + f = \frac{v^2}{gR} \qquad v \text{ in m/s and } R \text{ in m}$$

$$= \frac{V^2}{127R} \qquad \text{V in kmph and } R \text{ in m}$$

At equilibrium super elevation, ($f = 0$),

$$e = \frac{v^2}{9R} = \frac{V^2}{127R}$$

Maximum super Elevation (e_{max}):

- Plain and rolling terrain, snow bound hill terrain: 1 in 15 or 7%.
- Hill terrain without snow bond : 1 in 10 or 10%.

Design of super elevation:

(i) For all practical cases, we design for mixed traffic, i.e.

$$e = \frac{(0.75v)^2}{9R} = \frac{V^2}{225R}$$

(ii) Check the calculated value of e with e_{max} value, and the smaller of the two is considered.

Points to be noted

- At equilibrium super elevation, pressure on both wheels will be equal. Without super elevation pressure on outer wheel will be more.
- Allowable velocity of vehicle on horizontal curve with super elevation,

$$V = \sqrt{127(e+f)R}$$

Without super elevation,

$$V = \sqrt{127 f . R}$$

(iii) Calculate value of f with the design speed and maximum super elevation values.

$$f = \left(\frac{V^2}{127R} - e_{max}\right)$$

$$= \left(\frac{V^2}{127R} - 0.07\right) \qquad \text{(or 0.1 for hill terrain)}$$

If the value is less than 0.15, then the value of e is zero.

If the value of f is more than 0.15, restrict the speed at the horizontal curve. Restricted design speed is designed as follows:

(iv) $e_{max} + f = \dfrac{V^2}{127R}$

$$0.07 + 0.15 = \frac{V^2}{127R} \text{(give 0.1 instead of 0.07 for hill terrain.)}$$

Thus, the allowable speed can be found out.

EXTRA WIDENING

It is the extra width provided at horizontal curves. It is usually provided for curves of radius less than 300 m.

Total widening, $W_e = W_m + W_{ps}$

W_m – mechanical widening

W_{ps} – psychological widening

$$W_m = \frac{n\ell^2}{2R}$$

where, ℓ = length of wheel base ($\approx 6m$)

n = no. of lanes

$$W_{ps} = \frac{V}{9.5\sqrt{R}} \qquad V \text{ in kmph}$$

$$\therefore \quad W_e = \frac{n\ell^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

TRANSITION CURVES

It is provided between straight and circular curves to gradually introduce the curve, super elevation and extra widening

Types of transition curves:

(i) Spiral or clothoid (ideal transition curve)

Length of transition curve $\propto \dfrac{1}{\text{radius}}$

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

L.R = constant

(ii) Cubic parabola

(iii) Cubic spiral

(iv) Bernoullies' Lemniscate

Length of transition curve (L_s)

It is designed based on three conditions.

(i) Rate of change of centrifugal (radial) acceleration (c)

$$L_s = \frac{V^3}{cR} \qquad v \text{ in m/s}$$

$$c = \frac{80}{75+V} \qquad V \text{ in kmph}$$

$0.5 < c < 0.8$

(ii) Rate of change of super elevation

$L_s = e\,(\omega + \omega_e)N$ (pavement rotated about inner edge)

$$L_s = \frac{e(\omega+\omega_e)N}{2} \text{ (pavement rotated about centre line)}$$

$e \rightarrow$ rate of super elevation.

N $\rightarrow$ rate of change of super elevation.

(iii) Empirical formulae

$$L_s = 2.7\frac{V^2}{R}$$ plain and rolling terrain.

$$L_s = \frac{V^2}{R}$$ mountainous and steep terrain.

SETBACK DISTANCE

It is the distance between central line of road and an obstruction on the inner side of the curve to provide sufficient sight distance.

(i) If length of curve greater than sight distance ($L > S$)

Single lane road:

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

$$\alpha = \frac{S}{R} \qquad \left(\text{angle} = \frac{\text{arc}}{\text{radius}}\right)$$

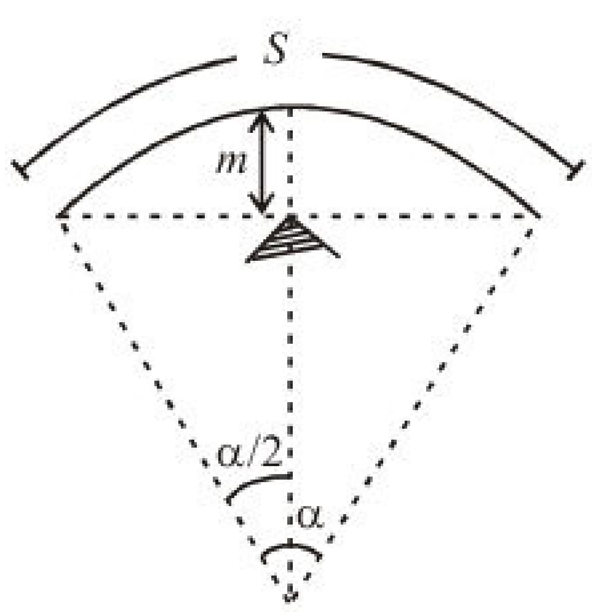
Note: $m \approx \dfrac{S^2}{8R}$

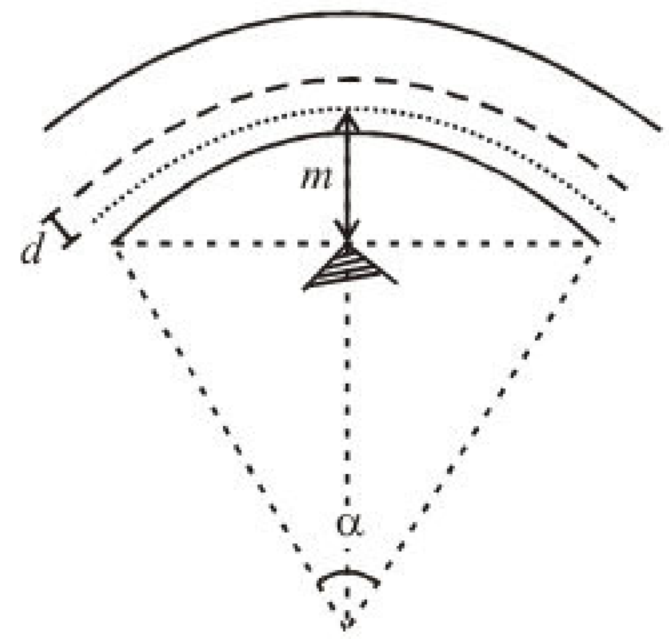
Multilane road:

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

$$\alpha = \frac{S}{R-d}$$

where, d = distance between central line of road and centre of inner road.

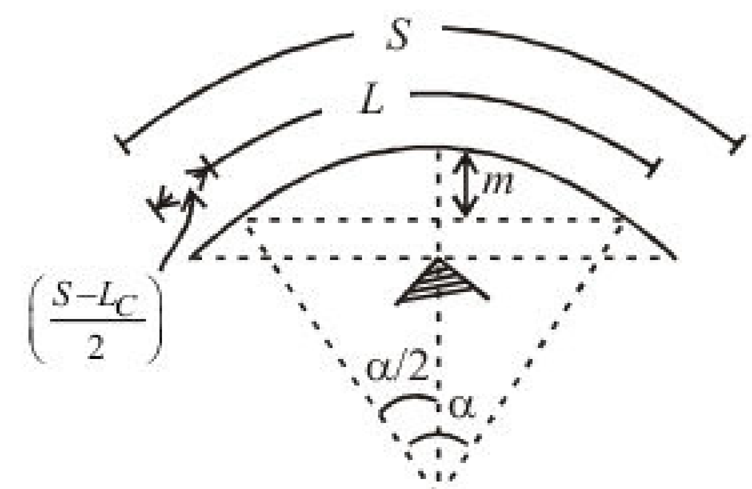




(ii) Length of curve less than sight distance ($L < S$)

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

$$\alpha = \frac{L}{R-d}$$



GRADE COMPENSATION

% grade compensation $= \dfrac{30+R}{R}$

Maximum value of grade compensation $= \dfrac{75}{R}$

R → radius of curve.

LENGTH OF VERTICAL CURVES

Length of vertical curve $= \dfrac{\text{Total change in gradient}}{\text{Rate of change of gradient}}$

Equation of curve : $y = \dfrac{N}{2L}.x^2$

(i) Summit Curve:

For stopping sight distance (SSD)		**For OSD, ISD**	
$L > SSD$	$L < SSD$	$L > OSD, ISD$	$L < OSD, ISD$
$L = \dfrac{NS^2}{(\sqrt{2H}+\sqrt{2h})^2}$	$L = 2S - \dfrac{(\sqrt{2H}+\sqrt{2h})^2}{N}$	$L = \dfrac{NS^2}{(\sqrt{2H}+\sqrt{2h})^2}$	$L = 2S - \dfrac{(\sqrt{2H}+\sqrt{2h})^2}{N}$
$\Rightarrow\ L = \dfrac{NS^2}{4.4}$	$\Rightarrow\ L = 2S - \dfrac{4.4}{N}$	$L = \dfrac{NS^2}{9.6}$	$L = 2S - \dfrac{9.6}{N}$

$L \rightarrow$ length of curve; $S \rightarrow SSD, OSD, ISD$; N = deviation angle;

$H \rightarrow$ height of eye level of driver above road surface (= 1.2 m);

$h \rightarrow$ height of obstacle above road surface (= 0.15 m)

(ii) Valley Curve:

Valley curve is usually made by two similar transition curves. Valley curve is designed based on two conditions:

(a) Comfort condition:

Length = $2 \times L_s$

where, L_s = Length of one transition curve

$$L_s = \frac{V^3}{CR} \qquad \text{(discussed earlier)}$$

$$R = \frac{L_s}{N} = \frac{L}{2N}$$

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

$$0.5 < C < 0.8$$

$$\therefore \quad L = 2L_s = 2\left[\frac{NV^3}{C}\right]^{1/2}$$

$N \rightarrow$ deviation angle

$C \rightarrow 0.61$ m/s^3 (rate of change of centrifugal acc.)

V in m/s

$L = 0.38[NV^3]^{1/2} \qquad V$ in kmph.

(b) Head light sight distance:

(1) $L > SSD$

$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha} = \frac{NS^2}{1.5 + 0.035S}$$

h_1 = average height of head light = 0.75 m

α = beam angle ($\approx 1°$)

(2) $L < SSD$

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

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

TESTING AND SPECIFICATIONS OF PAVING MATERIALS

1. **Subgrade:** The soil fill just below the pavement which receives load from the pavement and gives adequate support.

Important tests:

(i) Modulus of grade reaction (K): It is the pressure sustained (P) per unit deformation of subgrade (Δ) at specified pressure or deformation level.

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

Standard plate size = 75 cm diameter

Standard settlement = 1.25 mm = 0.125 cm

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

(ii) CBR Test (California Bearing Ratio):

$$\text{CBR (\%)} = \frac{\text{Load at 2.5 mm or 5 mm penetration}}{\text{Standard load at corresponding penetration}} \times 100$$

- Normally CBR value at 2.5 mm penetration is higher than that of 5 mm penetration or else the test is repeated.

$$\text{CBR}_{2.5\text{ mm}} > \text{CBR}_{5\text{ mm}}$$

2. **Stone aggregates:** Characteristics of stone aggregates and various tests to measure these properties are discussed below:

(i) Strength: Ability of an aggregate to withstand stresses or crushing load under gradually applied compressive load.

Aggregate crushing test

Aggregate crushing value

$$= \frac{\text{Wt. of crushed aggregate passing through 2.36 mm sieve}}{\text{Total weight of aggregate}} \times 100$$

$$= \frac{w_2}{w_1} \times 100$$

IRC recommendation: Aggregate crushing value:

For base course: $\ngtr 45\%$

For surface cource: $\ngtr 30\%$

(ii) Toughness: It is the resistance of a material against impact or sudden load.

Test: Aggregate Impact test

Aggregate impact value

$$= \frac{\text{Wt. of crushed aggregate retained on 2.36 mm sieve}}{\text{Total weight of aggregate}} \times 100$$

$$= \frac{w_2}{w_1} \times 100$$

IRC recommendations:

For wearing course : $\ngtr 30\%$

For base course (bituminous macadam) : $\ngtr 35\%$

For base course (wbm) : $\ngtr 40\%$

(iii) Hardness: It is the resistance to abrasion. Different tests are carried out to test abrasion.

(a) Los Angeles Abrasion test:

$$\text{Abrasive value} = \frac{\text{Wt. aggregate passing through 1.7 mm sieve}}{\text{Total weight of aggregate}} \times 100$$

IRC recommendation:

For cement concrete construction: $\ngtr 16\%$

For wearing course: $\ngtr 30\%$

For base course: $\ngtr 50\%$

(b) Deval abrasion test:

Same type of test as above but concluded on a different type of testing machine.

(c) Dorry abrasion test:

Similar to that of devel test but abrasive charges are not used. This test is obsolete.

BITUMINOUS MATERIALS

- Bitumen is a hydrocarbon obtained by fractional distillation of petroleum.
- If the bitumen contains some inert material, it is called asphalt.
- Jar is obtained by destructive distillation of natural organic materials like wood.

- If the viscosity of bitumen is reduced by any volatile dilutent, it is called cut back bitumen.
- If the bitumen is suspended in a finely divided condition in an aqueous medium and stabilized with an emulsifier, it is called an emulsion.

TYPES OF BITUMEN

- **A type:** Eg.: A30, A90
  S type: Eg.: S30, S90

Tests on Bitumen:

1. **Penetration Test:** It is used to determine hardness or consistency of bituminous materials. The distance traversed by standard needle in the bituminous materials is measured in 1/10th of a millimeter. Grading of bitumen is done by this value, e.g. 80/100 means penetration value of bitumen is between 80 and 100. At hot climate 30/40 is preferred.
2. **Ductility Test:** It is expressed as distance in 'cm' to which a standard briquette of bitumen can be stretched before it breaks.
   Rate of pull : 50 mm/min or 5 cm/min.
   This test measures elasticity and adhesiveness of bitumen. The ductility value usually varies from 5 cm to 100 cm. Desirable value : 50 cm.
3. **Viscosity Test:** It is used to specify the consistency of bitumen. Viscosity is the resistance of flow of the fluid. It is measured by orifice type viscometer. It is determined by measuring number of seconds required for 50 ml of material to flow through standard orifice.
4. **Float Test:** It is also used to measure consistency. Float test value is determined by measuring time taken in seconds by water to force its way into the float through the bitumen plug. Higher the value, stiffer the material.
5. **Softening Point Test:** It is the temperature at which a substance attains a particular degree of softening under standard test conditions. It is usually measured by Ring and Ball test. For high grade bitumen, softening point will be higher and penetration value will be lesser. Bitumen of higher softening point is preferred in warm climate areas.
6. **Specific Gravity Test:** Specific gravity is determined by a pycnometer. Pure bitumen has specific gravity values ranging from 0.97 to 1.02. Cutback bitumen usually has lower specific gravity. Jar has specific value ranging from 1.10 to 1.25.
7. **Flash and Fire Point Test:** It is measured by Pensky–Martens apparatus. Flash point is the lowest temperature at which vapour of a substance momentarily catches fire in form of flash. The minimum specified flash point value of bitumen is 175°C.
   Fire point is the lowest temperature at which the application of test flame causes the material to ignite and burn at least for 5 seconds under specified conditions.
8. **Spot Test:** It is used to determine overheated or cracked bitumen. Naptha solution is used for this test.
9. **Loss on Heating Test:** Bitumen is heated to 163°C for 5 hours. The specified value for bitumen used for pavement mixes is that it should not be more than 1%.
10. **Solubility Test:** Pure bitumen is completely soluble in carbon disulphide (CS_2) and carbon tetrachloride (CCl_4). Solubility is measured as percentage of original sample that dissolves in these solvents.
    In test with CCl_4, bitumen is considered to be cracked if blank residue is more than 0.5%.
    In test with CS_2, minimum proportion of bitumen soluble should be 99%.
11. **Water Content Test:** Minimum water content in bitumen should be less than 0.2% by weight.

CUTBACK BITUMEN

It is the bitumen whose viscosity has been reduced by a volatile dilutent. It is used for surface dressing and soil bitumen stabilization particularly at low temperature.

Types of Cutbacks:

1. **Rapid Curing (RC):** Dilutent will rapidly evaporate when used for construction. For RC, petroleum dilutent like naptha or gasoline is fluxed to bitumen.
2. **Medium Curing (MC):** For MC, bitumen is fluxed with intermediate boiling point solvents like kerosene or light diesel oil so that it won't evaporate faster.
3. **Slow Curing (SC):** For SC, bitumen is fluxed with high boiling point gas oil.

BITUMINOUS EMULSION

It is prepared by suspending finely divided bitumen in an aqueous medium and adding stabilizers to it. It is used mainly in maintenance repair works and for soil stabilisation. It can be used in wet weather. On application on roads, it break down and binder starts binding the aggregate.

Tar: It is obtained by destructive distillation of wood or charcoal. Tars are of five grades in increasing order of viscosity:

RT-1, RT-2, RT-3, RT-4, RT-5

RT-1 is of the lowest viscosity and is used for surface pointing whereas RT-5 of the highest viscosity is used for grating purposes.

Marshall Stability Test:

- Test is applicable to hot mix-paving mixture design using penetration grade bitumen and containing aggregate with maximum size of 2.5 cm.
- It is a type of unconfined compression strength test, in which a cylinder specimen of 10 cm diameter and 6.3 cm height is compressed radially at a constant rate of strain of 5 cm/min.
- Corresponding load carried by specimen at standard temperature (60°C) is called **Marshall Stability** value and the deformation at failure in units of 0.25 mm is recorded as Marshall flow value.
- The optimum binder content for aggregate mixture and anticipated traffic conditions is a compromise value which meets specified requirements for stability slow value and void content.

Design Specification :

Marshall stability = min. 340 kg
Flow value (0.25 mm units) = 8-17
Percentage air voids in mix. = 3-5%
Voids filled with bitumen = 75-85

DESIGN OF PAVEMENTS

Pavements are classified flexible and rigid pavement based on its structural behaviour.

Flexible pavement consists of series of layers with the highest quality material at the top layer to sustain the compressive stresses and wear and tear.

Rigid pavement consists of one course of concrete slab which takes up the loads.

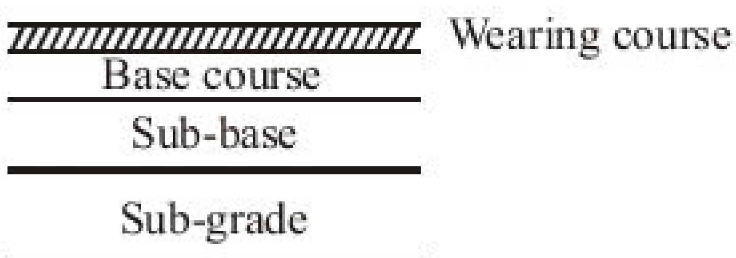
Components of pavements:

Wearing course: Gives smooth surface, watertight layer.

Base and sub-base: Improves load carrying capacity, transfers load to bottom.

Sub-grade: Natural soil prepared 50 cm thickness recommended.

Tests conducted to test strength: CBR test, California resistance value test, Triaxial test, Plate bearing test.



DESIGN FACTORS:

1. **Design Life:** It depends on type and importance of road. Varies from 15 to 30 years.
2. **Design Traffic:** It is based on 7 days 2 hours traffic count as per IRC–9.

   Anticipated traffic,

   $A = P[1 + r]^n$

   $P \to$ last counted no. of vehicles/class

   $r \to$ rate of growth of traffic (usually 7.5% is taken)

   $n \to$ no. of years

   $\therefore \quad A = P(1.075)^n$
3. **Maximum Wheel Load:**
   - It influences the quality of road surface.
   - Pavement design is based on 98th percentile axle load.

     Maximum legal axle load

     = 8,200 kg (flexible pavement)

     = 10.2 t (rigid pavement)

   Maximum equivalent single wheel load is half of maximum legal axle load.
4. **Contact Pressure:**

   $$\text{Contact pressure} = \frac{\text{Load on wheel}}{\text{Contact area}}$$

   - Contact area is taken circular in shape.
   - Influences quality of surface layer.
   - Contact pressure for road vehicles = 5-7 kg/cm^2

   $$\text{Rigidity factor} = \frac{\text{Contact pressure}}{\text{Tyre pressure}}$$
5. **Equivalent Single Wheel Load (ESWL):** To carry large roads, vehicles are provided with dual wheels. The total load will be less than 2 times load on each wheel.

   ESWL is calculated by equivalent deflection criterion (more reliable) or equivalent stress criterion.

   Equivalent stress criterion is used by the graph of ESWL with depth (Z)

   $s = d + 2a$

   $a \to$ radius of circular contact area

Design of flexible pavements:

1. **CBR Method (California Bearing Ratio)**
   - Thickness of pavement (t) (if CBR < 12%)

   $$t = \sqrt{P\left(\frac{1.75}{CBR} - \frac{1}{\rho\pi}\right)} = \sqrt{\frac{1.75P}{CBR} - \frac{A}{\pi}}$$

   where,

   P = wheel load (kg)

   $CBR = CBR\%$

   ρ = tyre pressure

   A = area of contact
2. **Triaxial Test Method:**

   Thickness of pavement (t)

   $$t = \sqrt{\left(\frac{3P \times Y}{2\pi E_s \Delta}\right)^a - a^2} \times \left(\frac{E_s}{E_p}\right)^{1/3}$$

   where,

   $P \to$ wheel load,

   $X \to$ traffic coeff.,

   Y $\to$ saturation coeff.

   E_s and $E_P \to$ modulus of elasticity of sub-grade and pavement $\left[t \propto \left(\frac{1}{E}\right)^{1/3}\right]$

   $\Delta \to$ design deflection

   $a \to$ area of contact

   $$\text{Stiffness factor} = \left(\frac{E_S}{E_P}\right)^{1/3}$$

DESIGN OF RIGID PAVEMENT

Radius of Relative Stiffness:

The sub-grade below the slab offers some degree of resistance to slab deflection. The slab deflection is measurement of magnitude of sub-grade pressure.

$$\text{Radius of gyration, } \ell = \left[\frac{Eh^3}{12(1-u^2)K}\right]^{1/4}$$

where,

$E \to$ modulus of elasticity of concrete

$K \to$ modulus of sub-grade reaction

$h \to$ slab thickness

$u \to$ Poisson's ratio of concrete (0.15)

Equivalent radius of resisting section (b):

It gives the radius of area resisting bending moment of the plate.

$$b = \sqrt{1.6a^2 + h^2} - 0.675h \qquad \text{if } a < 1.724h$$
$$= a \qquad a \geq 1.724h$$

where, $a =$ area of wheel load distribution $= \sqrt{\frac{P}{q\pi}}$

1. **Wheel Load Stress:**

   It acts not around the load but at a distance 'x' from corner bisector.

   where, $x = 2.58\sqrt{a\ell}$

2. **Westergaard's Equation for Wheel Loads:**

   Interior loading,
   $$S_i = \frac{0.316P}{h^2}\left[4\log_{10}\left(\frac{\ell}{b}\right) + 1.069\right]$$
   Edge loading,
   $$S_e = \frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{\ell}{b}\right) + 0.359\right]$$
   Corner loading,
   $$S_e = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{\ell}\right)^{3/5}\right]$$

   Modified Westergaard's Equation:

   These equations are recommended by IRC and are now used.

$$S_e = 0.529\left(\frac{P}{h^2}\right)(1 + 0.54\mu)\left[4\log_{10}\left(\frac{\ell}{b}\right) + \log_{10} b - 0.4048\right]$$
$$S_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{\ell}\right)^{6/5}\right]$$

3. **Temperature Stresses:**

   Temperature stresses can be due to variation in temperature due to daily variation and seasonal variation.

   (a) Warping stress: This is due to daily variation of temperature.

   At interior :
   $$S_{w(i)} = \frac{E\alpha t}{2}\left[\frac{C_x + \mu C_y}{1 - \mu^2}\right]$$
   At edge :
   $$S_{w(e)} = \frac{E\alpha t}{2}[C_x] \qquad \text{(whichever is higher)}$$
   or
   $$= \frac{E\alpha t}{2}[C_y]$$
   At corner :
   $$S_{w(c)} = \frac{E\alpha t}{3(1-\mu)}\sqrt{\frac{a}{\ell}}$$
   where,

   $\alpha \rightarrow$ coeff. of linear expansion

   $t \rightarrow$ temp. difference between top and bottom of slab

   $C_x \rightarrow$ coeff. based on $\frac{L_x}{\ell}$ in desired direction

   $C_y \rightarrow$ coeff. based on $\frac{L_y}{\ell}$ in right angle to above direction

   L_x and $L_y \rightarrow$ short and long dimensions of the slab.

   $\mu \rightarrow$ Poisson's ratio (00.15)

   (b) Frictional stress: It is induced at the bottom of slab due to uniform temperature variation.

   Force in slab due to movement = Frictional resistance due to sub-grade
   $$\Rightarrow \quad S_f \times h \times B = \left(B \times \frac{L}{2} \times h\right).r_c.f$$
   $$\therefore \quad S_f = \frac{r_c f.L}{2}$$
   where,

   $S_f \rightarrow$ unit stress developed in slab

   $L, B \rightarrow$ length and width of slab

   $r_c \rightarrow$ unit weight of concrete (2400 kg/m^3)

   $f \rightarrow$ coeff. of friction ≈ 1.5

Critical Stress Combinations

Mid-day:

- **During summer :** At edge,
  $S_{\text{critical}} = S_e + S_{w(e)} - S_f$
- **During winter :** At edge,
  $S_{\text{critical}} = S_e + S_{w(e)} + S_f$
- **Mid-night :** At corner,
  $S_{\text{critical}} = S_C + S_{w(C)}$

EXERCISE

1. 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 (%) is
   (a) 3.3 (b) 4.8
   (c) 5.3 (d) 6.8
2. The consistency and flow resistance of bitumen can be determined from the following
   (a) Ductility test (b) Penetration test
   (c) Softening point test (d) Viscosity test
3. The extra widening required for a two-lane national highway at a horizontal curve of 300 m radius, considering a wheel base of 8 m and a design speed of 100 kmph is
   (a) 0.42 m (b) 0.62 m
   (c) 0.82 m (d) 0.92 m
4. While designing a hill road with a ruling gradient of 6%, if a sharp horizontal curve of 50 m radius is encountered, the compensated gradient at the curve as per the Indian Roads Congress specifications should be
   (a) 4.4% (b) 4.75%
   (c) 5.0% (d) 5.25%
5. The design speed on a road is 60 kmph. Assuming the driver reaction time of 2.5 seconds and coefficient of friction of pavement surface as 0.35, the required slopping distance for two-way traffic on a single lane road is
   (a) 82.1 m (b) 102.4 m
   (c) 164.2m (d) 186.4 m
6. Match the following tests on aggregate and its properties

	TEST		PROPERTY
P.	Crushing test	1.	Hardness
Q.	Los Angeles abrasion test	2.	Weathering
R.	Soundness test	3.	Shape
S.	Angularity test	4.	Strength

   (a) P-2, Q-l, R-4, S-3 (b) P-4, Q-2, R-3, S-l
   (c) P-3, Q-2, R-l, S-4 (d) P-4, Q-l, R-2, S-2
7. The specific gravity of paving bitumen as per IS:73-1992 lies between
   (a) 1.10 and 1.06 (b) 1.06 and 1.02
   (c) 1.02 and 0.97 (d) 0.97 and 0.92
8. A combined value of flakiness and elongation index is to be determined for a sample of aggregates. The sequence in which the two tests are conducted is
   (a) elongation index test followed by flakiness index test on the whole sample.
   (b) flakiness index test followed by elongation index test on the whole sample.
   (c) flakiness index test followed by elongation index test on the non-flaky aggregates.
   (d) elongation index test followed by flakiness index test on non-elongated aggregates.
9. Which of the following stress combinations are appropriate in identifying the critical condition for the design of concrete pavements?

	Type of Stress		Location
P.	Load	1.	Corner
Q.	Temperature	2.	Edge
		3.	Interior

   (a) P-2, Q-3 (b) P-l, Q-3
   (c) P-3, Q-l (d) P-2, Q-2
10. The design speed for a two-lane road is 80 kmph. When a design vehicle with a wheel base of 6.6 m is negotiating a horizontal curve on that road, the off-tracking is measured as 0.096 m. The required widening of carriageway of the two-lane road on the curve is approximately
   (a) 0.55m (b) 0.65m
   (c) 0.75m (d) 0.85m
11. The probability that *k* number of vehicles arrive (i.e. cross a predefined line) in time *t* is given as $(\lambda t)^k e^{-\lambda t} / k!$, where λ is the average vehicle arrival rate. What is the probability that the time headway is greater than or equal to time t_1?
   (a) $\lambda e^{\lambda t_1}$ (b) λe^{-t_1}
   (c) $e^{\lambda t_1}$ (d) $e^{-\lambda t_1}$
12. In Marshall testing of bituminous mixes, as the bitumen content increases the *flow* value
   (a) remains constant
   (b) decreases first and then increases
   (c) increases monotonically
   (d) increases first and then decreases
13. Road roughness is measured using
   (a) Benkelman beam
   (b) Bump integrator
   (c) Dynamic cone penetrometer
   (d) Falling weight deflectometer
14. The following data are related to a horizontal curved portion of a two-lane highway: length of curve = 200 m, radius of curve = 300 m and width of pavement = 7.5 m. In order to provide a stopping sight distance (SSD) of 80 m, the set back distance (in m) required from the centre line of the inner lane of the pavement is
   (a) 2.54 (b) 4.55
   (c) 7.10 (d) 7.96
15. A vehicle negotiates a transition curve with uniform speed *v*. If the radiuses of the horizontal curve and the allowable jerk are *R* and *J*, respectively, the minimum length of the transition curve is
   (a) $R^3/(vJ)$ (b) $J^3/(Rv)$
   (c) v^2R/J (d) $v^3/(RJ)$
16. What is the relationship between camber (c) and longitudinal gradient (G) in normal design?
   (a) c = 2G (b) c = G
   (c) c = G/2 (d) c = G/4

17. Equation of height of camber of road of width w and slope 1 in n is

(a) $c = \frac{w}{2n}$ (b) $c = \frac{w}{n}$

(c) $c = wn$ (d) $c = 2wn$

18. The convexity provided to the carriage way between the crown and edge of pavement is known as

(a) gradient (b) camber

(c) slope (d) vertical curve

19. What is the stopping sight distance(SSD) for a design speed of 50kmph for a 2-way traffic on a single lane road. Take reaction time as 2 seconds and coeff. of friction 0.36

(a) 55.14m (b) 110.28m

(c) 27.57m (d) 26.8m

20. The reaction time for calculating SSD is taken as:

(a) 5 sec (b) 2.5 sec

(c) 0.5 sec (d) 10 sec

21. A vehicle travelling on clay, level pavement at 80 kmph had the brakes applied. The vehicle travelled 76.5 m before stopping. What is the coeff. of friction that has developed?

(a) 0.2 (b) 0.3

(c) 0.33 (d) 0.4

22. The safe SSD for a design speed of 50 kmph for a 2 lane and with coeff. of friction 0.37 is

(a) 61.3m (b) 81.7m

(c) 123.7m (d) 161.6m

23. Calculate the SSD for an ascending gradient of 5% for a design speed of 60 kmph (t = 2.5s, f = 0.35)

(a) 77.13m (b) 154.26m

(c) 87.13m (d) 164.26m

24. What is the intermediate sight distance (ISD) for a design speed of 50kmph with coeff. of friction 0.37?

(a) 61.3m (b) 30.6m

(c) 122.6m (d) none of these

25. A car is moving at a speed of 72 kmph on a road having 2% upward gradient. If the reaction time of driver is 1.5 seconds and f = 0.18. Calculate the distance moved by the vehicle before the car stops finally?

(a) 24m (b) 150m

(c) 1056m (d) 324m

26. The overtaking vehicle has a speed of 60 kmph and an acceleration of 0.9. The speed of overtaken vehicle is 40 kmph, on a two way traffic road. The safe overtaking sight distance is

(a) 261 m (b) 212m

(c) 282m (d) 255m

27. For a highway with design speed of 100 kmph, safe OSD is ($a = 0.53\ m/s^2$)

(a) 300m (b) 750m

(c) 320m (d) 470m

28. Minimum length of overtaking zone is equal to

(a) OSD (b) $20 \times$ OSD

(c) $3 \times$ OSD (d) $4 \times$ OSD

29. What is the super elevation required for a horizontal curve of 120 m and design speed of 60 kmph having coeff. of lateral friction 0.13 ?

(a) 0.11 (b) 0.13

(c) 0.011 (d) 0.03

30. Calculate the required super elevation for a horizontal curve of 135 m and design speed of 67 kmph. Where the pressure in inner and outer wheels should be equal?

(a) 0.026 (b) 0.02

(c) 0.16 (d) 0.26

31. A road is having a horizontal curve of 400 m radius on which a super elevation of 0.07 is provided. The coeff. of lateral friction mobilized on the curve when vehicle is travelling at 100 kmph is

(a) 0.007 (b) 0.13

(c) 0.15 (d) 0.4

32. What is the mechanical widening required for a road of 8 m width on a horizontal curve of 310 m. length of longest wheel base of vehicle is taken as 8 m.

(a) 0.106 (b) 0.206

(c) 0.196 (d) 0.204

33. The design speed of a 2 lane road is 65 kmph. When a vehicle with a design base of 6.8 m is negotiating a horizontal curve and the off tracking was measured as 0.09 m. The required widening of carriage way of the two lane road on the curve is approx.

(a) 0.55m (b) 0.6606m

(c) 0.76m (d) 0.65m

34. What is the shift of the transition curve of radius 280 m and length 56 m?

(a) 0.26 (b) 0.36

(c) 0.46 (d) 0.56

35. A 2 way horizontal curve has a length of 200 m, radius of 300 m and width of pavement is 8 m. For a SSD of 75 m, what is the required set back distance from the centre line of inner lane of the pavement?

(a) 2.36m (b) 2.26m

(c) 2.16m (d) 1.16m

36. What is the equation for length of transition curve when the pavement is rotated about inner edge?

(a) e.W.N (b) $\frac{eWN}{2}$

(c) $e(W + W_e)N$ (d) $\frac{e(W + W_e)N}{2}$

37. The ideal form of curve for a summit curve is

(a) lemniscates (b) Parabolic

(c) Circular (d) Spiral

38. Given the sight distance as 120 m. the height of driver's eye is 1.5 m height of object is 0.15 m. Grade difference of international gradient is 0.09.the required length of summit parabolic curve is

(a) 25m (b) 125m

(c) 250m (d) 500m

39. The important factor to be considered for the design of summit curve on highway is

(a) Comfort of passenger