HIGHWAY ENGINEERING

Order :-

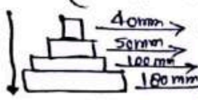
Roman roads → Tresaguet. → Telford → macadam construction

$\underbrace{\text{Tresaguet}}_{\text{french}}$ $\underbrace{\text{Telford}}_{\text{Scottish}}$

1) Roman roads :-
- stone block used
- no Gradient
- High Thickness (0.75-1.2m)

② Tresaguet roads :- modification in roman roads (french roads)
- Drainage provision (slope given)
- Subgrade moisture condition
- Thickness → 30cm.

③ Telford roads (Scottish road) • slope : 1 in 45


40mm → Gravel wearing course / surface
50mm → Broken stone surface
100mm → Broken stone layer of larger stones
180mm → Single size stone for foundation

④ macadam construction :- Different from All other methods (1st time who suggested heavy foundation in stone not required.)
- slope :- 1 in 36 (subgrade drainage)
- Subgrade Compaction.
- size of Broken stone for top layer → Basis of stability ; → under animal-drawn vehicle
- Total Thickness - 25cm (uniform) from edge to centre.

Jaikar committee (1927) ① central Govt. should take care of roads in national intrest.
(II) Long term planing (20 yer plans)
(III) Semiofficial Technical Body (IRC, 1934)
(IV) audition tax (duty on MS, vehicle tax) → CRF
(V) CRRI, 1950 → for R&D
Roorki

Nagpur Road plan (1943-63) :- $\boxed{\frac{16\,km}{100\,km^2}}$ 4 → NH, SH, District road (MDR, ODR), village Road

- Based on Geographical, Agriculture, Popullation + $\boxed{15\%\text{ allowance}}$ → Agriculture ; → Industrial development
- assuming star-grid pattern, this plan developed
- NH + SH + MDR = ?
  ODR + VR = ?

Bombay Road plan (1961-81) : $\left(\frac{32\,km}{100\,km^2}\right)$ ⑤ → 4 + Express way
- Traffic engg. cell in each state
- Fund for Highway → direct → motor vehicle ; → indirect (betterment Levy, Cesson - land revenue, toll, tax on HSD for vehicle / motor)

Short coming of Nagpur, Bombay Plan :-
1- plans were not part of total transportation plan of country.
2- not conciev to meet need of freight & passenger movement by road.

Lucknow road plan :- (1981-2001) $\frac{81\,km}{100\,km}$
- energy conservation, environment, Quality of roads considred.
- 3 roads types → Primary (Expressway + NH) ; → Secondry (SH + MDR) ; → Tertiary (ODR + VR)

$\boxed{NH = \frac{Area}{50}}$

SH → $A/25$; → $62.5 \times T (\geq 5000) - NH$

MDR → $A/12.5$; → $90 \times T (\geq 5000$

total road Length = 4.74 (town + village) or 82 km / 100 km2

VR (rural road) = total road Length - NH - SH - MDR

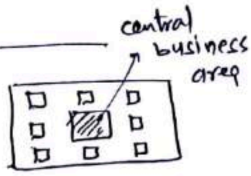
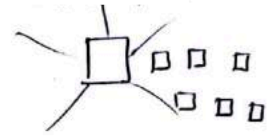
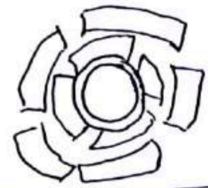
factors controlling Alignment :-

(i) obligatory points	Ex. Bridge site, Zoo, town, mandir
(ii) Traffic requirement	• O&D study (Desire line) Show trend of traffic
(iii) Geometric Requirement	• site distance Requirement
(iv) economy	• cost/Benefit ratio,
(v) Hydrological factor, drainage factors	

Engineering Survey for Highway :-

(1) map study	• possible Alternate route • alignment avoiding Hill etc
(2) Reconnisance	• no. of cross drainage str • soil type • source of construction material • HFL • Approx gradient
(3) Preliminary survey	• to survey various Alternate alignment { • soil survey • material survey • Traffic survey
(4) final location	Based on preliminary survey.
(5) Detailed survey	• Temporary Benchmark established at 250m & at All drainage & underpass structure. • Levelling along final centre line

Road pattern :-

Rectangular/ Block pattern	Ex. चंडीगढ़ 
radial / star & Block pattern	Ex. 
radial/ star & circular Pattern	Ex. कनॉटपैलेस दिल्ली 
Hexagonal Pattern	
min Travel pattern	

Geometric design objective
(I) efficiency of Traffic operation ↑
(II) safety increases (at reasonable cost)

Highway Geometric design deals —
(I) design of vehicle dimension
(II) Road user characteristic
(III) Topography
(IV) Highway classification (traffic volume)
(V) design speed
(VI) Horizontal curve
(VII) vertical curve
(VIII) Gradient
(IX) Sight distance

Vehicle dimension :-
(I) width ⟶ determine pavement width
(II) Length ⟶ governs turning path
(III) Height ⟶ define vertical clearance

width	Length	Height
2.5 – motor vehicle 2.7 – transport vehicle	≤ 2axle 9.5 11.25	double decker bus ⇒ 4.75

Road user characteristic :-
P → perception time – Nervous system
I → Intellection – पुरानी यादें / नये विचार
E → emotion – डर, गुस्सा
V → volition – Act

- AASHTO → Pedestrian speed = 1.2 m/s
- reaction time — time to respond particular situation (0.5 – 4 sec) ⟶ depends on situation.

Terrain/Topography :-

Plain	% cross slope 0 – 10
rolling	10 – 25
mountain	25 – 60
steep	> 60

cross slope ↑
(Radius of curvature ↑ R)
⇓
Construction cost ↑

design speed ↓ R ↓ construction cost ↓

Design speed :- → vehicle can continuously travel safely under favourable condition.
Imp
→ Basic parameter → determine all Geometric Parameters like sight dist., Hor. curve, Ver. curve

Terrain	NH/SH design speed (V)		Radius (R)	
	Ruling	Minimum	Ruling min.	Absolute min.
Plain	100	80	360	230
rolling	80	65	230	155
Mountain	50	40		
steep	40	30		

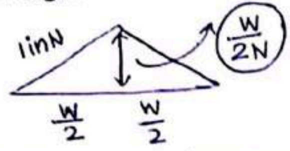
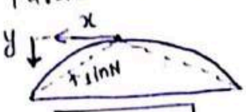
note :- Principle of max. Utility :- used to find Priority
- assign factor based on population like 0.5, 1, 2
- more population ⟶ more factor
- find utility per unit length, Highest will get priority no.

Cross-section elements :-
1 – Pavement surface characteristic :-
Friction, smoothness or roughness, light reflection, Drainage

Roughometer	Bump indicator
• gives (IRI) international roughness index	• gives unevenness index 1500 mm/km → good

* white road	• good visibility in night • Cause glaring in day
* Black road	• no glaring in day But poor visibility in night

② **Camber** :- Slope provided to road surface in transverse direction to drain off the rainwater water from road surface.

straight line camber	Parabolic camber
	 $\boxed{y = \frac{2x^2}{NW}}$ for fast-moving vehicle
Very flat cross slope (CC pavement)	

Surface type	light – heavy rainfall (%)
CC & High Bituminous	1.7 – 2
Thin Bituminous	2 – 2.5
WBM & gravel pavement	2.5 – 3
Earthen	3 – 4

Camber (%) ⇒ Earthen > Gravel > WBM > CC > High Bituminous

note :- if excess camber provided →
- erosion
- unequal wear of tyres
- discomfort

∵ Tendency of most vehicle to run along centre line hence problem of toppling of Bullock cart & Truck (heavy loaded).

note :- shoulder camber ⇒ [Pavement camber + 0.5% steeper]

↳ But min 3%.

- on superelevated section
  Shoulder camber = Pavement camber.

③ **Width of carriageway** :-

single lane = 3.75
multiple lane = 3.5 × n
(without Kerb)

Imp.
2 lane + raised kerb = 7.5m

- Intermediate Carriage = 5.5 [1 < n < 2]
  ↳ to give manouvering

④ **Traffic Separator / median** :- fn → to prevent head on collision (जो इधर से उधर आ रहे)

IRC :-
desirable = 5m
min = 3m
(where land restricted)

(But urban area = Absolute = 1.2m)

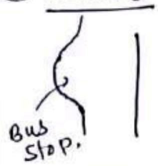
⑤ **Shoulder** :- → along road edges

fn → for accomodation of stopped vehicle as an emergency land for vehicle.
- Provide latiral support for Base & Surface course.

Desirable → 4.6m
min → 2.5m for 2 lane rural highway Imp

⑥ Parking lane

⑦ **Bus Bays** → provided by recessing the kerb (पीछे हटा देना) for Bus stop.



⑧ **Service road / frontage road** :- Give access to control highway like expressway.
or to avoid congestion in expressway.

⑨ cycle track ⑩ footpath

⑪ **Guard rail** :- when height of fill > 3m
- Provided at edge of shoulder usually when road is on embankment.

∴ They also give better visibility of curve at night under headlights of vehicles.

(12) Formation width / road way width :-

⇒ carriageway (includes median) + both Shoulders

(13) Right of way :- or road land width :-

↳ land required for the road along its alignment. (carriageway + Shoulders + road margin)

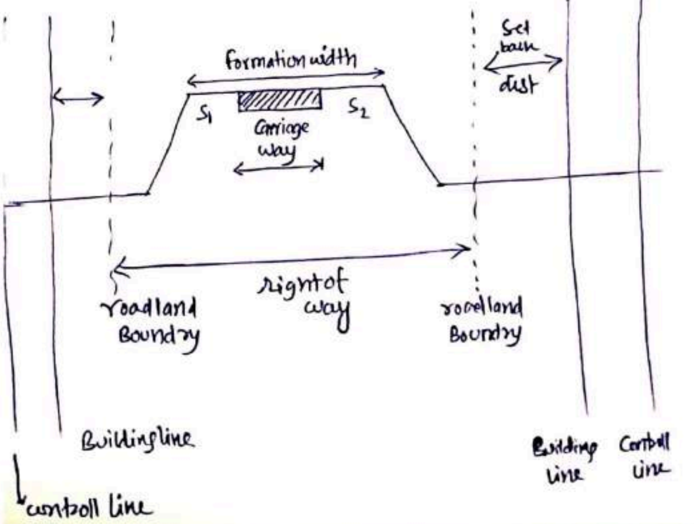
- Width of land required should be adequate to accomodate all the cross-sectional elements of highway.

Right of way govern by —

(I) formation width
(II) Height of embankment or cutting depth
(III) Side slope of embankment
(IV) sight distance considerations.
(V) Scope of future widening of road.

- Buildingline :- Between road & Building line There is no building at All

Controll line :- desirable to exercise controll on nature of Building activity for a further distance beyond the building line up to what are known as controll line



note Imp.

NH/SH (Plain + rolling)

Right of way 30-60 (45-Avg)
Building line 80m
REDMI NOTE 5

Sight distance :- Geometric design of road should be such that any obstruction on road length could be visible to driver from some distance ahead, this distance ⟶ sight distance

Stopping sight dist. / nonpassing sight dist / Absolute min sight dist :-
(SSD)

dist. available at any spot having sufficient length to enable the driver to stop a vehicle travelling at design speed safely without collision with any other obstruction.

$$SSD = \underbrace{\text{lag distance}}_{\text{distance travel by vehicle during reaction time}} + \underbrace{\text{braking distance}}_{\text{during braking operation}}$$

$$SSD = (v \cdot t) + \left(\frac{v^2}{2gf}\right) \longrightarrow \left\{ \frac{1}{2}mv^2 = \text{workdone} = (\mu N) \times l = f W l \right.$$

$m = \frac{W}{g}$

IRC: $t_R = 2.5$

$$\boxed{SSD = 0.278\, V t_R + \frac{V^2}{254 f}} \quad (f = a/g)$$

IRC 0.35–0.40: f → longitudinal cofficient of friction $\boxed{f = 0.35}$ at $V = 100$

(speed बढ़ेगा f घटेगा)

&

$$\boxed{SSD = .278 V t_R + \frac{V^2}{254(f \pm n)}}$$

↗ (+)
↙ (−)

$$\frac{1}{2}mv^2 = \left[fW \pm W \times \frac{n}{100}\right] l$$

∵ $\sin\theta = \tan\theta$ for small 'θ'

Important points (SSD) :-

(1) only divided highway (2 way) ⟶ grade effect must be consider.

- undivided Highway (2 way) ⟶ grade effect should not be considered.

(2) Single lane 2 way :- $\boxed{SSD = 2 \times SSD \text{ calculated}}$

(3) on vertical curve :- SSD :- length which a driver from height 1.2m have visibility of an obstruction of height 0.15m

(4) if SSD not available at any section of road :-

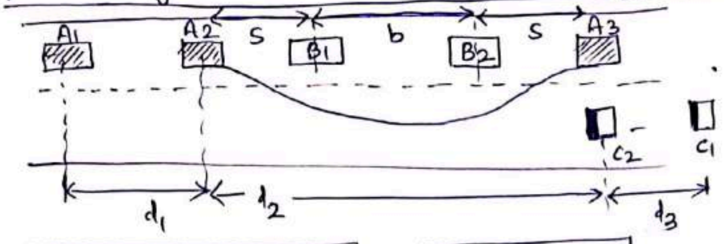
then speed limit by < Warning Sign / Speed limit Regulation sign.

OSD

overtaking sight distance / safe passing sight distance :-

(i) min distance open to the vision of driver of vehicle intending to overtake the slow vehicle ahead safely against the traffic in the opposite direction.

(ii) It is measured along the centre line of the road over which a driver with his eye level 1.2m above the road surface can see the top of an object 1.2m above the road surface.



$\boxed{d_1 = 0.278 V_b \cancel{t_R}}$ 2 sec $\qquad \boxed{d_3 = 0.278 VT}$ → design speed

$d_2 = b + 2S = v_b T + \frac{1}{2} a T^2 \qquad T = \sqrt{\frac{4S}{a}}$

$\boxed{S = 0.2 V_b + 6 = 0.7 v_b + 6}$ (6 → L) $\qquad \boxed{a = 0.92 m/s^2 @ 65 \text{ kmph}}$

$\boxed{\begin{array}{l} V_b = V - 16 \text{ kmph} \\ v_b = v - 4.5 \text{ kmph} \end{array}}$ (L → avg. length of vehicle = 6m)

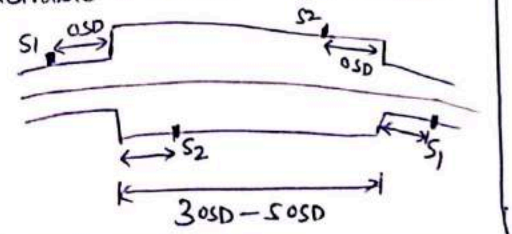
note :- (i) if one way road then $\boxed{d_3 = 0}$

(ii) if $n \geq 4$ lane, not neccesary to provide OSD but sight distance > SSD

overtaking sight distance ⟶ no effect of grade Imp.

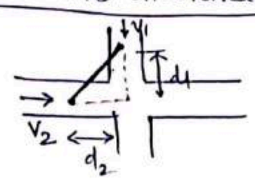
overtaking zone :- when OSD can not be provided throughout the length of Highway then for dedicated overtaking operation, overtaking zones are made.

disirable = 5×OSD $\qquad$ min = 3×OSD



- S_1 → overtaking zone begin
- S_2 → end of overtaking zone

sight distance at Intersection :-



d_1 = SSD for V_1

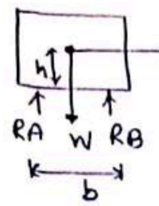
d_2 = SSD for V_2

Intermediate sight distance ISD = 2×SSD
(stretch where required OSD can not be provided)

Head light sight distance :-

distance visible to the driver during night driving under the illumination of headlight.

Horizontal curve :-



centrifugal force

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

$$\text{impact factor} = \frac{P}{W} = \frac{v^2}{Rg}$$

- centrifugal force is countracted by transverse friction (latiral coff. of friction) b/w tyre and surface.
- effect of cf
  - overturning (about outer wheel)
  - skidding (in latiral direction)

① for no overturning :- $\boxed{W \times b/2 \geq P \times h}$ or $\boxed{P/W \leq b/2h}$ **

Just onverge of overturn

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

$$\Downarrow$$

$$\frac{v^2}{Rg}$$

noti:- when vehicle is just about to overturn $RA = 0$

② for no skidding :- $\boxed{P/W \leq f}$ → latiral

$(fW \geq P)$

for skidding before overturn $\boxed{f < b/2h}$ Imp

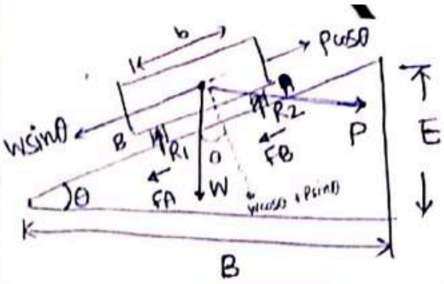
Superelevation :- to counter effect of CF (overturn or skidding)

- outer edge of pavement is raised wrt inner edge, Thus providing transverse slope throught the horizontal curve, This transverse inclination to pavement is known as superelevation / cant / banking.

- when outer edge is raised → then component of weight will act opposite to CF, Thus countract.

noti:-

	e_{max}
Plain/rolling	7% (Hill + snow)
Hilly	10%
Builtup	4%



at eqb :- $\boxed{P\cos\theta = W\sin\theta + f_A + f_B}$ $\left\{ \begin{array}{l} R_A + R_B \\ = P\sin\theta \\ + W\cos\theta \end{array} \right\}$ ($f_A = fR_A$, $f_B = fR_B$)

Imp

$$\boxed{\frac{P}{W} = \frac{V^2}{gR} = \frac{\tan\theta + f}{1 - f\tan\theta} = \frac{e+f}{1-ef}}$$

$\because$ normally $f = 0.15$ $\theta < 4°$ $\therefore 1 - f\tan\theta \simeq 1$

& for small θ $\sin\theta = \tan\theta = e$

$$\therefore \boxed{e + f = \frac{v^2}{gR} = \frac{V^2}{127R}}$$

(v → m/s, V → Kmph)

case-1 :- if there is no friction $(f=0)$ → then Pressure on both the wheels are same $(R_1 = R_2)$ Imp

$(\therefore W\sin\theta = P\cos\theta)$ $\because R_1 + R_2 = W\cos\theta + P\sin\theta$

taking moment about A:-

$$R_1 \times b - [W\cos\theta + P\sin\theta] \times b/2 + (P\cos\theta - W\sin\theta)h = 0$$

$$\boxed{R_1 = R_2}$$

case-2 :- if no superelevation is provided $(e=0)$

$$\boxed{\therefore f = \frac{V^2}{127R}}$$ → this result in very high coff. of friction.

Design of superelevation :- (IRC)

① $e = \frac{(0.75V)^2}{127R} = \frac{V^2}{225R}$ { find e at 75% V & neglect f

② $e \leq 0.07$ then provide actual 'e' otherwise step-3

③ if $e > 0.07$ $f = \frac{V^2}{127R}$

if $f < 0.15$ then provide $e = 0.07$

↓

otherwise restrict speed

$$\boxed{V_{max} = \sqrt{127R(e+f)}}$$ *

noti:-

fast moving vehicles (मौत का कुआं)	higher e without f is safe [CF → fully countract by weight of vehicle/superelevation]
slowing moving vehicle	lower 'e' considering 'f' is same [CF → countract by e & f]

noti:- Radius beyond which no superelevation required

$$e + \cancel{f}_{0} = \frac{(0.75V)^2}{127R} = \frac{V^2}{225R}$$

$$R_{Ruling} = \frac{V^2}{127(e+f)}$$

Imp NH/SH

	Ruling	Absolute min
Plain	360	230
Rolling	230	155

Extra widening (E_W) = mechanical widening E_m + Psychological widening E_P

$(n \geq 2)$ $\left(\frac{nl^2}{2R}\right)$ $\left(\frac{V}{9.5\sqrt{R}}\right)$

1- for 1 way :- no psychological widening req.

2- R > 300 → no extra widening Req.

3- In hilly areas :- (sharp curve) (R<50)

Provide fully extrawidening on inner side

(∵ easy to cut hill on inner side)

4- (50 < R < 300) Horizontal curve + TC (transition curve) :-

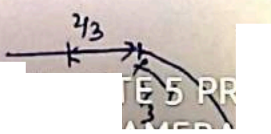
half + half → both side

- Starts from TC and end at TC.

5. Horizontal curve without TC :-

↳ inside of curve

{ • 2/3rd at end of straight section (before circular section)
and 1/3rd is provided on circular curve. }



Transition Curve :-

- provided to change the horizontal alignment from straight to circular curve.
- Radius varies from ∞ to certain value.

objective :-

1- Introduce CF gradually ∴ avoid sudden jerk

hence comfort ↑↑

2- Gradual introduction of superelevation, extrawidening

•-

IRC :- spiral Transition curve → best

∵ fullfill requirement of Ideal Transition curve

1- Rate of change of centrifugal acceleration is consistent.

2- $l \propto \frac{1}{R}$

3 - Calculation easy

4 - setting in field easy

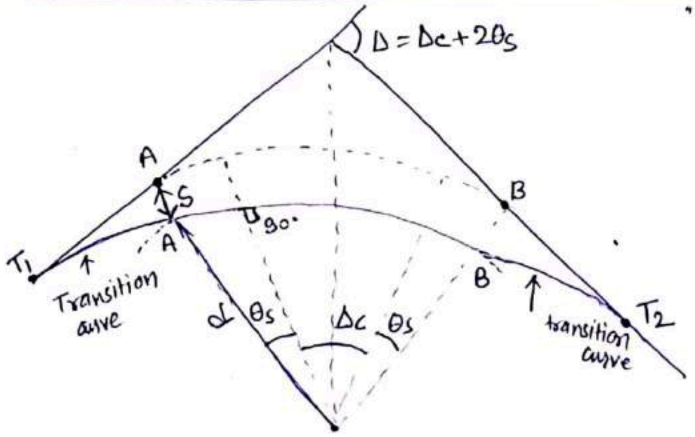
offset method | Polar Deflection angle method

length of Transition curve :-

Rate of change of centrifugal acceleration (C)	$L = \frac{v^3}{CR}$ $C = \frac{80}{75+V}$ $0.5 \leq C \leq 0.8$ m/	
Rate of change of superelevation	Pavement rotation about inner side $L = eN(W+E$ ——— centreline $L = \frac{eN}{2}(E_W+$ N = 150 → Plain & rolling N = 100 → Built up N = 60 → Hilly	
Empirical formula	Plain & rolling	$L = \frac{2.7V^2}{R}$
	Hill	$L = \frac{V^2}{R}$

Shift :- $\boxed{S = \frac{L_s^2}{24R}}$

when transition curve is introduced b/w a straight & circular curve, the circular-curve has to be shifted so that transition curve meet the circular curve tangentially.



(i) $\boxed{\Delta = \Delta_c + 2\theta_s}$ $\left\{ \theta_s = \frac{L_c}{2R} \text{ radian} \right.$

$L_c = \frac{2\pi R}{360} \times \Delta_c$

(ii) tangent length $\boxed{T_s = \frac{L_s}{2} + (R+s)\tan\frac{\Delta}{2}}$

(iii) Total length of curve $\boxed{L_c + 2L_s}$

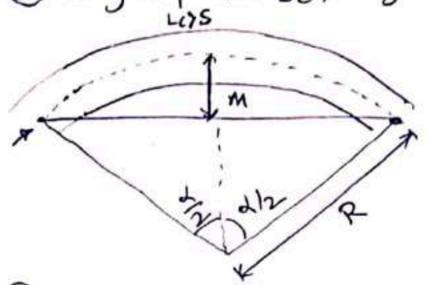
Setback distance (m) :- [basically clearance req.]

- distance required from centre line of Horizontal Curve to an obstruction on inner side of curve to provide adequate adequate sight distance at horizontal curve.

- m depends on
  - SSD/ISD/OSD
  - radius of curve
  - Length of curve

case-A :- for single lane road :-

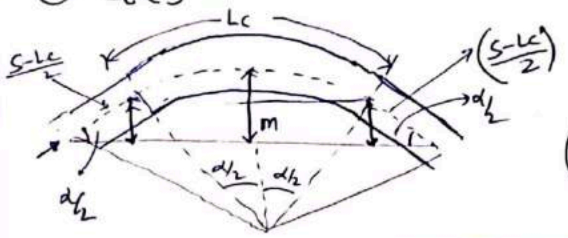
(1) Length of curve $L_c >$ sight distance (s)



$\boxed{m = R - R\cos\alpha/2}$

$\left\{ \frac{S}{\alpha} = \frac{2\pi R}{360} \right\}$

(2) $L_c < S$

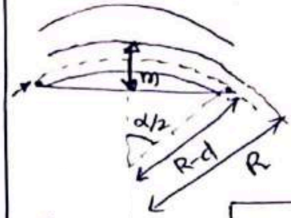


$\left(\frac{L_c}{\alpha} = \frac{2\pi R}{360} \right)$

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

case-B :- 2 lane road :-

(i) $L_c > S$



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

$\left\{ \frac{S}{\alpha} = \frac{2\pi(R-d)}{360} \right\}$

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

$\boxed{\frac{L_c}{\alpha} = \frac{2\pi(R-d)}{360}}$

Grade compensation : Reduction in gradient at horizontal curve, which is intended to offset the extra tractive effort at curve.

- Grade compensation $= \left(\frac{30+R}{R}\right)\%$

  max $\frac{75}{R}\%$

But imp. $\boxed{\text{compensated Gradient} \geq 4\%}$

Curve Resistance :- $\Rightarrow \boxed{T - T\cos\alpha}$ additional Tractive force is required to negotiate the curve.

Gradient :

Ruling gradient	• max. gradient which designer attemps to design the vestical profile of road
limiting gradient	• L.G stretch is limited and must be sandwitched by either straight roads or easier grades. • when R.G cost is more
Exceptional Gradient	very steeper gradient given at unavoidable situations · stretch ⊁ 100m.
min. gradient	where surface drainage is important. Concrete drain ⇒ 1/500; open Soil drain ⇒ 1/200

Imp noti :- In railway more allowable grade is less than highway.

(∵ steel wheels on steel rails have lower frictional cofficient than rubber tyre on Pavement)

Vestical curve :- The curve provided at the change of gradient.

horizontal curve → to provide change in direction to the central line of road (Alignment)

Summit curve / concave downward / convex upward :-

• design govern by → $\boxed{\text{sight distance}}$ *

• Ideal summit curve → $\boxed{\text{circular}}$

{ ∵ It offers equal sight distance at every point on curve }

[for very small deviation angle → circular & parabolic curve are almost congruent.

• Practically used summit curve — $\boxed{\text{Parabolic}}$

{ • comfortable transition from 1 gradient to another. Thus excellent riding comfort
• easy laying down.

• noti :- Parabolic curve preferred over circular curve ·

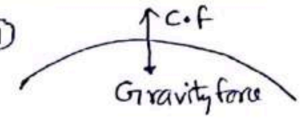
(I) flatter at top

(II) Rate of change of gradient = constant

$\Rightarrow y = ax^2+bx+c \quad \frac{d^2y}{dx} = 2a$

summit curve imp. points :-

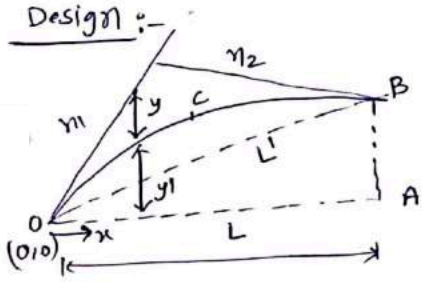
(1)



It relieves pressure on tyre & spring of vehicle.

(2) vestical deviation angle on road are so small because summit curve prescribed by sight distance are so long and easy that such is automatically rended imperceptible to travellers.

Design :-



for small deviation Angle OA = OB = OCB

$\boxed{y = n_1 x - y'}$ *

simple parabolic eqn of summit curve

$y' = ax^2 + bx + c$

$\therefore \boxed{c = 0}$

$\frac{dy'}{dx} = 2ax + b$

$\therefore \boxed{b = n_1}$

$x = 0 \quad y' = 0$

$x = 0 \quad \frac{dy'}{dx} = n_1$

$x = L \quad \frac{dy'}{dx} = n_2$

$n_2 = 2aL + n_1 \qquad a = \frac{n_2 - n_1}{2L}$

$\therefore y' = \left(\frac{n_2 - n_1}{2L}\right)x^2 + n_1 x$

Imp : $\because y = n_1 x - y'$

Parabolic eqn of summit curve.

$$\boxed{\therefore y = \left(\frac{n_1 - n_2}{2L}\right) x^2 = ax^2 = \left(\frac{N}{2L}\right) x^2}$$

$\therefore \frac{dy}{dx} = \frac{N}{2L}(2x) \quad \& \quad \frac{d^2y}{dx^2} = \left(\frac{N}{L}\right)$

(RE)($\frac{1}{R}$)

Radius of curvature of summit curve :-

$$\text{Curvature}\left(\frac{1}{R}\right) = \frac{\left(\frac{d^2y}{dx^2}\right)}{\left[1+\left(\frac{dy}{dx}\right)^2\right]^{3/2}}$$

∵ vertical curves are generally flat

$$\therefore \frac{dy}{dx} \simeq 0$$

$$\therefore \frac{1}{R} = \frac{d^2y}{dx^2} = \frac{N}{L}$$

$\boxed{\therefore \text{radius of curvature}(R) = L/N}$

Highest point on summit curve $\boxed{x = \frac{n_1 L}{N}}$

- for purpose of layout of drainage - appurtenances for ascertaining vertical - clearance in restricted location as - road under Bridges.

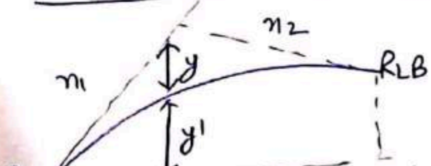
$$\because y' = \left(\frac{n_2 - n_1}{2L}\right)x^2 + n_1 x$$

for Highest point $\frac{dy'}{dx} = 0$

$$\boxed{x = \frac{n_1 L}{N}}$$

note :- when 2 grades are unequal, curve will be tilted and highest point on the curve would lie on the side of flatter gradient.

Calculation of ordinate of summit curve :-



$$\left\{\begin{array}{l} y' = ax^2 + bx + c \\ y = \left(\frac{N}{2L}\right)x^2 \end{array}\right\}$$

$$\left\{\begin{array}{l} (RL)_x = (RL)_A + (n_1 x) - (y) \\ (RL)_B = (RL)_A + (n_1 \times L) - \left(\frac{N}{2L}\right)(L)^2 \end{array}\right\}$$

Length of summit curve :-

↳ Govern by sight distance criteria.

$$\left\{\begin{array}{l} \text{drivers eye above road surface} = 1.2m \\ \text{height of object above pavement} = 0.15m \end{array}\right\}$$

Length of curve > SSD	$\boxed{L = \frac{NS^2}{2(\sqrt{h_1}+\sqrt{h_2})^2}}$ $h_1 = 1.2 \quad h_2 = 0.15$ $\therefore \boxed{L = \frac{NS^2}{4.4}}$
L < SSD	$L = 2S - \frac{2(\sqrt{h_1}+\sqrt{h_2})^2}{N}$ $\boxed{L = 2S - \frac{4.4}{N}}$
OSD & ISD: L > S	$h_1 = 1.2 \quad h_2 = 1.2$ $\boxed{L = \frac{NS^2}{9.6}}$
L < S	$\boxed{L = 2S - \frac{9.6}{N}}$

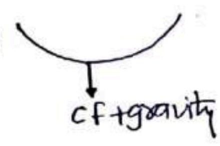
note:- imp

Design speed (kmph)	max. grade change not required curve	min Length of vertical curve
100	0.5	60
80	0.6	50

Valley curve / sag curve / concave upward / convex downward :-

① no restriction to sight distance during daytime.

② visibility is reduced during night → in absence of street light so visibility source is only head lights. Hence valley curve design taking into head light sight distance.

③ 

hence impact to vehicle more hence Jerk & discomfort to passenger.

④ design factor

- comfort — { Impact free movement of vehicle at design speed }
- Safety — { availability of SSD under headlight of vehicle for night driving. }

⑤ for gradually introducing and increasing centrifugal force acting downward →
Imp hence Best shape → Transition curve.

$\boxed{\text{Cubic parabola is generally preferred}}$

⑥ if deviation angle is small then → path traverse by spiral, Lemniscate, Cubic parabola are same.

⑦ during night, under head light driving condition head light sight distance should be atleast equal to SSD, There is no problem of OSD at night since other vehicle with head light could be seen from considerable distance.

Length of valley curve :-

Provide 2 similar TC of equal Lengths.

$$\boxed{y = bx^3 = \left(\frac{2N}{3L^2}\right)x^3 \quad \text{cubic parabola}}$$

Imp note:- for small deviation angle we generally use parabolic curve.

Design Basis of valley curve :-

① comfort Criteria

- impact free movement (no Jerk)

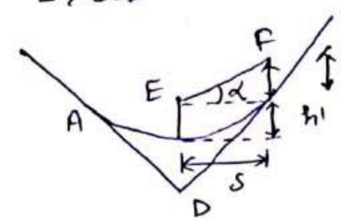
$$\boxed{L = 2\sqrt{\frac{NV^3}{C}}} = 2L_s$$

C → allowable rate of change of centrifugal acceleration.

② Safety criteria

- driver should have adequate head-light sight distance during night.

Ⓐ $L > SSD$



Imp assume small deviation angle → Parabolic curve

$y = ax^2 = \frac{N}{2L}x^2$, $y \to h' + S\tan\alpha$, $x \to S$

$$\boxed{L = \frac{NS^2}{2(h' + S\tan\alpha)}}$$

h' → height of headlight beam ⇒ 0.75 m
α → head light beam inclination ⇒ 1°

Ⓑ $L < SSD$

$$\boxed{L = 2S - \frac{2(h' + S\tan\alpha)}{N}}$$

Imp note:- while SSD calculation we don't consider gradient as min. sight is at Lowest point & beyond that there is no gradient

Trafficstudy → aim: planning, Geometricdesign

Traffic characteristic	Traffic study & analysis	Traffic controll regulation
1- roaduser characteristic	1-Trafficvolume	1- Intersection, Interchange
2- vehicle characteristic	2- Speed study (spot speed; Speed & delay study)	2- Rotary
3-Braking characteristic	3- O&D study	3- Traffic-signals
$a = gf$, $v^2 = 2gfs$	4-Traffic flow characteristics	4-Trafficsign
	5- Trafficcapacity	5- Road markings.
	6- Parkingstudy	
	7-Accidentstudy.	

Braking Test :- aim → toget skid resistance of pavement.

→ atleast 2 measurements are needed

Braking distance$(l) = \frac{v^2}{2gf}$ $\quad a = \frac{v}{t} = gf$

$\eta = \frac{f \text{ by braking Test}}{f_{max}}$

Traffic volume count :-

(i) manual	• By watch
(ii) photo-graphy (videography)	• By video
(iii) mechanical method	(1) Pneumatic hose (Automatic, count no. of axles) (2) Loop detector (3) magnetic detector (4) multiple pen recoder {combination of manual & mechanical}
(iv) multiple [illegible]	Automatic count of vehicle & classifies.

How to represent Traffic volume data :-

AADT	• annual Average daily traffic • takes avg. of whole year (∴ in this seasonal variation included) • aim → to know relative Importance of road
ADT (≥ 7 day & < 1 year)	• average Daily Traffic • Include weakly variation (sat, sunday)
Trend chart	• shows volume trend over year. aim → planning, expansion, design, regulation
volume flowdiagram	• needed for Intersection design

30th Highest hourly volume → 29 time Jam in a year

note :- if we design by taking peak hourly volume it will be too costly.

hence IRC :- 30th Highest hourly volume @ 8–10 % of AADT

note :- To get AADT ⟶ difficult & costly

∴ count for 15min, 25 min (periodic volume count)

used to calculate ↓

Hourly expansion factor	$\frac{\text{total 24hrs volume}}{\text{उस घंटे का volume}}$
Daily "	⇒ $\frac{\text{7 day trafficvolume (ADT)}}{\text{उस दिन का Traffic volume}}$
monthly "	⇒ $\frac{\text{365day Trafficvolume (AADT)}}{\text{ADT for particular month.}}$

Spot speed by → enoscope, pressure contact tube, loop deflector, radar Doplar

(i) Time mean speed (time fix) → A.M $= \frac{V_1+V_2+V_3}{3} = V_t$

(ii) Space mean speed (space fix) → H.M $= \frac{3}{\frac{1}{V_1}+\frac{1}{V_2}+\frac{1}{V_3}} = V_s$

$V_t > V_s$

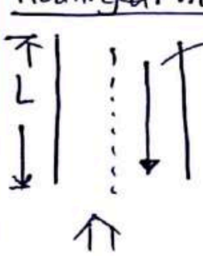
Arithmetic mean (AM) & Harmonic mean (HM)

- Modal speed → at which Greatest proportions of vehicle moves.
- 85th percentile speed → upper safe limit
- 15th " → lower "
- 98th " → Highway Geometric design

Speed & Delay study :-

1- Floating car method / riding check method (for 2 lane traffic, 4 observer needed)
2- license plate method
3- Interview method
4- Photography "
5- Elevated observation "

Floating car method :- (for 2 lane, 4 observer needed)



n_a → जब इस दिशा में move करें तो left hand side में कितना traffic

n_y → overtaking − overtaken

$$\boxed{q = \frac{n_a + n_y}{t_a + t_w}}$$

$$\boxed{\text{average journey time } (\bar{t}) = t_w - \frac{n_y}{q}}$$

$$\boxed{\text{average journey speed} = L/\bar{t}}$$

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

running speed = L / running speed

Peak hour factor (PHF) :-

for 15 min $= \frac{V_{60}}{4 \times V_{15}}$ $\left[0.25 - 1\right]$ ($\frac{1}{4}$)

for 5 min $= \frac{V_{60}}{12 \times V_5}$ $\left[\frac{1}{12} - 1\right]$

note :- Imp

- spot study → regulatory measure (40)
- Space mean speed study (VS) → traffic flow study
- Journey speed → delay speed
- Running speed → road condition

Origin & destination (O&D) study :-

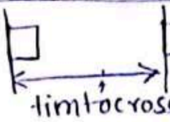
1- Road side Interview	disadvantage → vehicle has to stop for interview
2- license plate	use when area → small
3- Return post card method	when traffic heavy, few will return postcard
4- Tag on car method	when Traffic heavy and moves continuously.
5- Home Interview	sample size to be more to get accurate result (0.5−10%)
6- work spot Interview	Ex. factory.

Presentation of O&D data :-

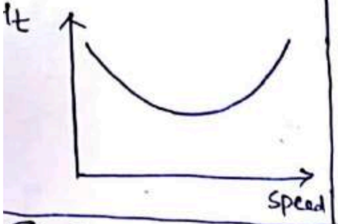
1- O & D Table	no. of trips between different zones.
2- Desire line	width ∝ Trips in both direction
3- Pie chart	• circle draw. diameter ∝ no. of trips
4- Contour line	• Shape of contour would indicate General traffic-need of data.

Headways :-

① Time headways (H_t)

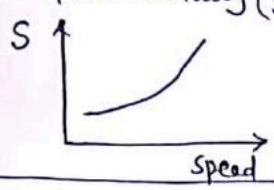


time to cross this distance



$$\boxed{\text{Traffic volume } (q) \ (veh/hr) = \frac{1}{H_t\left(\frac{hr}{veh}\right)}}$$ *

② Space headway (S)



density per lane (k)

$$= \frac{1}{\text{avg. space Headway } (S)}$$

Poison Distribution :- Prob. of having 'n' vehicle arriving in 't' time

$\lambda \to$ Avg. veh/sec

$$\boxed{P = \frac{e^{-\lambda t} (\lambda t)^n}{n!}}$$

→ Special case :- Prob. of zero vehicle (n=0) in 't' time.

$$\boxed{P(0) = P(h \geq t) = e^{-\lambda t}}$$

or Prob. of time headway ($h \geq t$)

→ (−)ve exponential distribution

मतलब कोई vehicle नहीं आया

note:-

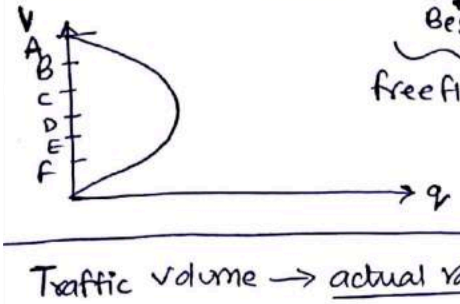
no. of time headway = Prob. of time headway × observed vehicle.

Traffic capacity :- max. rate of flow on road with certain level of service characteristic.

$\boxed{\text{6 category of service from A to F}}$ *

A → Best — free flow

F → worst / forced / Breakdown flow



Traffic volume → actual rate of flow

Theoretical / Basic capacity → (Ideal)

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

H_t → sec.

S → (min space gap + Length of vehicle)

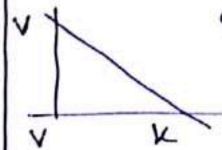
0 ≤ possible capacity ≤ Basic or Theoretical capacity

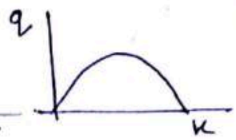
Green shield model :-

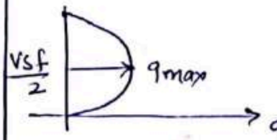
$$\boxed{V_s = V_{sf}\left(1 - \frac{k}{k_j}\right)}$$

V_s → space mean speed

V_{sf} → free mean speed — affect by Geometry & surface condition of road.



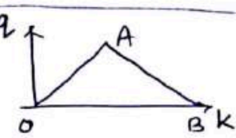




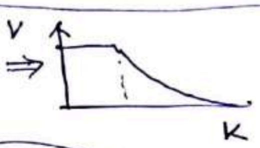
$$\boxed{q = k\,V}$$

q → volume, k → density, V → speed

Special if



⇒



in OA :- $q = kV$ → (V = constant)

($y = mx$) type

in AB

$y = -mx + c$

$q = -mk + c$

$kV = -mk + c$

$\boxed{V = -m + c/k}$ → hyperbolic

PCU :- ⇒ $\dfrac{\text{capacity of roadway when only passenger car}}{\text{type of vehicle}}$

factor's affecting PCU :- (I) vehicle speed (II) Length and width of vehicle (III) Transverse & longitudinal gap allowed b/w vehicle of small class in the speed range consideration.

	PCU
Pedal cycle / motor cycle / scooter (2 wheeler)	= 0.5
Passenger car / Autorickshaw / Tempo / tractor	= 1
cycle rishaw	= 1.5
Bus / Truck / Tractor + trailor	= 3
Horse drawn vehicle	= 4
Small bullock cart	= 6
large "	= 8

Parallel parking :-

(i) equal spacing $\boxed{N = \frac{L}{6.6}}$

□□□□

(ii) 2cars placed close $\boxed{N = \frac{L}{6.75}}$

□□ □□ □□

Angleparking :-

30° (सबसे कम गाड़ी)	$\frac{L-0.85}{5.1}$ → सबसे ज्यादा
45°	$\frac{L-2}{3.6}$
60°	$\frac{L-2}{2.9}$
90° (सबसे अधिक गाड़ी)	$\frac{L}{2.5}$ → सबसे कम

N ⇒ no. of spaces

L ⇒ kerb length.

Accident Records :-

(1) Location files	• useful in Identification of points of High accidents
(2) Spot maps	Show accidents by spot, pin, symbols
(3) Condition diagram	Show all imp. physical condition of an accident
(4) collision diagram	Show approximate path of vehicle/ Pedestrian involves accidents

Perfectly elastic collition $(e=1)$ $= \frac{\text{Velocity of separation}}{\text{vel. of approach}}$

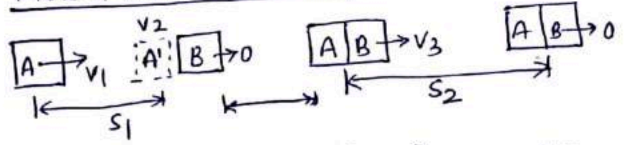
⇓

(दोनों आपस में velocity exchange कर लेते हैं) $V_B' - V_A' = V_A - V_B$

Perfectly plastic collision $(e=0)$

↳ दोनों चिपक जाते हैं $(V_B' = V_A')$

Parked vehicle accident :-



Just before collision $v_2^2 = v_1^2 + 2(-gf)s_1$

$v_1^2 = v_2^2 + 2gfs_1$

at collision $m_A v_2 + m_B \times 0 = (m_A + m_B) V_3$

after collision $0 = v_3^2 + 2(-gf)s_3$

$\boxed{V_3 = \sqrt{2gfs_3}}$

Total conflict = vehicular conflict + Pedistrial conflict

Pedistrial conflict: 2-2 ⇒ 8

Vehicular conflict → major conflict, minor conflict

minor conflict → diverging conflict, merging conflict

road type	vehicular conflict	major + minor
2-2	24	16 + 8
2-1	11	7 + 4
1-1	6	4 + 2

To Reduce controll ⟶ "Intersection" controll

(i) passive controll	• when Traffic volume Less • road user has to follow role Ex. sign, marking, ▽ Giveway
(ii) active controll	• forced to follow path suggested by traffic controll agency. Ex. signal, Grade separated Intersection
(iii) semi controll	Ex. rotary, chanelisation • driver gently guided to avoid conflict

Intersection

→ At grade Intersection (Ex. Rotary)

→ Grade separated Intersection (Ex. Interchange)

At grade Intersection:

Imp

- road meets about same Level
- allowing traffic manoever like diverging, merging, crossing, weaving

Ex. Traffic Island → Divisional Island, channelising ", Pedestrian loading, rotary

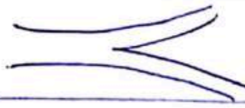
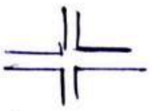
Grade separated Intersection:

- Permits cross flow of traffic at level without intruption.

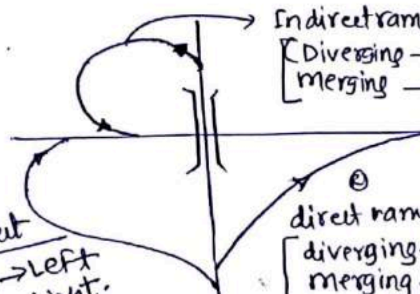
Ex (i) crossing 2 Highways

(ii) 1 highway + Local road

Interchange (grade separated Intersection) :-

Trumpet Interchange	• 3 Legs	
② Diamond Interchange	• 4 legs  • Req. min. land • suit most cases • involve only small extra travel dist for right turning Traffic	
③ Clover-leaf Interchange		• cross 2 major roads of equal Importance in rural area.
④ Rotary Interchange	where sufficient land available	
⑤ Directional Interchange		

Ramp :-



Rotary :-(at grade Intersection) :-

① when 500 – 3000 PCU/hr
(ii) right turning traffic > 30%.
(iii) > 4 legs

operation in rotary → diverging, merging, weaving (merging + diverging) Traffic

① Speed $V = 40$ kmph (rural)
$V = 30$ kmph (Urban)

② $R_{entry} < R_{central\ Island} < R_{exit}$

$R_{central\ Island}$ ⇓ $\boxed{1.33 * R_{entry}}$

R_{exit} ⇓ $\boxed{(1.5-2) * R_{entry}}$

R_{entry}: rural $V=40$, $R = 20-35$; urban $V=30$, $R = 15-25$

radius of rotary (no superelevation)

$$\boxed{R = \frac{v^2}{125 f}}$$

③ weaving Length $\boxed{L = 4W}$ → width of weaving section

V=40	Lmin = 45 m
V=30	Lmin = 30 m

④ width of weaving section $\boxed{W = \left(\frac{e_1 + e_2}{2}\right) + 3.5}$

e_1 → entry width e_2 → exit width

⑤ width of carriageway at entry & exit $\boxed{\text{min} = 5m}$

⑥ exit angle < entry Angle
$\theta = 30°$ $\theta = 60°$ (Ideal)

⑦ $$\boxed{Q_{PCU/hr} = \frac{280W\left(1 + \frac{e}{W}\right)\left(1 - \frac{P}{3}\right)}{1 + \frac{W}{L}}}$$

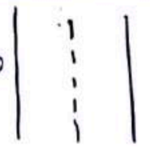
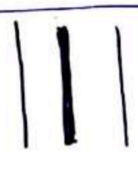
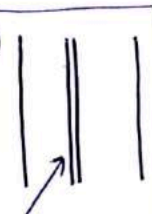
W ⇒ 6 to 18
$\frac{e}{W} = 0.40 - 1$
$P = 0.40 - 1$
$\frac{W}{L} = 0.12 - 0.40$

⑧ P = weaving ratio = $\frac{\text{Crossing traffic}}{\text{total Traffic}} = \frac{b+c}{a+b+c+d}$

Traffic controll Device

Imp: sign, signals, markings

Road markings :-

① 	• Broken Longitudinal lines • may cross
② 	• solid Longitudinal lines • not to cross (except entry, exit, side road or to avoid stationary object)
③  yellow	• Double solid line • Indicate max. Restrictions. Only in emergency we can cross.

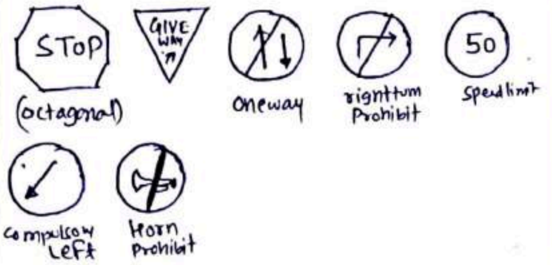
Traffic signs :-

① mandatory or Regulatory sign

- These inform the road users of Laws & regulations.
- must follow (violation is legal offense)
- all circular in shape (except stop & Giveway)

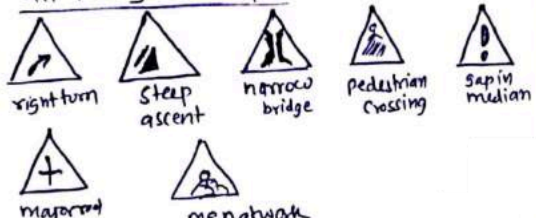
noti :- $\boxed{\text{Border Red O, white Background}}$

Exception – STOP :- red Background



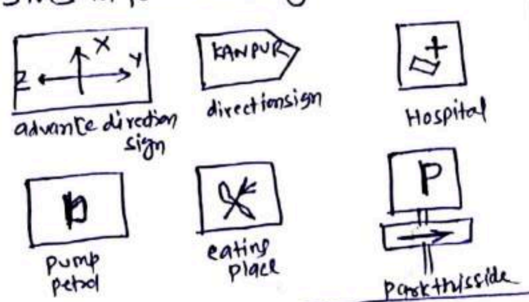
② Cautionary, warning signs

- warn road users of existing of certain Hazards.
- all Triangular shape



③ Informatory signs

- all rectangular
- gives information & guidance to road users

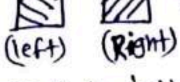


Road delineator :- In night, to provide visual assistance about road Alignment.

↳ Reflectors are used on delinators for better night visibility.

① Roadway Indicator :- tell about edge of road

② Hazard Marker (Black & yellow)



③ object marker :- Used to indicate hazard and obstruction within the flowpath.

Ex. channelising island close to intersection.

Traffic signal :-

(I) simultaneous system (II) Alternate system
③ simple progressive system
④ flexible progressive system → (Best)

signal design method :- ① Approximate method
(II) Trial cycle method (V15)
(III) IRC method
(IV) Webster method :- (most Rational method)

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

$Y \to (Y_1 + Y_2 \cdots)$

$L \Rightarrow$ total lost time in all phase

$$\boxed{L = \underbrace{n}_{\text{no. of phases}} \times \underbrace{t_L}_{\text{avg. signal cycle lost time} = 2\,sec} + \underbrace{R}_{\text{all red time}}}$$

$(\therefore L = 2n + R)$

effective green time

$$\boxed{G_1 = (C_o - L)\frac{Y_1}{Y}} \quad \boxed{G_2 = (C_o - L)\frac{Y_2}{Y}}$$

noti :- $P = 60t$ $Q = 60t^2$ → dist in 2hrs.
Find within 1 hr. max space headway.
$S = 60t - 60t^2$ $\frac{ds}{dt} = 0$ $t = 0.5$
$\therefore S_{max} = 15$ km/hr.

flixible pavement :- (IRC: 37)

surfacecourse → Highest Quality matirial
Basecourse
Subbase
Subgrade

flexible pavement drive stability →
(I) Graintograin contact
(II) Aggregate interlock
(III) particle friction & cohesion

- Transfer of load from top tobottom layer by grain to grain contact
- load carrying capacity from load distribution Property (not from its bending / flexural strength)
- Reflects the deformation of lower layer
(मतलब if subgrade undulated → surface pavement is also undulated)

major flexible pavement surface failure :-
1- fatigue cracking (II) Rutting (III) Thermal Cracking
in IRC 37: 2018 only these 2 criteria considered.

function of flexible pavement layers :-

1- subgrade → layer of top natural soil Prepared to recieve stress from layer aboveit.

2- Base course & subbase (broken stone Agg)
- flexible
  - load distribution property
  - subsurface drainage
- Rigid
  - prevent pumping
  - protect subgrade against frostaction.

3- wearing / surface course :- directly contact with Trafficload, superior in Quality.
fn → to provide friction, smoothness, drainge offer water tightness.

note:-
Imp (I) stability of wearing course → marshall Stability Test
(II) Evaluation → Benkle beam Test, Plate Test

Rigid pavement :- load transfer throgh layer to layer from top to bottom
- load carrying capacity by slab itself through Bending action.
- analysis using elastic theory.
{ assume pavement as an elastic plate resting over an elastic foundation }

major Rigid pavement failure
1- fatigue cracking → In India only Parameter todesign.
2- Mud pumping → settlement due to heavy load

Rigidity factor(RF) = contact pressure / type pressure
contact pressure → wheelload / area of imprint

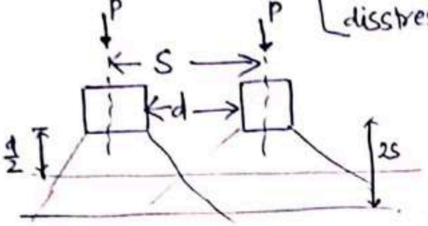
RF = 1   TP = 0.7 MPa
RF < 1   TP > 0.7
RF > 1   TP < 0.7

note:- type under compression CP > TP
Tension CP < TP

Trafficload consideration in design
- fixed Traffic approach (used in airport design)
  - Heaviest vehicle consider
  - no of repetition not consider
  - multiple wheel load converted into ESWL
  - one single load movement is sufficient to cause damage to pavement.
- fixed vehicle approach (in Highway design)
  - design govern by no. of repetition of standard axle.
  - standard axle load 8160kg or 8200kg or 80kN or 8.2ton
  - convert into eq. no. of std. axle by using EALF (eq. axle load factor)

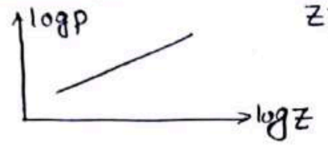
ESWL (eq. single wheel load) → use in fix traffic approach design (airport)

- consider equivalency in terms of
  - stress (in syllabus)
  - strain
  - Deflection
  - disstress



$Z \le \frac{d}{2}$	ESWL = P
$Z \ge 2S$	ESWL = 2P

otherwise



EALF (eq. Axle load factor) → used in Higway design.

$$\boxed{EALF = \left(\frac{\text{axle load}}{\text{std. axle load}}\right)^4} \rightarrow \text{"forth power Law"}$$

$$\boxed{\text{vehicle damage factor (VDF)} = \frac{\text{eq. no. of std. axle}}{\text{no. of vehicle}}}$$

axle	either side wheel	EALF
single	single	$\left(\frac{\text{axleload}}{65}\right)^4$
	double	$\left(\frac{\text{axleload}}{80}\right)^4$
Tandem	double	$(\text{axleload}/148)^4$
Tridem	double	$(\text{axleload}/224)^4$

sample size for axle load survey	
vehicles	sample size
<3000	20 % } of CVPd
3000–6000	15 %
>6000	10 %

method of flexible pavement design :-

1- empirical (based on physical property and strength of soil subgrade) [GI, CBR, CR (stabilometer), Mclead]

2- Semiempirical / semi Theortical :- (Triaxial Test) (Based on stress-strain function)

3- Theortical method :- (Based on mathematical computation)

- Burminstir method → Based on 2 elastic Theory.

GI method :-

GI	
0–1	Good
2–4	fair
5–9	Poor
10–20	very poor

surface course, Base course Thickness → fn(GI, traffic)

Subbase Thickness → fn(GI) → total − Basecourse thickness − surface course Thickness.

$$\boxed{GI = 0.2a + \left(\frac{0.2}{40}\right)ac + \left(\frac{0.2}{20}\right)bd}$$

p → % finer (75μ)

$a = P - 35$ } ≯ 40
$b = P - 15$

$c = w_L - 40$ } ≯ 20
$d = I_p - 10$

limitation :- does not consider Quality of material used in pavement.

CBR method :- Based on strength parameter of subgrade soil & subsequent pavement material.

$$\boxed{T_{cm} = \sqrt{\frac{1.75P}{CBR\%} - \frac{A}{\pi}}} \rightarrow \boxed{CBR < 12\%} \quad \boxed{A = \pi a^2}$$

IRC : (i) CBR Test on remoulded soil (Insitu Test not suggested for design)

(ii) soil compacted to OMC to get proctor density.

(iii) Test sample soaked for 4 days before Testing (in dry zone (< 50cm rain) → not soaked)

(iv) min 3 Test sample at same moisture content, same Proctor density.

(v) if variation > permissible limit then take 6 samples.

CBR	Permissible variation
0–10	3 %
10–30	5 %
30–60	10 %

(vi) top 50cm of subgrade compacted atleast upto 95–100 % of Proctor density

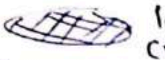
(vii) no. of heavy vehicle for design $\boxed{A = P(1+r)^{n+10}}$ P → Present 7 day Avg; n → no of year of last count & completion of construction.

(viii) design thickness applicable for single axle load (80kN), tandem axle load (148kN). For Higher axle load, increase thickness further.

(ix) when subbase has more no. of aggregates > 20mm CBR value of material will not valid for design of subsequent layer above them.

IRC method of design (IRC-37)

fatigue cracking

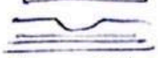


looks like Crocodile

Imp ⇓

Tensile strain at bottom of Base course layer

Rutting



Permanent deformation

Imp ⇓

vertical comp. strain at top of subgrade

Imp

upto 30msa	20% of area	20mm in 20% of length
>30msA	10% of area	10 mm in 10% ———

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

ϵ_t → tensile strain

N_f → no. of cumulative standard axle to produce 20% cracked surface area.

$$N_r = 4.1656 \times 10^{-8} \times \frac{1}{(\epsilon_v)^{4.5337}}$$

ϵ_v → vertical comp. strain

N_r → no. of cumulative std. axle to produce rutt depth of 20 mm

$$msA = \frac{365[(1+r)^n - 1]\ DAF}{r}$$

r = 5% as per IRC

$A = P(1+r)^x$ → last count to completion

design life NH/SH ⇒ 15 year Expressway = 20 yr.

VDF = eq. no. of std. axle/commercial vehicle

Single lane road ⇒ 1
2 lane single carriageway = 0.75

} based on total no of vehicle in both direction

California-resistance value Test :-

Stabilometer R value
cohesionmeter C value

$$T_{cm} = \frac{K(TI)(90-R)}{C^{1/5}}$$

K → 0.166

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

Triaxial method :-

$$T_{cm} = \sqrt{\left(\frac{3PXY}{2\pi E_s \Delta}\right)^2 - a^2}\ \left[\frac{E_s}{E_P}\right]^{1/3}$$

E_s → Subgrade, E_P → Pavement

X → traffic coefficient (ADT पर आधारित)

Y → rain " (Based on Avg. annual rainfall)

Δ = 0.25 cm (design deflection)

Mc-Leod Test :- from plate load Test

$$T = K \log P/S$$

P → wheel load kg
S → total subgrade support kg
T → req. thickness of gravel Base
K → Base course constant depend on loaded area

Burmister method :- (layered system)

flexible :- $\Delta = 1.5\, pa/E_s$

rigid $\Delta = 1.18\, pa/E_s$

note:- $\frac{1.5}{1.18} = 1.27$ & $\frac{1.18}{1.50} = 0.78$

$K = P/\Delta = \dfrac{P}{0.125\,cm}$ Plate load Test | modulus of subgrade reaction (K)

$\Delta = 1.18\,pa/E_S \longrightarrow$ rigid

Imp.

$K_1 a_1 = K_2 a_2$ | IRC:- $\boxed{K_{75} = 0.50\,K_{30}}$

radius of relative stiffness :- by westergard

$$l_{cm} = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{0.25} \qquad \mu = 0.15$$

Radius of resisting section

(i) $a < 1.724h \quad b = \sqrt{1.6a^2 + h^2} - 0.675h$

(ii) $a > 1.724h \quad b = a$

wheel load stress by Westergard :-

interior $\dfrac{0.316P}{h^2}\left[4\log(l/b) + 1.069\right]$

edge $\dfrac{0.572P}{h^2}\left[4\log(l/b) + 0.359\right]$

corner $\dfrac{3P}{h^2}\left[1 - \left(\dfrac{a\sqrt{2}}{l}\right)^{0.6}\right]$

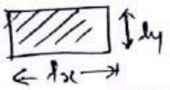
warping stress / Temp. stress :- due to daily variation in Temperature
~~Hdd~~ Temp. gradient across slab thickness

interior $\dfrac{E\alpha T}{2}\left[\dfrac{C_x + \mu C_y}{1 - \mu^2}\right]$

edge $\max\left[\dfrac{E\alpha T}{2}C_x, \dfrac{E\alpha T}{2}C_y\right]$

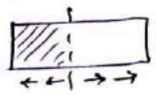
corner $\dfrac{E\alpha T}{3(1-\mu)}\sqrt{a/l}$

$\underbrace{C_x, C_y}_{\text{Bradbury warping coefficient}} \longrightarrow f^n(l_x, l_y)$

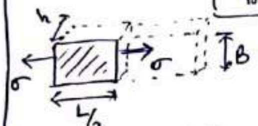


frictional stress :- due to seasonal variation
- due to change in overall temperature of slab

in winter $\longrightarrow$ Tensile stress (T)
in summer $\longrightarrow$ comp. stress (C)



in winter slab try to contract from both side ∴ half distance consider in Analysis / calculations



$\sigma(B \times h) = f\left[\gamma(B \times \tfrac{L}{2} \times h)\right]$

$$\therefore \sigma = \frac{f L w}{2} = \frac{f L \gamma}{2}$$

actual variation (zero at corners)

assumed variation

(1) wheel load stress :- $S_c > S_e > S_i$
corner stress max ∵ discontinuity in both direction

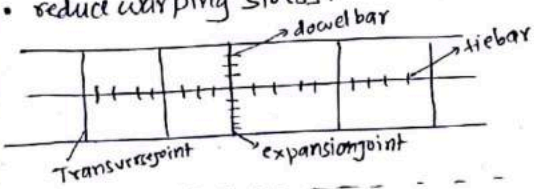
(2) warping / Temp. stress min $\rightarrow$ corner (∵ weight is min) (resistance min)
max $\rightarrow$ interior, edge

note:- combination of wheel load stress & Temp. stress $\Rightarrow$ edge more critical hence design based on edge region however checking at corner

	wheel load stress	daily warping stress	seasonal frictional stress
interior	C / T (bottom)	day T (bottom)	Winter (tension)
edge	C / T (bottom)	day T (bottom)	winter (tension)
corner	T (top) / C	T (top) night	zero (winter tension)

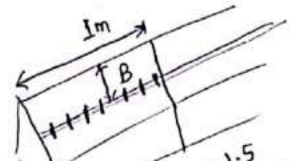
Joint :- in concrete construction joints are - discontinuity which are introduced in concrete construction for various purpose.

① construction Joint ↓ The surface where 2 successive placement of concrete meet	• whenever construction work stops - temporarily these are provided. • could be either along the longitudinal or transverse direction. • Should be located where SF & BM → low, where member is supported by other member and 18 m apart in huge structure. • should not be provided at corner of wall or corner of pavement. • where High shear resistance is required at the construction joint, shear key may be provided. • Preferably at a location where stresses are zero. • These are vertical joints cut into wall that allows the concrete to shrink without noticeable harm. • construction joint reduce the thermal & shrinkage cracks & hence they should be planned accurately for their location in the structure.
② Expansion Joint $\frac{\delta}{2} = L\alpha\Delta T$ δ → max. compression allowed.	• in transverse direction to allow movement of slab due to temp. & subgrade moisture variation. imp. • max. spacing b/w Expansion joint = 140 m • IRC Joint Thickness = 2.5cm. • dowel bars are placed in it (parallel to traffic direction) • dowel bars → develop bending, bearing, shear stress & helps in Load Transfer. • IRC η of load transfer = 40%. (dowel) distance at which SF becomes zero from max. loaded dowel = 1.0 l • dowels 25-40 mm dia / ~~400~~ 500-mm length • IS456 :- if length of concrete str. > 45 m Expansion joint provided.
③ contraction Joint	• in transverse direction • to take care of contraction of slab due to shrinkage of concrete. 'or' To regulate crack, to ensure that crack due to shrinkage & moisture formed at predetermined location. note :- where reinforcement is not provided, The max. spacing b/w contraction joint = 4.5m • without reinforcements $\frac{L}{2}$ → S $\boxed{S = \frac{fLw}{2}}$ $w = \gamma = 2400 \text{kg/m}^3$ $f = 1.5$ S → permissible tensile stress in concrete $(0.8 \frac{kg}{cm^2})$ • reinforcement :- $\sigma_{st} \cdot A_{st} = f[w B \times \frac{L}{2} \times h]$ σst → permissible Tensile stress in concrete 1400 kg/m2
④ longitudinal Joints	• in longitudinal direction • if slab width more then provide • reduce warping stress.



Tiebars :- not to withstand load
• ensure 2 slabs remains firmly together
• size 1cm bar

note :- load Transfer to adjacent slab - due to aggregate interlock (not tiebar).



$$\underbrace{A_{st}\,\sigma_{st}}_{\text{tiebar},\ 1400\frac{kg}{m^2}} = \overset{1.5}{f}\,[\overset{2400 kg/m^3}{\gamma_c} \times 1 \times B \times h]$$

imp.

$$\boxed{\text{length of Tiebar} = 2 \times \underbrace{\text{development length}}_{\frac{\phi\sigma_{st}}{4\tau_{bd}}} + \text{gap}}$$

flexible pavement failure

- **Surface defect**
  - streaking
- **Cracks**
  - Alligator cracks
  - Reflection cracking
  - edge cracking
- **Deformation**
  - corrugation
  - rutting
- **Disintegration**
  - potholes
  - stripping
  - ravelling
  - loss of agg.

Alligator or map cracking or crazing	• Interconnected cracks • due to overheating of Bitumen • mainly due to fatigue and Localised weakness in underlying weakness
Reflection cracking	• due to Joint & cracks in pavement layer underneath • when Bitumen layer over cracked cement concrete or Bitumen pavement. Treatment → cutback/emulsion Used
edge cracking	• frayed edge • edge broken • wornout shoulders
Corrugation	(लहर) → cross → across ~~~ • regular undulation/ripple across bitumen surface
Rutting Groove in wheel	• longitudinal depression due to heavy channelised traffic • rut are usually width of wheel path Resons → improper compaction of layers, lacking in stability of mix to support the traffic and leading to Plastic movement laterally under traffic
Potholes (surface + Base course)	• Bowl shape extend till Base course • due to localised disintegration of material • due to ingress of water through surface course.
stripping	• loss of Bond • loss of strength & material from surface • separation of Bitumen adhering to surface of aggregates particle in presence of moisture.

Ravelling ↓ Surface course.	• Removal of larger surface aggregate leaving craters • Progressive disintegration of surface due to failure of Binder to hold the material together
Loss of aggregate	• due to insufficient Binder used • occures in surface with surface dressing
Bird bath ↓ subgrade failure	• deformation which may be caused by localised or variable Subgrade failure

Disstress	meaning
Settlement	General Lowering of road surface
Subsidence	due to poor drainage, a localised rather abrupt lowering of road surface
Depression	dish type localised Deformation
distortion	irregular Deformation of Road

Road drainage system	Location
Vertical sand drain	High embankment in soft soil
Causeway and culvert	Cross-drainage in road Alignment
scupper and Catchwater basin	Hill roads
Inlet gratings	urban road drainage

note:- in rutting & depression → patching work

Rigid pavement failure :-

(I) Scaling of concrete	• deteriorates the concrete. Reason (1) deficiency in mix (2) Presence of some chemical - impurity which damage mix. (3) Excessive vibration.
(II) shrinkage cracks	• normally develop during curing (Just after construction) • can be in any direction.
(III) spalling of Joint	• Joint का खराब होना • due to faulty alignment of filler - material • doesnot extend vertically through slab but intersect at any Angle
(IV) warping crack	• if Joint are not properly designed it prevent expansion of slab leads to development of excessive - stress, This stress cause - formation of warping crack near edge Joint. note :- ∴ Hinge Joint provide in slab to avoid warping cracks
Imp (V) mud Pumping	• pumping noticed after rain in clay - subgrade factors → (I) Extent of slab deflection (II) Type of subgrade soil (III) Amount of free water

Pavement evaluation

- Structural evaluation
  - (I) Plate bearing Test
  - (II) Benkle beam method
- Pavement - surface condition evaluation
  - (I) Bump Indicator (unevenness Index)
  - (II) Roughometer (Profilometer)

overlay thickness
- By CBR method
- By Benkle beam Deflection method

Imp [flexible over flexible pavement]

Benkle beam method :- (flexible over flexible overlay)

• Large rebound Deflection → weak pavement
∴ need more overlay Thickness

$$\boxed{D_c = \bar{D} + K\bar{\sigma}} \qquad \bar{D} = \frac{\Sigma D_i}{n} \qquad \bar{\sigma} = \sqrt{\frac{\Sigma(\bar{D} - D_i)^2}{n-1}}$$

IRC ($K = 1$)

• characteristic deflection after temp. correction
$\Rightarrow \boxed{D_c - 0.0065(T - 35)}$ $T°C$

• Deflection noted in rainy season if not, then in dry season
clay ⇒ Ans × 2
sand ⇒ Ans × (1.2 - 1.3)

• overlay Thickness :- equivalent to granular - material of WBM Layer

$$\boxed{h_{mm} = 550 \log \frac{D_c}{D_a}} \qquad \boxed{A = P(1+r)^{n+10}}$$

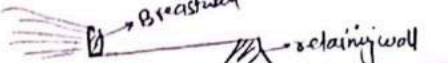
A	Da mm
150-450	1.5
450-1500	1.25
1500-4500	1

note :-
Bitumen concrete / Bitumen macadam with Bitumen surface course
then equivalency factor = 2

Types of coats used in flexiblepavement :-

Prime-coat	• first Application of Low-Viscosity liquid Bituminous-material over an existing Porus or absorbent pavement surface like the WBM base course. • objective of Priming :- toplug in the capillary voids of Porous surface and to bond the lase mineral particles on the existing surface, using the low viscosity binder, which can-penetrate into voids. • Promotes bond (adhesion) b/w base and wearing course. • to plug capillary voids in Base-course and upward movement of water restricted.
Tack coat	• spray of Bituminous material over an existing surface which is relatively impervious like an existing bituminous-surface or a cement concrete pavement Ex. for laying Bitumen carpet over water bound macadam surface. note:- Traffic closed, otherwise dust, dirt on surface over tack coat surface.
Seal coat	(i) to seal the surfacing against the ingress of water. (ii) To develop skid resistance texture. (iii) To enliven an existing dry or weathered bituminous surface. (iv) Slow oxidation & prevent damage from sun's harmfull rays.

Structure in hill roads :-



(1) Breast wall	• construct to buttress (सहारादेना) the uphill slope to road c/s • should be strong enough to withstand earthpressure of soil behind along surcharge caused by slope.
(2) Retaining wall	need to retain the fill portion of Highway c/s
(3) check walls	• small retaining str • constructed in series on sloping hillface to check slides and to provide overall stability of hill face.
(4) Grabian wall	• Breastwall / Retainingwall / checkwall constructed with dry stone masonary encashed in wire mesh. • used as toe protection wall where road runs parallel to stream. •
(5) Parapet wall	• needed to give protection, Psychology, Physically to motorist while-travelling on roads with steep valley-Slope.

$$\boxed{\text{Apparent specific gravity} = \frac{A}{A-C}}$$

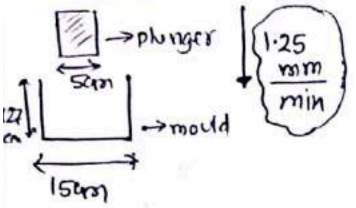
$$\boxed{\text{Bulk specific gravity} = \frac{A}{B-C}}$$

A → mass of oven dry agg. in air
B → ——— saturated ———
C → ——— in water

viscosity @60°C ← VG 30 → 3030 indicates range of viscosity of Bitumen

max viscosity (100+20)·30 poise
min viscosity (100−20)·30 poise

CBR Test :-

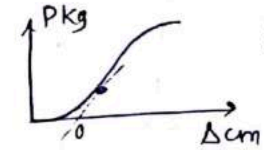


Imp
MOST specification subgrade
20% < 2msa   30% > 2msa

• min 3 specimen, soak for 4 days before testing.

• Penetration	Std. load P	Std. stress ($P/\frac{\pi}{4}\times5^2$)
2.5mm	1370 kg	70 kg/cm²
5 mm	2055	105 kg/cm²

$CBR_{2.5} > CBR_5$ { if not then repeat; if again then $CBR = CBR_5$ }



if intial portion → concave draw tangent → cut at x will be taken as 0.

• variation > permissible then take 6 sample

CBR%	Permissible
0-10	3%
10-30	5%
30-60	10%

Plate bearing Test :- to get supporting power of subgrade represented by K (kg/cm³)

$$\boxed{k = P/0.125\,cm}$$

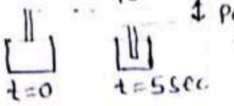
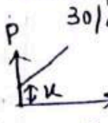
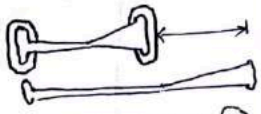
• To minimize series of stacked plate put.
• load settlement reading noted till Δ=0.175cm
• एकबार में 0.25 mm का settlement increament के हिसाबसे load निकाले जाये

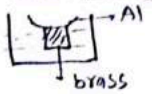
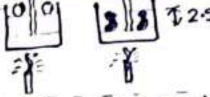
correction:
- moisture/soaking: $k \propto P$, $\frac{k_1}{P_1} = \frac{k_2}{P_2}$
- dia of plate: $\boxed{k_1 a_1 = k_2 a_2}$

Aggregate Tests :-

(i) Crushing Test	Strength	• 12.5⊖ – 10⊕ mm / 3 layer / 25 blow / 2.36⊖ mm $\frac{W_2}{W_1}\times100$ crushing value surface course ≯30%, Base course ≯45%
(ii) Abrasion Test * Loss Angeles Abrasion Test * Devels – * Dorry –	Hardness	• Best Test for aggregate • impact + Abrasion (b/w ball & agg.) + Attrition (b/w Agg) • 12.5⊖ – 10⊕ mm / 1.76mm • steel ball dia = 4.8cm • steel ball numbers depends on grading (Ex. grade A agg. 12 no. of balls) • total rotation 500–1000 • rpm 30–33 (depends on grading) Abrasion value surface course ≯30% • coff. of hardness = $\left[20 - \frac{\text{loss in wt}}{3}\right]$
(iii) Impact Test	Toughness	• 12.5⊖ 10⊕ / 2.36⊖ / 14kg – 38cm hammer • 3 layer – 25 blows But by hammer 15 blows per layer at not less than 1 second. • wearing course ≯30% Bituminous macadam ≯40%
(iv) Soundness Test	durability or weathering resistance	• conduct accelerated weathering test cycles. • Na_2SO_4/$MgSO_4$ (16–18hr) → oven 105–110°C • after 5 cycle wt. measure • loss in wt ≯12% (Na_2SO_4), ≯18% ($MgSO_4$)
(v) Shape Test	Shape factor	• Flakiness Index (≯15%) Least dimension < 0.6 mean size आवश्यक हुआ Agg. पर Elongation Index (≯15%) करें Greatest dimension > 1.8 mean size • Angularity no. (0 to 11) ⇒ 67 – % solid volume ↳ measure voids in Excess of 33% $AN = 67 - \frac{100W}{CG_a}$ (W → wt of Agg in cylinder; C → water capacity (kg) / wt of water in same cylinder)
(vi) Specific Gravity	2.6–2.9	G↑ good Quality
(vii) water absorption Test	Porosity	≯0.6% of wt of Aggregates
(viii) Bitumen adhesion Test (Static Immersion Test)	adhesion	• agg with Bitumen ⇒ water में 40°C पर 24hr डुबाये रखें • IRC Strip value of agg. ≯5% (generally 2–2.5)% note:- Stripping problem when – Bitumen mixture is permeable to water.

Bitumen Test :

(1) Penetration Test (25°c)	Hardness or softness of Bitumen	• only for Bitumen • not for tar (∵ too soft) • unit = $\frac{1}{10}$ mm  t=0 t=5sec ↕ Penetration 6-7 mm मतलब 60-70 grade • Penetration ∝ $\frac{1}{\text{softening point}}$ • Hot climate → Hard Bitumen used मतलब more viscous ∴ Less penetration 30/40 used. • $P = AT + K$ (P ↓ Penetration, T → temp.)  $A = 0.0015 - 0.0016$
(2) Viscosity Test (25°C)	viscosity (measure resistance of flow)	$\boxed{\text{viscosity} \propto \text{time}}$  v type orifice 3-10mm; time noted to fill (50-200cc) (1st) furol viscosity (for Liq. Bituminous material) (2nd) orific viscosity for tar & cut back Bitumen viscosity Less note: (i) efflux viscometer → Liq. Bituminous material (ii) method used as → Std. Tar viscometer → saybolt furol → Red bord → englir
(3) Ductility Test (27°c) $\boxed{\text{BIS} \rightarrow 75cm \text{ min}}$	adhesiveness or elasticity of Bitumen	• distance (cm) that briquette can be stretched before breaking → ductility • Briquette size (1×1) cm²  • pull rate = 1.25×40 = 50 mm/min = cm/min (5)
(4) Specific gravity Test (27°c) or Pyconometer Test	By Pyconometer	Bitumen ⇒ 0.97 – 1.02 Tar ⇒ 1.10 note :- cut back G↓ depend on type and proportion of diluent used.

(5) float Test (50°c)	Consistency	• Generally for consistency Penetration, viscosity Test used • But for certain consistency these Test not applicable hence use float Test. • modified viscosity Test used with Small qnt of very viscous Bitumen material  Al, brass $\boxed{\text{Float value} \propto \text{stiffness} \propto \text{time}}$ FTV • at which water force its way through Bitumen Plug ——→ Float value
(6) Ring & Ball Test	(dia = 0.95cm) steel ball softening point	 thermometer ↕ 2.54 cm at which Bitumen attains particular degree of softness under std. Test condition. 'or' Temp. at which Bitumen passes from solid to Liq. consistency note:- 1- paving grade 80/100 SP = 35-50°c 2- for no Bleeding SP = max. atm. temp + (5-10)°c 3- High SP → less Temp. susceptibility ∴ Prefer in warm climate
(7) Flash & Fire Test	By Pensky marten close cup & open cup	• min flash point of Bitumen = 175°c [safe limit to heat Bitumen ⇒ 50° less from flash point] Flash point ⇒ lowest temp °c at which Application of test flame causes the vapour from Bitumen to catch fire momentarily in form of Flash. Fire Test :- causes Bitumen to ignite & Burn for at least 5 sec under specified condition of Test
(8) Solubility Test with Tri-chloroethylene	impurity & free carbon content	Insoluble material ≯ 1% (मतलब A min. value of 99% is desired) • Bitumen → cracked if in CCl_4 insoluble material > 0.5%
(9) SPOT Test	to know Cracked Bitumen	Cracked Bitumen if insoluble material > 0.5% (2 gm Bit. + 100 gm ccl_4 → wash/dry → weight % में निकालते)
(10) loss on heating Test or Accelerated heat Test	loss in wt ≯ 1% grade 150/200 ≯ 2%	• Bitumen $\xrightarrow{T\uparrow}$ loss its volatile → hardness • Better Bitumen → loss less after heating 50 gm Bitumen $\xrightarrow[\text{for 5 hr}]{163°C}$ Residue
(11) water absorption Test	≯ 0.2% by weight	• water कम से कम होना चाहिये to prevent foaming of Bitumen when it is heated above Boiling point of water

(58)

(W)

Aggregate

- Silica → Hydrophillic → attracted to water
- Limestone (LB) → Hydrophobic → attracted to Bitumen

Property	Bitumen (0.97 - 1.02)	Tar (1.10)
color	Black to dark Brown	Black to dark brown
Production	Petroleum product made by distillation of petroleum crude	destructive distillation of wood or coal
Solubility	in CS_2, CCl_4	soluble in Toluene (C_7H_8)
ductility	less ductile	more ductile than Bitumen
Temp. Susceptibility	Less	more, ∴ greater variation in viscosity with Temperature
Carbon content	Less	more free carbon content, can be seen from solubility Test
	oxidise slowly, Thermoplastic, chemically Inert	
Resistance in water	more (insoluble in water)	Less

Different grades of Bitumens :-

(I) Paving grade	construction work of road & airfield
(II) Industrial Grade	for water proofing of structure and industrial floor
(III) Penetration grade 30/40	∴ Penetration Less (Hard) → road with High Traffic (Expressway, urban road, factory road) → Hot mix work in area where difference b/w max & min temp is Less than 25°C
(IV) Penetration grade 60/70	• Hot mix work for Bitumen macadam and Bitumen concrete for superior type of road with high traffic and in normal summer Temp. • Surface dressing • for premix work in High Altitude • Premix work in road with less traffic Intensity.

Bitumen layer	% Bitumen
Surface Dressing	2 %
Bit. macadam	3.3 – 3.5 %
Bitumen Concrete	6 – 7 %
mastic Asphalt	15 – 20 %

Blown Bitumen / oxidised Bitumen

- 95/15 → Penetration Value; 95 ↓ Softening point
- Produced by passing air through soft Bitumen mixture under controlled condition

Type of Tar	uses
RT1 (Lowest viscosity)	Surface painting
RT4	Premix in Macadam
RT5 (Highest viscosity)	Grouting

As no. ↑ viscosity ↑

∴ RT5 > RT4 > RT1

Ashphalt :- when Bitumen contains inert material / minerals

Cut back Bitumen :- viscosity ↓↓ by volatile diluent
(cold region)

note :- ज्यादा viscosity reduce करनी है तो ज्यादा diluent मिलाना पड़ेगा

	Solvent	∴ Bitumen = 100 − Solvent
RC-0 & SC-0	45	55
RC-5 & SC-5	15	85

Cut back classification (Based on Hardening after Application)

Rapid curing cut back (RC)	Ex. Naphtha, petrol, Gasoline. • Petroleum distillate which will rapidly evaporate if used in construction.
medium-curing cutback (MC)	Ex. kerosine, Light disel oil • with Intermediate Boiling solvent MC use :- use in Premix with Less quantity of fine aggregate
slow curing cutback (SC)	High Boiling point diluent • SC use :- use in premix with Appreciable qnt of fine aggregate

Bitumen Emulsion :- 2 phase system consisting of 2 immiscible liquid where droplet of Bitumen are suspended.

- In MRR work ✓
- Patchup work ✓
- wet weather (in rainy season) ✓
- Soil stablization in desert ✓

mixdesignmethod
1- marshall method → msyllabus
2- Hubbard field "
3- Haveem method
4- Smith Triaxial "

Bitumen mix Requirement
1- Stability
2- Durability
3- flexible
4- Skid resistance
5- Workability.

marshall Design specification:
1- Stability - min 340 kg
2- flow value - 8-16
(0.25 mm unit)
3- V_v % = 3 to 5%
4- VFB % = 75-85%

optimum Bitumen content SGV

$$= \frac{\text{Binder}\left\{\begin{matrix}\text{max} \\ \text{Stability} \\ \text{value}\end{matrix} + \begin{matrix}G_m \\ \text{value}\end{matrix} + \% 4 V_v\right\}}{3}$$

1- for evaluation of Performance of Bituminous mix → (flow value Test, Stability Test)

2- Stability Test (60°C) → max load supported by specimen

loading rate = 5 cm/min [same as bitumen ductility Test]

3- flow value Test → measure deformation (0.25mm unit)

if deformation 4mm → then flow value = $\frac{4}{0.25}$ = 16

मतलब reading 16 → flow value

4- mix with High stability value & Low flow value is not Desirable ∵ mix develop crack due to heavy moving Load.

1- G_t (Theortical spaific gravity) → with considering air voids

$$\boxed{G_t = \frac{100}{\frac{w_1}{G_1} + \frac{w_2}{G_2} + \frac{w_3}{G_3} + \frac{w_4}{G_4}}}$$

where $w_1 = \frac{W_1}{W} \times 100$

2- Bulk specific Gravity $\boxed{G_m = \frac{W}{V \cdot \gamma_w} = \frac{W_{mould}}{V_{mould} \times \gamma_w}}$

3- % air voids $\boxed{V_v \% = \frac{G_t - G_m}{G_t} \times 100}$

4- voids in mineral Aggregate (VMA)

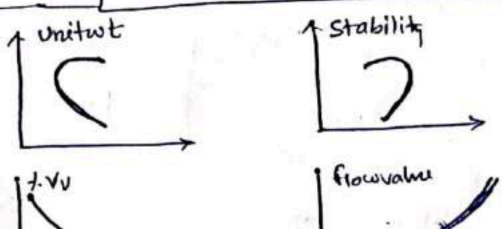
$$\boxed{VMA\% = \% V_v + \% V_b}$$

$$\boxed{\% V_b = (W_b \%) \times \frac{G_m}{G_b}}$$

5- voids filled with Bitumen VFB

$$\boxed{VFB = \frac{\% V_b}{\% V_v + \% V_b} \times 100 = \frac{\% V_b}{\% VMA} \times 100}$$

US
VF
VFB
VMA



x axis → Bitumen

14/4/2020

flexible pavement :- (IRC: 37)

surface course → Highnest Quality matirial
Base course
Subbase
Subgrade

flexible pavement drive stability →

(I) Grain to grain contact
(II) Aggregate interlock
(III) particle friction & cohesion

- Transfer of load from top to bottom layer by grain to grain contact
- load carrying capacity from load distribution Property (not from its bending / flexural strength)
- Reflects the deformation of lower layer
(मतलब if subgrade undulated → surface pavement is also undulated)

major flexible pavement surface failure :-

1- fatigue cracking (II) Rutting (III) Thermal Cracking

in IRC 37:2018 only these 2 criteria considered.

function of flexible pavement layers :-

1- subgrade → layer of top natural soil Prepared to recieve stress from layer above it.

2- Base course & subbase (broken stone Agg)

→ Flexible
- load distribution property
- subsurface drainage

→ Rigid
- prevent pumping
- protect subgrade against frost action.

3- wearing / surface course :- directly contact with Traffic load, superior in Quality.

f^n → to provide friction, smoothness, drainage offer water tightness.

note:-

Imp (I) stability of wearing course ——→ marshall Stability Test

(II) Evaluation ——→ Benkle beam Test, Plate Test

Rigid pavement :- load transfer through layer to layer from top to bottom

- load carrying capacity by slab itself through Bending action.
- analysis using elastic theory.

{ assume pavement as an elastic plate resting over an elastic foundation }

major Rigid pavement failure

1- fatigue cracking → In India only parameter to design.

2- Mud pumping → settlement due to heavy load

Rigidity factor (RF) = contact pressure / tyre pressure

contact pressure → wheel load / area of imprint

RF = 1 TP = 0.7 MPa
RF < 1 TP > 0.7
RF > 1 TP < 0.7

note:- tyre under compression CP > TP
——— Tension CP < TP

Traffic load consideration in design

→ fixed Traffic approach (used in airport design)
- Heaviest vehicle consider
- no of repetition not consider
- multiple wheel load converted into ESWL
- one single load movement is sufficient to cause damage to pavement.

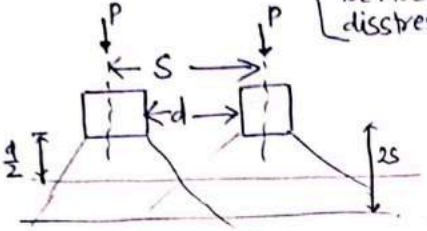
→ fixed vehicle approach (in Highway design)
- design govern by no. of repetition of standard axle.

• standard axle load 8160 kg or 8200 kg or 80 kN or 8.2 tonn

- convert into eq. no. of std. axle by using EALF (eq. axle load factor)

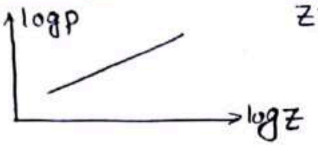
ESWL (eq. single wheel load) → use in fix traffic approach design (airport)

- consider equivalency in terms of → stress (in syllabus), strain, Deflection, disstress



$Z \le \frac{d}{2}$	ESWL = P
$Z \ge 2S$	ESWL = 2P

otherwise



EALF (eq. Axle load factor) → used in Higway design.

$$\boxed{EALF = \left(\frac{\text{axle load}}{\text{std. axle load}}\right)^4} \rightarrow \text{"forth power Law"}$$

$$\boxed{\text{vehicle damage factor (VDF)} = \frac{\text{eq. no. of std. axle}}{\text{no. of vehicle}}}$$

axle	either side wheel	EALF
single	single	$\left(\frac{\text{axleload}}{65}\right)^4$
	double	$\left(\frac{\text{axleload}}{80}\right)^4$
Tandem	double	$(\text{axleload}/148)^4$
Tridem	double	$(\text{axleload}/224)^4$

sample size for axle load survey

vehicles	sample size
<3000	20% } of CVPd
3000–6000	15%
>6000	10%

method of flexible pavement design :-

1- empirical (based on physical property and strength of soil subgrade)
[GI, CBR, CR (stabilometer), Mclead]

2- Semiempirical / semiTheortical :- (Triaxial Test)
(Based on stress-strain function)

3- Theortical method :- (Based on mathematical computation)

- Burminstir method → Based on 2 elastic Theory.

GI method :-

GI	
0–1	Good
2–4	fair
5–9	Poor
10–20	very poor

Surface course, Base course Thickness → fn(GI, traffic)

Subbase Thickness → fn(GI)
→ total − Basecourse thickness − Surface course Thickness.

$$\boxed{GI = 0.2a + \left(\frac{0.2}{40}\right)ac + \left(\frac{0.2}{20}\right)bd}$$

$P \rightarrow$ % finer (75μ)

$a = P - 35$, $b = P - 15$ } ≯ 40

$c = w_L - 40$, $d = I_p - 10$ } ≯ 20

limitation :- does not consider Quality of material used in pavement.

CBR method :- Based on strength parameter of subgrade soil & subsequent pavement material.

$$\boxed{T_{cm} = \sqrt{\frac{1.75P}{CBR\%} - \frac{A}{\pi}}} \rightarrow \boxed{CBR < 12\%} \quad \boxed{A = \pi a^2}$$

IRC : (i) CBR Test on remoulded soil (Insitu Test not suggested for design)

(ii) soil compacted to OMC to get Proctor density.

(iii) Test sample soaked for 4 days before Testing (in dry zone (<50cm rain) → not soaked)

(iv) min 3 Test sample at same moisture content, same Proctor density.

(v) if variation > permissible limit then take 6 samples.

CBR	Permissible variation
0–10	3%
10–30	5%
30–60	10%

(vi) top 50cm of subgrade compacted atleast upto 95–100% of proctor density

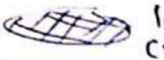
(vii) no. of heavy vehicle for design $\boxed{A = P(1+r)^{n+10}}$ — P → present 7 day Avg; n → no of year of last count & completion of construction.

(viii) design thickness applicable for single axle load (80kN), tandem axle load (148kN). For Higher axle load, increase thickness further.

(ix) when subbase has more no. of aggregates > 20mm CBR value of material will not valid for design of subsequent layer above them.

IRC method of design (IRC-37)

fatigue cracking

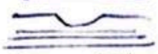


lookslike Crocodile

Imp

Tensile strain at bottom of Basecourse layer

Rutting



Permanent deformation

Imp

vertical comp. strain at top of subgrade

Imp

upto 30msa	20% of area	20mm in 20% of length
>30msA	10% of area	10 mm in 10%

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

$\epsilon_t \rightarrow$ tensile strain

$N_f \rightarrow$ no. of cumulative standard axle to produce 20% cracked surface area.

$$N_r = 4.1656 \times 10^{-8} \times \frac{1}{(\epsilon_v)^{4.5337}}$$

$\epsilon_v \rightarrow$ vertical comp. strain

$N_r \rightarrow$ no. of cumulative std. axle to produce rutt depth of 20 mm

$$mSA = \frac{365[(1+r)^n - 1]\ DAF}{r}$$

r = 5% as per IRC

$A = P(1+r)^x \rightarrow$ last count to completion

design life NH/SH ⇒ 15 year Expressway = 20 yr.

VDF = eq. no. of std. axle/commercial vehicle

Single lane road ⇒ 1

2 lane single carriageway = 0.75

} based on total no of vehicle in both direction

California-resistance value Test :-

Stabilometer R value.

cohesionmeter C value

$$\boxed{T_{cm} = \frac{k(TI)(90-R)}{C^{1/5}}}\ ; \quad \boxed{(TI) = 1.35(EWL)^{0.11}}$$

$k \rightarrow 0.166$

Triaxial method :-

$$T_{cm} = \sqrt{\left(\frac{3PXY}{2\pi E_s \Delta}\right)^2 - a^2}\ \left[\frac{E_s}{E_p}\right]^{1/3}$$

$E_s \rightarrow$ Subgrade, $E_p \rightarrow$ Pavement

X → traffic cofficient (ADT पर आधारित)

Y → rain " (Based on Avg. annual rainfall)

Δ = 0.25 cm (design deflection)

Mc-leod Test :- from plate load Test

$$\boxed{T = k \log P/S}$$

P → wheel load kg

S → total subgrade support kg

T → rep. thickness of gravel Base

k → Basecourse constant depends on loaded area

Burminster method :- (layered system)

flexible :- $\Delta = 1.5\, pa/E_s$

rigid $\Delta = 1.18\, pa/E_s$

note :- $\frac{1.5}{1.18} = 1.27$ & $\frac{1.18}{1.50} = 0.78$

$K = P/\Delta = \dfrac{P}{0.125\,cm}$ Plate load Test | modulus of subgrade reaction (K)

$\Delta = 1.18pa/E_s \longrightarrow$ rigid

Imp.

$K_1 a_1 = K_2 a_2$ | IRC :- $\boxed{K_{75} = 0.50 K_{30}}$

radius of relative stiffness :- by westergard

$$l_{cm} = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{0.25} \qquad \mu = 0.15$$

Radius of resisting Section

(i) $a < 1.724h \quad b = \sqrt{1.6a^2 + h^2} - 0.675h$

(ii) $a > 1.724h \quad b = a$

wheel load stress by Westergard :-

interior $\quad \dfrac{0.316P}{h^2}\left[4\log\left(\frac{l}{b}\right) + 1.069\right]$

edge $\quad \dfrac{0.572P}{h^2}\left[4\log\left(\frac{l}{b}\right) + 0.359\right]$

corner $\quad \dfrac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$

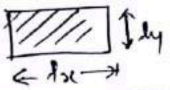
warping stress / Temp. stress :- due to daily variation in Temperature
~~Hdd~~ Temp. gradient across slab thickness

interior $\quad \dfrac{E\alpha T}{2}\left[\dfrac{C_x + \mu C_y}{1-\mu^2}\right]$

edge $\quad \max\left[\dfrac{E\alpha T}{2}C_x, \dfrac{E\alpha T}{2}C_y\right]$

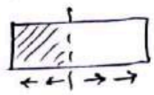
corner $\quad \dfrac{E\alpha T}{3(1-\mu)}\sqrt{a/l}$

$\underbrace{C_x, C_y}_{\text{Bradbury warping coefficient}} \longrightarrow f^n(l_x, l_y)$

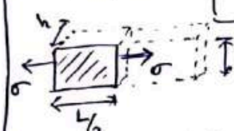


frictional stress :- due to Seasonal variation
- due to change in overall temperature of slab

in winter $\longrightarrow$ Tensile stress (T)
in summer $\longrightarrow$ comp. stress (C)



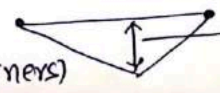
in winter slab try to contract from both side ∴ half distance consider in Analysis / calculations



$\sigma(B\times h) = f\left[\gamma\left(B\times\frac{L}{2}\times h\right)\right]$

$$\boxed{\therefore \sigma = \frac{f l w}{2} = \frac{f l \gamma}{2}}$$

actual variation (zero at corners)



assumed variation $\boxed{}$

(1) wheel load stress :- $S_c > S_e > S_i$
corner stress max ∵ discontinuity in both direction

(2) warping / Temp. stress $\quad$ min $\rightarrow$ corner (∵ weight is min) (resistance min)
max $\rightarrow$ interior, edge

note :- combination of wheel load stress & Temp. stress $\Rightarrow$ edge more critical hence design based on edge region however checking at corner

	wheel load stress	daily warping stress	seasonal frictional stress
interior	C, T (bottom)	day, T (bottom)	Winter (tension)
edge	C, T (bottom)	day, T (bottom)	winter (tension)
corner	T (top), C	T (top), night	zero (winter - tension)

REDMI NOTE 5 PRO

Joint :- in concrete construction joints are - discontinuity which are introduced in concrete construction for various purpose.

① Construction Joint

↓

The surface where 2 successive placement of concrete meet

- whenever construction work stops - temporarily these are provided.
- could be either along the longitudinal or transverse direction.
- Should be located where SF & BM → low, where member is supported by other - member and 18 m apart in huge - structure.
- should not be provided at corner of well or corner of pavement.
- where High shear resistance is - required at the construction joint, shear key may be provided.
- Preferably at a location where stresses are zero.
- These are vertical joints cut into wall that allows the concrete to shrink - without noticeable harm.
- construction joint reduce the thermal & shrinkage cracks & hence they should be planned accurately for their - location in the structure.

② Expansion Joint

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

$\delta \to$ max. compression Allowed.

- in transverse direction to allow movement of slab due to temp. & subgrade moisture variation.
- imp. max. spacing b/w Expansion joint = (140) m
- IRC Joint Thickness = 2.5 cm.
- dowel bars are placed in it (parallel to traffic direction)
- dowel bars → develop bending, bearing, shear stress & helps in Load Transfer.
- IRC η of load transfer = 40%. (dowel) distance at which SF becomes zero from max. loaded dowel = 1.0 l
- dowels 25-40 mm dia / 400- 500 mm length
- IS456 :- if length of concrete str. > 45 m Expansion joint provided.

③ Contraction Joint

- in transverse direction
- to take care of contraction of slab due to shrinkage of concrete.

'or' To regulate crack, to ensure that crack due to shrinkage & moisture formed at predetermined Location.

note :- where reinforcement is not - provided, The max. spacing b/w - contraction joint = 4.5 m

- without reinforcements $\leftarrow$ S, $L/2$

$\boxed{S = \frac{f L w}{2}}$ $w = \gamma = 2400 \text{ kg/m}^3$ $f = 1.5$

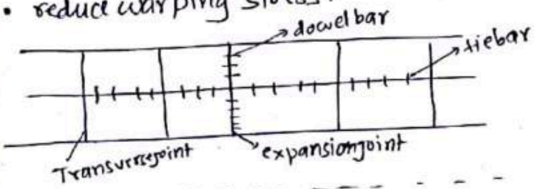
$S \to$ permissible tensile stress in concrete $(0.8 \frac{kg}{cm^2})$

- reinforcement :- $\sigma_{st} A_{st} = f\left[w B \times \frac{L}{2} \times h\right]$

$\sigma_{st} \to$ permissible Tensile stress in concrete 1400 kg/m2

④ Longitudinal Joints

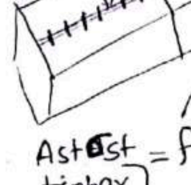
- in longitudinal direction
- if slab width more then provide
- reduce warping stress.



Tiebars :- not to withstand load

- ensure 2 slabs remains firmly together
- size 1 cm bar

note :- load Transfer to adjacent slab - due to aggregate interlock (not tiebar).



$$\underbrace{A_{st}}_{\text{tiebar}} \underbrace{\sigma_{st}}_{1400 \frac{kg}{m^2}} = \overset{1.5}{f}\left[\overset{2400 \text{kg/m}^3}{\gamma_c} \times 1 \times B \times h\right]$$

imp.

$\boxed{\text{length of Tiebar} = 2 \times \text{development length} + \text{gap}}$, $\frac{\phi \sigma_{st}}{4 \tau_{bd}}$

flexible pavement failure

Surface defect	Cracks	Deformation	Disintegration
• streaking	• Alligator cracks	• corrugation	• potholes
	• Reflection cracking	• rutting	• stripping
	• edge cracking		• ravelling
			• loss of agg.

Alligator or map cracking or crazing	• Interconnected cracks • due to overheating of Bitumen • mainly due to fatigue and Localised weakness in underlying weakness
Reflection cracking	• due to Joint & cracks in pavement layer underneath • when Bitumen layer over cracked cement concrete or Bitumen pavement. Treatment → cutback/emulsion Used
edge cracking	• frayed edge • edge broken • wornout shoulders
Corrugation	(लहर) → cross → across • regular undulation /ripple across-bitumen surface
Rutting Groove in wheel	• longitudinal depression due to heavy-channelised traffic • rut are usually width of wheel path Resons → improper compaction of layers, lacking in stability of mix to support the traffic and leading to Plastic movement laterally under traffic
Potholes (surface + Base course)	• Bowl shape extend till Base course • due to localised disintegration of matrial • due to ingress of water through surface-course.
stripping	• loss of Bond • loss of strength & matirial from surface • separation of Bitumen adhering to surface of aggregates particle in presence of moisture.
Ravelling ↓ Surface course.	• Removal of larger surface aggregate leaving craters • Progressive disintegration of surface due to failure of Binder to hold the matrial together
Loss of aggregate	• due to insufficient Binder used • occures in surface with surface dressing
Bird bath ↓ subgrade failure	• deformation which may be caused by localised or variable subgrade failure

Disstress	meaning
Settlement	General Lowering of road surface
Subsidence	due to poor drainage, a localised rather abrupt lowering of road-surface
Depression	dish type localised Deformation
distortion	irrgular Deformation of Road

Road drainage sytem	Location
Vertical sand drain	High embankment in soft soil
Causeway and culvert	Cross-drainage in road Alignment
scupper and Catchwater basin	Hill roads
Inlet gratings	urban road drainage

note:- in rutting & depression → patching work

Rigid pavement failure :-

(I) Scaling of concrete
- deteriorates the concrete.
- Reason (1) deficiency in mix
- (2) Presence of some chemical - impurity which damage mix.
- (3) Excessive vibration.

(II) shrinkage cracks
- normally develop during curing (Just after construction)
- can be in any direction.

(III) spalling of joint
- Joint का खराब होना
- due to faulty alignment of filler - material
- does not extend vertically through slab but interset at any Angle

(IV) warping crack
- if Joint are not properly designed it prevent expansion of slab leads to development of excessive - stress, This stress cause - formation of warping crack near edge Joint.

note :- ∴ Hinge Joint provide in slab to avoid warping cracks

Imp

(V) mud Pumping
- pumping noticed after rain in clay - subgrade

factors →
(I) Extent of slab deflection
(II) type of subgrade soil
(III) Amount of free water

Pavement evaluation

- Structural evaluation
  - (I) Plate bearing Test
  - (II) Benkle beam method
- Pavement - surface condition evaluation
  - (I) Bump Indicator (unevenness Index)
  - (II) Roughometer (Profilometer)

overlay thickness
- By CBR method
- By Benkle beam Deflection method

Imp [flexible over flexible pavement]

Benkle beam method :- (flexible over flexible overlay)

- Large rebound Deflection → weak pavement ∴ need more overlay Thickness

$$\boxed{D_c = \bar{D} + K\bar{\sigma}} \qquad \bar{D} = \frac{\sum D_i}{n} \qquad \bar{\sigma} = \sqrt{\frac{\sum(\bar{D} - D_i)^2}{n-1}}$$

IRC ($K = 1$)

- characteristic deflection after temp. correction $\Rightarrow \boxed{D_c - 0.0065(T - 35)}$ $T\,°C$
- Deflection noted in rainy season if not, then in dry season
  - clay ⇒ Ans × 2
  - sand ⇒ Ans × (1.2 - 1.3)
- overlay Thickness :- equivalent to granular - material of WBM Layer

$$\boxed{h_{mm} = 550 \log \frac{D_c}{D_a}} \qquad \boxed{A = P(1+r)^{n+10}}$$

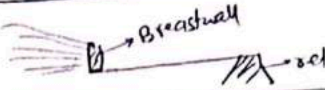
A	Da mm
150-450	1.5
450-1500	1.25
1500-4500	1

note :-
Bitumen concrete / Bitumen macadam with Bitumen surface course then equivalency factor = 2

Types of coats used in flexible pavement :-

Prime-coat	• first Application of Low-viscosity liquid Bituminous-material over an existing porous or absorbent pavement surface like the WBM base course. • objective of priming :- to plug in the capillary voids of porous surface and to bond the lose mineral particles on the existing surface, using the low viscosity binder, which can-penetrate into voids. • Promotes bond (adhesion) b/w base and wearing course. • to plug capillary voids in Base-course and upward movement of water restricted.
Tack coat	• spray of Bituminous material over an existing surface which is relatively impervious like an existing bituminous-surface or a cement concrete pavement Ex. for laying Bitumen carpet over water bound macadam surface. note:- Traffic closed, otherwise dust, dirt on surface over tack coat surface.
Seal coat	(I) to seal the surfacing against the ingress of water. (II) To develop skid resistance texture. (III) To enliven an existing dry or weathered bituminous surface. (IV) Slow oxidation & prevent damage from sun's harmfull rays.

Structure in hill roads :-



(1) Breast wall	• construct to buttress (सहारादेना) the uphill slope to road c/s • should be strong enough to withstand earth pressure of soil behind along surcharge caused by slope.
(2) Retaining wall	need to retain the fill portion of Highway c/s
(3) check walls	• small retaining str • constructed in series on sloping hill face to check slides and to provide overall stability of hill face.
(4) Gabion wall	• Breast wall / Retaining wall / checkwall constructed with dry stone masonary encashed in wire mesh. • used as toe protection wall where road runs parallel to stream. •
(5) Parapet wall	• needed to give protection, Psychology, Physically to motorist while-travelling on roads with steep valley-Slope.