Civil Engineering

13

Highway

CONTENTS

1 Introduction to Highway

Note:
Roman Roads → Tresaguet construction → Met calf construction → Telford constructions → Macadam construction.

John Macadam (1756 – 1836) was the first person to put forward a concept which suggested that heavy foundation stones are not required at all at the bottom layer

Development of highway planning in India: After first world war (28/07/1914 to 11/11/1918) as more motor vehicles came on road necessity of proper road planing came into light. So a **Road Development committee** headed by **Mr. M.R. Jayakar** was appointed by the government.

Recommendations

(*a*) 20 years long term planning programmes.
(*b*) Establishment of Indian Road Congress (IRC) in 1934 for holding of periodic road conferences to discuss about road construction and development.
(*c*) Introduction of central road fund is 1929, which imposed duty on motor spirit, vehicle taxation, license fee etc.
(*d*) Central Road Research Institute (CRRI) in 1950 (near Apollo metro station – New Delhi) to carry out research and development work.

Important year's of highway development

1. Nov. 1927 → Jayankar committee formed.
2. Feb. 1928 → Recommendations by Jayankar committee
3. 1929 → central road fund
4. 1934 → Indian road congress
5. 1939 → motor vehicle act
6. 1943 – 63 Nagpur road plan (finished in 1961)

7. 1950 Central Road Research Institute
8. 1956 National highway act
9. 1961 – 81 Bombay road plan
10. 1981 – 01 Lucknow road plan

NAGPUR PLAN (1943 – 63)

1. Roads are divided into four classes :
   (*a*) National Highways
   (*b*) Provincial and state highways
   (*c*) District roads
   (*d*) Village roads
2. Recommendations for star and grid pattern
3. Road density of 16 Km per 100 Km Square
4. Completed in 1961

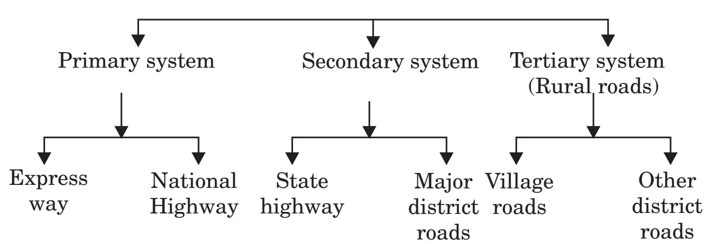
BOMBAY PLAN (1961 – 81)

1. Road density of 32 km per 100 km square, 40% of length would be surfaced
2. Construction of 1600 km of Expressway included in plan
3. Highway financing from those also who get indirect benefits. Like cess in land revenue, toll projects and tax on diesel oil.
4. Traffic Engineering cell in each state.

LUCKNOW PLAN (1981 – 01)

- The first two plans were not the part of total transportation plan of the country.
- The first two plans didn't meet the needs of freight and passenger movement by road.

1. The roads were classified as



2. Road density of 82 km per 100 km square

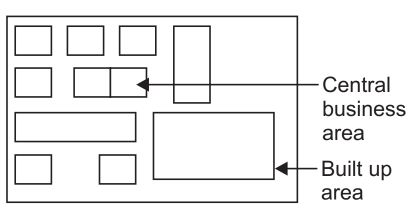
3. Expressway's to be constructed on major traffic corridors.
4. National Highway should form square grid of 100 km × 100 km.
5. Energy conservation, environmental quality of roads and road safety measures were also given due importance in this plan.

Comparison of Nagpur plan and Bombay plan

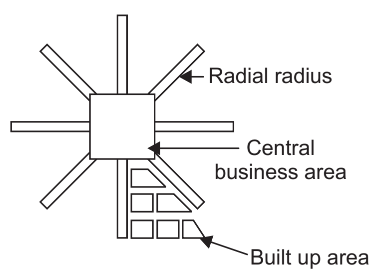
1. Nagpur plan gave **two** formulae, one for metalled roads and other for unmettaled roads while Bombay plan gave **five** different formulae for each class of road *i.e.* NH, SH, MDR, ODR, and VR.
2. Nagpur road plan divides area into agricultural and Non-agricultural area while Bombay road plan divides it into three parts developed and agricultural area, semi-developed area, undeveloped and uncultivated area.
3. Nagpur road plan formula does not takes into account the towns with very large population. They divided the population in only **two** groups 2001–5000 and above 5000 While Bombay road plan divides it into nine groups.
4. Length of railways deducted in calculating the highway length during Nagpur plan while in Bombay plan it is emphasised to develop highway system independently so in Bombay road plan it is not deducted.
5. A 15% increase in calculated road length of both categories for development of agriculture and industry during next 20 years was decided in Nagpur road plan. While in Bombay road plan this allowance was kept as 5%.
6. Bombay road plan provided 1600 Km of Expressway out of proposed National Highways.

ROAD PATTERNS

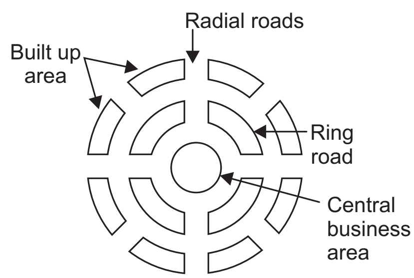
(*a*) Rectangular or block pattern



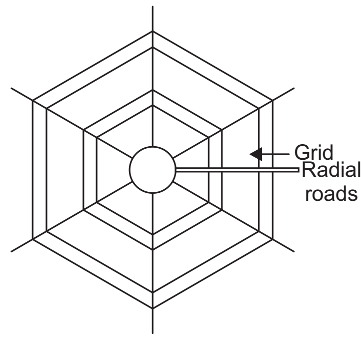
(*b*) Radial or star and block pattern



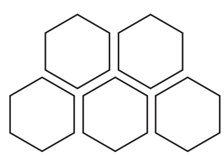
(*c*) Radial or star and circular pattern



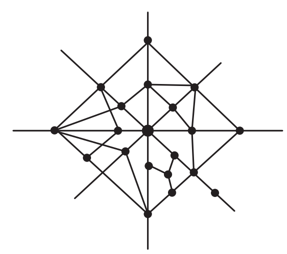
(*d*) Radial or star and grid pattern



(*e*) Hexagonal pattern



(*f*) Minimum travel pattern



Note:
Chandigarh → Rectangular and block pattern
New Delhi → Radial and circular pattern at cannought place
Nagpur road plan formulated star and grid pattern.

Studies in planning Survey

Planning Surveys

Economic studies		Population, its distribution and classification. Trend of population growth; Listing of agricultural and industrial development, their future trends-classification and listing of these details; other activities viz. Income per capita banking, post office etc.
Financial Studies	Data collected Must confirm to; Adequacy, Accuracy, Availability, Accessibility	Source of income, Revenue from taxation on road transport Living standard, future trends-details like vehicle registration, Court fees and Local taxes etc.
Traffic or road use studies		Traffic volume, traffic flow patterns—O and D studies Mass transportation facilities, Accidents—their costs, trends; Growth of vehicular traffic, passenger trips and good movements.
Engineering studies		Road location and alignment studies, Classification; Types of roads in use; Maintenance problems—Soil and topography studies; Road life studies.

Highway Alignment: Factors controlling highway alignment are.

(*a*) **Obligatory points:** Control points governing the alignment, which deviate the highway from its shortest or earlest path

(*b*) **Traffic:** Origin and destination studies should be carried out and desire lines to be drawn, New roads should then be aligned or per desire line, traffic flow pattern and future trends.

(*c*) **Geometric design:** Horizontal alignment of the road to be adjusted based on minimum radius of curvature and transition curves. Vertical alignments are based on visibility, passenger comforts etc.

(*d*) **Economy:** Initial cost of construction can be decreased if high embankment and deep cuttings are avoided and Highways are aligned as per balanced cutting and filling of earth,

(*e*) **Other considerations:** Road alignments are sometimes even based on political constituencies. Other considerations include drainage, hydrological features etc.

Engineering Surveys for Highway Locations

1. **Map study:** To have an idea of several alternate routes, locations of valleys, lakes, ponds, bridges, contours etc.
2. **Reconnaissance:** A field survey of land along the proposed alternative routes of the map in the field is studied. All relevant details not available on map are collected and noted down.
3. **Preliminary survey:** To compare different proposals, to workout the cost and quantity of earthwork and to finalise the best alignment. Its procedure involves following steps.
   (*a*) Primary traverse
   (*b*) Topographical features
   (*c*) Levelling works
   (*d*) Drainage and hydrological data studies
   (*e*) Soil survey
   (*f*) Material survey
   (*g*) Traffic survey
   (*h*) Determination of final centre line.
4. **Final location and detailed survey:** Marking of centre line of field and then a detailed survey is carried out for collecting necessary information for the preparation of plans and construction details of highway project. Temporary bench marks are fixed at intervals of about 250 meters and at all drainage and under pass structure.

2 Geometric Design

Designing of visible dimensions (both in horizontal and vertical plane) of highway is called geometric design.

Factors controlling geometric design:

(*i*) Road user characterstics

(*ii*) Vehicle characterstics

(*iii*) Safety requirements

(*iv*) Environmental considerations

(*v*) Economy

(*vi*) Topography

(*vii*) Functional classification

(*viii*) Traffic volume and composition

(*ix*) Design speed.

- The total time required for **perception, intellection, emotion** and **volition** (PIEV) that is from the instant the object comes in the line of sight of the driver to the instant he arrives at a decision under **normal circumstances** is called **reaction time.** As per IRC, its **2.5 sees** (90^{th} percentile reaction time).
- **Design Vehicles** are those whose dimensions and weight are adopted for determining the elements of highway design. Max permissible width of vehicle is **2.44 m.**
- The Max. speed at which vehicles can continuously travel safely under favourable conditions is called design speed.
- **Ruling design speed** is the speed which is used as guiding criteria for correlating various geometric design features.
- Where site conditions, cost etc. do not permit ruling design speed then the speed is decreased to **minimum design speed.**
- Topography of the land, through which the road passes is known as terrain.

Functional classification of Roads

Non-urban roads or rural roads
- Express ways
- National highways
- State highways
- Major district roads
- Other district roads
- Village roads

Urban streets
- Express ways
- Arterial streets
- Sub-arterial streets
- Collector streets
- Local streets

Terrain	% Cross-slope
Plain	0-10
Rolling	10-25
Mountainous	25-60
Steep	> 60

Cross-sectional elements

1. **Friction:** As per IRC: coefficient of longitudinal friction is 0.35–0.4 depending on speed where as that of lateral friction is 0.15. Lack of adequate friction causes slipping or skidding

   Slipping: Wheel revolves more than corresponding longitudinal movement.

   Skidding: When longitudinal movement on road is more than wheels revolution.

2. **Unevenness:** Unevenness index is the cumulative measure of vertical undulation of the pavement surface recorded per unit horizontal length of the road. A value less than **1500 mm per km** is considered **good**. Pavement surface condition is measured by **Bump-Indicator** in terms of unevenness index.
3. **Light reflection:** Concrete roads have better visibility and less glare.
4. **Drainage:** Both geometry and texture of pavement surface should help in draining out water from the surface in less time.

Camber or cross fall: It's the rising of the middle of the road surface in the transverse direction to drain off rain water from road surface.

- Camber is measured in 1 in *n* or *n*%
- For cement concrete pavement. Camber is in straight line otherwise parabolic.
- For providing the desired amount and shape of camber, **templates** or **camber boards** are used.

Surface type	Heavy rain	Light rain
Concrete/Bituminous	2%	1.7%
Gravel/WBM	3%	2.5%
Earthen	4%	3.0%

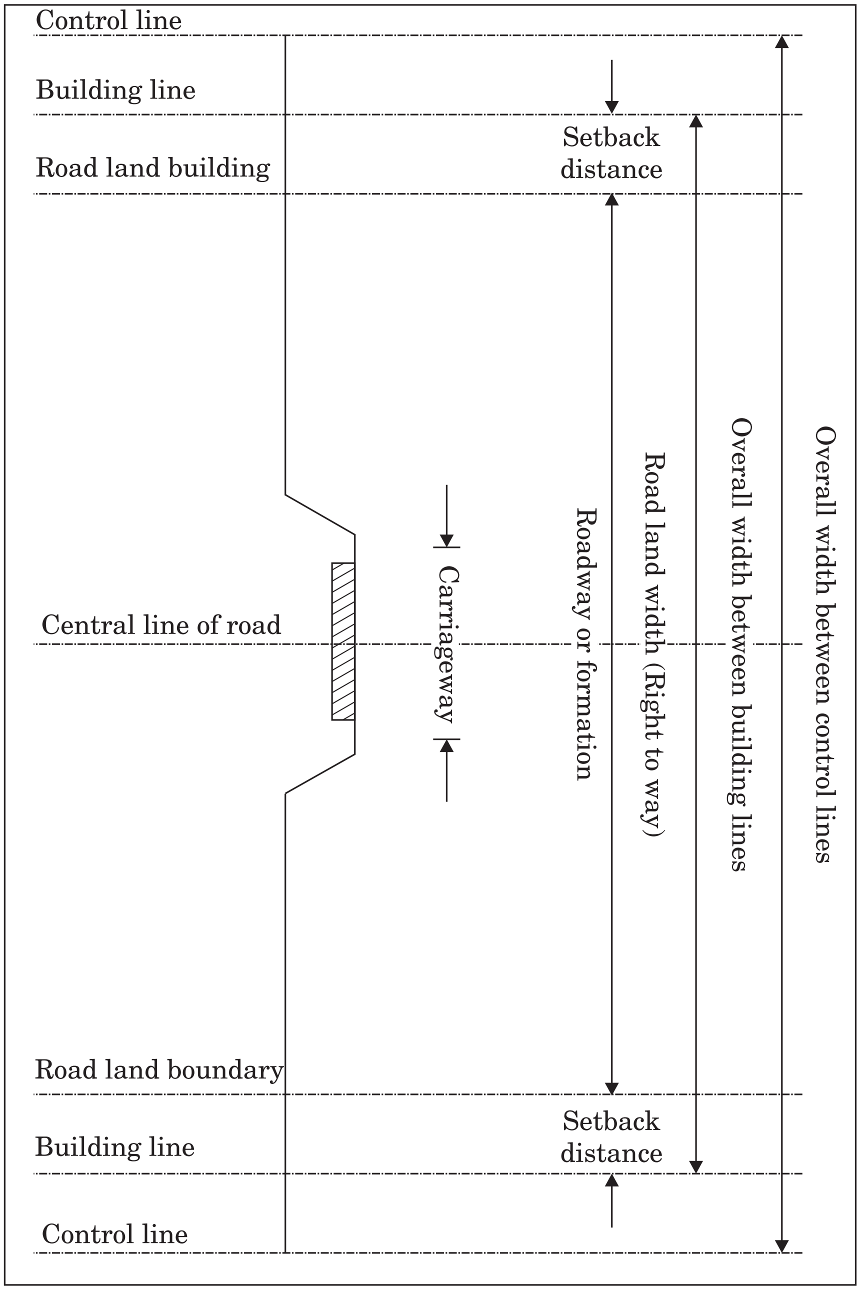
Width of Carriage way: It is decided on the basis of capacity which depend on traffic lane and number of lanes.

IRC Specification for Carriage way width

Single lane	3.75
Two lane, no kerbs	7.0
Two lane, raised kerbs	7.5
Intermediate carriage	5.5
Multi-lane	3.5

Median or Traffic Separators: It prevents head on collision between vehicles moving in opposite directions on adjacent lanes. It helps to channelize traffic and segregate slow traffic to protect pedestrians.

As per IRC, minimum desirable width for median is for rural highways and can be reduced to 3 m if land is restricted.


Control line
Building line
Road land building
Setback
distance
Carriageway
Roadway or formation
Road land width (Right to way)
Overall width between building lines
Overall width between control lines
Central line of road
Road land boundary
Building line
Setback
distance
Control line

Sight Distance: The distance from which any types of obstruction on the road length could be visible to the driver from some distance ahead is called Sight Distance.

- Stopping Sight Distance (SSD)
- Intermediate Sight Distance (ISD)
- Overtaking Sight Distance (OSD)
- Head Light Sight Distance
- Safe Intersection Sight Distance

(*i*) **Stopping Sight Distance:** It is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle travelling at a design speed safely without collision with any obstruction.

S.S.D = lag distance + Braking distance

v = design speed, m/see^2

t = reaction time (2.5 sees)

g = acceleration due to gravity (m/see^2)

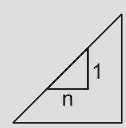
f = coefficient of longitudinal friction (0.35)

$$\text{S.S.D} = vt + \frac{v^2}{2gf}$$

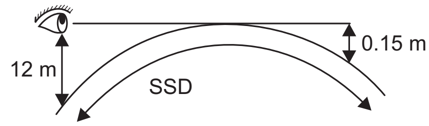
Speed (km/hr)	< 30	40	50	60	> 80
f	0.40	0.38	0.37	0.36	0.35

Note:
When vehicle is moving up (+) or down (–) the grade (n) then

$$\text{S.S.D} = v\,t + \frac{v^2}{2g\left(f \pm \frac{n}{100}\right)}$$

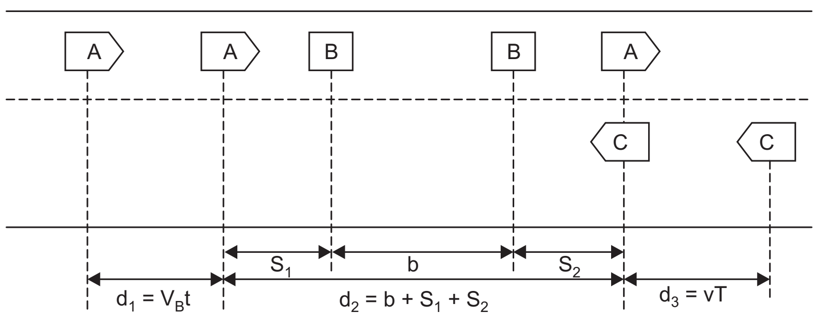


- Effect of grade should be considered for divided highway but not for undivided highway.
- Single lane roads on which two way traffic is permitted, stopping distance is **twice** the minimum stopping distance to stop both vehicles coming from opposite direction.
- For S.S.D on vertical curves height of driver eye is taken as **1.2 m** and that of obstruction as **0.15 m**.



(*ii*) **Intermediate Sight Distance (ISD):** It is taken as **twice** the stopping sight distance.

(*iii*) **Overtaking Sight Distance (OSD):** Minimum distance open to the vision of the driver of a vehicle intending to overtake the slow vehicle ahead safely against the traffic in the opposite direction.



Minimum O.S.D = $d_1 + d_2 + d_3$

- For overtaking vehicle B, vehicle A will reduce its speed to that of vehicle B (V_B) for a reaction time (t) of nearly 2 secs to decide or confirm to overtake B.

  So $$d_1 = V_B t$$

- Let 'T' be the time taken by A to overtake B by travelling distance d_2. In that very time vehicle C, which is moving at deign speed $V_C = v$ will travel distance d_3 so $d_3 = vT$
- Now as in time T, vehicle A accelerates and overtakes B by travelling d_2, in that very time vehicle B travels distance b at constant velocity V_1 so $b = v_b$ T and $d_2 = v_b t + \frac{1}{2} a T^2$ where 'a' is the acceleration of vehicle A.

  So $$v_b T + \frac{1}{2} a T^2 = b + S_1 + S_2$$

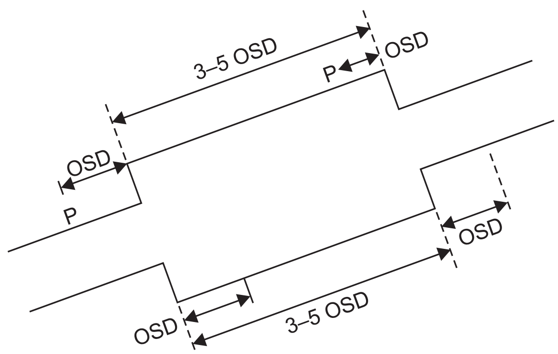
  If $$S_1 = S_2 = S = 0.7 V_B + 6$$

  and $$v_b T = b \text{ then } 2S = \frac{1}{2} a T^2$$

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

Note:
It V_B is not given then its (V – 16) km/hr where V is the design speed in km/hr or (v – 4.5) m/sec where v is design speed in (m/sec).

- When no vehicle is expected from opposite direction ie on divided highways and on roads with one way traffic regulation. OSD = $d_1 + d_2$
- As per IRC, on divided highways with four or more lanes, only sight distance should be greater than stopping sight distance.
- No separate design's are there for highway on grades.

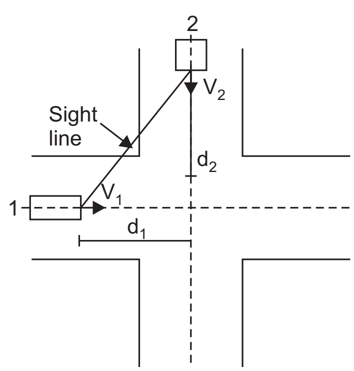


Overtaking Zones

(*iv*) Sight distance at intersection:

S.S.D for 1 = $d_1 = v_1 t$

S.S.D for 2 = $d_2 = v_2 t$



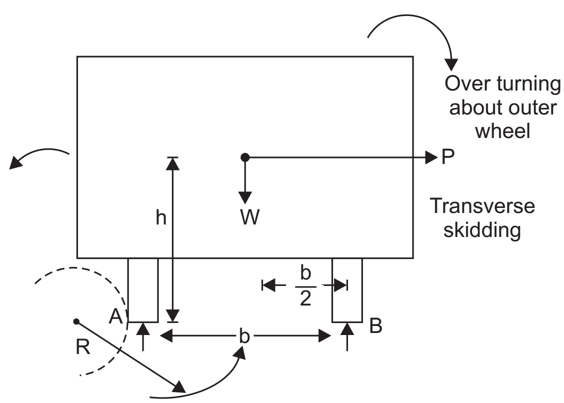
3 Horizontal Alignment

It includes the radius of circular curve, design of super elevation, extra widening at horizontal curves, design of transition curve and set back distance.

Design speed

Type	Plain	Rolling	Hilly	Steep
NH & SH	100–80	85–65	50–40	40–30
MDR	80–65	65–30	40–30	30–20
ODR	65–50	50–40	30–25	25–20
VR	50–40	40–35	25–20	25–20

The presence of horizontal curve imparts **centrifugal force** P which is a reactive force **acting outward** on a vehicle negotiating it.

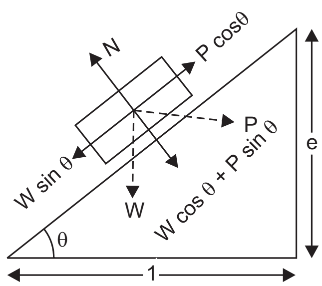


So centrifugal force = P = $\dfrac{mv^2}{R} \Rightarrow \dfrac{P}{W} = \dfrac{v^2}{Rg}$.

$\dfrac{P}{W}$ is centrifugal ratio or **impact factor**.

- To prevent overturning about outer wheel $\frac{b}{2h} \geq \frac{v^2}{gR}$.
- To prevent transverse skidding $f > \frac{v^2}{gR}$.

Super-elevation: Rising of the outer edge of the road with respect to inner edge in order to contract the effect of centrifugal force is called Super elevation.



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

For $\theta < 40$

$$1 - f\tan\theta \approx 1, \tan\theta = e$$

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

Note:
Equilibrium super elevation is when $f = 0$. It results in situation in which pressure on outer and inner wheels become equal.

As $f = 0$ so $e = \frac{v^2}{gR}$

If $e = 0$ then $f = \frac{v^2}{gR}$

For fast moving vehicles roads are designed assuming minimum friction and maximum super elevation while for slow moving vehicles roads are designed assuming maximum friction and minimum super elevation.

Design of Super-elevation

Basic equation $e + f = \frac{v^2}{gR}$; put $f = 0$ and get $e_1 = \frac{(0.75v)^2}{gR}$

Is $e_1 < 0.07$

- YES → Provide $e = e_1$
- NO → Find $f_1 = \frac{v^2}{gR} - 0.07$. Is $f_1 < 0.15$
  - YES → $e = 0.07$
  - NO → Put $e = 0.07$ $f = 0.15$ the safe allowable speed $V_a = \sqrt{0.22gR}$

Note:

Max super elevation for plain and rolling terrain, hilly terrain bound by snow = 0.7

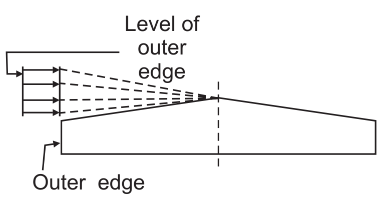
For hilly terrain not bound by snow its = 0.10

For Urban roads is = 0.04

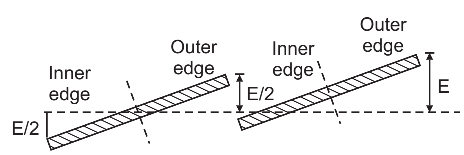
Minimum super elevation for drainage purpose = 2–4%

Attainment of super-elevation (done in transition curve)

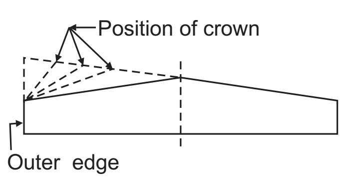
- Elimination of crown of cambered section
  - Rotation of outer edge
  - Shifting crown outwards
- Rotation of pavement
  - About the centre line
  - About the inner edge



(*a*) Outer edge rotated about the crown.



Method (1), rotating about centre line
Method (2), rotating about the inner edge.



(*b*) Crown shifted outwards (diagonal crown method).

Note:
In rotating the pavement about the centre line, the vertical profile remains unchanged and there is advantage in balancing the earth work while in rotating the pavement about the inner edge leads to drainage problem as well as centre of the pavement is raised resulting in altered vertical alignment.

Ruling Radius of Horizontal curve: It is the minimum possible radius of the circular curve on which a vehicle moving at **design speed** can pass the curve safely. For R_{ruling} maximum value of super elevation (7% or 10%) and coefficient of friction (0.15) are adopted

$$R_{ruling} = \frac{v^2}{g(e+f)}$$

Absolute Minimum radius of horizontal curve: It is the minimum possible radius of the circular curve on which a vehicle moving at **minimum possible speed** (designed for that highway) can pass the curve safely

$$\boxed{R_{absmin} = \frac{v^2 \min}{g(e+f)}} \quad e, f \text{ are maximum}$$

Note:
Radius of the curve to be adopted should always be greater than ruling minimum and even in most adverse case it should be greater than absolute minimum.

Extra Widening (We): It is the additional width of carriage way that is required on a curved section of a road over and above that required on a straight alignment. It has two components.

Mechanical Widening

When a vehicle negotiates on horizontal curve then the rear wheel follows a path of shorter radius than the front wheel its called **off-tracking**

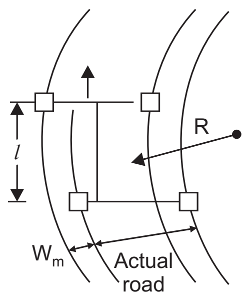
$$W_m = \frac{nl^2}{2R}$$

Psychological widening

This is done due to the tendency of the drivers to drive close to the edges of the pavements on curves.

$$W_p = \frac{v}{2.64\sqrt{R}} = \frac{V}{9.5\sqrt{R}}$$

$$W_e = \frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}}$$



$l \rightarrow$ length of wheel base (6.1 m)

$n \rightarrow$ no. of lanes.

Note:
On single lane road, its sufficient to provide mechanical widening only.
- If R > 300 m, no extra widening will be required.
- For multi-lane roads, the pavement widening may be calculated by adding half the widening for two lane roads to each line.

Horizontal transition curve: It is provided to charge the horizontal alignment from straight to circular curve gradually and has a radius which decreases from infinity at the straight end (target point) to the desired radius of the circular curve at the other end (point of tangency)

Note:
IRC recommends **Spiral** Curve for horizontal transition.

Length of horizontal transition curve

1. Rate of change of centrifugal acceleration (driver's comfort criteria)

$$L_{S_1} = \frac{v^3}{cR} \quad v \rightarrow \text{m/sec},\ R \rightarrow m$$

$$C = \frac{80}{75 + V} \quad V \rightarrow \text{km/hr},\ 0.5 \leq C \leq 0.8,\ C \rightarrow \text{m/sec}^3$$

2. Rate of introduction of super elevation (passenger's comfort criteria)

Plain and rolling Terrain (Rate (N) = 1 in 150)

$$L_{S_2} = 35\frac{v^2}{R} = 2.7\frac{V^2}{R}$$

Sleep and Hilly Terrain (Rate (N) = 1 in 60)

$$L_{S_2} = 12.96\frac{v^2}{R} = \frac{V^2}{R}$$

3. Method of introduction of super elevation

Rotation of Outer edge wrt centreline

$$L_{S_3} = \frac{e(W + We)N}{2}$$

Rotation of pavement about inner edge

$$L_{S_3} = eN\,(W + We)$$

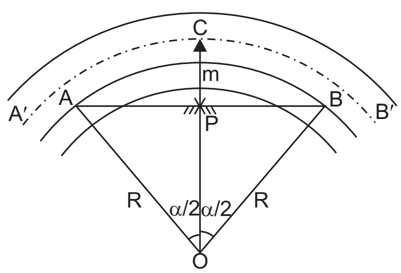
Length of transition curve $L_S = \max\,(L_{S_1}, L_{S_2}, L_{S_3})$

Note:
When a transition curve is introduced between straight and circular curve then the circular curve has to be shifted inwards so that transition curve meets the circular curve tangentially. This is called shift.

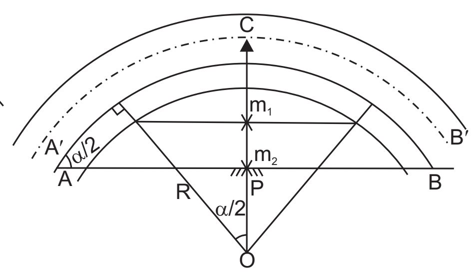
$$\text{Shift 's'} = \frac{L_S^{\,2}}{24R}$$

Set Back distance: It's the clearance distance required from the **centre line** of the horizontal curve to an obstruction on the **inner side** of the curve to provide adequate sight distance at a horizontal curve.

Step's to find any set back distance (*m*)



S.S.D < Length of curve
Case (i)



S.S.D > Length of curve
Case (ii)

1. Draw the centre line of curve A′CB′ (as set back distance is to be measured from here).
2. Calculate S.S.D and draw it on the inner lane of the road *i.e.*, AB
3. Join AB from the straight line.
4. Then the distance CP is the setback distance, where P is the point of obstruction.

In case (*i*) $$m = R - R\cos\frac{\alpha}{2}$$

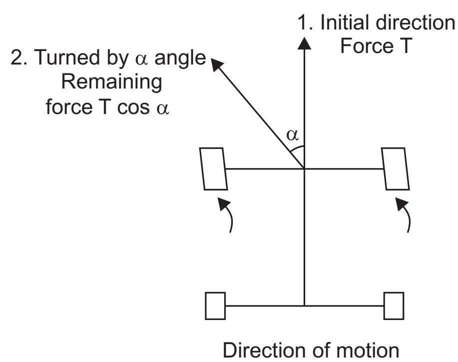
In case (*ii*) $$m = m_1 + m_2$$

$$m_1 = R - R\cos\frac{\alpha}{2}$$

$$m_2 = \frac{(SSD - L_C)}{2}\sin\left(\frac{\alpha}{2}\right)$$

Curve Resistance: It is the loss of tractive force when a **rear wheel** driven vehicle negotiates on a **horizontal curve**.

Curve resistance = Remaining force = T – T cos α



Note:
There is no curve resistance in case of front wheel driven vehicle.

4 Vertical Alignment

It is a road profile in which elevation is on vertical axis and horizontal distance is along the centre line of the road on horizontal axis.

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

IRC specifications for Road Gradient is different terrains (%)

Terrain	Ruling	Limiting	Exceptional
Plain/Rolling	3.3	5	6.7
Hilly	5	6	7
Steep	6	7	8

- **Ruling gradients** is the maximum gradient with which designer attempts to **design** the vertical profile of the road.
- **Limiting gradient** is to be adopted when ruling gradient results is very high **increase is cost** of construction due to cutting and filling.
- **Exceptional gradient** are given at **unavoidable situations.** They are limited to a stretch of 100 m in a single run.
- **Critical length** of the grade is the maximum length of the **ascending gradient** which a loaded truck can operate without reduction in speed or more than **25 km/hr.**

Note:
A minimum gradient is also to be provided for drainage purpose for concrete drains it is 1 in 500, for open soil drains its 1 in 200.

Grade compensation: Reduction is vertical gradient due to the horizontal curve, which is intended to off set the extra tractive effort involved at the curve.

$$\text{Grade compensation} = \frac{30 + R}{R}\,\%,\ R \rightarrow \text{Radius of curve in m}$$

$$\text{Maximum value} = \frac{75}{R}\,\%$$

Note:
No compensation required if grade is flatter than 4%

Summit–Curve: These are vertical curves with **convexity upwards.** Its design is governed by criteria of **sight distance.** Generally **parabolic curves** are used as summit criteria.

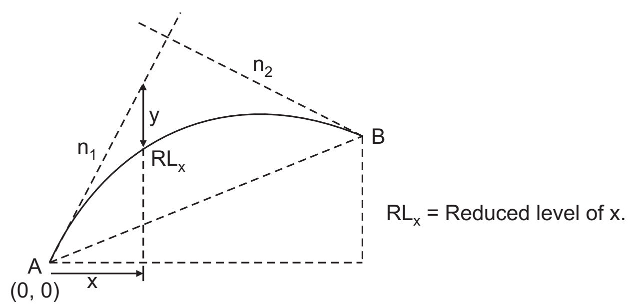
Note:
Circular curves offer equal sight distance at every point on the curve.

(*i*) Equation of curve $y = \frac{Nx^2}{2L}$ where $N = n_1 - n_2$

(*ii*) Radius of curvatures $= \frac{L}{N}$

(*iii*) Highest point on sumit curve at $x = \frac{n_1 L}{N}$

(*iv*) $RL_X = RL_A + n_1 x - \frac{N}{2L} x^2$



Note:
Highest point on the summit curve always lie on the side of flatter gradient

(*v*) Length of summit curve (L)

SSD is given

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

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

OSD/ISD is given

$L > OSD/ISD$ $L = \frac{NS^2}{9.6}$

$L < OSD/ISD$ $L = 2S - \frac{9.6}{N}$

Note:
In case of very small deviations the length required sometimes comes out to be negative indicating that there is no problem of sight restriction at the summit curve.

Valley Curves : Also known as sag curves. There are the vertical curves having **convexity downwards.** Its design is governed by **comfort criteria** as well as **safety criteria**. Generally **cubic parabola** is preferred for vertical valley curve.

Length of valley curve (L → max of both criteria's)

Comfort criteria

$$L_S = 2\sqrt{\frac{NV^3}{C}}$$

$C \leq 0.6$ m/See^3

$V \rightarrow$ m/see

$N = n_1 - n_2$

Safety criteria (Head light sight distance)

L > SSD

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

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

L < SSD

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

$$L_S = 2S - \frac{1.5 + 0.0\ 35\ S}{N}$$

where h_1 = height of head light beam ≈ 0.75 m

α = head light beam inclination ≈ 1°

Note:
While calculating S.S.D we neglect the effect of grade as it will be both in up and down grade.

5 Traffic Engineering: Characteristics

To achieve free and rapid how to traffic with least number of accidents

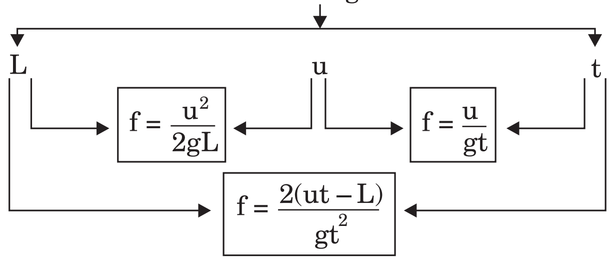
Traffic Characteristic

Road User/Driver's Characteristics	Vehicular Characteristics	Breaking Characteristics
● Physical (Vision, hearing strength etc.)	● Vehicle Dimensions (For width, number of lanes, parking facilities)	● For safety of Vehicle operation, stopping distance and spacing between two consecutive Vehicles
● Mental (Knowledge, skill, experience etc.)	● Weight of Vehicle (for pavement thickness)	
● Psychological (Fear, anger, attitude, maturity etc.)	● Power of Vehicle (for permissible gradients)	
● Environmental (atmospheric conditions, locality etc.)	● Speed of Vehicle (for Geometric design of big roads)	

Braking Test: At least **2 of the 3 measurements are needed**

1. Braking distance L (m)
2. Initial speed u (m/sec)
3. Duration of brake application t (sec)

To find coefficient of longitudinal friction 'f'



6 Traffic Engineering Studies

Traffic surveys for collecting traffic data is also called census.

1. **Traffic Volume Study:** It is the study of no. of vehicles crossing a section of road per unit time. Measured in vehicle/day or vehicles per hour.

$$q = \frac{n \times 3600}{T} \text{ V}ph$$

n = no. of vehicles passing in time T sec.

q = equivalent hourly flow.

Conducted by toll plaza ticketing, Registration offices, statistical approach, interview, check post, modern global positioning studies.

Traffic volume count is done with the help of mechanical counters or manually using pneumatic tube, multi-pen recorder.

Presentation of Traffic Volume Data

(*i*) **Annual Average Daily Traffic (AADT):** Count the number of vehicles, passing a point for a year than divide it by 365. It includes **seasonal variations** also

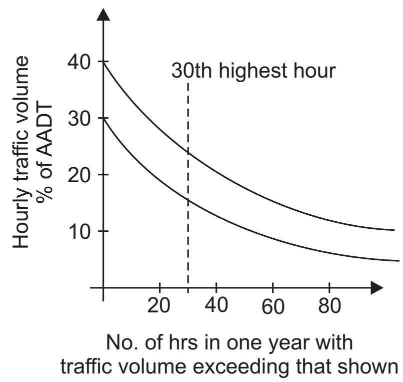
(*ii*) **Average Daily Traffic (ADT):** Count the number of vehicles passing a point for a period of 'D' days and then divide it by 'D' where D is the no. of days greater than 7 and less than 365. It includes **Weekend Variations** also.

(*iii*) **Trend chart:** Showing trend of volume over years.

(*iv*) **Traffic flow map along the route:** Thickness of line along the route represents the volume along the route.

(*v*) **Volume flow diagrams:** are drawn at intersections indicating the show of volume in different directions at intersections.

(*vi*) **Thirteenth highest hourly volume:** It is the hourly volume that will be exceeded only 29 times in a year and all other hourly volumes of the year will be less than this value.



Note:
If the roads are designed as per 30th highest hourly volume then the % probability of congestion in a year will be $\frac{29 \times 100}{24 \times 365}$ **= 0.331%**

(*vii*) Periodic Volume Counts: These are used to calculate expansion factors

$$\text{Hourly expansion factor} = \frac{\text{Total Volume for 24hr period}}{\text{Volume for particular hour}}$$

$$\text{Daily expansion factor} = \frac{\text{Average total volume for a weak}}{\text{Average volume for particular day}}$$

$$\text{Monthly expansion factor} = \frac{\text{AADT}}{\text{ADT of that month}}$$

2. Speed studies: Speed of vehicles vary with time and space.

- Spot speed study
- Speed and delay study

Spot speed: It is measured using Enoscope, pressure contact tubes, loop deflector and Doppler radar. Average of spot speed is done in two way.

Time mean speed (V_t)

Arithemetic mean of speed of vehicles passing a point on a highway during an internal of time.

$$V_t = \frac{\Sigma V_i}{n} \quad \text{or} \quad V_t = \frac{\Sigma q_i V_i'}{\Sigma q_i}$$

Space means speed (V_s)

Average speed of vehicles over a certain road length at any time. It is the **harmonic mean** of the speed.

$$V_s = \frac{n}{\Sigma \frac{1}{V_i}} \quad \text{or} \quad V_s = \frac{\Sigma q_i}{\Sigma \left(\frac{q_i}{V_i'}\right)}$$

V_i = observed instantaneous speed of i^{th} vehicle (km/hr)

n = No. of vehicles observed

V_i' = mean velocity of vehicles in the speed range.

q_i = No. of vehicles in the i^{th} speed range.

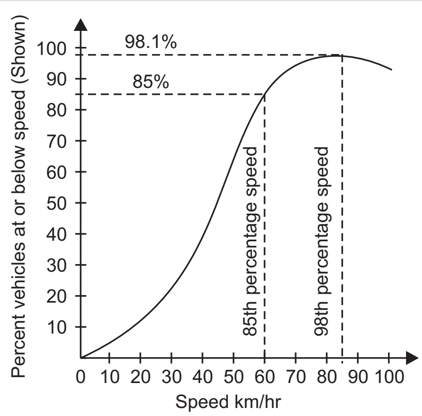
Running speed (excludes stop delays)

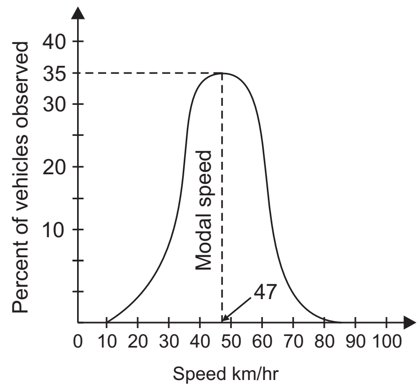
$$= \frac{\text{Length of travel}}{\text{Total time in which vehicle was running}}$$

$$\text{Journey speed (includes stop delay)} = \frac{\text{Length of travel}}{\text{Total Journey time}}$$

Note:

- $V_t > V_s$ as Arthematic mean > Harmonic mean
- Running speed > Journey speed
- Reciprocal of V_s gives average travel time of all vehicles.
- Spot speed study cannot be used to find density of vehicles





Presentation of spot speed data

98^{th} percentile speed ⇒ Design speed

85^{th} percentile speed ⇒ Safe speed

15^{th} percentile speed ⇒ Lower speed

Modal speed is the speed with which largest number of vehicles move.

Speed and delay studies: are carried out over a long distance and hence it is possible to determine the traffic density. It helps in planning and taking remedial measures to tackle delay at specific locations.

Various methods for carrying out speed and delay study are

(*i*) Floating car method

(*ii*) Licence plate method

(*iii*) Interview technique

(*iv*) Elevated observation

(*v*) Photographic technique

Floating car methods: Four observers are required

$$\bar{t} = t_w - \frac{y}{q}$$

$$q = \frac{x + y}{t_a + t_w}$$

q = Traffic volume in N–S-direction.

$\bar{t}$ = Average journey time in NS direction

t_w = Journey time of vehicle in NS direction (with traffic).

t_a = Journey time of vehicle in SN direction (against traffic).

x = Number of vehicles in NS direction when test vehicle is moving in SN direction.

y = Number of vehicles (overtaking -overtaken) when vehicle moving in NS direction

$$\text{Running time} = \bar{t} - \text{stop delay}$$

$$\text{Running speed} = \frac{l}{\text{Running time}}$$

3. **Origin and destination studies:** These studies are helpful in planning new highways and improving new existing services. It is also used in planning **mass rapid transit system**. (MRTS)

   Method of collection of data

   (i) **Road side interview method:** Quick collection of data.

   (ii) **Licence plate method:** For small area's like business centres.

   (iii) **Return post card method:** For heavy traffic

   (iv) **Tag on car method:** Continuously moving heavy traffic

   (v) **Home interview method:** Care should be taken while selecting the sample size

   (vi) **Work spot interview method:** By interviews in offices factories etc. O and D data is presented is several forms 1. O and D table 2. Desires lines. 3. pie-chart. 4. Contour lines.

   Note:
   Desire lines are straight lines connecting the origin points with destinations. The width of such desire lines is drawn proportional to the number of trips in both directions.

4. **Traffic capacity studies**

   Traffic volume (q): Number of vehicles passing through a point during specified unit of time expressed in vehicle/hour or vehicle/day.

   Traffic density (*k*): Number of vehicles occupying a unit length of a lane or roadway at a given instant expressed in vehicle/kilometre.

$$q = kV \quad \text{where V = space mean speed}$$

   Time headway (*hi*): It is the time interval between the passes of rear bumper of successive vehicle at a point

$$\text{Traffic volume (Veh/hr)} = \frac{1}{\text{Avgerage Time headway(hr/veh)}}$$

   Space headway (S_i): Distance between the rear bumper of successive vehicle

$$\text{Density per lane} = \frac{1}{\text{Average space headway}}$$

Traffic Capacity: Maximum no. of vehicles in a lane or a road that can pass a given point in unit time. Expressed in vehicles/hour/lane.

Basic capacity	Possible capacity	Practical capacity
(Theoretical capacity)	Under **prevailing**	**(Design capacity)**
for nearly **ideal** roadway and traffic conditions	roadway and traffic conditions.	It varies from zero to basic capacity.

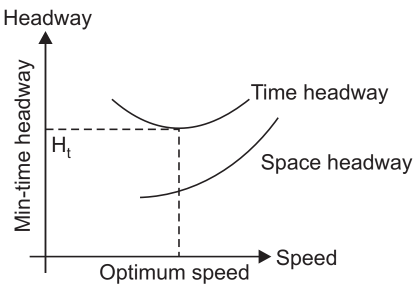
Maximum theoretical capacity 'c':

$$C = \frac{1000\,V}{S} \qquad C = \frac{3600}{H_t}$$

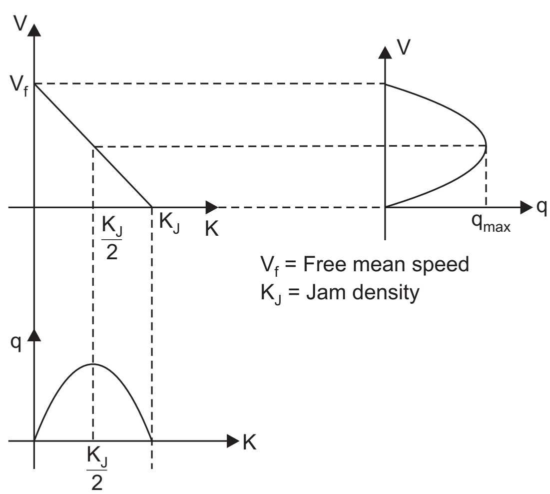
V = space mean speed (km/hr)

S = Minimum space headway (m)

H_t = Minimum time headway (Sec)



Relation between speed, density and volume (Given by Green-Shield)



V_f = Free mean speed

K_J = Jam density

$$V = V_f - \left(\frac{V_f}{K_J}\right)K$$

$$q = (V_f)\,K - \left(\frac{V_f}{K_J}\right)K^2$$

$$q = (K_j)\,V - \left(\frac{K_f}{V_J}\right)V^2$$

$$q_{max} = \frac{V_f K_J}{4}$$

Note:
Highest traffic density will occur when the vehicles are practically standing still on a given route but in this case traffic volume will tend to zero.

Capacity is the quantitative measure where as level of service is the qualitative measure of How. There are six level of services from free flow (A) to forced Flow(F).

Passanger car unit (PCV): It is the ratio of capacity of roadway when there are passanger cars only to the capacity of same roadway when there are vehicles of that class only. For motor cycle its 0.5, for tempo, auto rickshaw its 1.0 and for large Bullock cart its 8.

5. **Parking study:** It is covered using video recording

On street or kerb parking
- Max. Vehicles can be parked when angle is 90°.
- 45° angle is considered best for parking.

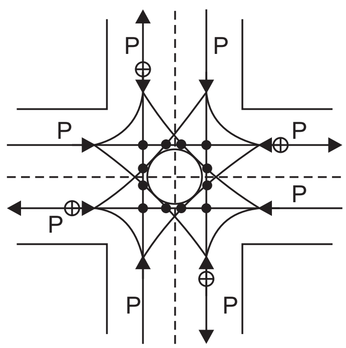
Off-street parking facilities.
- Separate parking place away from kerb
- There is no undue congestion and delay on the road.

6. **Accident Studies:** To find out the reason and cause behind accident and to take preventive measures. Various records are kept as.
   (*i*) **Location files:** Identification of points of high accident.
   (*ii*) **Spot maps:** Accident spots are marked by pins and symbols on map.
   (*iii*) **Condition diagram:** All important physical conditions at accidental area.
   (*iv*) **Collision diagram:** Approximate path of vehicles and pedestrians involved in accident.

7 Traffic Control Regulation

Intersection: It is an area where two or more roads join or cross. At traffic intersection change in direction of movement may occur.

Crossing conflicts are major conflicts where as merging and diverging conflicts are minor conflicts.



Conflicts in a traffic signal

- ● 4 Through traffic
- ● 4 Right turn
- ● 8 Right turn-Through
- ⊕ 4 Merging
- ▷ 4 Diverging
- P 8 Pedestrain

Total = 32 Conflicts

Number of potential conflicts:

(*a*) Both roads are two way = 24

(*b*) One road is two way, other one-one way = 11

(*c*) Both roads are one way = 6

Intersection Control

Passive control
- Where traffic is less
- Road Signals and Road makings

Semi-control
- Driver are guided gently
- Channelization and Rotaries

Active control
- Traffic signals
- Grade separated intersection

Types of Intersection

At grade Intersection (Traffic Islands)
- Divisional Island
- Channelizing Island
- Pedestrian loading Island
- Rotary

Grade-seperated intersection (Interchange)
- Trumpet Interchange
- Diamond Interchange
- Clover leaf Interchange
- Rotary Interchange
- Directional Interchange

AT GRADE INTERSECTIONS

Divisional Islands Separate the opposing flow of traffic on a highway with four or more lanes. By dividing the highway into two one way roads the head on collisions are eliminated.

Channelizing Islands are used to guide the traffic into proper channel through the intersection area.

Pedestrian loading Islands are provided at regular bus stops and similar places for the protection of passengers. During crossing a multilane highway pedestrian refuge island after two or three lanes is desirable.

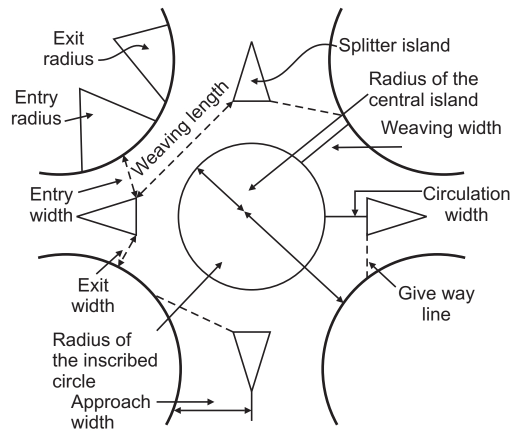
Rotary Island is a large central island of a rotary intersection, this island is much large than the central island of channelized intersection. Here vehicles from converging arms are forced to move round in island in one direction and weave out of the rotary movement into their desired directions,

Guide for Selection of Rotaries

(*i*) Relatively equal traffic on roads which are approaching rotary.
(*ii*) Suitable when number of approach roads is more than four.
(*iii*) Beneficial when right turning traffic is very high.
(*iv*) Upper limit → 3000 vehicles/hour, Lower limit → 500 vehicles/hour.

Design Elements

(*a*) Design speed for Urban areas/Restricted location is 30 km/hr while that of Rural areas is 40 km/hr.



Design of Rotary

(*b*) Radius at entry

Rural areas → 20 – 35 m

Urban areas → 15 – 25 m

(*c*) Radius at exit = 1.5 to 2 times radius at entry

(*d*) Radius of central Island = $\frac{4}{3} \times$ Radius of entry

(*e*) Minimum weaving length

For Rural areas = 45 m

For urban areas = 30 m

(*f*) Minimum width of carriage way be at least 5 m with necessary widening to account for the curvature of road.

(*g*) Width of non-weaving section = width of widest single only into the rotary

(*h*) Width of weaving section

$$W_{weaving} = \frac{e_1 + e_2}{2} + 3.5$$

e_1 = entry width (m)

e_2 = exit width (m)

(*i*) Idealised entry angle is 60° and exit angle is 30°

(*j*) Capacity of the rotary

$$Q = \frac{280\, w \left(1 + \frac{e}{w}\right)\left(1 - \frac{p}{3}\right)}{\left(1 + \frac{w}{l}\right)}$$

Q = practical capacity *i.e.* PCU/hour

w = width of weaving section

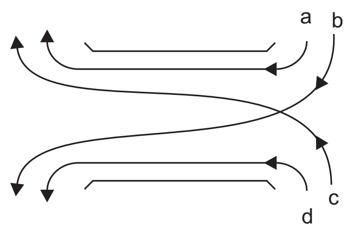
$$e = \frac{e_1 + e_2}{2}$$

e_1 = entry width

e_2 = exit width

l = length of weaving section

p = proportion of waving traffic

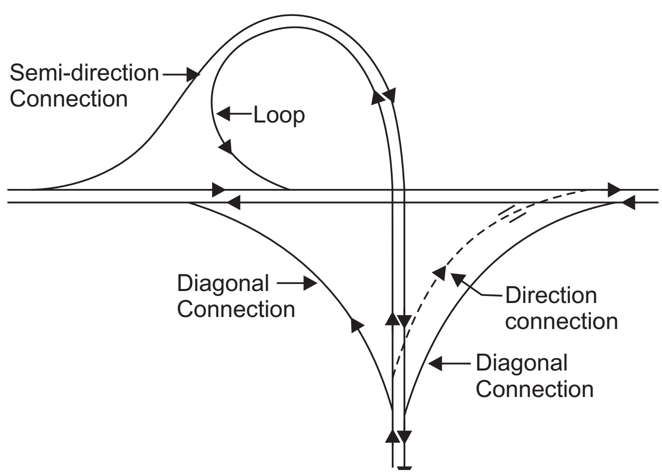


$$p = \frac{b + c}{a + b + c + d}$$

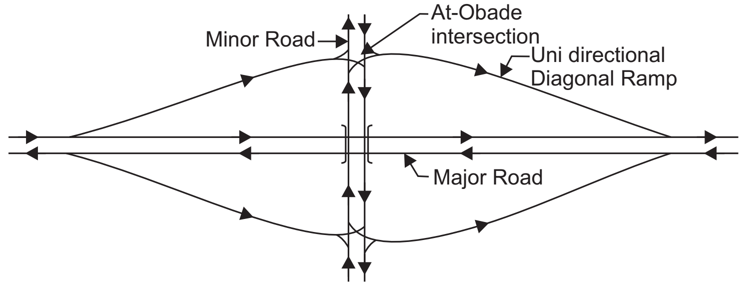
Note:
p will be calculated at all the weaving section and highest value will be adopted.

GRADE SEPARATED INTERSECTION

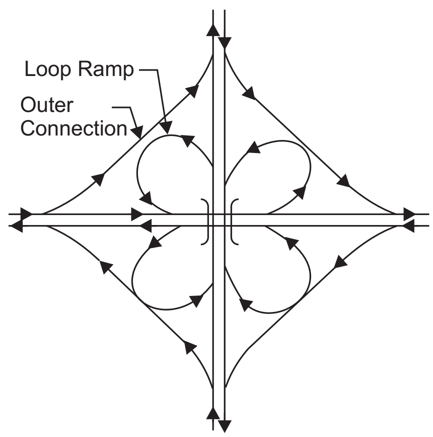
- It permits the cross flow of traffic at different levels without interruptions.
- A grade separation is a crossing of a highway and a railway, two highway or a pedestrian walkway and a highway at different levels.



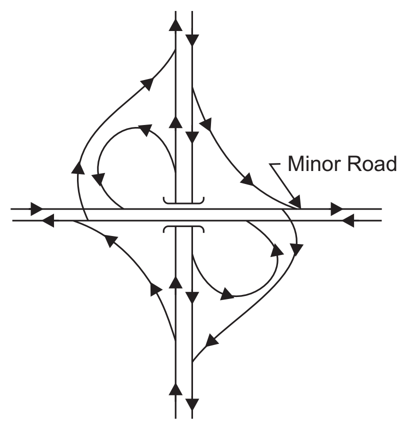
Trumpet Interchange



Diamond Interchange

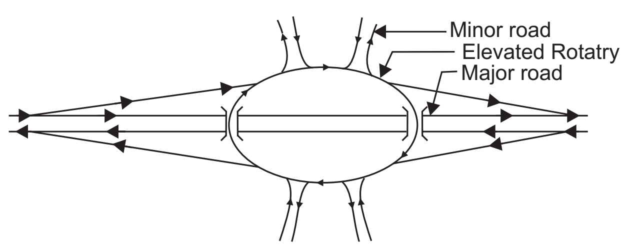


Full Cloverleaf



Partial Cloverleaf

- Diamond interchange is the simplest of the 4 leg interchange.
- Diamond interchange is ideal for both urban and rural traffic but the right turning traffic has to cover extra travel distance.
- For crossing of two major roads of equal importance in rural areas clover leaf interchange is preferred.



Rotary Interchange

- Rotary interchange is useful where a number of roads intersect at the interchange and sufficient land is available.
- Directional interchange requires more than one structure or a 3 level structure. These are operationally more efficient but most expensive.

Traffic Control Devices

All the traffic signals, signs, pavement marking or other devices placed or created with the approval of a traffic authority having the necessary jurisdiction to regulate, warn or guide traffic.

Classification of traffic signs

Mandatory/ Regulatory

- Violation is a legal offence
- Stop, give way, horn prohibited, speed limit, compulsory left

Cautionary/ Warning

- Existence of hazardous conditions.
- Hair pin bend, major road ahead, men at work

Informatory

- For guiding the road user
- Petrol pump, hospital, direction sign.

Traffic signal: These control devices alternately direct the traffic to stop and process at intersection using red and green traffic lights signals automatically

- Traffic control signals
  - Fixed time signal
  - Semi-actuated signal
  - Special traffic signal
- Pedestrian signal
- Special traffic signal

Co-ordination of Traffic Signal System

- **Simultaneous System**: All the signals along a given road show same indication at the same time
- **Alternate System**: Alternate signals or group of signals show opposite indications in a route at same time
- **Simple Progressive System**: A time schedule is so permitted that a continuous operation of groups of vehicle along the main road is possible
- **Flexible Progressive System**: Automatically vary the length of cycle or cycle division with the computer

Note:
Simple progressive system is considered to be the best.

Various methods of signal design

(*a*) Trial cycle method
(*b*) Webster method
(*c*) Approximate method
(*d*) IRC method

Webster Method:

Optimum cycle time (Sec)

$$= \frac{1.5\,L + 5}{1 - Y}$$

$$L = nt_L + R$$

$$Y = \sum_{i=1}^{n} \frac{q_i}{S_i}$$

n = No. of phase
t_L = Start up loss time
R = All red time
q_i = Critical lane volume for phase (max. volume per lane)
S_i = Saturation flow for that phase

$$S_i = \frac{3600}{\text{time-head way (secs)}}$$

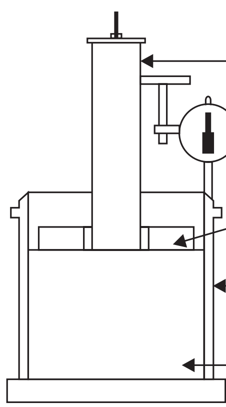
Road width	3 m	3.5 m	4 m	4.5 m	5 m	5.5 m
$S\left(\frac{PCU}{hr}\right)$	1850	1890	1950	2250	2350	2990

Note:
Y should not be greater than 1.
Webster method is the most rational design method.

- **IRC method** is an **approximate method**, where optimum cycle time is checked by Webster method.
- Pedestrian walking speed to taken as 1.2 m/sec with initial walk period of 7 secs.
- Minimum green time for vehicular traffic as taken as 16 secs.
- Cycle time should be in multiple of 5 secs.

8 Highway Material

1. **Pavement Material Soil:** Various tests are performed on soil to check its shearing strength bearing strength and penetration value.
   (*a*) **California bearing ratio (CBR) test:** Developed by California division of Highway for classifying and evaluating soil sub grade and base course materials for flexible pavements.

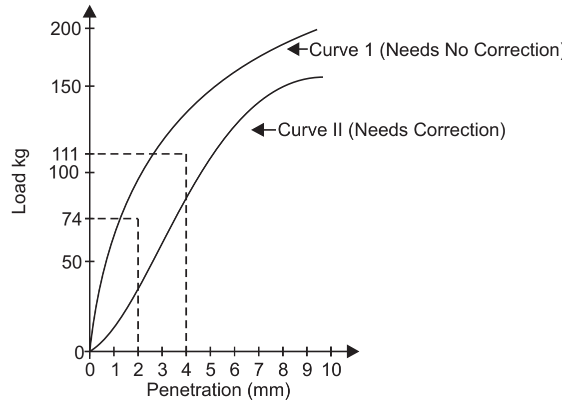


- Empirical test, which measures the strength of material and its **not** the true representation of resilent modulus.
- Diameter of piston = 50 mm
- Rate of standard penetration = 1.25 mm/min.
- The pressure upto a penetration of 12.5 mm and its ratio to the bearing value of Standard Crushed Rock is termed as CBR
- 4 days soaked remoulded sample is used
- Average value of 3 test specimens is reported as CBR.

$$\text{CBR} = \frac{\text{load carried by specimen}}{\text{load carried by standard specimen}} \times 100$$

- Load carried by std specimen at

$$2.5 \text{ mm} \rightarrow 1370 \text{ kg } (70 \text{ kg/cm}^2)$$
$$5 \text{ mm} \rightarrow 2055 \text{ kg } (105 \text{ kg/cm}^2)$$



- It value of CBR at 2.5 mm > value of CBR at 5 mm, adopt CBR value of 2.5 while if value of CBR at 2.5 mm < value of CBR at 5 mm. Repeat the test and even then if value of CBR at 5 mm comes greater then adopt the greater value.

Typical CBR values of soil and their Ratings.

Soil	Range of CBR values	Rating
Clay	2–5	Very poor subgrade
Silt	5–8	Poor subgrade
Sand	8–20	Fair to good subgrade
Gravel	20–30	Excellent subgrade
	30–60	Good sub-base
	60-80	Good base
	80 Std crushed stones	Best base

(*b*) **Plate bearing test:** To evaluate the support capability of soil. It is applicable in the design of both **rigid** and **flexible** pavement. It is a **field** test.

- Diameter of plate = 75 cm
- Seating load = 320 kg

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

where K = Modulus of subgrade reaction.

P = Loading pressure corresponding to the settlement of 1.25 mm.

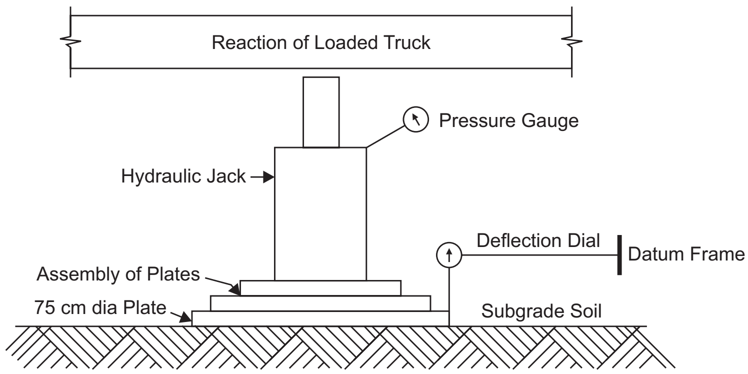
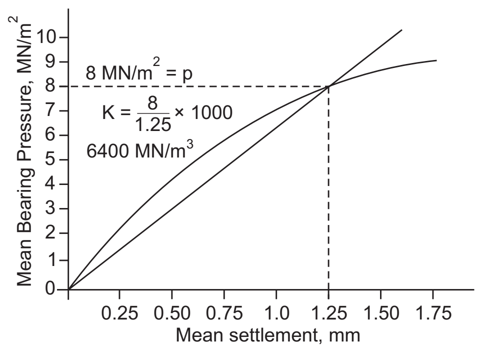


Plate Bearing test



Mean Settlement

$$K_{75} = K_{30} \times \frac{30}{75}$$

K_{75} = K when 75 cm diameter plate is used.

K_{30} = K when 30 cm diameter plate is used.

$$K_{soaked} = \frac{K_{unsoaked}}{P_{unsoaked}} \times P_{soaked}$$

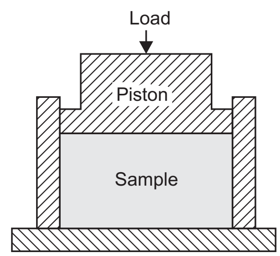
K_{soaked} = K in soaked condition

$K_{unsoaked}$ = K in unsoaked condition.

2. **Pavement Material Aggregate:** By volume aggregate generally accounts for 92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete. Various desirable properties of aggregate are strength, Hardness, Toughness, Shape of Aggregates, Adhesion, Durability and freedom from deleterious particles.

(*a*) Crushing test: Gives **strength** of Aggregates

- Aggregates passing from 12.5 mm and retained on 10 mm.
- Filled in cylinder of 11.5 cm diameter and 18 cm height in three layers.
- Each layer tampered 25 times and weighted W_1.
- Then sample is subjected to 40 tonnes of load at the rate of 4 tones per minute.



Crushing test setup

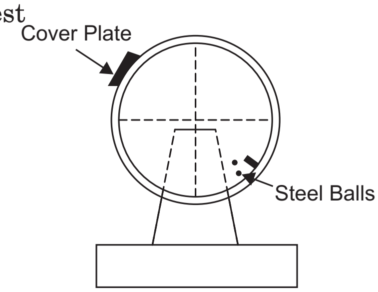
- Crushed aggregate passed through **2.36 mm sieve** and passing material weighs W_2.

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

(*b*) Abrasion test: Gives **hardness** of Aggregates

(*i*) Loss Angles abrasion test
(*ii*) Devel abrasion test
(*iii*) Dorry abrasion test.

- Diameter of drum = 700 mm,
- length = 520 mm
- Cast Iron balls of 48 mm diameter and 340–445 gm weight.



Loss Angeles abrasion test setup

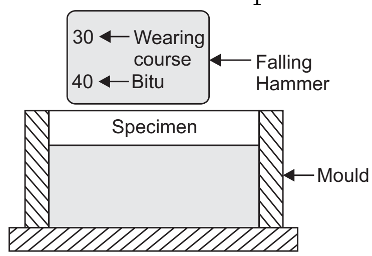
- Aggregate quantity used = 5–10 kg
- Speed of rotation = 30–33 rpm
- Material is sieved through **1.7 mm sieve** and % is thus calculated.

(*c*) Impact test: Gives **toughness** of Aggregates

- Aggregate passing 12.5 mm and retained on 10 mm sieve.
- Filled in cylinder of 10.2 mm diameter and 5 cm height in 3 layers.
- Each layer tampered 25 times and weighted W.
- 15 blows from metal hammer of 13.5–14 kg from 38 cm.

- Crushed aggregate passed through 2.36 mm sieve and passing material weighs W_2.

Aggregate Impact Value = $\frac{W_2}{W_1} \times 100$



Note:

Coefficient of hardness = $20 - \frac{\text{loss of weight in grams}}{3}$

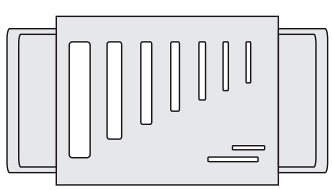
(d) Soundness test: Gives resistance of aggregate to weathering action (*i.e*, **Durability**)

- Aggregates of specified size are subjected to cycle of alternate wetting in a saturated solution of either **sodium sulphate** or **magnesium sulphate** for 16–18 hours and then dried in oven at 105–110°C to a constant weight. After 5 cycles, loss in weight is determined by serving out under sized particles.
- Loss in weight should be less than 12% when sodium sulphate is used and 18% when magnesium sulphate is used.

(e) Shape test: Gives idea of **workability** and **stability** of mix.

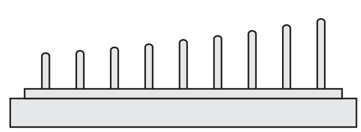
Flakiness Index

Percentage by weight of aggregate particles whose least dimension is less than **0.6 times** their mean size.



Elongation Index

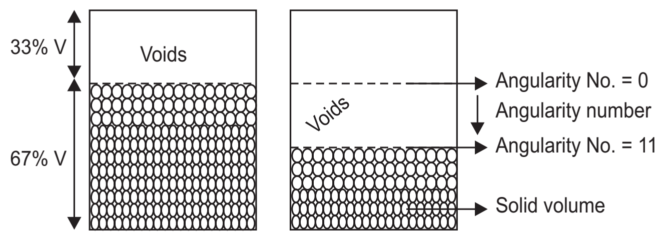
Percentage by weight of aggregate particles whose greatest dimension is **1.8 times** their mean dimension.



(*f*) **Angularity Number:** Measures the voids in excess of 33%.

Angularity Number = 67 – % Solid volume.

- Higher the angularity no, more angular is the aggregate.
- It varies from 0 to 11.



Rounded gravel in well compacted state

(*g*) **Specific gravity and water absorption:**

$$G_{app} = \frac{M_D/V_N}{D_W}$$

G_{app} = Apparent specific gravity

M_D = Dry mass of aggregate

D_W = Density of water

$$G_{Bulk} = \frac{M_D/V_B}{D_W}$$

V_N = Net volume of aggregate excluding volume of adsorbed water.

V_B = Total or Bulk volume of aggregate including volume of adsorbed water

- Difference between the apparent and bulk specific gravities is the water permeable voids of the aggregates.
- The specific gravity of aggregates is normally between 2.5 to 2.9 and water absorption values range from 0.1 – 2.0 percent.

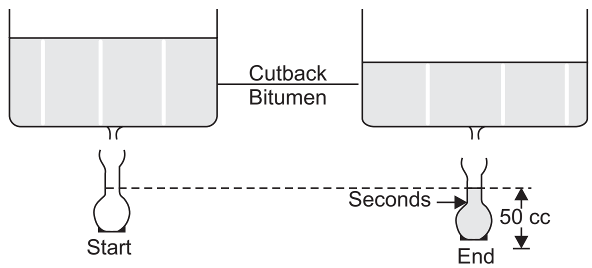
(*h*) **Bitumen adhesion test:** Gives **stripping value** of aggregates.

- Adhesion problem occurs only when the aggregate is wet or cold.
- As per IRC, **static immersion test** is performed. In this test an aggregate fully coated with binder is immersed in water maintained at 40°C temperature for 24 hours

Note:
IRC has specified maximum stripping value as 5%.

3. **Pavement Material Bitumen:** It is considered flexible material from structural point of view. Most common source of bitumen is through **Petroleum crude.** Indian crude does not yield good bitumen for rural work except **Digboi** bitumen of Assam.

(*a*) **Viscosity test:** Done by STV (Standard Tar Viscometer). Say bolt Furol, Redwood and Engler.

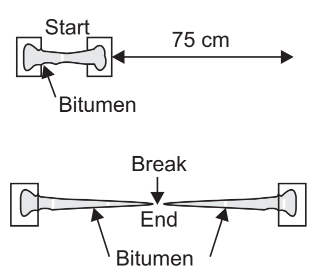


The viscosity of liquid bitumen is measured by **Efflux Viscometer.** Viscosity is indirectly measured as the time required to pass a measured quantity (50 to 200 ml) of bitumen through the orifice (of diameter 3–10 mm) at a constant temperature.

Furol Viscosity is standardised test.

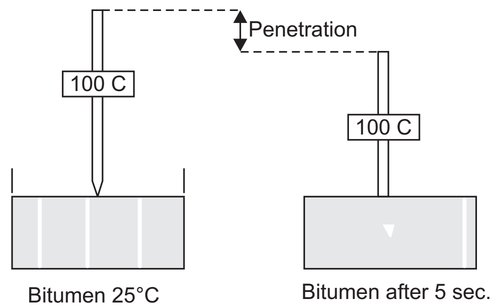
(*b*) **Ductility test:** Ability to **deform** under load

- Measured by stretching a standard briquette of bitumen having cross-sectional area of 1 cm^2 at a temperature of 27°C and rate of pull being 5 cm/min.



- As per indian standards, minimum ductility value is 75 cm. for grades 45 and above.

(*c*) **Penetration test: Resistance to flow** or measurement of **hardness** of bitumen.

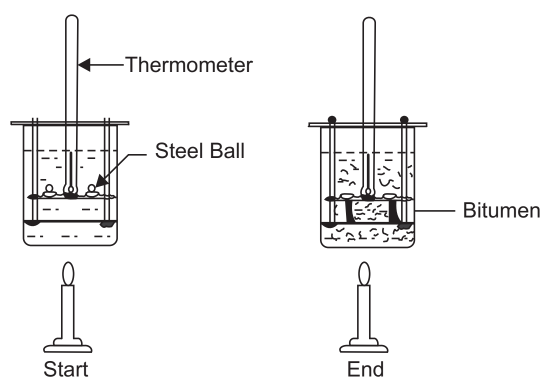


- Distance penetrated in sample by a standard pointed needle at 27°C when a 100 gm of load is applied for 5 secs.
- Unit of penetration is 1/10 mm.
- 80/100 means penetration of 8–10 mm.

Note:
Penetration test is not required in tar.

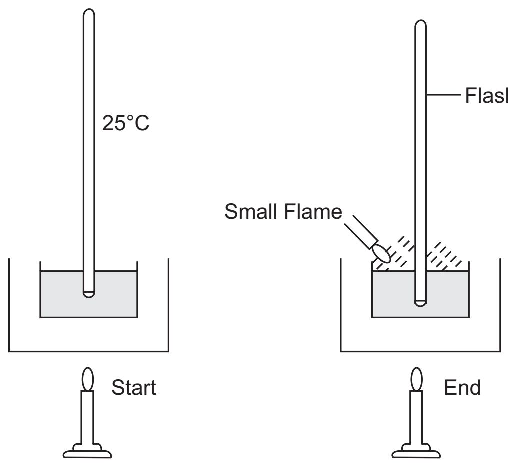
(*d*) **Softening point:** It is done to ensure safety.

- Done by **ring and ball** apparatus.
- Softening point is the temperature at which bitumen attains a particular degree of softness under standardised test conditions.
- It indicates the temperature at which bitumen passes from solid to liquid consistency.



(e) Flash and Fire Point

Flash point is the lowest temperature in degree celsius at which the application of a test flame causes the vapour from bitumen to **catch fire momentarily** in the form of flash.



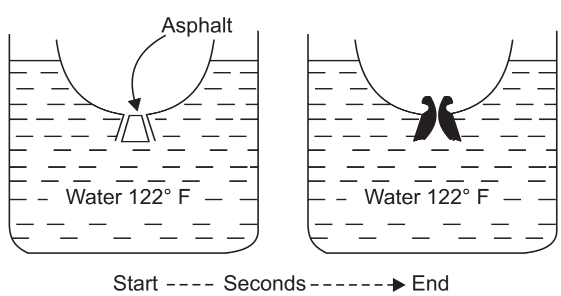
Fire point is the lowest temperature in degree celsius at which the application of test flame causes the bitumen to **ignite and burn** atleast 5 secs under specified test conditions.

(f) Specific gravity: Determined by **Pycnometer.**

- At 27°C it 1.00 for pure bitumen its range is 0.97 to 1.02.
- Tar has specific gravity more than bitumen (1.10 to 1.25)

(g) Float test: For viscosity of bitumen

- It is time in secs required for a small plug of chilled bitumen which is held in an open mould attached to the bottom of a saucer to become sufficiently fluid, when the saucer is floated in water at 50°C.



Note:

Type of Bitumen	Use
Penetration grade 30/40	Areas where temperature difference range is less than 25°C, Roads with high volume of traffic.
Penetration grade 60/70	Superior type of roads with high traffic in normal summer temperature.
Cutback bitumen	Cold weather condition.
Emulsion	Wet conditions (Rainy season) maintenance work, soil stabilisation in deserts.

Cut back Bitumen: Bitumen whose viscosity is reduced by adding volatile diluents.

Types of cutback

Rapid curing (RC)

Penetration value 80/120

Eg: Petroleum

Medium curing (MC)

Good wetting property

Eg: Kerosene, light diesel oil

Slow curing (SC)

Blending bitumen with high boiling point gas or oil.

Note:

- The cutbacks are also designated by numbers. The bigger the number, the thicker or viscous it will be.
- MC – 2 will be thicker than MC – 1 but RC – 5 and SC – 5 will have same viscosity.

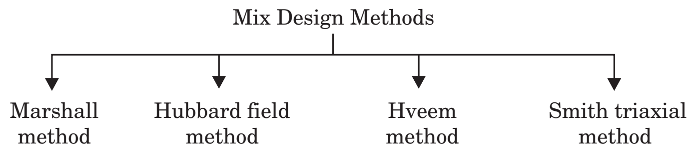
Tar: Produced by **carbonization of coal**. RT – 1 is used for surface painting while RT – 5 is used for grouting.

Note:

Tar is soluble in Toluene while Bitumen is soluble in carbon disulphide and carbon tetra chloride.

Tar is more temperature susceptible, shows greater viscosity variations with temperature.

Bitumen is more water resistant.



Marshall Mix Design: This **wet** mix design determines the optimum moisture content. **Stability test** and **flow test** provides the performance prediction measure for the marshall mix design methods.

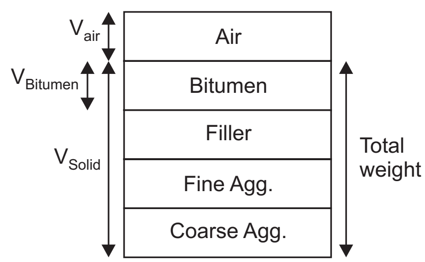
Stability: Maximum load carried by the specimen at a standard temperature of 60°C and expressed in kg.

Flow: It is measured as determination in units of 0.25 mm between that load and maximum load during stability test.

Properties of the Mix

1. Theoretical specific gravity (G_t)

$$G_t = \frac{\text{Total weight}}{(\text{volume of solid})\,\gamma_w}$$



2. Bulk specific gravity (G_m)

$$G_m = \frac{\text{Total weight}}{(\text{Total volume})\,\gamma_w}$$

$$= \frac{\text{Weight in Air}}{\text{Weight in Air-Weight in water}}$$

> **Note:**
> $G_t > G_m$ always.

3. Percentage Air voids (V_v):

$$V_v = \frac{\text{Volume of air}}{\text{Total volume}} \times 100$$

4. Percentage volume of bitumen (V_b):

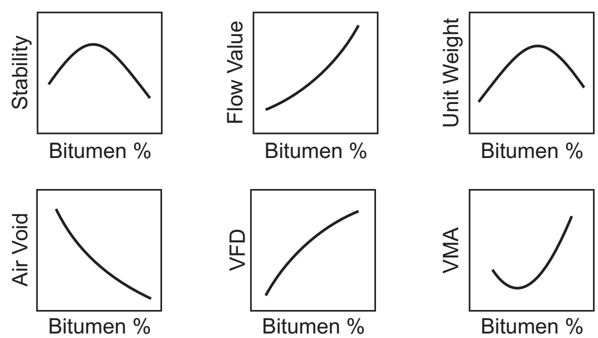
$$V_b = \frac{\text{Volume of bitumen}}{\text{Total volume}} \times 100$$

5. Voids in mineral aggregate (VMA):

$$\text{VMA} = \frac{\text{Volume of (Air + Bitumen)}}{\text{Total volume}} \times 100$$

6. Voids filled with Bitumen (VFB):

$$\text{VFB} = \frac{\text{Volume of Bitumen}}{\text{Volume of (Air + Bitumen)}} \times 100$$



Marshall graphical plots

Note:
Optimum binder content will be the average value of bitumen obtained from the graphs of stability, (bulk specific gravity and percentage air voids.)

Marshall Mix design specification

Test property	Value
Stability	340 kg
Flow value	8–16 units
Percentage air voids	3–5
VFB	75–85

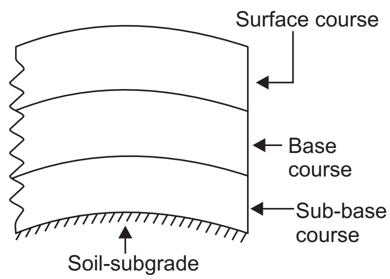
9 Pavement Design

Pavement: Load bearing and load distributing component of a road.

Classification

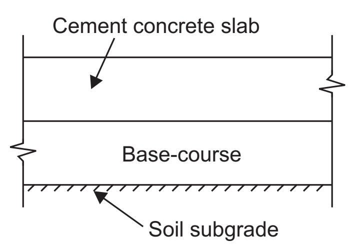
Flexible | Rigid | Semi-rigid | Composite

- In flexible pavement compressive stresses are transmitted to the lower layer by **grain to grain** transfer through the point of contact.



Flexible pavement

- In flexible pavement if the lower layer of the soil subgrade is undulated, the flexible pavement surface also gets undulated.
- **Bituminous concrete** is one of the best flexible layer materials.
- In rigid pavement (which is constructed as concrete slab) strength depends on its **flexural strength** or beam action of the slab for withstanding the wheel load.



Rigid-pavement

- The critical condition of stress in the rigid pavement is the maximum flexural stress occurring in the slab due to wheel load and the temperature changes.
- A semi-rigid pavement derives its strength both by load spreading and flexural action. It is made by using materials like pozzolonic concrete (lime-flyash-aggregate mix), lean cement concrete or soil cement etc.
- Composite pavement has layers made up of materials having different properties. Eg: A lean concrete base having a roller compacted concrete slab over it and bituminous concrete surfacing at the top.

Pavement components

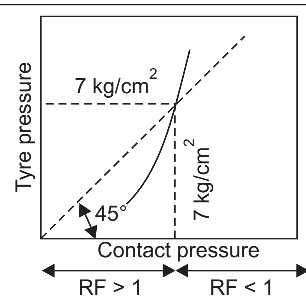
- Soil subgrade
  - Load is ultimately taken by soil-subgrade.
  - Top 50 cm layer should be compacted at OMC.
- Sub base and base course
  - In flexible pavement it improves load carrying capacity.
  - In rigid pavement it prevents pumping and protects subgrade against frost action.
- Wearing course
  - To provide a smooth riding surface.

Contact Pressure and Tyre pressure:

$$\text{Rigidity factor} = \frac{\text{Contact Pressure}}{\text{Tyre Pressure}}$$

$$\text{Contact pressure} = \frac{\text{Wheel load}}{\text{Area of imprint}}$$

Tyre pressure	R.F.
> 0.7	< 1
= 0.7	< 1
< 0.7	> 1



Note:

- When there is high pressure in tyre's then tyre comes in tension. And obviously then contact pressure will be less than tyre pressure.
- Tyre pressure is a important for upper layers while contact pressure is important for bottom layers.

Traffic Fore cost

$$N = 365\ P(1 + r)^x \frac{[(1+r)^n - 1]}{r}$$

N = **Cummulative** number of **commercial** vehicles during **design** life.

r = rate of increase of traffic expressed in **fraction** *i.e.* 0.075 **per year**.

p = Number of **commercial** vehicles per day at **last count**.

x = Construction period in **year's**.

n = Design life in years.

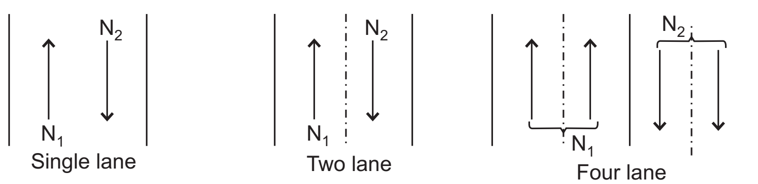
Here, $P(1 + r)^x = A$, where A can be given as. Initial design traffic in Vehicle per day in the year of completion of construction.

Note:

- This value of N is then modified by multiplying it with lateral distribution factor (LDF) and Vehicle damage factor (V.D.F.)

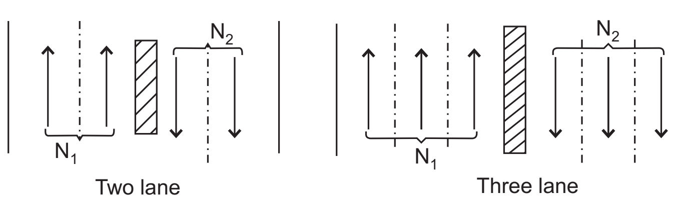
Lateral Distribution Factor (L.D.F.)

1. Single carriage way

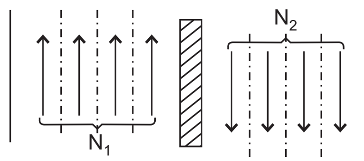


$LDF = 1\ (N_1 + N_2)$ $LDF = 0.50\ (N_1 + N_2)$ $LDF = 0.40\ (N_1 + N_2)$

2. Dual carriage way



$LDF = 0.75\ (\max (N_1, N_2))$ $LDF = 0.6\ (\max (N_1, N_2))$



Four lane

$$LDF = 0.45\,(\max\,(N_1, N_2))$$

Vehicle Damage Factor (VDF): It is equivalent number of standard axles per commercial vehicle. It is a multiplier to convert the number of commercial vehicles of different axle loads and axle configuration to the number of standard axle load repetitions.

For eg: If 500 Vehicles is equivalent in 4000 standard axles then

$$VDF = \frac{4000}{500} = 8$$

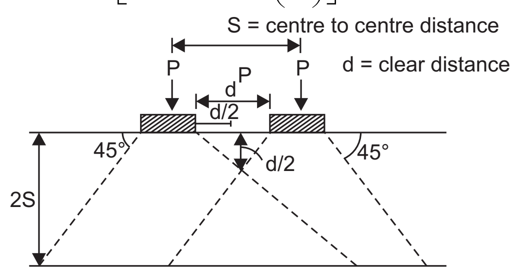
Load consideration in Design

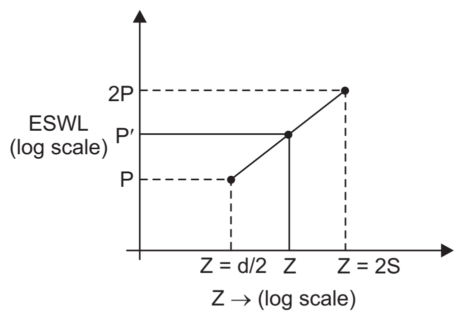
- Fixed traffic approach (Equivalent Single Wheel Load-ESWL)
- Variable traffic and variable vehicle approach
- Fixed Vehicle Approach (Equivalent Axel Load Factor-EALF)

Equivalent Single Wheel Load

Load on a single tyre which will cause an equivalent magnitude of pre-selected parameters at a given location to that resulting from the multiple wheel load at same location.

$$\log P' = \log P + \left[\frac{\log 2P - \log P}{\log 2S - \log\left(\frac{d}{2}\right)}\right] \times \left[\log Z - \log\left(\frac{d}{2}\right)\right]$$





Note:
This approach is used in **Airport pavement Design**.

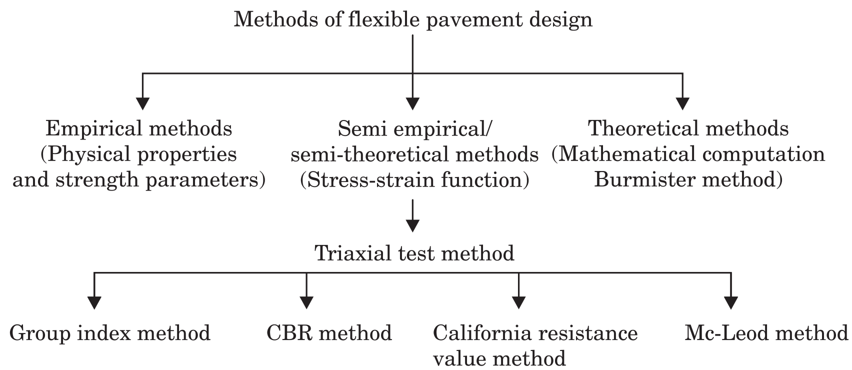
Equivalent axle load Factor (EALF): It defines the damage caused to the pavement by one application of the axle load under consideration relative to the damage caused by single application of standard axle load of 80 kN.

$$\text{EALF of a axle load} = \left(\frac{\text{axle load}}{\text{standard axle load}}\right)^4$$

$$\text{Eg: 240 kN axle load has EALF} = \left(\frac{240}{80}\right)^4 = 81$$

Flexible Pavement Design 10

Methods of Flexible Pavement Design



1. **Group Index Method:** Arbitrary index assigned to the soil types in numerical equations posed on percentage fineness, liquid limit and plasticity index.

$$\text{G.I} = 0.2a + 0.005ac + 0.01bd$$

For a, b, c, d → Refer soil classification.

> **Note:**
> - Thickness of surface course and base course is function of both Traffic volume and group index while that of Sub-base course depends only on Group Index.
> - Quality of material is not considered in this method as it suggests the same thickness for poor or good quality material.

2. **California bearing Ratio method:**

Pavement thickness, $t = \sqrt{\left(\frac{1.75}{\text{CBR}}\right) - \left(\frac{A}{\pi}\right)}$

Applicable only when CBR < 12%

t = thickness in cm

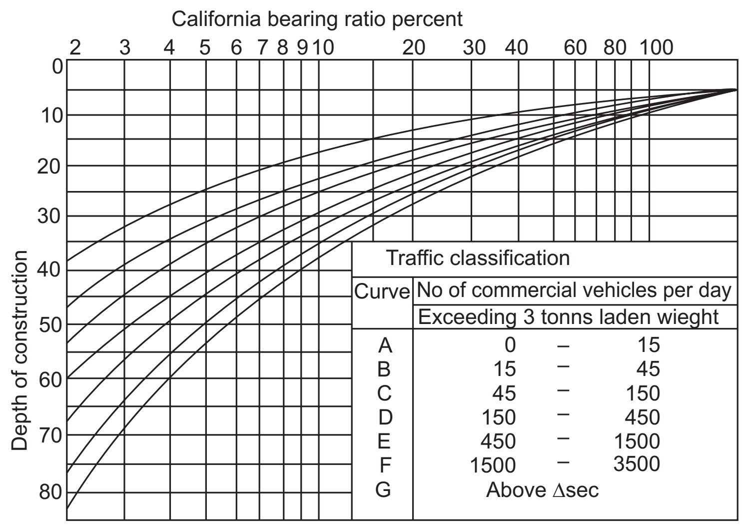
P = wheel load in kg

CBR = in percentage

A = Area of contact; cm^2

where A = πr^2

r = radius of contact area



Note:

- There are 7 curves from A to G in CBR design chart by IRC 37.
- For finding the thickness of pavement directly from the chart only two things are needed.
  (*a*) No. of commercial vehicles per day exceeding 3 tonnes.
  (*b*) CBR % of soil-subgrade over which the pavement is to be made.
- In CBR method also, it gives total thickness required over the subgrade irrespective of the quality of material used in component layers.

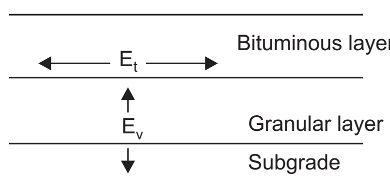
IRC 37, Recommendations for CBR test

1. **Remoulded** soil should be tested in laboratory after soaking it for **4 days**.
2. Soil should be compacted at OMC to proctor density.

3. At least **3 samples** should be tested.
4. Top 50 cm subgrade should be compacted to atleast **95 to 100%** of proctor density.
5. Annual rate of increase in vehicles is taken as **7.5%**.
6. The design thickness is considered applicable for single axle loads upto 8200 kg and tendem axle loads upto 14500 kg.

IRC recommendations for flexible pavement design:

1. It considers **fatigue cracking** and **Rutting** as major flexible pavement failures.
2. Fatigue cracking in bituminous layers looks like **crocodile** cracking and Rutting is the permanent deformation caused due to deformation in subgrade.
3. Fatigue is caused due to tensile strain (E_t) at the bottom of bituminous layer while Rutting is caused due to vertical strain (E_v) at the subgrade top.



4. For fatigue cracking, cracking in 20% of area has been considered for traffic upto 30 MSa and 10% beyond 30 MSa.
5. For Rutting, the limiting value recommended as 20 mm in 20% of length upto 30 MSa and in 10% length for traffic beyond 30 MSa.

$$N_R = 4.1656 \times 10^{-8}\left(\frac{1}{E_v}\right)^{4.5337}$$

$$N_f = 2.21 \times 10^{-4}\left(\frac{1}{E_t}\right)^{3.89}\left(\frac{1}{E}\right)^{0.854}$$

N_R = Number of cumulative standard axles to produce rutting of 20 mm.

N_F = Number of cumulative standard axles to produce 20% cracked surface area.

E = Elastic modulus of bituminous surfacing.

6. IRC gives design chart for pavement thickness depending on CBR of subgrade (**Range 2 to 10%**) and design traffic in MSa (**Range 1 to 150 MSa**)

7. If adequate data is not available then by IRC, **"Guidelines for traffic prediction on Rural highways"** an average annual growth rate of **7.5%** may be adopted.
8. It annual growth rate data for commercial vehicles is not available or it is less than 5%, a growth rate of **5%** may be adopted **(IRC : SP 84 – 2009)**
9. Commercial vehicles are the vehicles having gross vehicle weight of 30 kN.
10. Design life for **Expressways** and **Urban roads** may be **20 years** or more. For **National Highway** and **State highways** it minimum of **15 years** for other category roads its 10 to 15 years.
11. Conversion of different axle load repetitions into equivalent standard axle load repetitions. Can be done as

    (*a*) Single axle with single wheel on either side = $\left(\frac{\text{Axle load in kN}}{65}\right)^4$

    (*b*) Single axle with dual wheel on either side = $\left(\frac{\text{Axle load in kN}}{80}\right)^4$

    (*c*) Tandem axle with dual wheels on either side = $\left(\frac{\text{Axle load in kN}}{148}\right)^4$

    (*d*) Tridem axle with dual wheel on either side = $\left(\frac{\text{Axle load in kN}}{224}\right)^4$

3. California Resistance Value Method

Thickness of pavement t (cm) = $\frac{(K)(TI)(90 - R)}{C^{1/5}}$

K = Numerical constant = 0.166

R = Stabilometer value

C = Cohesionometer value

Traffic Index TI = 1.35 $(EWL)^{0.11}$

EWL = Equivalent wheel load

EWL = $\sum$ (EWL constant) × (AADT)

Note:

$$\frac{t^1}{t^2} = \left(\frac{C_2}{C_1}\right)^{1/5}$$

Number of Axle	EWL Constants	AADT
2	330	N_1
3	1070	N_2
4	2460	N_3
5	4620	N_4

Then $\text{EWL} = 330\,N_1 + 1070\,N_2 + 2460\,N_3 + 4620\,N_4$

4. **M_C – Leod Method:** Thickness of gravel base required

$$t\text{ (cm)} = \text{K log 10 (P/S)}$$

P = Gross wheel load, kg

S = Total subgrade support, kg

K = Base course constant, depends on loaded area

5. **Tri–Axial test method:**

Single layer system, Pavement thickness

$$T = \sqrt{\frac{3PXY}{2\pi E_S \Delta} - a^2}$$

Two layer system, pavement thickness

$$T = \left\{\sqrt{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2}\right\}\left\{\frac{E_S}{E_P}\right\}^{1/3}$$

P = Wheel load, (kg)

E_S, E_P = modulus of elasticity of subgrade and pavement (kg/cm^2)

X = Traffic coefficient

Δ = Design deflection (0.25 cm)

Y = Saturation coefficient

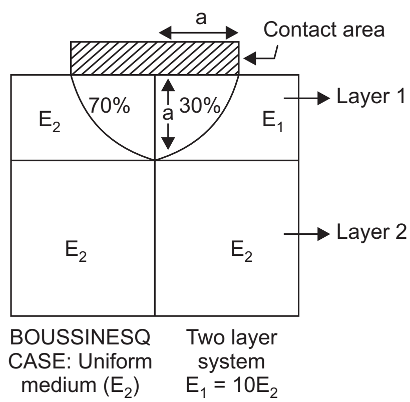
a = radius of contact area (cm)

Note:

- $\left(\frac{E_S}{E_P}\right)^{1/3}$ is known as stiffness factor.
- The relation between pavement layers of thickness t_1 and t_2 with elastic modulas E_1 and E_2 is given by $\frac{t_1}{t_2} = \left(\frac{E_2}{E_1}\right)^{1/3}$.

6. **Burmister method:** It is a **layered system analysis** in which the pavement is composed of flexible layers of materials placed in such a way that the elastic modules of top layer of is highest.

- Length and width of section (*i.e.*, horizontal dimensions) are considered infinite but depth or thickness (*i.e.*, vertical dimension) is considered finite.
- Vertical stress on subgrade are reduced from 70 to 30 percent by introducing a pavement layer of thickness equal to radius of the load, having elastic modules 10 times to that of subgrade soils elastic modulus.



Displacement relationship

for Flexible plate

$$\Delta = 1.5\frac{pa}{E_S}\cdot F_2$$

for Rigid plate

$$\Delta = 1.18\frac{pa}{E_S}\cdot F_2$$

D = Design deflection

p = contact pressure at road surface

E_S = modulus of elasticity of soil subgrade

a = Radius of contact area.

F_2 = Deflection factor depends on $\frac{E_S}{E_P}$ and $\frac{h}{a}$;

h = depth of layer 1.

11 Design of Rigid Pavement

Modulus of sub-grade reaction (K)

Cement concrete pavement rests on soil foundation which can be treated as a spring having a spring constant K.

$$K = \frac{p}{0.125} \text{ kg/cm}^3$$

As per IRC $K_{25\text{ cm}} = 0.5\, K_{30\text{ cm}}$

where p = pressure in plate bearing test (kg/cm^2) corresponding to 1.25 mm settlement.

Radius of Relative Stiffness: It is the relative stiffness of slab to sub-grade.

$$l \text{ (cm)} = \left[\frac{Eh^3}{12\,K(1-\mu^2)}\right]^{1/4}$$

E = modulus of elasticity of cement concrete in kg/cm^2 (3×10^5 kg/cm^2)

h = slab thickness in cm

K = modulus of sub-grade reaction

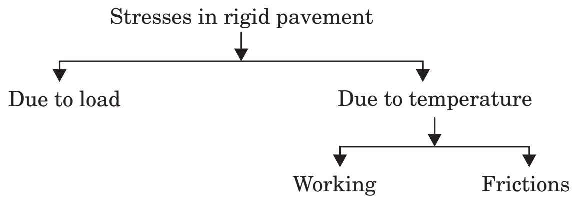
μ = concrete's poisson ratio = 0.15

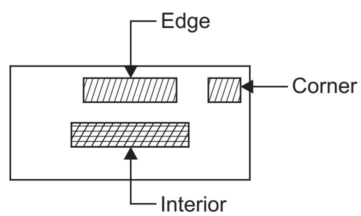
Equivalent Radius of Resisting Section: It is the radius of small area of the pavement which is resisting the bending moment of a plate due to loading. As per **Westergard**.

$$b \text{ (cm)} = \begin{cases} \sqrt{1.6a^2 + h^2} - 0.675h, & a < 1.724\,h \\ a, & \text{otherwise} \end{cases}$$

a = radius of wheel load distribution (cm)

h = Slab thickness (cm)





(*a*) Stresses due to load (by westergard)

$$\sigma_{corner}\ (\text{kg/cm}^2) = \frac{3p}{h^2}\left(1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right)$$

$$\sigma_{edge}\ (\text{kg/cm}^2) = \frac{0.572\,p}{h^2}\left(4\log_{10}\left(\frac{l}{b}\right) + 0.359\right)$$

$$\sigma_{internal}\ (\text{kg/cm}^2) = \frac{0.316\,p}{h^2}\left(4\log_{10}\left(\frac{l}{b}\right) + 1.069\right)$$

Note:

σ_{corner} is tensile stress at top of slab while σ_{edge} and $\sigma_{internal}$ are tensile, stresses at the slab bottom.

(*b*) Stresses due to change in temperature: It is of two types

(*i*) Warping stresses: (Due to **daily variation** in temperature)

$$\sigma_{t\ corner} = \frac{E\,\alpha\,t}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

$$\sigma_{t\ edge} = \max\left\{\frac{C_x\,E\,\alpha\,t}{2}, \frac{C_y\,E\,\alpha\,t}{2}\right\}$$

$$\sigma_{t\ internal} = \frac{E\,\alpha\,t}{2}\left(\frac{C_x + \mu C_y}{1-\mu^2}\right)$$

α = thermal expansion coefficient of concrete

t = temp difference betweeen top and bottom of slab.

C_x, C_y = coefficient depending upon $\frac{L_x}{l}, \frac{L_y}{l}$ respectively.

Note:
During Night, tensile stresses develop at the top of slab and Vice Versa for day.

(ii) **Frictional stresses:** Stresses developed due to **seasonal variation** of temperature and no temperature gradient is considered across the thickness.

Note:
In winter's tension develops in the slab while in summer compression develops in the slab.

Critical combination of stresses

	Corner	Edge	Interior
Wheel load	Maximum	Intermediate	Minimum
Temperature	Minimum	Intermediate	Maximum

Note:
Designing is done using edge region stress and checking is done for corner region.

Combinations

(*a*) Summer and Mid-day (At edge)

$$\sigma_{load} + \sigma_{warping} - \sigma_{friction}$$

(*b*) Winter and Mid-day (At edge)

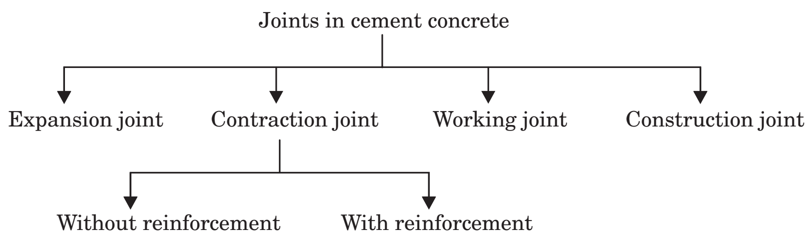
$$\sigma_{load} + \sigma_{warping} + \sigma_{friction}$$

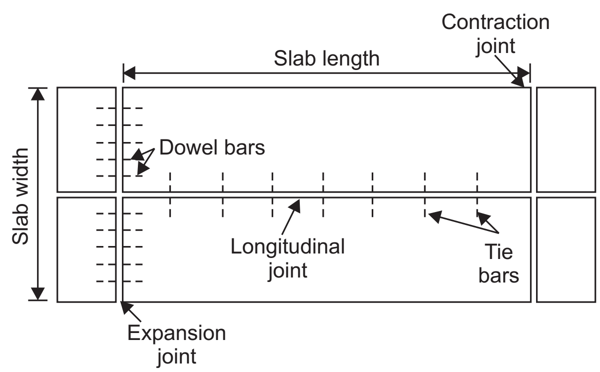
(*c*) Mid-Night (At Corner)

$$\sigma_{load} + \sigma_{warping}$$

Note:
At day time, critical stresses develop at edge's while at night they develop at corner.

Generally maximum stress occur at summer mid-day.





Location of Joints

1. **Expansion:** Provided to prevent expansion due to **rise in temperature** with respect to construction temperature.

- Provided at 50 – 60 m spacing if construction is in winter and 90 to 120 m if construction is done in summers.
- For rough interface the spacing is generally kept at 140 m.
- Approximate gap width is 20 to 25 mm.
- For load transference across the transverse joint, **dowel bars** are placed.

$$L = \frac{\delta}{2\,\alpha\,\Delta T}$$

L = maximum spacing between expansion joint.

δ = Gap of expansion joint.

α = coefficient of thermal expansion.

ΔT = rise in temperature.

2. **Contraction Joint:** To provide control due to **Shrinkage and moisture Variation.**

(*a*) When no reinforcement has been provided

$$L = \frac{2\sigma_{st}}{f\,\gamma_{conc.}}$$

σ_{st} = permissible tensile strength in concrete.

f = Coefficient of friction between concrete and base.

$\gamma_{conc.}$ = Unit weight of concrete.

Note: For $f = 1.5\ \gamma_{conc.}\ 24\ kN/m^3$, then $\sigma_{st} = 0.8\ kg/cm^2$
Maximum spacing without reinforcement is **4.5 m.**

(*b*) When reinforcement is provided in the slab.

$$L = \frac{2\sigma_{st}\,A_{st}}{Bh\,\gamma_{conc.}\,f}$$

A_{st} = Area of steel in complete width of slab.

h = depth of slab.

3. **Warping Joints:** These are provided to relieve stresses due to warping. These are known as hinged joints They are rarely needed.
4. **Construction Joints:** These are provided at the end of a day's work or when work is stopped unexpectedly due to interruption for more than 30 minutes.

   Longitudinal Joint: These are provided along the length of the pavement to reduce the warping stress. These are provided with **tie bars**.

Note:
Tie bars are not designed as load transfer device but ensures that two slabs remain firm together.
Length of tie bar = 2 development length (L_d)

$$L_d = \frac{\sigma_{st}\,\phi}{4\,Z_{bd}}$$

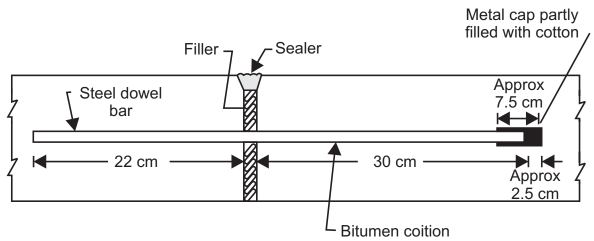
ϕ = dia of bar (nearly 10 mm)

Z_{bd} = bond stress between steel and concrete.

σ_{st} = permissible tensile stress in steel.

Dowel bar: Load transfer device across transverse joint and they keep the two slab at same height.

- Length between 40 cm to 73 cm, nearly **60 cm**.
- Diameter of bar varies between 20 mm to 30 mm.
- Spacing between dowel bars is kept at 30 cm.



Expansion joint with Dowel Bar

- Mild steel round bars are bonded at one end while the other side is kept free.
- Stresses in dowel bar are given by **Brad bury Analysis**.
- Stresses in dowel bars are

Shear | **Bending** | **Bearing**

$$P_S = \sigma_s \times \frac{\lambda d^2}{4} \qquad P_{bend} = \sigma_s \times \frac{\sigma_b \times 2d^3}{L + 8.8\delta} \qquad P_{bearing} = \frac{\sigma_{br}\ L^2 d}{12.5(L + 1.5\delta)}$$

L = embedded length of dowel bar (cm)
δ = Gap of joint (cm)

Note: Load transfer capacity of the dowel bar is assumed to be 40% of the wheel load.
The distance on either side of the load position upto which the group of dowel bars are effective in load transfer is taken as 1.8 l where l = radius of relative stiffness.

12 Highway Maintenance

Maintenance

Routine maintenance
Filling up of pot holes and patch repairs etc almost round the year

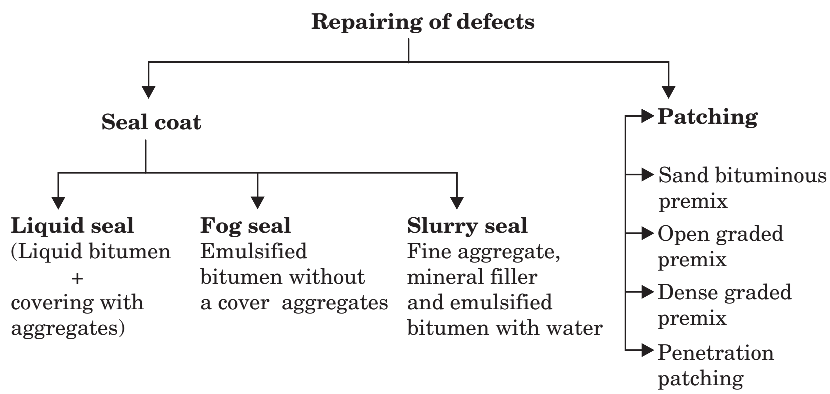
Periodic maintenance
Renewal of wearing course of pavement surface and preventive maintenance of items.

Special repairs
Major restoration or upgrading of pavement though reconstruction or overlay application

Defects of Flexible pavement

1. **Surface defects**
   (*a*) **Fatty surface:** Bituminous binder moves upward
   (*b*) **Hungry surface:** Loss of aggregates
   (*c*) **Smooth surface:** Very low skid resistance
   (*d*) **Streaking:** Alternate lean and heavy lines of bitumen
2. **Cracks**
   (*a*) **Hair line cracks:** Short and fine cracks at short interval
   (*b*) **Alligator or map cracking:** Random deep cracks
   (*c*) Longitudinal cracks
   (*d*) **Edge cracks:** At 0.3 – 0.5 m from inside edge
   (*e*) Shrinkage or Transverse cracks
   (*f*) Reflection or Sympathetic cracks – over joints
3. **Disintegration**
   (*a*) **Stripping:** Separation due to poor bitumen adhesion.
   (*b*) **Ravelling:** Progressive disintegration of the surface
   (*c*) **Pot hole:** Bowl shaped holes extending into base course
   (*d*) Edge breaking
   (*e*) **Loss of aggregate:** Some portion of aggregate remains intact, while from other places it is lost.

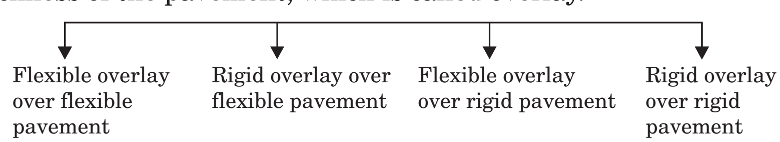
4. **Deformation:**
   (*a*) **Slippage:** Relative movement between surface layer and layer beneath.
   (*b*) **Rutting:** Longitudinal depressions on the surface.
   (*c*) **Corrugation:** Regular undulations.
   (*d*) **Shoving:** Localised bulging due to plastic movement with in layer.
   (*e*) **Shallow depressions:** Size nearly 25 mm.



Defects of rigid pavements

1. Scaling of cement concrete
2. Shrinkage Cracks
3. Spalling of joints
4. Warping cracks
5. Mud pumping
6. Structural cracks.

Overlay: Strengthening may be done by providing additional thickness of the pavement, which is called overlay.



1. **Flexible overlay over flexible pavement**

$$h_o = h_d - h_e$$

h_o = overlay thickness required (cm)

h_d = Design thickness required (cm)

h_e = Total thickness of existing pavement (cm)

Benkelman Beam Deflection method:

Characteristic deflection (D_C) → $D_C = D + t\sigma$

Where D = design deflection

σ = Standard deflection

t = depends on % of deflection values to be covered in design.

Over lay thickness design

$$h_o = \frac{R}{0.434}\log_{10}\frac{D_c}{D_a} \quad \text{Ruiz's Equation.}$$

h_o = thickness of Bituminous overlay in cm

R = Deflection reduction factor depending on the overlay material.

$$h_o = 550\log_{10}\frac{D_c}{D_a} \quad \text{As per 1 RC}$$

h_o = Thickness of granular or WBM overlay in mm.

$D_c = \bar{D} + 6$, after applying the corrections for pavement temperature and subgrade moisture,

D_a = 1.00, 1.25 and 1.50 mm if the projected design traffic A is 1500 to 4500, 450 to 1500, and 150 to 450 respectively

2. Rigid overlay over rigid pavement

$h_o = (h_d^n - \times h_e^b)^n$

h_o = Rigid overlay thickness

h_d = Design thickness

h_e = existing pavement thickness.

3. Flexible overlay over rigid pavement

$h_f = 2.5\,(fh_d - h_e)$

$h_b = 1.66\,(fh_d - h_e)$

h_f = flexible overlay thickness

h_e = Existing rigid pavement thickness

h_d = Design thickness of rigid pavement

f = factor which depend upon modulus of existing pavement.

h_b = Thickness of bituminous overlay.