HAND WRITTEN NOTES:

OF

CIVIL ENGINEERING

SUBJECT:

HIGHWAY ENGINEERING
Important Years:

1. Jaykesham Four
   - Formed in \( \rightarrow \) Nov. 1927
   - Submitted report \( \rightarrow \) 1928

2. Central Road Fund \( \rightarrow \) 1928

3. Indian Road Congress \( \rightarrow \) 1934

4. Motor Vehicle Act \( \rightarrow \) 1939

5. First 20 Years Road Plan \( \rightarrow \) 1943-63
   \[ \text{[Nagpur Road Plan]} \]

6. CRI (Central Road Research Institute) \( \rightarrow \) 1950

7. 2nd 20 Years Road Plan \( \rightarrow \) 1961-81
   \[ \text{[Bombay Road Plan]} \]

8. 3rd 20 Years Road Plan \( \rightarrow \) 1981-2001
   \[ \text{[Lucknow Road Plan]} \]

9. National Highway Act \( \rightarrow \) 1956
Jaykai Committee recommendation

In 1928 Jaykai Committee submitted its report with following recommendations:

1. Road development should be considered as a matter of national interest.
2. An extra tax on petrol should be devised for road development works. Results was Central Road Fund (1928)
3. A semi official technical body should be formed to act as an advisory body on various aspects of road. (Results - IRC)
4. A research organisation should be instituted to carry out research and development works. (Results - CRRI - 1950)

Road plans:

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| 3. | Target| 16km/100sqkm | 32km/100sqkm | 82km/100sqkm | Area
| 4. | Total road length target | 5.29 lakh km | 10.57 lakh km | 27.02 lakh km |
Target
Expenditure
44.8 crore
5200 crores

6. Other points
1. NH
2. SH
3. MDR
4. ODR
5. VR

Added
1. 1600 km out
   Expressway
2. 5% allowance
   for future development

Classification
1. Primary
2. Expressway
3. NH

4. Secondary
5. SH
6. MDR

5. Tertiary
6. ODR
7. VR

* Different road patterns *

1. Rectangular and block pattern

2. Star and block pattern
1) stem and circular

2) C.P.

3) stems and grid pattern

Indian roads have been developed on stem and grid pattern.
Hexagonal
**Geometrical design**

1. **Terrain classification**

   Types
   
   - Steep terrain: > 60°
   - Mountainous terrain: 25 to 60°
   - Rolling terrain: 10 to 25°
   - Plain terrain: < 10°

   Cross slope is the maximum slope of the terrain available in that area.

2. **Design vehicle**

   - Maximum width = 9.44 m (3.10 m)
   - Maximum height:
     1. Single deck = 3.80 m
     2. Double deck = 4.70 m

   - Maximum length:
     1. Single unit with two axles = 10.7 m
(2) Single unit > 2 axle = 12.2 m
(3) Tractor + Trailer = 18.3 m

3. Carriageway width

- Single lane road = 3.75 m
- Two lane road = 7.00 m

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Friction:

There are two types:

(a) Longitudinal coefficient of friction

\[ u = f = 0.35 \]

Applicable
Limiting application of brakes

(b) Lateral coefficient of friction

\[ u = f = 0.15 \]

In lateral direction movement of vehicles (Ex. In case of superelevation) or curves

Skid: when brakes are applied.

\[ \text{Skid} \quad \longrightarrow \text{L} \]

Slip: when accelerating

\[ \text{Slip} \quad \longrightarrow \text{X or less} \]

(3) Unevenly index:

This is the cumulative value of undulation.
on a road surface measured in cm/km of road.

Type of pavement | uneven index
--- | ---
(1) Good pavement | < 150 cm/km
(2) Satisfactory | 250 cm/km
(3) Unsatisfactory [Uncomfortable] | > 350 cm/km

(3) Camber: Central portion of road, w.r.t. edges

Purpose: to drain off water from road surface

Type of pavement | Light Rainfall | Heavy Rainfall
--- | --- | ---
(1) Cement Concrete | 1.7 - (1 in 60) | 2.1 - (1 in 35)
(2) High Bituminous | - | -
(3) Thin Bituminous | 2.1 - (1 in 35) | 2.5 - (1 in 20)
(4) WBM/Gravel | 2.5 - (1 in 40) | 3.0 - (1 in 33)
(5) Earth Road | 3.7 - (1 in 33) | 4.7 - (1 in 25)

Design Speed:

NH 8 SH
pavement design done for rolling speed."

Sight distance :-

As per IRC sight distance requirement:

1. on horizontal curve :-

2. on vertical curve :-
For stopping sight distance

For intermediate or overtaking sight distance

1. **Stopping sight distance**: Total distance required to a vehicle to stop = Lag distance + Braking distance

In reaction time (lag distance) [brakes applied]

SSD
Lag distance,

Distance travelled for total reaction time

\[ V \cdot t_R = 0.278 V \cdot t_R \quad \text{(\(V\text{=kmph}\))}

Reaction time: 0.5 sec to 5 sec.

Generally: 2.5 to 3 sec. considered

PIEV Theory:

1. \(P\rightarrow\) Perception:
   Time to send sensation from eyes to brain

2. \(I\rightarrow\) Intellation:
   Time to rearrange different thoughts, analysing the situation by brain.

3. \(E\rightarrow\) Emotion:
   Time elapsed in emotional sensation.

4. \(V\rightarrow\) Volition:
   Time for final decision.

5. Braking distances:
**Assumptions:**

1. Brakes are fully applied & wheels are fully jammed
2. Vehicle moves just by sliding over road surface.

\[ \text{K.E. Lost} = \text{work done} \]

\[ \frac{1}{2} m v^2 = (\text{force of resistance}) \times S \]

\[ = (m g \sin \theta + f) \cdot s \]

\[ = (m g \sin \theta + f \cdot m g \cos \theta) \cdot s \]

\( s = \text{distance} \)

**Braking distance**

\[ s = \frac{v^2}{2 g (\sin \theta + f \cos \theta)} \]

\[ s = \frac{v^2}{2 g \cos \theta (\tan \theta + f)} \]

For small \( \theta \), \( \theta \approx 1 \)
\[ s = \frac{v^2}{2g \left( f + s \cdot \sin \theta \right)} \]

\[ L = \frac{v^2}{2g \left( f + s \cdot \sin \theta \right)} \]

When movement is downward

In this case

\[ L = \frac{v^2}{2g \left( f - s \cdot \sin \theta \right)} \] (downward)

Total stopping signal distance

\[ \text{SSD} = 0.278 \, v \cdot t_r + \left( \frac{0.278 \, v}{2g \left( f + s \cdot \sin \theta \right)} \right)^3 \]
- Cases

1. One way road (one way traffic)
2. One lane road (two way traffic)
   [Also called intermediate sight distance or meeting sight distance]
3. Two lane road (two way traffic)
4. Head light sight distance

- Overtaking sight distance

\[ a = \text{acceleration} \]
speed of $A$ (overtaking vehicle) = $v_A$

speed of overtaken vehicle $B$ = $v_B$

speed of opposite side vehicles $C$ = $v_C$

\[ \text{Distance } d_1 : \]

Distance travelled by vehicle $A$ in reaction time.

[vehicle $A$ is forced to move with same speed that of speed of vehicle $B$.]

\[ d_1 = v_B \cdot tr = 0.278v_B \cdot tr \quad - (1) \]

$tr$ = Reaction Time. (2.5 to 3.0 sec)

Distance $d_2$:

Distance travelled by $A$ in overtaking $B$.

\[ d_2 = v_B \cdot T + \frac{1}{2} a T^2 \]

\[ d_2 = 0.278v_B \cdot T + \frac{1}{2} a T^2 \quad - (2) \]

Minimum clearance required:

\[ s = 0.7v_B + \overline{f} \]

\[ s = (0.7v_B + 6) \]

\[ s = (0.7 \times 0.278v_B + 6) \]

\[ s = 0.2v_B + 6 \]

$s = 0.20v_B + 6$
where 0.7 sec = reaction time for vehicles moving back to back.

\[ d_2 = 2s + v_B \cdot T \]

Equating 2 and 3:

\[ v_B \cdot T + \frac{1}{2} a T^2 = 2s + v_B \cdot T \]

\[ T = \frac{us}{a} \]

3. Distance \( d_3 \):

\[ d_3 = 0.278 \cdot v_c \cdot T \]

Total overtaking sight distance

\[ OSD = d_1 + d_2 + d_3 \]

Value of acceleration: (depends on the speed)

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>25</th>
<th>30</th>
<th>40</th>
<th>50</th>
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<th>80</th>
<th>100</th>
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<td>1.3</td>
<td>1.24</td>
<td>1.11</td>
<td>0.77</td>
<td>0.53</td>
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<td>OSD (m)</td>
<td>90</td>
<td>165</td>
<td>235</td>
<td>340</td>
<td>470</td>
<td>640</td>
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superelevation:

Superelevation is provided on curve to counteract the effect of centripetal force.

\[
\begin{align*}
\text{forces} \\
mg & \rightarrow \text{weight} \\
\frac{mv^2}{R} & = \text{centripetal force} \\
F & = f \cdot R = -f \left( mg \cos \theta + \frac{mv^2 \sin \theta}{R} \right) \\
\text{Equating all forces along the surface of road} \\
mg \sin \theta + f & = \frac{mv^2}{R} \cos \theta \\
mg \sin \theta + f \cdot (mg \cos \theta + \frac{mv^2 \sin \theta}{R}) & = \frac{mv^2 \cos \theta}{R} \\
g \tan \theta + fg + f \cdot \frac{v^2}{R} \tan \theta & = \frac{v^2}{R}
\end{align*}
\]
\[ g (f + \tan \theta) = \frac{v^2}{R} (1 - f \cdot \tan \theta) \]

Put \( \tan \theta = c \), \text{ super elevation} (S.E.)

\[ g (f + c) = \frac{v^2}{R} (1 - f \cdot c) \]

\[ \left( \frac{f + c}{1 - fc} \right) = \frac{v^2}{gR} = \frac{(0.278v)^2}{9.81R} = \frac{v^2}{127R} \]

\[ \left( \frac{e + f}{1 - fe} \right) = \frac{v^2}{127R} \quad (\text{Eq. A}) \]

Max. value of \( e \) is 10.7, and \( f = 0.15 \) so \( ef \) value is small, so \( (1 - ef) \) term is neglected, or \( = 1 \)

So super elevation

\[ e + f = \frac{v^2}{127R} \quad (\text{Eq. B}) \]

**Design steps:**

1. Max. super elevation is allowed:
   - (a) on plain and rolling terrain = 0.07 (7.7%)
   - (b) on hilly road = 0.10 (10.1%)
   - (c) on urban road with frequent intersection = 0.04 (4.4%)
Min. super-elevation = camber slope

Sim steps:

1. First S.E. is calculated for 75% of design speed (without considering f value)

\[
e = \frac{(0.75V)^2}{127R}
\]

\[
e = \frac{V^2}{225R}
\]

2. \( e \) calculated above is less than \( e_{max} \). Permissible super-elevation hence its O.K.

3. \( e < e_{max} \) hence O.K.

Provide \( e \) value calculated

4. If \( e_{cal} > e_{max} \)

\( e_{lim} = e_{max} \) and check value of \( f \) considering full design speed.

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

\[
e_{max} + f = \frac{V^2}{127R}
\]
f = \left( \frac{v^2}{127R} - e_{\text{max}} \right) \leq 0.15

if \ f < 0.15 \ (\text{O.K.}) \ \text{provide} \ e_{\text{max}} \ \text{(23)}

4. \ \text{if calculated} \ > f_{\text{max}} (0.15)

\text{than limit the speed} \ [\text{restricted max speed}]

\begin{align*}
e_{\text{max}} + f_{\text{max}} &= \frac{V_{\text{max}}^2}{127R} \\
V_{\text{max (allowed)}} &= \sqrt{127R \left( e_{\text{max}} + f_{\text{max}} \right)}
\end{align*}

5. \ \text{special case:}

If no super-elevation is provided \ \text{max speed on a curve}

\begin{align*}
V_{\text{max}} &= \sqrt{127R \cdot f_{\text{max}}}
\end{align*}

\underline{Minimum \ radius \ of \ curve}

\begin{align*}
R_{\text{min}} &= \frac{V_{\text{max}}}{127 \left( e_{\text{max}} + f_{\text{max}} \right)} \quad \text{[at max speed]} \\
R_{\text{min}} &= \frac{v^2}{127 \left( e + f \right)} \quad \text{[at rolling speed]}
\end{align*}
Extra widening:-

Extra widening is required on curves.

Ways:-
1. Mechanical widening
2. Hydrological widening

Mechanical widening:-

In triangle OAB:

\[ R^2 + d^2 = (R + E_w)^2 \]

\[ R^2 + d^2 = R^2 + E_w^2 + 2R \cdot E_w \]

\[ d^2 = E_w (E_w + 2R) \]

\[ \therefore E_w + 2R = 2R \]
\[ E_w = \frac{u^2}{2R} \]

if \( n = \) number of lanes

\[ E_w = \frac{nu^2}{2R} \]

(2) Psychological widening:

Due to tendency to keep vehicles away from other vehicles.

\[ E_{pw} = \frac{V}{9.5\sqrt{R}} \]

Total external widening:

\[ E_w = \frac{nu^2}{2R} + \frac{V}{9.5\sqrt{R}} \]

Transition curve:

For highway transition curve

\[ y = \frac{x^3}{6RL} \]

\( y = \frac{y_3}{6RL} \)
Length of transition curves

Based on rate of change of radial acceleration

\[ L = \frac{v^3}{CR} \]

- \( v \) = speed in m/sec
- \( C \) = rate of change of radial acceleration (m/sec^2/sec)
- \( R \) = radius in meter

Value of \( C \)

\[ C = \frac{80}{75 + V} \]

Values are:

\[ 0.50 \leq C \leq 0.80 \]

Based on rate of change of superelevation.

If pavement is rotated about edge.
Rise of outer edge
\[ x = (W + Ew) \tan \theta \]
\[ x = (W + Ew) e \]

Length of Transition Curve
\[ L = N \cdot x \]

3. If pavement is rotated about centre

Rise of outer edge
\[ x = \left( \frac{W + Ew}{2} \right) e \]

Length of T.C. = \(N \cdot x\)

Length of Transition Curve
1. In plain and rolling terrain = 150x
2. In built up area = 100x
3. In hilly area = 60x
By empirical formula:-

On plain and rolling terrain

\[ L = \frac{2.7 V^2}{R} \]

Mountaneous and steep

\[ L = \frac{V^2}{R} \]

Shift of curve:

\[ S = \frac{L^2}{24 R} \]

Set back distance:

Set back distance is minimum clearance required from center of road at any obstruction on inner side of curve, so that full sight distance (SSD, or OSID or ISSD) is available.
Throughout the length of curve.

Note: Radius of curve and set back distance measured from centre of road.

Case 1:
If length of curve > sight distance
One lane road (le > 5)

\[ \frac{S}{2} = \frac{2\pi R}{360} \]

\[ d = \frac{360 S}{2\pi R} \]

\[ \Rightarrow \frac{d}{2} = \frac{180S}{2\pi R} \]
set back distance
\[ m = CD = OC - OD \]
\[ m = R - R \cos \frac{\theta}{2} \]

Case 2: one lane road \((L_c < S)\)

\[
\frac{L_c}{d} = \frac{2\pi R}{360}
\]
\[
d = \frac{360L_c}{2\pi R}
\]
\[
d = \frac{180L_c}{\pi L_c}
\]

set back distance \((m)\)
\[ m = EH = EF + FI \]
\[ m = (OE - OF) + OD \]
\[ m = \left( R - R \cos \left( \frac{\theta}{2} \right) \right) + \left( \frac{S - L_c}{2} \right) \sin \frac{\theta}{2} \]

**Case-3**

Two lane road \((L_c > s)\)

→ Set back distance from centre of road

→ Radius \(R\) from centre of road

→ Radius on \(= (R-d)\)

\(d = \text{half of one lane}

→ Sight distance

→ Measured along centre line of inner lane.

\[ \frac{s}{d} = \frac{2\pi(R-d)}{360} \]

\[ d = \frac{360\theta}{2\pi(R-d)} \]
\[ \frac{d^2}{2} = \frac{180s}{2\pi (r-d)} \]

**set back distance**

\[ m = CE = OC - OE \]

\[ m = r - (r-d) \cos \frac{t}{2} \]

**case 4** Two lane road \((Lc < s)\)

\[ \frac{Lc}{d} = \frac{2\pi (r-d)}{360} \]

\[ \phi = \frac{360Lc}{2\pi (r-d)} \]

\[ \frac{d^2}{a} = \frac{180Lc}{2\pi (r-d)} \]
Set back distance

\[ m = \frac{E}{H} \]

\[ = \frac{E}{H} + \Delta H \]

\[ - (\Delta - \Delta E) + DJ \]

\[ m = \left[ R - (R - d) \cos \frac{\pi}{2} \right] + \frac{s - Lc}{2} \sin \frac{\pi}{2} \]

design of vertical alignment –

**Different gradients**

**A. Ruling gradients:** Maxm gradient that can be provided in most general condition of road, traffic (values)

1. Plain gradient 1 in 30
2. Mountainous 1 in 20
3. Steep region 1 in 16.7

**B. Limiting gradient:**

Due to cost factors as per topography, gradient can be increased to limiting gradient value

1. Plain and rolling 1 in 20
2. Mountainous 1 in 16.7
3. Steep gradient 1 in 14.3
Exceptional gradient:

In very Extraordinary situation, when there is no option main gradient that can be avoided is called exceptional gradient.

Plain and rolling
1 in 15

Mountaneous
1 in 14.3

Steep
1 in 12.5

Minimum gradient:

⇒ 1 in 500 is required to drain off water

in concrete drain

⇒ 1 in 200 on interior surface

Lve resistance:

A curved track Tractive force available

= T \cos \alpha

the direction of movement

curve resistance = (T - T \cos \alpha)
Reduction of grade at the location of curve

Grade compensation:

\[ \frac{30 + R}{R} \% \text{, subjected to max. value of } \left( \frac{75}{R} \right) \% \]

Ex. For a mountainous region at the location of a curve, if \( R = 120 \text{ m} \), what max. ruling gradient can be provided.

**Sol.**

Ruling gradient = 1 in 20 = 0.05

[For mountainous]

Grade compensation:

\[ \frac{30 + R}{R} \]

\[ \frac{30 + 120}{120} = \frac{150}{120} \]

\[ \text{Max. } \frac{75}{R} = \frac{75}{120} \% = 0.625 \% \]

\[ = \frac{0.625}{100} = 6.25 \times 10^{-3} \]

Compensated gradient:

\[ 0.05 - 6.25 \times 10^{-3} = 0.04375 \]

\[ = 1 \text{ in } 22.86 \]

[Diagram with labels: 1m, 100m, 32.86]
elliptic curve
0. summits curve
1. valley curve

range in gradient - \( (\theta) \)

\[ N = \left| \frac{1}{n_1} - \frac{1}{n_2} \right| \]

General formula

\[ N = \left| \frac{1}{20} - \frac{1}{15} \right| \]

\[ N = \frac{1}{20} + \frac{1}{15} = 0.166667 \]

Summit curve = (simple parabola)

Use 1 when \((L_c > S)\)

\( H = 1.20 \text{m} \)

SSD \( (S) \)

For stopping sight distance
In this case two transition curve are provided back to back to form the valley curve.

Length of one transition curve is:

$$L_s = \frac{V^3}{C \cdot R}$$  \(21\)

Radius of transition curve at junction

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

$$L_s = \frac{V^3}{C} = \frac{N \cdot V^3}{C \cdot L_s}$$

$$L_s = \frac{N \cdot V^3}{C}$$

$$L_s = \sqrt{\frac{N \cdot V^3}{C}} = \left(\frac{N \cdot V^3}{C}\right)^{\frac{1}{2}}$$

Total length of T.O.C.

$$L = 2L_s = 2\left(\frac{N \cdot V^3}{C}\right)^{\frac{1}{2}}$$

Length of valley curve

$$L = 2\left(\frac{N \cdot V^3}{C}\right)^{\frac{1}{2}}$$

$$N = \text{Total change in radius}$$

$$V = \text{m/sec} \quad C = \text{m/sec}^3$$
Equation of parabola

\[ y = a x^2 \]
\[ = \left( \frac{N}{2L} \right) x^2 \]

\[ h_1 + \tan \beta = \frac{N}{2L} (S)^2 \]

Length of valley curve (when \( L > S \))

\[ L = \frac{NS^2}{2 (h_1 + \tan \beta)} \]

where
- \( N \) = Total change in gradient
- \( S \) = Sight distance (CSSD/OSD/PDD) in meter
- \( h_1 \) = Height of head light above road surface

\[ h_1 = 0.75 \] if not given

\[ \beta = \text{Beam angle of head light} \]

\[ \beta = 1^\circ \] if not given
If length $L < S$

Length of valley curve

$$L = 2S - \frac{2 (\text{hit safety})}{N}$$
The driver of a vehicle travelling 60 kmph up a gradient required just less to stop this vehicle after he applies the brakes, than drives avelling at same speed down the same gradient \( \mu = 0.4 \), What is the \( \mu_0 \) gradient.

\[ \begin{align*}
\mu_0 &= \tan \theta \\
\theta &= \sin^{-1}(\mu_0) \\
S_1 &= S_2 - \frac{v^2}{2\mu (f + s)} \\
S_2 &= \frac{v^2}{2\mu (f - s)} \\
S_2 - S_1 &= 9 \\
\frac{v^2}{2\mu(f-s)} - \frac{v^2}{2\mu(f+s)} &= 9 \\
\frac{(0.278 \times 60)^2}{2 \times 9.81 (0.4 - s)} - \frac{(0.278 \times 60)^2}{2 \times 9.81 (0.4 + s)} &= 9 \\
\frac{1}{0.4 - s} - \frac{1}{0.4 + s} &= \frac{9}{14.18}
\end{align*} \]
Length of curve required to fulfill IRC condition

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

\[ L = \frac{NS^2}{(\sqrt{2x_1} + \sqrt{2x_0.15})^2} \]

For SSD

For OSD or BSD &

\[ L = \frac{NS^2}{4.4} \]

Length of curve

\[ L = \frac{NS^2}{(\sqrt{2x_1} + \sqrt{2x_1})^2} = \frac{NS^2}{9.6} \]

\[ L = \frac{NS^2}{9.6} \]
\[
\text{if } (L_c \geq S) \quad (42)
\]

Length of curve = \(2S - \frac{\sqrt{R_h + R_n}}{N}\)

For SSD:
\[
L = 2S - \frac{4y}{N}
\]

For OSID:
\[
L = 2S - \frac{3.6}{N}
\]

Valley curve & \text{ (cubic parabola) is used for}

Highway valley curve

Two criteria:
1) Comfort condition
2) Head light sight distance

Comfort condition:

\(N = \text{(Total change) in gradient}\)
\[
\frac{0.4 + s - 0.4 + s}{(0.4 - 8)(0.4 + 8)} = 0.63467 \\
2.8 = 0.4^2 - s^2 \\
0.63467 \\
3.15 s = 0.16 - s^2 + s \\
s^2 + 3.15 s - 0.16 = 0 \\
S = 0.009 = 0.05 \text{ (in 20.4) \hspace{1cm} shape}
\]

The speed of overtaking and overtaken vehicles are 80 \(v_a\) and 60 \(v_b\) kmph.
\[a = 2.5 \text{ kmph/sec.}\]

Calculate safe passing distance.

1. Single lane one way traffic \((d_1 + d_2)\)
2. Three lane both way traffic \((d_1 + d_2 + d_3)\)

\[\text{Reaction time} = 2.8 \text{ sec}\]

When speed on opposite side not given, then take \((v_a = v_c)\)
Distance \( d_1 = 0.278 \times 60 \times 9 = 33.36 \text{ m} \)

Distance \( d_2 \)

Min. distance bw two vehicles
\[
s = 0.2 V_B + 6
\]

\[
s = 0.2 \times 60 + 6 = 18 \text{ m}
\]

Time \( T \) = \[
\sqrt{\frac{us}{a}} = \sqrt{\frac{u \times 18}{0.278 \times 2.5}} = 10.188 \text{ sec.}
\]

Distance
\[
d_2 = 2s + b = 2 \times 18 + 0.278 \times 9 \times 10.188 = 205.8 \text{ m}
\]

Distance \( d_3 \)
\[
= 0.278 V_c \times T
\]

\[
= 0.278 \times 80 \times 10.188 = 226.40 \text{ m}
\]

\( V_c \) not give take \( V_A = V_c \)

For one lane / one way
\[
OSD = d_1 + d_2 = 33.36 + 205.8 = 239.16 \text{ m}
\]

Three lane / two way traffic
\[
OSD = d_1 + d_2 + d_3 = 33.36 + 205.8 + 226.4
\]

\[
= 465.56 \text{ m}
\]
For total OSD = 466M

\[ \text{Min length of overtaking zone} = 3 \times \text{OSD} = 3 \times 466 = 1398M \]

Desirable length = \( 5 \times \text{OSD} = 5 \times 460 = 2300 \)

Overtaking zone \((3 \times \text{OSD})\)

\[ \text{Required length} = 5 \times \text{OSD} = \text{Desirable length} \]

**Homework**

1. [ ]
2. [ ]
3. [ ]

1995

In 1992, while designing a highway in a built-up area, it was necessary to provide a horizontal curve of radius 325m. Design the following geometrical details:

1. SE
2. Ew
3. Length of T-Co

Desired speed = 65km/hr
Length of wheel base = 6.1m
Pavement width = 10.5m
\[ R = 325 \text{m} \]
\[ V = 65 \text{mph} \]
\[ u = 6.1 \text{m} \]
\[ w = 10.5 \text{m} \]
\[ n = \frac{10.5}{3.5} = 3 \]

1. Super-elevation

a) Design for 75\% of design speed

\[ e = \left( \frac{0.75V}{127R} \right)^2 = \left( \frac{0.75 \times 65}{127 \times 325} \right)^2 = 0.00575 \]

\[ e_{\text{max}} = 7.1 \text{m} \]

\[ e < e_{\text{max}} \text{ (hence OK)} \]

b) Check the value of \( f \)

for full design speed

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

\[ f = \frac{65^2}{127 \times 325} - 0.00575 = 0.045 < 0.15(0.5) \]

Provide max. for both values

\[ f = 0.05 \text{m} \]

2. Extra widening

\[ E_w = \frac{nud^2}{8R} + \frac{V}{g.51R} = \frac{3 \times 6.12}{2 \times 325} + \frac{6.5}{9.5 \times 325} = 0.055 \text{m} \]
Total width of road

\[ W + Ew = 10.5 + 0.55 = 11.05 \text{m} \]

3. Length of transition curve
   a. Rate of change of radial acceleration
      \[ L = \frac{V^2}{cR} \]
      \[ c = \frac{80}{75 + V} = \frac{80}{75 + 65} = 0.57 \]
      \[ 0.57 \times 3.25 \]
      \[ L = 31.85 \text{m} \]

   b. As per rate of change of super-elevation
      Total cause of outer edge (Assume)
      \[ \chi = (W + Ew) c = (11.05) \frac{5.75}{100} = 0.635 \text{m} \]
      \[ L = 100 \times \chi = 100 \times 0.635 = 63.5 \text{m} \]

   c. Empirical formula
      \[ L = \frac{2.7 V^2}{R} = \frac{2.7 \times 65^2}{325} = 35.1 \text{m} \]
A truck with c.n. at \( x = 1.4\text{ m} \) and \( y = 1.0\text{ m} \) is travelling on a curve road of radius 200m and \( e = 0.05 \). Determine max. safe speed to void both slipping and overturning. Coefficient of side friction = 0.15. Sketch explain and derive the expression.

For slipping condition, all the forces along the surface of road should be in equilibrium.
\[ m \sin \theta + F = \frac{mv^2}{R} \cos \theta \]

\[ m \sin \theta + f (C_m (\cos \theta + \frac{mv^2}{R} \sin \theta)) = \frac{mv^2}{R} \cos \theta \]

\[ \tan \theta_0 + \left[ f g + f \frac{v^2}{R} \tan \theta_0 \right] = \frac{v^2}{R} \]

\[ \frac{e+f}{1-e+f} \frac{v^2}{8K} \]

Max speed.

\[ -v = \sqrt{\frac{9.81 \times 200 \times (0.05 + 0.15)}{(1 - 0.05 \times 0.15)}} \]

\[ v = 19.88 \text{ m/sec} = 71.52 \text{ km/hr} \]

(2) For overturning

Vehicle may overturn about point B.

Equating moment of all forces about B

\[ \frac{mv^2}{R} \cos \theta \times y = mg \sin \theta \times y + (C_m \cos \theta + \frac{mv^2}{R} \sin \theta) \times x \]

\[ \frac{v^2}{R} y = g \tan \theta + g x + \frac{v^2}{R} \tan \theta x \]

\[ \frac{v^2}{R} y = g \cdot e \cdot y + j \cdot x + \frac{v^2}{R} \cdot e \cdot x \]
\[ v = \frac{g(x+ey)}{(y-ex)} \]

\[ \frac{v^2}{gR} = \frac{x+ey}{y-ex} \]

\[ v_o = \sqrt{\frac{(x+ey)}{(y-ex)} xgR} \]

\[ v_{max} = \frac{(1.4+0.05 \times 1.7)}{(1.4-0.05 \times 1.7)} \times 9.81 \times 200 \]

\[ v_{max} = 42.27 \text{ m/sec} = 152.05 \text{ km/h} \]

The maximum speed will be allowed to take minimum

\[ v_{max} = 71.52 \text{ km/h} \]

A rectangular bridge span of length \( L \) and width \( W \), is used on a horizontal curve. If the roadway is 8m wide and minimum clearance of 1m is desired from the edge of pavement and bridge railing, show that the minimum radius of curvature is

\[ R = \frac{L^2}{8(W-10)} + \frac{(W-10)}{2} \]
\[ \frac{1}{2} \times \frac{1}{2} = (w - 10) \left(2r - (w - 10)\right) \]

\[
\frac{L^2}{4(w - 10)} = 2r - (w - 10)
\]

\[
2r = \frac{L^2}{4(w - 10)} + (w - 10)
\]

\[
R = \frac{L^2}{8(w - 10)} + \frac{w - 10}{2}
\]

---

**Question**

A vertical parabolic curve is to be used under a grade separation structure. The minus grade on the left side is 4.4%, and plus grade is 3.4%. Intersection of two grade is at 1356 m and at an elevation of 251.487 m.

The curve passes through a fixed point at a chainage of 1601 m and R1 of 260 m.

Find the length of curve.

**Solution**

Equation of parabolic curve

\[ h = k \cdot x^2 \]

\[ h \] is distance from first tangent
For point C ($h_1$)

R.L.O.F. point $P = 260^m$

R.L.O.F. point $Q = R.L.O.F. C - 41.0^m$ C.T.

$CT = 460 - 415 = 25^m$

$h_1 = PQ = 260 - 250.48 = 9.52^m = kx^2$

For point $P$, value of $k$

$x = (d+25)$

$1.0c. (d+25)^2 = 9.52$ —(1)

For point $B$

$h_2 = BS + SR = 0.03d + 0.04d = 0.07d = kx^2$
\[ h_2 = kx^2 = k(24)^2 = 0.07y \]

For point B = (x = 24)

\[ R = \frac{0.07y}{uy^2} = \frac{0.07}{uy} = 0.07 \text{ (value)} \]

From 1 and 2

\[ \left( \frac{0.07}{uy} \right) (y + 25)^2 = 9.52 \]

\[ x^2 + 50d + 625 = \frac{9.52 \times y}{0.07} \]

\[ x^2 - 994y + 625 = 0 \]

\[ d = 4.9289 \text{ or } 4.9273 \]

Total length of curve

\[ t = \&d = 9.8546 \text{ m} \]

Example: An ascending gradient of Line 60 meets a descending gradient of Line 50. Find out length of summit curves for a stopping sight distance of 180 m.

\[ \text{Line 60} \]

\[ \text{Line 50} \]

\[ \text{Line 60} \]

\[ \text{Line 50} \]

\[ L \]

\[ K \]
\[
N = \left| \frac{1}{n_1} - \frac{1}{n_2} \right|
\]

\[
N = \left| \frac{1}{60} - \left( -\frac{1}{50} \right) \right| = \frac{5+6}{300} = \frac{11}{300}
\]

Assuming worst case curve (lc > s)
\[
L = \frac{N s^2}{4.4}
\]

\[
L = \frac{\frac{11}{300} \times (180)^2}{4.4} = 270m
\]

\[
L > s, \text{ so assumption is correct, hence (OK)}
\]

A valley curve of a straight highway is formed by a down gradient 1 in 20 meeting an up gradient 1 in 30. Design the length of valley curve to fulfill both comfort condition and headlight sight distance condition.

\[
c = 0.60 \, \text{m/s}^2 \quad \text{tr} = 2.5s
\]

Design speed = 80 km/hr.

1. Comfort condition

\[
x = L_s - L_s - L_s
\]
Length of curve

\[ L = 2L_5 = 2 \times \left( \frac{N \cdot V^3}{C} \right) \]

\[ N_1 = \frac{1}{20} \quad N_2 = \frac{1}{30} \]

\[ N = \left( \frac{1}{N_1} - \frac{1}{N_2} \right) = \left| \frac{-1}{20} - \frac{1}{30} \right| = \frac{5}{600} \]

\[ L = 2 \times \left[ \frac{50}{600} \times (0.278 \times 80)^3}{0.60} \right]^{1/2} \]

\[ L = 78.3 \text{ m} \]

2. Head light side distance

\[ S = 0.278 \cdot V \cdot t \cdot r + (0.278)^2 \left( \frac{t \pm 5.4}{2t} \right) \]

Assuming \( L_c > S \)

\[ S = 0.278 \times 80 \times 7.5 + (0.278 \times 80)^2 \]

\[ 2 \times 81 \times (0.35 \pm 50) \]
SSD (cs) = 127.63 m, \[ \text{consider } \eta = 0.75, \ B = 1' \text{ if not given standard} \]

\[ L = \frac{N s^2}{2 (n_1 + s n_\eta)} \]

\[ = \frac{500 \times 127.63^2}{2 \left[ 0.75 + 127.63 \times 0.75 \right]} \]

\[ = 228.93 \text{ m} \]

\[ 	ext{say } = 228 \text{ m} \]

228 m > s

Hence O.K.

Assumption is correct.

Provide length of curve = 228 m, [provide max. length, is it both condition]
Traffic Engg.

Topic to discussion
Traffic characteristics
- Road use characteristic
- Vehicular characteristic
- Parking characteristic

Traffic studies
- Traffic volume
- Traffic density
- Speed study
- C 8 D study
- Traffic flow study
- Traffic capacity
- Parking study
- Accident study

Traffic operations and control
- Traffic regulations
- Traffic control devices

Traffic signs
- Regulatory sign & police
- Warning sign & others
- Informational sign & Just for information
- Traffic signal
- Traffic island
- Traffic rotary design
  - Design of intersection & grade separation
  - Parking and lighting

4. Traffic planning
5. Geometric design

**Braking Characteristics**

Diagram:

- Brakes applied
- Time
- Retardation
- V = 0

**Assumptions**

1. After application of brakes, wheels are fully jammed.
2. Vehicle is just skidding over road surface.
3. Brake efficiency = 100%
4. Friction coefficient (f) is utilised.
5. In case brake efficiency is less than 100%...
\[ \text{Observed} \times 100 = \frac{\text{Brake efficiency}}{f_{\text{max}}} \]

A vehicle travels a distance after application of brakes.

\[ F \cdot E = \text{work done} \]

\[ \frac{1}{2} m v^2 = F x s \]
\[ \frac{1}{2} m v^2 = f \cdot m g \cdot s \]

\[ v^2 = 2 g f \cdot s \]
\[ v = \sqrt{2 g f s} \]

\[ \text{Observed} = \frac{v^2}{2 g s} \]

If time taken = t sec.

\[ \text{retardation} = a \]

\[ -a = \frac{v - u}{t} = \frac{0 - v}{t} \]

\[ a = \frac{v}{t} \]

\[ v^2 = u^2 + 2 g s \]

\[ a = \text{Give} = \text{Retardation.} \]
\[ a = \frac{v - v_0}{t} \]
\[ f = \frac{a}{g} \]

\[ f = \text{average skid resistance} \]

\[ S = ut + \frac{1}{2} at^2 \]
\[ = vt - \frac{1}{2} \frac{v}{t} t^2 \]
\[ = vt - \frac{1}{2} vt \]
\[ S = \frac{vt}{2} \]

**Question:** A vehicle moving at 65 kmph, speed was stopped by applying brakes and the length of skid marks was 25.50 m. If average skid resistance is known to be 0.70, determine the brake efficiency and left vehicle.

Calculate:
1. Time taken
2. Retardation.
\[ v = 6.5 \text{ km/h} \]
\[ v = 85.5 \text{ m/s} \]

\[ v = 65 \text{ km/h} = 0.278 \times 65 = 18.07 \text{ m/sec} \]

Average skid resistance

\[ f = \frac{v^2}{2gs} \]

\[ f = \frac{(18.07)^2}{2 \times 9.81 \times 85.5} = 0.6526 \]

Brake efficiency

\[ = \frac{0.6526 \times 100}{6.70} = 93.23 \% \]

Time taken

\[ s = \frac{vt}{2} \Rightarrow t = \frac{2s}{v} \]

\[ = \frac{2 \times 25.50}{18.07} = 2.82 \text{ sec} \]

Retardation

\[ a = gf = 9.81 \times 0.6526 = 6.40 \text{ m/sec}^2 \]

\[ a = \frac{v}{t} = \frac{18.07}{2.82} = 6.40 \text{ m/sec}^2 \]
If a vehicle takes \( t = 0.5 \text{ sec} \) to stop and the skid marks observed are \( s = 4.6 \text{ m} \). Calculate:

1. Initial speed of vehicle
2. Average skid resistance
3. Retardation.

\[ t = 0.5 \text{ sec} \]

\[ s = 4.6 \text{ m} \]

1. **Initial speed \( v \)**
   
   \[ s = \frac{vt}{2} \]
   
   \[ v = \frac{2s}{t} = \frac{2 \times 4.6}{0.5} = 20.4 \text{ m/sec} \]
   
   \[ v = 73.54 \text{ mph} \]

2. **Retardation \( f \)**
   
   \[ f = \frac{v^2}{2s} \]
   
   \[ f = \frac{(20.4)^2}{2 \times 4.6} = 0.463 \]

3. **Retardation \( a \)**
   
   \[ a = gt \]
   
   \[ a = 9.81 \times 0.463 = 4.54 \text{ m/sec}^2 \]
Traffic study:

Traffic volume:

Number of vehicle passing from a road section one unit of time.

Units = vehicle/hr or vehicle/day

1. Hourly volume
2. Daily volume

Traffic volume can be represented as ADT or AADT (Average annual daily traffic).

All class of vehicles are converted into one class of vehicles (passenger car) using a conversion factor (PCU).

Different type of vehicle PCU
1. Passenger car, tempo, tractor, bullock cart
2. Bus, truck, agricultural tractor-trailer unit
3. Motorcycle, scooter, pedal cycle
4. Cycle rickshaw
5. Horse drawn vehicles
6. Small bullock cart and hand cart
7. Large bullock cart
1. Trend chart:-
   Showing volume trends over a period of years.
   2007  2008  2009  2010  2011
   450   560   790   860   1850  Event: peak

2. Variation Chart:-
   Showing variation of volume.

3. Traffic flow maps:
   on different roads.

4. 30th highest hourly volume

The value that has been exceeded 24 times is called 30th highest hourly volume.
Traffic density:
Number of vehicles found at a particular instant on a road in 1 km length is called traffic density.

\[
\text{unit} = \text{vehicles/km}
\]

\[
\text{speed of vehicle} = \text{km/hr}
\]

Relation btw. volume, density, speed:

\[
\text{volume} = \text{density} \times \text{speed}
\]

\[
\frac{\text{veh}}{\text{hr}} = \frac{\text{veh}}{\text{km}} \times \frac{\text{km}}{\text{hr}}
\]

\[
\text{speed} = \text{density} \times \text{relationship for a particular road was found to be}
\]

\[
V = 42.76 - 0.22K
\]

where \( V \) = speed in km/hr
and \( K \) = density in veh/km
Find the capacity of road.

Give your comment on the results. Sketch density vs flow and show important traffic flow parameter.

$$u = 42.76 - 0.22K$$

Capacity of road (volume that can be accommodated on road)

$$C = \text{volume} = \text{density} \times \text{speed}$$

$$C = K (42.76 - 0.22K)$$

$$C = 42.76K - 0.22K^2$$

For $$C = 0$$

$$42.76K - 0.22K^2 = 0$$

$$K(42.76 - 0.22K) = 0$$

$$K = 0$$

$$42.76 - 0.22K = 0$$

$$K = \frac{42.76}{0.22} = 194.35 \text{ vehicle/km}.$$

Flow $$F$$

$$C$$

2018 veh/hr

[Graph of parabolic equation from parabolic variation]
For \( c \) to be max

\[
\frac{dc}{dk} = 0
\]

\[
42.76 - 2 \times 0.22k = 0
\]

\[
k = \frac{42.76}{2 \times 0.22} = 97.18
\]

\[
c = 42.76 \times 97.18 = 2078 \text{ veh/hr}
\]

**Important Values**

1. Volume is zero at zero density.
2. Volume increases if density in increasing and shall be max at \( k = 97.18 \text{ veh/km} \).
3. After this value, volume is reduced and again becomes zero at \( k = 140.36 \text{ veh/km} \).

Max n flow observed

\[
= 2.78 \text{ km/hr}
\]
1. **Origin and Destination Study** (C0 and D study)
   - Road side interview
   - License plate method
   - Return post card method
   - Tag on car method
   - Home interview method
   - Work spot interview method

**Presentation:**
- Desire wine are prepared
- Thickness of desire wine
- Show volume on that road

**Capacity:** The traffic volume that can be accommodated on a road is called capacity.

1. **Basic Capacity:**
   - Basic capacity is the max. traffic volume that can be achieved in most ideal condition of traffic and road.

2. **Possible Capacity:** The traffic volume that may be found on a road in different condition
   - In worst case, = 0
   - In most ideal case – basic capacity.
0 ≤ possible capacity ≤ basic capacity
practical capacity:

It is the traffic volume that is on in general condition of road. Traffic most of the time.

Theoretical maximum capacity:

1) As per velocity and distance maintained below two vehicles.

\[ V \text{ km} = \frac{1000 \, V \text{(m)}}{s} \text{ km/h} \]

\[ V \text{ km/h distance travelled in 1 hour} \]

Theoretical max. capacity

\[ C_{\text{max}} = \frac{1000 \, V}{s} \left( \frac{\text{veh}}{\text{hr}} \right) \]

\[ V = \text{speed in km/h} \]

\[ s = \text{minimum distance between two vehicles} \]

\[ s = (0.7V + d) \]

\[ s = (0.2V + l) \]

0.7 sec = perception reaction time
If time headway btw two vehicles = \( t_h \) sec.

\[
C_{\text{max}} = \frac{3600}{t_h} \quad (\text{veh/hr})
\]

one vehicle pass m in \( t_h \) sec.

\[
C_{\text{max}} = \frac{3600}{t_h} \quad (\text{veh/hr})
\]

Q1: Estimate max theoretical capacity of a highway for one away one lane traffic moving at 65 km/hr speed consider average length of vehicle = 5.2 m and time headway btw two vehicles = 2.5 sec.

Soln

1. As per speed
   \[d = 5.2 \text{ m}\]
   \[s = (0.7v + \varphi) = (0.7 \times 65 + 5) = 68.5 \text{ m}\]

2. Theoretical Capacity (max)

\[
C_{\text{max}} = \frac{1000v}{s} = \frac{1000 \times 65}{68.20} = 1040 \text{ veh/hr}
\]

Q2: As per time headway = 2.5 sec

\[
C_{\text{max}} = \frac{3600}{t_h} = \frac{3600}{2.5} = 1140 \text{ veh/hr}
\]

6. Accident Study:
   1. Type 1-
      1. A moving vehicle hit a parked vehicle
   2. Type 2 -
      2. Two vehicles moving at sight angle collide at an intersection
      3. A moving vehicle collide with an object
      4. Head on collision
For collision \( v_A > v_B \)

velocity of Approach = \((v_A - v_B)\)

After collision

velocity of separation = \((v_B' - v_A')\)

Newton law of collision:

As per this law, velocity of separation bears a constant ratio with velocity of approach. This ratio is called "coefficient of restitution" denoted by \( e \)

\[
e = \frac{\text{velocity of separation}}{\text{velocity of approach}} = \frac{v_B' - v_A'}{v_A - v_B}
\]

Range below 0 to 1

Perfectly elastic collision

\( e = 1.0 \)

\[
e = \frac{v_B' - v_A'}{v_A - v_B} = 1.0
\]
Perfectly plastic collision

\[ (v_A' - v_B') = (v_A - v_B) \]

\[ e = 0 = \frac{v_B' - v_A'}{v_A - v_B} \]

\[ v_B' - v_A' = 0 \]

\[ v_B' = v_A' \]

It means both body will move without separation.

Momentum Equation:

\[ (\text{As per conservation of energy}) \]

Total momentum before collision = Total momentum after collision

\[ m_A - v_A + m_B - v_B = m_A - v_A' + m_B - v_B' \]

![Diagram](image)

Apply forces

Movement of vehicle when brakes are applied

Brake efficiency = 100%

\[ K.E. \text{ loss} = \text{ work done} \]
\[ \frac{1}{2} m v_1^2 - \frac{1}{2} m v_2^2 = F \times S = f \cdot m g \cdot S \]

\[ v_1^2 = v_2^2 + 2g f \cdot S \]

\[ v_1^2 = \sqrt{v_2^2 + 2g f \cdot S} \]

**Case 1**: Collision of a moving vehicle with a parked vehicle.

**Assumption**

1. Collision is perfectly plastic.
2. Break efficiency is 100%.

**Before Collision**

\[ v_1^2 - v_2^2 = 2g f \cdot S_1 \]
\[ v_1 = \sqrt{v_3^2 + 2g f \cdot s_1} \quad (1) \]

**Momentum Equation:**

Total momentum just before collision = Total momentum just after collision

\[ m_A \cdot v_2 + m_B \cdot 0 = (m_A + m_B) v_3 \]

\[ v_2 = \left( \frac{m_A + m_B}{m_A} \right) v_3 \quad (2) \]

**After Collision:**

For vehicle A and B

\[ v_3^2 - v_0^2 = 2g f \cdot s_2 \]

\[ v_3^2 = 2g f \cdot s_2 \]

\[ v_3 = \sqrt{2g f \cdot s_2} \quad (3) \]

**Steps:**

1. **Given Values:**
   - \( s_1 \)
   - \( s_2 \)
   - \( m_A \)
   - \( m_B \)
   - \( f \)

2. Calculate \( v_3 \) from Eq.(3)

3. Calculate \( v_2 \) from Eq.(2)

4. Calculate \( v_1 \) from Equation (1)
A vehicle apply brakes and skid through a distance $u_0m$ before colliding another parked vehicle, the weight of which is $0.60 \times f$ of $f$.

From fundamental principles, calculate initial speed of moving vehicles if distance which both vehicle skid is $12m$. $f=0.60$.

Show the various step and assumption me each step.

\[ W_B = 0.60 \times W_A \]

\[ M_B = 0.60 \times M_A \]

After collision:

For vehicle $(A+B)$:

\[ v_3^2 = 2g f \times s_2 \]

\[ v_3 = \sqrt{2 \times 9.8 \times 0.60 \times 12} \]

\[ v_3 = 11.88 \text{ m/sec} \]
(1) **Momentum Equation**

\[ m_A v_2 + m_B 0 = (m_A + m_B) v_3 \]

\[ v_2 = \frac{m_A + m_B}{m_A} \times v_3 \]

\[ = \frac{m_A + 0.60 m_A}{m_A} \times 11.80 = 13.017 \]

(2) **Better Collision for A**

\[ v_1^2 - v_2^2 = 2\alpha f s_1 \]

\[ v_1 = \sqrt{v_2^2 + 2\alpha f s_1} \]

\[ v_1 = \sqrt{(15.017)^2 + 2 \times 9.8 \times 0.60 \times 140} \]

\[ v_1 = 28.853 \text{ m/sec} \]

\[ v_1 = 103.8 \text{ Kmph} \]

**Case 2**: Two vehicle moving at right angle collide at an intersection.

![Diagram](image)
Given values
- $S_{A1}, S_{A2}, S_{B1}, S_{B2}, f, M_A, M_B$

Find out
- $V_{A1}, V_{A2}, V_{A3}, V_{B1}, V_{B2}, V_{B3}$

After collision case:

For $A$

$V_{A3}^2 = 0^2 = 2g.f \cdot S_{A2}$

$V_{A3} = \sqrt{2g.f \cdot S_{A2}} $  \hspace{1cm} (1)$

For $B$

$V_{B3} = \sqrt{2g.f \cdot S_{B2}} $  \hspace{1cm} (2)$

Momentum equation:

Total moment in the direction of $x$ axis for vehicle $A$

$M_A \cdot V_{A2} + M_B \cdot 0 = M_A \cdot V_{A3} \cdot \cos \theta_A + M_B \cdot V_{B3} \cdot \sin \theta_B$

$V_{A2} = V_{A3} \cdot \cos \theta_A + \left( \frac{M_B}{M_A} \right) V_{B3} \cdot \sin \theta_B$  \hspace{1cm} (3)$

Total moment in the $y$ direction for vehicle $B$

$m_A \cdot 0 + M_B \cdot V_{B2} = M_A \cdot V_{A2} \cdot \sin \theta_A + M_B \cdot V_{B3} \cdot \cos \theta_B$

$V_{B2} = \left( \frac{M_A}{M_B} \right) V_{A3} \cdot \sin \theta_A + V_{B3} \cdot \cos \theta_B$  \hspace{1cm} (4)$
Before collision

For A
\[ V_{A1}^2 - V_{A2}^2 = 2gf \cdot S_{A1} \]
\[ V_{A1} = \sqrt{V_{A2}^2 + 2gf \cdot S_{A1}} \]  --- (5)

For B
\[ V_{B1}^2 - V_{B2}^2 = 2gf \cdot S_{B1} \]
\[ V_{B1} = \sqrt{V_{B2}^2 + 2gf \cdot S_{B1}} \]  --- (6)

Due. Two vehicles A and B approaching at right angle A from west and B from south, collide with each other.

1. Skid direction after collision
   \[ 50^\circ \text{ N} \text{ E} \]  \[ 60^\circ \text{ E of N} \]
2. Initial skid distance before collision
   \[ 35 \text{ m} \]  \[ 20 \text{ m} \]
3. Skid distance after collision
   \[ 15 \text{ m} \]  \[ 36 \text{ m} \]
4. Weight
   \[ 0.750 - \text{t B} \]  \[ 6 \text{t} \]
5. \( f = 0.55 \)

Calculate initial speed of two vehicles.
After Collision:

Let A: \[ V_{A3} = \sqrt{2g \cdot s_{A2}} \]

\[ V_{A3} = \sqrt{2 \cdot 9.81 \cdot 0.55 \cdot 15} = 12.72 \text{ m/sec} \]

for B: \[ V_{B3} = \sqrt{2 \cdot 9.81 \cdot 0.55 \cdot 36} = 19.71 \text{ m/sec} \]

Momentum Equation

\[ \theta_A = 130^\circ, \quad \theta_B = 60^\circ \]

In the diagram, \( \vec{V} \) is the initial velocity of A relative to B.

\[ M_A \cdot V_{A3} + M_B \cdot V_{B3} = M_A \cdot V_{A3} \cos \theta_A + M_B \cdot V_{B3} \sin \theta_B \]

\[ V_{A3} = \frac{V_{A3} \cos \theta_A + \frac{M_B}{M_A} V_{B3} \sin \theta_B}{M_A} \]

\[ V_{A3} = 12.72 \cdot \cos 130^\circ + \frac{1}{0.75} \cdot 19.71 \cdot \sin 60^\circ \]

\[ V_{A3} = 14.58 \text{ m/sec} \]
In the direction $y$-direction,

\[ m_A \cdot 0 + m_B \cdot v_{B2} = m_A \cdot v_{A2} \cdot \sin \theta_A + m_B \cdot v_{B3} \cdot \cos \theta_B \]

\[ v_{B2} = \frac{m_A}{m_B} \cdot v_{A2} \cdot \sin \theta_A + v_{B3} \cdot \cos \theta_B \]

\[ v_{B2} = 0.75 \times 12.72 \times \sin 60^\circ + 13.71 \times \cos 60^\circ \]

\[ v_{B2} = 17.16 \text{ m/sec} \]

3. Before collision

For A

\[ v_{A1} = \sqrt{v_{A2}^2 + 2g \cdot s_{A1}} \]

\[ v_{A1} = \sqrt{(14.58)^2 + 2 \times 9.81 \times 0.55 \times 35} = 24.29 \text{ m/sec} \]

\[ = 87.35 \text{ kmph} \]

For B

\[ v_{B1} = \sqrt{v_{B2}^2 + 2g \cdot s_{B1}} \]

\[ v_{B1} = 22.58 \text{ m/sec} \]

Design of signal timing

General principle of signal design

- Types:

  1. Two-phase system

  ![Diagram of two-phase system]
Type 2: Four phase system

For two phase system

Properties:

1. Red time on one road = (Green + Amber time on another road)

   \[ R_A = G_B + A_B \]

   \[ R_B = G_A + A_B \]
5. Unseen time on two roads is decided as per traffic volume on two roads.

\[
\frac{u_{1A}}{u_{1B}} = \frac{n_{A}}{n_{B}}
\]

3. Amber time - yellow time provided just after unseen time.

There are two purposes

- Length of vehicle
- Traffic sign
- SSD

4. Two: Allow the vehicle approaching the intersection to stop before the intersection.

For vehicle 1:
- Initial speed is \( v \) (\( v \) in m/sec).
- Retardation is \( a \), \( -a = \frac{v - 0}{t} \Rightarrow t = \frac{v}{a} \)
- Minimum time required to stop the vehicle (Amber time)
- \( t_{r} = t + \text{Braking time} \)
- \( t_{1} = t_{r} + \frac{v}{a} \)
To allow all these vehicles that are in danger area (within SSD curve) to go.

Maximum time required to cross (say vehicle no-2)

time = \frac{\text{Total distance}}{\text{Velocity}} = \frac{(\text{SSD} + \text{W} + \text{U})}{v}

t_2 = \left(\frac{\text{SSD} + \text{W} + \text{U}}{v}\right)

Amber time should be max. of \( t_1 \) and \( t_2 \)

Methods for designing signal timing:

1. Three phase method:

In this case traffic volume is used.

If 15 minutes traffic count on two roads are \( n_a \) and \( n_b \)

Assume a cycle time \( T \) sec.

Number of vehicles approaching the intersection on two roads in one cycle time
\[ X_A = \frac{\eta_A}{15 \times 60} X_T \]
\[ X_B = \frac{\eta_B}{15 \times 60} X_T \]

Average time required for one vehicle to cross the intersection = time headway = \( t \) sec.

Green time required on two roads:

\[ \begin{align*}
T_{iA} &= X_A \times t \\
T_{iB} &= X_B \times t
\end{align*} \]

<table>
<thead>
<tr>
<th>( T_{iA} )</th>
<th>( a_A )</th>
<th>( R_A )</th>
<th>( T_{iB} )</th>
<th>( a_B )</th>
</tr>
</thead>
</table>

Total cycle time:

\[ T_i = (T_{iA} + a_A) + (T_{iB} + a_B) \]

Calculated cycle time \( (T_i) \) should be equal to assumed cycle time \( T (\text{sec}) \).

If not, assume another cycle time and repeat the process.
It is min traffic count on two roads at 150 and 120 vehicle per lane. The amber time on two road is 5 sec. Design signal timing by said cycle period average time headway is 2.5 sec.

\[ n_A = \frac{150 \text{ veh}}{15 \text{ min} \text{ / lane}} \]
\[ n_B = \frac{120 \text{ veh}}{15 \text{ min} \text{ / lane}} \]

**Trail 1**

Assume cycle time = 60 sec.

No. of vehicle approaching two road in one cycle time.

\[ X_A = \frac{n_A}{15 \times 60} \times 60 = \frac{150}{15 \times 60} \times 60 = 10 \]

\[ X_B = \frac{n_B}{15 \times 60} \times 60 = \frac{120}{15 \times 60} \times 60 = 8 \]

Time headway = \( t_h = 2.5 \text{ sec.} \)

Green time required

\[ v_{1A} = 10 \times 2.5 = 25 \text{ sec.} \]
\[ v_{1B} = 8 \times 2.5 = 20 \text{ sec.} \]

Total cycle time

\[ = (2 \times X_A + t_h) + (2 \times X_B + t_h) \]
\[ = (25 + 2.5) + (20 + 2.5) = 55 \text{ sec.} \]
2nd Method

\[ T = \lambda_1 n + \lambda_2 A + \lambda_3 B + A_B \]

\[ = (\lambda_1 x t_{th}) + A_n + (\lambda_2 x t_{n}) + A_B \]

\[ = \left( \frac{\eta_n}{15 \times 60} \times T \times x t_{n} \right) + 5 + \frac{\eta_B}{800} \times T \times x t_{th} + 5 \]

\[ = \frac{150}{900} \times T \times x 2.5 + 10 + \frac{120}{900} \times x 2.5 \times t_{th} \]

\[ T = 0.416T + 10 + 0.333T \]

\[ T = \frac{10}{(1 - 0.416 - 0.333)} = 33.88 \text{ say } 40 \text{ sec.} \]

Approximate Method

If there are two roads (A) and (B)

Width of Road (A) = WA

Width of Road (B) = WB
Traffic volume (design volume per lane)

On road A = \( n_A = \frac{1500}{3} = 500 \text{ veh/hr/lane} \)

On road B = \( n_B = \frac{300}{1} = 300 \text{ veh/hr/lane} \)

Design steps:

Green time (minimum) required for pedestrian signal.

\[ t_{\text{pa}} = (7 \text{ sec.}) + \frac{w_A}{1.2} \rightarrow \text{time for pedestrian to cross} \]

\[ \downarrow \]

\[ \text{(initial work period)} \]

\[ V = 1.2 \text{ m/seg = speed of pedestrian} \]

\[ t_{\text{pb}} = 7 \text{ sec.} + \frac{w_B}{1.2} \]

Minimum red time on two roads

\[ R_A = t_{\text{pa}} \]
\[ R_B = t_{\text{pb}} \]

Minimum green time required on two roads (for traffic)

\[ R_A = t_{\text{pa}} + A_B \quad \Rightarrow \quad t_{\text{pa}} = R_A - A_B \]
\[ R_B = t_{\text{pa}} + R_B \quad \Rightarrow \quad t_{\text{pa}} = R_B - A_B \]
Considers any one week time over as calculated above and another is found using traffic volume at two roads.

\[ \frac{u_{1A}}{u_{1B}} = \frac{n_{A}}{n_{B}} \]

[Max of \( n_{A} \) and \( n_{B} \) is chosen.]

If \( u_{1B} \) is considered than \( u_{1A} \) calculate

\[ u_{1A} = \frac{n_{A}}{n_{B}} \times u_{1B} \]

(8)

4. Total cycle time

\[ T = (u_{1A} + A_{A}) + (u_{1B} + A_{B}) \]

- **Traffic @**

- **Traffic @**

- **[Pedestrian for @ traffic]**

- **Dw & Donat walk period**

- ** clearance interval**

- **P walk period**
3. \[ \text{RA} = \text{UA} + \text{AB} \]
   \[ \text{RB} = \text{UA} + \text{AN} \]

4. Do not walk period (pedestrian signal)
   \[ \text{Dwn} = \text{UA} + \text{AN} \]
   \[ \text{Dwb} = \text{UB} + \text{AN} \]

5. Clearance interval
   \[ \text{CIA} = \frac{WA}{1.2} \]
   \[ \text{CIB} = \frac{WB}{1.8} \]

6. Walk period on two roads
   \[ \text{WA} = \text{RA} - \text{CIA} \]
   \[ \text{WB} = \text{RB} - \text{CIB} \]

Note: Using approximate method, design signal timing on an intersection of two roads (A) and (B)

<table>
<thead>
<tr>
<th>Road</th>
<th>Width of Road</th>
<th>Traffic Volume (Total)/hr</th>
<th>Amber Time on two Roads</th>
<th>No. of Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18 m</td>
<td>900 veh/hr</td>
<td>5 sec</td>
<td>2 lane</td>
</tr>
<tr>
<td>B</td>
<td>7.5 m</td>
<td>350 veh/hr</td>
<td>5 sec</td>
<td>2 lane</td>
</tr>
</tbody>
</table>
Design four lane on two roads

\[ \eta_A = \frac{500}{100} \text{ v/hr/kane} \]
\[ \eta_B = \frac{350}{100} \text{ v/hr/kane} \]

Step 1: Minimum for pedestrians

1. \[ \text{time} = \frac{\text{WA}}{1.2} + 7.0 + \frac{18}{1.2} = 29.8 \text{ sec} \]

2. \[ \text{time} = 7.0 + \frac{7.5}{1.2} = 13.25 \text{ sec} = 14 \text{ sec} \]

Step 2: Minimum on traffic

- 22 sec.
- 14 sec.

Step 3: Minimum on traffic

- 14 - 5 = 9 sec.
- 17 sec.
Let us consider max.

\[ u_{TB} = 17.8 \text{ sec} \]

\[ \frac{v_{TA}}{u_{TB}} = \frac{2}{3} \Rightarrow u_{TA} = \frac{u_{TB} \times v_{TB}}{v_{TA}} = \frac{350}{280} \times 17 = 21.8 \text{ sec} \]

\[ u_{TB} = \frac{v_{TB}}{v_{TA}} \times \eta_n = \frac{350}{450} \times 9 = 7.8 \text{ sec} \]

If \( u_{TA} \) is considered

\[ v_{TA} = 28 \text{ sec} \]

\[ 0_{TB} = \frac{v_{TB}}{v_{TA}} \times \eta_n = \frac{350}{450} \times 9 = 7.8 \text{ sec} \]

Total cycle time

\[ = (u_{TA} + PA) + (u_{TB} + MB) \]

\[ = (22 + 8) + (17 + 5) \]

\[ = 43.8 \text{ sec} \]

\[ \text{Ta} = 27.8 \text{ sec} \]

\[ \text{Ra} = 28.8 \text{ sec} \]

\[ \text{Pa} = 27.8 \text{ sec} \]

\[ \text{WB} = 18 \text{ sec} \]

\[ \text{Pa} = 29.5 \text{ sec} \]

\[ \text{WB} = 18 \text{ sec} \]

\[ \text{Ra} = 28.8 \text{ sec} \]
4. \( R_A = \text{number of } A = 15 + 5 = 20 \)
\( R_B = \text{number of } B = 4 + 15 = 27 \)

4. Do not walk period
\( D_W = \text{number of } W = 21 \)
\( D_{WB} = \text{number of } WB = 22 \)

5. Clearance Minimum:
\[ C_{EA} = \frac{W_A}{12} = \frac{18}{12} = 1.5 \text{ sec} \]
\[ C_{EB} = \frac{W_B}{12} = \frac{7 + 5}{12} = 6.25 \approx 7 \text{ sec} \]

6. Walk period
\( W_A = 22 - 15 = 7 \text{ sec} \)
\( W_B = 27 - 7 = 20 \text{ sec} \)

7. Webster's Method

In this method, normal flow values and saturation flow values on different roads are used for design of signal cycle time.

If there are two roads:
- Normal flow (design value)
  \( \text{Road } A = Q_A \)
  \( \text{Road } B = Q_B \)
- Saturation flow values are
  \( \text{Road } A = S_A \), \( \text{Road } B = S_B \)
Saturation Flow Values

Road width: 3.0 3.5 4.0 4.5 5.0

\( S = 850 \quad 1250 \quad 1950 \quad 2250 \quad 2550 \)

(saturation flow)

Steps:

1. \( y_A = \frac{Q_A}{S_A} \)

2. \( y_B = \frac{Q_B}{S_B} \)

\( Y = y_A + y_B \)

3. Total cycle time

\( L = 2n + R \)

\( n = \) Number of phase

\( R = \) All road time (168 sec.

4. Optimum cycle time

\( C_0 = \frac{L + 5}{Y} \) sec.

5. Green time required on two road

\( Q_{IA} = \frac{y_A}{Y} (C_0 - L) \)

\( Q_{IB} = \frac{y_B}{Y} (C_0 - L) \)
Due to design similar timing for two road A and B.

Traffic volume of these two road are:

**Road A:**
- Width of road: 15m
- No. of lanes: 4
- Normal flow in one direction: 465 veh/hr/lane

**Road B:**
- Width of road: 8m
- No. of lanes: 2
- Normal flow in one direction: 350 veh/hr/lane

In opposite direction:

If curr red time = 15 sec, use Webster's method and design for 2-phases.

\[ q_A = 465 \text{ veh/hr/lane} \quad \text{[max 40% traffic A]} \]
\[ q_B = 350 \text{ veh/hr/lane} \quad \text{[max 40% traffic B]} \]

**Saturation flow:** Consider half of total width of road A for saturation flow.

**Road A:**
- For 7.50 width (from table)
- \( S_A = \frac{525 \times 7.50}{2} = 3937.5 \text{ veh/hr} \) [for two lane]
- \( S_A \text{ per lane} = \frac{3937.5}{2} = 1969 \text{ veh/hr/lane} \)
Road (R) per road width = 1-0 or one lane

\( SB = 1950 \) veh/hr/ lane

3) \( Y_A = \frac{Q_A}{S_A} = \frac{465}{1969} = 0.236 \)

\( Y_B = \frac{Q_B}{S_B} = \frac{350}{1950} = 0.18 \)

\( Y = 0.416 \)

b) Total loss time

\( L = 2N + R \quad \text{no. of phase (2)} \)

\( L = 2 \times 2 + 15 = 19 \) sec.

c) Optimum cycle time

\( C_0 = \frac{1.5L + 5}{1 - Y} = \frac{1.5 \times 19 + 5}{1 - 0.416} = 57.36 \) sec.

\( C = 60 \) sec

Green time

\( T_A = \frac{Y_A}{C_0} (C - L) = \frac{0.236}{0.416} \times (58 - 19) = 23.36 \) sec.

\( T_B = \frac{Y_B}{C_0} (C - L) = \frac{0.18}{0.416} \times (58 - 15) = 16.81 \) sec.

Total cycle time = \( T_A + T_B + T_B + T_B = 32.5 + \ldots \) sec.
4. TAC METHOD:

Combination of Approximate and Wester Method

1. Calculate small cycle time using approximate method.

\[ T_{\text{sec}} = (g_A + A_A) + (g_B + A_B) \]

2. Check for minimum green time required for vehicles accumulated.

No. of vehicle accumulated on two road in one cycle time

\[ x_A = \frac{n_A}{60 \times 60} \times T \]

\[ x_B = \frac{n_B}{60 \times 60} \times T \]

\[ \text{min green time} \leq 6 \text{ sec for 1st vehicle and 2 sec for all vehicles after 1st vehicle} \]

1. On road A for \( x_A \) vehicle

\[ t_{\text{min}} = 6 \text{ sec} + (x_A - 1) \times 2 \text{ sec} \]

2. On road B for \( x_B \) vehicle

\[ t_{\text{min}} = 6 \text{ sec} + (x_B - 1) \times 2 \text{ sec} \]

\[ t_{\text{min}} = (2x_B + 4) \text{ sec} \]

\[ t_{\text{min}} \leq 6 \text{ sec} \]

Hence O.K.
A Right angle intersection has two roads A and B. Design a two phase signal system using IRC method and using following data.

<table>
<thead>
<tr>
<th></th>
<th>Road A</th>
<th>Road B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of road</td>
<td>2.5 m</td>
<td>7.5 m</td>
</tr>
<tr>
<td>No. of lane</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Traffic volume in one dir</td>
<td>1850 veh/hr</td>
<td>350 veh/hr</td>
</tr>
<tr>
<td>Traffic volume in other direction</td>
<td>1360 veh/hr</td>
<td>290 veh/hr</td>
</tr>
<tr>
<td>Amber time</td>
<td>5 sec.</td>
<td>5 sec.</td>
</tr>
</tbody>
</table>

\[\eta_A = \frac{1850}{2} = 925 \text{ veh/hr/lanne} \]

\[\eta_B = \frac{350}{1} = 350 \text{ veh/hr/lanne} \]
1. Use approximate method to approximate.

2. Minimum green time required for pedestrian signal:

\[ \text{\( u_{PA} = 7.8 \text{sec} + \frac{W_A}{1.2} = 7 + \frac{94}{1.2} = 27.8 \text{sec} \)} \]

\[ \text{\( u_{PB} = 7.8 \text{sec} + \frac{W_B}{1.2} = 7 + \frac{7.5}{1.2} = 13.25 \leq 14 \text{sec} \)} \]

3. Green time for traffic signal:

\[ \text{\( R_A = u_{PA} = 27.8 \text{sec} \)} \]

\[ \text{\( R_B = u_{PB} = 14 \text{sec} \)} \]

\[ \text{Green Time} \]

\[ \text{\( u_{TA} = R_A - A_A = 14 - 5 = 9.8 \text{sec} \)} \]

\[ \text{\( u_{TB} = R_B - A_B = 27 - 5 = 22 \text{sec} \)} \]

4. Consider:

\[ \text{\( u_{IB} = 32 \text{sec} \) (Max value in \( u_{TA} \) and \( u_{TB} \)} \]

\[ \frac{u_{TA}}{u_{IB}} = \frac{\eta_A}{\eta_B} \]

\[ \text{\( u_{TA} = \frac{617}{350} \times 22 = 38.78 \text{ sec} \)} \]

5. Total cycle time

\[ T = (u_{TA} + A_A) + (u_{TB} + A_B) \]

\[ T = (39 + 5) + (22 + 5) \]

\[ T = 44 + 27 = 71 \text{ sec} \]

6. Number of vehicles accumulated on two roads

7. Number of vehicles accumulated on one cycle time.
\[ x_A = \frac{617}{60 \times 60} \times 71 = 12.17 \text{ sec. NOS.} \]

Green time required

\[ g_{Amm} = 6 + (13-1) \times 2 = 30 \text{ sec.} < 35 \text{ sec.} \quad \text{Hence O.K.} \]

\[ g_{Bmm} = 6 + (7-1) \times 2 = 18 \text{ sec} < 22 \text{ sec.} \quad \text{Hence O.K.} \]

\[ x_B = \frac{350}{60 \times 60} \times 71 = \text{say 7 NOS.} \]

\[ y_{mm} = 350 \text{ VEH/HR/LANE} \]

\[ q_a = 617 \text{ VEH/HR/LANE} \]

\[ q_b = 350 \text{ VEH/HR/LANE} \]

Saturation flow value

\[ q_{sA} = \text{for 12m width)} \]

\[ = 5.25 \times 12 = 6300 \text{ VEH/HR/LANE} \]

\[ = \frac{6300}{3} = 2100 \text{ VEH/HR/LANE} \]

\[ q_{sB} = \text{for 3.75m wide road)} \]

\[ = \frac{1890 + 1950}{2} = 1920 \text{ VEH/HR/LANE} \]
\[ Y_A = \frac{qA}{sA} = \frac{617}{2100} = 0.294 \]

\[ Y_B = \frac{qB}{sB} = \frac{350}{1920} = 0.182 \]

\[ y = Y_A + Y_B = 0.294 + 0.182 = 0.476 \]

**Total Loss Time**

\[ L = 2y + t \]

\[ = 2 \times 0.476 + 16 = 20.8 \text{ sec} \]

**Optimum Cycle Time**

\[ c_0 = \frac{1.5L + 5}{1 - y} = \frac{1.5 \times 20 + 5}{1 - 0.476} = 67.8 \text{ sec} \]

\[ t_A = \frac{Y_A}{y} (c_0 - L) = \frac{0.294}{0.476} (67.20) = 25 \text{ sec} \]

\[ t_A \text{ (time for } \text{A) hence ok} \]

\[ t_B = \frac{Y_B}{y} (c_0 - L) = \frac{0.182}{0.476} (67.20) = 18 \text{ sec} \]

\[ \text{Hence ok.} \]

\[ \begin{array}{c|c|c|c|}
\hline
Y_A & Y_B & A_B = 27 & T_A \\
\hline
33 & 5 & & \\
\hline
\end{array} \]

\[ \begin{array}{c|c|c|c|}
\hline
T_B & & & \\
\hline
P_B & \text{Pedestrian B) } & \text{Pedestrian \text{B} } & \\
\hline
\end{array} \]

\[ \begin{array}{c|c|c|c|c|c}
\hline
A_B = 44 & C_B = 32 & D_w = 37 \text{ sec} & P_B & \text{Pedestrian B) } & \\
\hline
\end{array} \]

\[ \begin{array}{c|c|c|}
\hline
P_B & \text{Pedestrian B) } & \text{Pedestrian \text{B} } & \\
\hline
\end{array} \]

\[ \begin{array}{c|c|c|c|c|c}
\hline
P_A & \text{Pedestrian A) } & \text{Pedestrian \text{A} } & \\
\hline
\end{array} \]
Red time = $678 + 22 + 5 = 27$ sec.

$RB = 678 + 22 = 900$ sec.

Donat walk period

$D_{WA} = 678 + 22 = 900$ sec.

$D_{WB} = 22 + 22 = 27$ sec.

Clearance time:

$CT_{A} = \frac{24}{1.2} = 20$ sec.

$CT_{B} = \frac{7.5}{1.2} = 6.25 \approx 7$ sec.

Walk period:

$WA = 900 - 20 = 880$ sec.

$WB = 44 - 7 = 37$ sec.

A driver travelling at speed limit of 40 mph is cited for crossing an intersection the claimed it, duration of amber display was improper and consequently a conflict zone existed at that location. Using following data, determine whether claim was correct.

Amber duration = 0.5 sec.

Comfortable deceleration = 3 m/s²

Car travel time = 0.6 sec

Intersection width = 15 m
Amber display time is required for two purposes:

1. To stop the vehicle approaching the intersection.
   - Time required to stop: \( t = \frac{v}{a} \)
   - \( t = 5 + \frac{0.278 \times 50}{3} \approx 6.13 \) sec
   - Amber time provided: 4.50 sec

2. To allow the vehicle in danger area to cross the intersection.

\[
SSD = 0.278 \times v + a + \left( \frac{0.278 \times v}{2a} \right)^2
\]

\[
SSD = 0.278 \times 50 \times 1.5 \times 5 + \frac{0.278 \times 250}{2 \times 0.35 + 0}
\]

\[
SSD = 20.85 + 28.14 = 48.99 \text{ m}
\]
Total time required to cross

\[ \frac{S + D + W + U}{0.278V} \]

\[ = \frac{4.3 + 15 + 4.6}{(0.278)(50)} \]

\[ = 4.935 \text{ sec.} \]

> 4.50 sec.

Yes, driver claim is correct.

Design of Rotary intersection:

1) Circular Rotary

2) Elliptical Rotary
3. Turbine Rotary:

- Tangential Rotary

(105°)

- Design Speed:
  - Rural Area: 40 kmph
  - Urban Area: 30 kmph

- Radius of rotary (minimum radius of traffic island):
  - No super-elevation is provided [Curves slope is provided to drain off water]
  - \( e = 0 \)

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

\[ R_{\text{min}} = \frac{v^2}{127f} \]

Here, value of \( f = 0.113 \) → Rural Area [40 kmph]

\( f = 0.47 \) → Urban Area [30 kmph]
4) As per IRC,
   Radiation of entry (Rentry)
   Rural area = 20 to 35 m (40 kmph)
   Urban area = 15 to 25 m (30 kmph)
   Minimum radius of central island
   \[ R_{min} = 1.035 \times R_{entry} \]

3) Width of carriageway

2) At entry \( e_1 \)
   Minimum = 5.0 m
   As per approaches road width
   7.0 m
   10.0 m
   14.0 m

6.5 m
7.0 m
8.0 m
2. Weaving section \( e_2 \)
   \[ e = \frac{e_1 + e_2}{2} \]

3. Width of weaving section
   \[ w = \left( \frac{e_1 + e_2 + 3.5}{2} \right) \]

4. Length of weaving section
   \[ L = 4 \times w = 4 \text{ times of width of weaving section} \]

   
   The value not given than recommended value
   
   \[ 30 \text{ kmph} \rightarrow 20 \text{ to } 60 \text{ m} \]

   \[ 60 \text{ kmph} \rightarrow 45 \text{ to } 105 \text{ m} \]

5. Capacity of portal -
   \[ Q_p = \frac{280w\left(1 + \frac{e}{w}\right)(1 - \frac{p}{3})}{\left(1 + \frac{w}{L}\right)} \]

   Where

   - \( w \) = width of weaving section
     \[ = \left( \frac{e_1 + e_2 + 3.5}{2} \right) \]

   - \( e \) = \( \frac{e_1 + e_2}{2} \)

   - \( L \) = length of weaving section

   - \( p \) = weaving ratio
     \[ = \frac{bt+c}{at+bt+ct+d} = \frac{\text{Total weaving traffic}}{\text{Total traffic}} \]
In a weaving section of type of movement of traffic can occur which is a, b, c, and d. It

\[ p = \frac{b + c}{a + b + c + d} \]

Weaving ratio

It is the ratio of number of weaving traffic (crossing to each other) to the total number of traffic in one weaving portion between any two legs.

A road intersection has legs designated as 1, 2, 3, 4, and 5. Leg 1 in N-S direction and others are marked clockwise. The traffic volume in (pcu/hr)

<table>
<thead>
<tr>
<th>Leg</th>
<th>Traffic Volume (pcu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>37</td>
</tr>
<tr>
<td>12</td>
<td>66</td>
</tr>
<tr>
<td>13</td>
<td>122</td>
</tr>
<tr>
<td>14</td>
<td>122</td>
</tr>
<tr>
<td>15</td>
<td>65</td>
</tr>
<tr>
<td>v41</td>
<td>18.2</td>
</tr>
<tr>
<td>v42</td>
<td>54</td>
</tr>
<tr>
<td>v43</td>
<td>18</td>
</tr>
<tr>
<td>v45</td>
<td>116</td>
</tr>
<tr>
<td>v52</td>
<td>13.9</td>
</tr>
<tr>
<td>v53</td>
<td>62</td>
</tr>
<tr>
<td>v54</td>
<td>15</td>
</tr>
<tr>
<td>v55</td>
<td>65</td>
</tr>
</tbody>
</table>
Find the weaving ratio between Leg 1 and 2. What is the use of this value? Draw a sketch showing traffic volume between 1 and 2.

\[ \text{Only clockwise traffic flow.} \]

\[ a = v_{12} = 37 \]

\[ b = v_{13} + v_{14} + v_{15} = 303 + 64 + 52 = 419 \]

\[ c = v_{12} + v_{13} + v_{52} = 132 + 54 + 132 = 308 \]

\[ d = v_{u3} + v_{53} + v_{54} \]

\[ = 18 + 62 + 15 = 95 \]

\[ p = \frac{b + c}{a + b + c + d} = \frac{37 + 419}{37 + 419 + 308 + 95} = 0.846 \]
Traffic flow in an urban area at right angle
Intersection of two major roads in the design years
are given below:

Both roads = 15 m wide

<table>
<thead>
<tr>
<th>Approach Road</th>
<th>Left Turning</th>
<th>Straight Turning</th>
<th>Right Turning</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>415</td>
<td>650</td>
<td>300</td>
</tr>
<tr>
<td>East</td>
<td>300</td>
<td>550</td>
<td>250</td>
</tr>
<tr>
<td>South</td>
<td>350</td>
<td>400</td>
<td>225</td>
</tr>
<tr>
<td>West</td>
<td>400</td>
<td>500</td>
<td>300</td>
</tr>
</tbody>
</table>

Design a roundabout intersection and check for its practical capacity making suitable assumptions.

[Diagram of roundabout with traffic volumes indicated]
weaving ratio between different legs

\[ a = 415 \]
\[ b = 650 + 300 = 950 \]
\[ c = 500 + 225 = 725 \]
\[ d = 200 = 200 \]

\[ \text{weaving ratio} = \frac{bt \cdot c}{a + bt + c} \]
\[ = \frac{350 + 725}{415 + 950 + 725 + 300} \]
\[ = 0.70 \]

\[ \text{weaving ratio} = \frac{300 + 850}{300 + 800 + 950 + 300} \]
\[ = 0.745 \]

\[ p = 0.71 \]

\[ \text{weaving ratio} = \frac{300 + 850}{400 + 800 + 650 + 225} \]
\[ = 0.699 \]

capacity

\[ Q_p = \frac{280w \left( 1 + \frac{g}{w} \right) \left( 1 - \frac{p}{3} \right)}{\left( 1 + \frac{w}{L} \right)} \]
Entry width \( e_i = 6.5 \times (15.5 / 2) = 7.5 \) m

\[ e_{1} = 7.5 \text{m} \]

Width of non weaving section \( e_2 = e_1 = 7.5 \text{m} \)

\[ e = \frac{e_1 + e_2}{2} = 7.5 \text{m} \]

Weaving portion width

\[ w = e_1 + e_2 + 3.5 = 7.50 + 7.50 = 11.00 \text{m} \]

Length of weaving portion \( l_w = 4 \times 11 = 44 \text{m} \)

Capacity \( q_p = \frac{280 \times 11 \left( 1 + \frac{7.5}{11} \right)}{\left( 1 + \frac{11}{44} \right)} \left( 1 - \frac{7.5}{3} \right) \)

\[ q_p = 3114.9 = 3115 \text{ veh/hr} \]

Road width = 15m
Pavement design

Type of pavement:

1. Flexible pavement:
   Flexible pavement are constructed by using stone aggregate with or without some binder material. Ex: Earth, bitumen etc., WBM or bituminous road are example.

   Generally consists of four layers:

   1. Surface course
   2. Base course
   3. Sub-base course
   4. Soil sub-grade (Natural ground)

   Road transfer is by grain to grain transfer.

   Pavement may be deflected in the shape of bottom surface due to any localised depression.
It has very low or negligible flexural strength. (It can not take 

Rigid Pavement:
- Rigid pavement are constructed by using cement concrete [PCC, RCC, PCC]
- consists of generally three layers.

1. Pavement (Cement concrete)
2. Lean concrete (Base course 1:5:10)
3. Soil Subgrade

- Load transfer is by slab action.
- Solid, rigid pavement can bridge over localized depressions, not deflected in the shape of bottom surface.

- It has sufficient flexural rigidity. Bending stress can be resisted.

3. Semi rigid pavement:
- It binder material of better quality like solid cement, lime, pozzolanic cement are
used with some aggregate, the pavement will have better strength and rigidity than flexible pavement. These are called semi-rigid pavement.

Design of Flexible pavement:

Some important points:

1. Maxm legal axle load as per IRC

\[ = 8170 \text{ kg} \]

2. Equivalent single wheel load \( E_{SWL} \)

\[ = 4085 \text{ kg} \]

3. Stress at a depth point at depth due to load from a wheel
1. If \( p \) = total wheel load
   \( a \) = radius of contact area
   
   Tyre pressure
   \[ p = \frac{P}{A} = \frac{P}{\pi a^2} \]

   Stress at \( z \) depth below the load
   Boussinesq's Equation
   \[ \sigma_z = p \left[ 1 - \frac{z^3}{(a^2 + z^2)^{3/2}} \right] \]

2. ESWL for a dual wheel assembly

   If \( d \) = clear distance between two wheels
   \( s \) = Centre to centre distance between wheels

   Upto \( d / 2 \) depth \( \rightarrow \) ESWL = \( p \)
   Beyond \( 2s \) depth \( \rightarrow \) ESWL = \( 2p \)
between $\frac{1}{2}$ and $2$ as $E_{SWL}$ values can be interpreted on a log scale.

Due: Calculate $E_{SWL}$ value for a dual wheel assembly carrying 20,500 kg each for pavement thickness of 15, 20, and 25 cm. If centre to centre distance between tyres is 30 cm, clear distance between wall is $18 = 12$ cm.
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Log_{10}(Depth)</th>
<th>ESWL</th>
<th>Log_{10}ESWL</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.778</td>
<td>2050</td>
<td>3.311</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.765</td>
<td>2.699</td>
<td>3.431</td>
<td>= 3.31 + \frac{3.31 - 3.31}{1.765 - 0.778}</td>
<td></td>
</tr>
<tr>
<td>1.301</td>
<td>2.544</td>
<td>3.469</td>
<td>= 3.31 + \frac{3.302}{1.301 - 0.778}</td>
<td></td>
</tr>
<tr>
<td>1.398</td>
<td>3.149</td>
<td>3.498</td>
<td>= 3.31 + \frac{0.302}{1.398 - 0.778}</td>
<td></td>
</tr>
<tr>
<td>1.778</td>
<td>3.100</td>
<td>3.613</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Methods for design of Flexible pavements

1. Group Index Method  

- Group index value is used for design of pavement required over a soil.

\[ \text{Index} = 0.2a + 0.005ac + 0.01bd \]

Here:

\[ a = P - 35 \] Prentice
\[ b = P - 15 \] Prentice
\[ c = WL - 40 \] Plus
\[ d = Ip - 10 \] Plus

Here:

\[ P = \% \] of the soil passing 0.074 mm sieve.

\[ WL = \text{Liquid limit} \]

\[ Ip = \text{Plasticity Index} \]

\[ Ip = WL - WP \]

\[ WP = \text{Plastic limit} \]

A value of group index may be 0 to 50, with a lower number indicating a stiffer or stronger soil. A higher number indicates a softer or weaker soil.
The thickness of pavement is found as per group index value, using tables and graphs.

**Table:**

<table>
<thead>
<tr>
<th>Soil Value</th>
<th>Base + Surface (T₁)</th>
<th>Sub-base (T₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4</td>
<td>15 cm</td>
<td>10 cm</td>
</tr>
<tr>
<td>5-9</td>
<td>20.5 cm</td>
<td>-20 cm</td>
</tr>
<tr>
<td>10-20</td>
<td>30 cm</td>
<td>30 cm</td>
</tr>
</tbody>
</table>

**Diagram:**

```
T
  |     |
  | T₁  |
  |     |
  |  T₂ |
  |     |
  | soil sub-strate |
```

**Limitations:**

- For all type of material used in pavement, thickness suggested same. Thickness does not depend upon quality of materials.
A soil subgrade has following data
(a) Soil passing through 0.074 mm sieve = 60%.
(b) $w_L = 45\%$, $w_p = 25\%$.

Calculate thickness of pavement required above the soil subgrade using group index method.

Use Table 1 as shown above.

\[ P = 60\% \]
\[ w_L = 45\% \]
\[ w_p = 25\% \]

\[ I_p = w_L - w_p = 45 - 25 = 20\% \]

\[ a = p - 35 = 60 - 35 = 25 \text{ (not OK)} \]
\[ b = p - 15 = 60 - 15 = 45 \text{ (not OK)} \]
\[ c = w_L - w_o = 45 - 40 = 5 < 20 \text{ OK} \]
\[ d = I_p - 10 = 20 - 10 = 10 < 10 \text{ OK} \]

Group index:
\[ 0.7a + 0.005aq + 0.01bd \]
\[ = 0.7(25) + 0.005(45)(25) + 0.01(10)(40) \]
\[ = 18.75 + 0.5625 + 4 \]
\[ = 23.3125 \text{ (say 20)} \]

Total thickness of pavement
1. Surface + base = 30 cm
2. Sub base = 30 cm

Total = $T = 30 + 30 = 60$ cm
CBR Method
(California Bearing Ratio Method)

- CBR Value:

A solid sample is put into a cylinder and a piston (plunger) is penetrated using loads. Load and penetration value are noted.

The value of load required for 2.5 mm penetration (P₁) and 5.0 mm penetration (P₂) are compared with standardized load values.

- Standardized load value: Load required for 2.5 mm and 5.0 mm penetration over standardized aggregate.
Standard load values are

2.5mm penetration = 1370 kg
5.0mm penetration = 2055 kg = 2055 kg.

4) CBR Values

\[ \text{CBR} = \frac{\text{Load over soft}}{\text{Standard load}} \times 100 \]

For 2.5 mm

\[ \text{CBR} = \frac{P_1}{1370} \times 100 \]

For 5.0 mm

\[ \text{CBR} = \frac{P_2}{2055} \times 100 \]

5) Generally 2.5mm penetration CBR values is higher, if it is accepted as CBR values.

6) If 5.0mm CBR value is higher,

then the test is repeated and if same results are obtained again the 5.0mm CBR value (Chirner value) is accepted as CBR value.

- Graph blow load and penetration curve

- Normal curve \( P_1 \) and \( P_2 \) taken for 2.5 and 5.0mm penetration.

- If failure occurs without reading or initial concavity due to the soil compacted by hand not properly then amends are made.
If there is an initial concavity in the graph curve 2, this is due to false settlement at initial stage. In this case, a tangent is drawn from the steepest point and origin is shifted to the cutting point of this tangent with x-axis. $P_1'$ and $P_2'$ are read using shifted scale.

Design of pavement based on CBR values

Thickness of pavement

$$ T = \sqrt{\frac{1.75 \, P}{CBR} - \frac{A}{\pi}} $$
\[ T = \left[ \frac{1.75 \, P}{CBA} - \frac{A \times P}{\pi \times P} \right] / 25 \]

\[ T = \left[ \frac{1.75 \, P}{CBA} - \frac{P}{\pi \times P} \right] \quad \text{[} A \times P = P \text{]} \]

\[ T = \left[ \frac{P \left(1.75 - \frac{1}{\pi \times P} \right)}{CBA} \right] \]

where

- \( P \) = wheel load (kN)
- \( p \) = tyre pressure (kPa cm²)
- \( A = \frac{P}{p} \) = contact area (cm²)
- \( CBA = CBA \text{ value in } \% \)

Load acting on the circular area

[Diagram of load acting on the circular area]
quality of material used in pavement is not considered.

Thickness can be found for a limited CBR value only. \[ T = \frac{1.75 \times 10^3}{C_{BR}} \]

CBR test was conducted for soil subgrade and following results were obtained.

**Per cent** 0.5 1.0 1.5 2.0 2.5 3.0 4.0 5.0 7.5 10

<table>
<thead>
<tr>
<th>Per cent</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>4.0</th>
<th>5.0</th>
<th>7.5</th>
<th>10</th>
</tr>
</thead>
</table>

Above this soil subgrade following materials were used:

1) Compacted soil having CBR = 6.01.
2) Poorly graded gravel CBR = 13.01.
3) Well graded gravel CBR = 48.01.
4) Bituminous surface with uniform thickness
   - Wheel load = 4500 kg
   - Tyre pressure = 75 kg/cm²

Calculate thickness of different classes of pavement using CBR method.

1) Graph load and penetration
2) CBR value of soil subgrade.
P_1 = 60 \text{ kg} \\
P_2 = 83 \text{ kg}

\text{CBR}(2.5) = \frac{60}{1370} \times 100 = 4.384

\text{CBR}(6.0) = \frac{83}{2025} \times 100 = 4.044

\text{CBR value} = 4.384

\text{CBR value of soil subgrade} = 4.384

\text{Wheel load} \quad P = 4500 \text{ kg}

\text{Tyre pressure} \quad P = 710 \text{ kN/m}^2

\text{Contact area} \quad A = \frac{P}{p} = \frac{4500}{710} = 6.3586 \text{ cm}^2
Total thickness of pavement required over soil subgrade (CBR = 4.38%)

\[ T_1 = \sqrt{\frac{1.75p}{CBR} - \frac{A}{\pi}} = \sqrt{\frac{10.75 \times 4500}{4.38} - \frac{642.86}{\pi}} \]

\[ = 33.01 \text{ cm} \text{ say 40 cm} \]

- 40 cm, well graded gravel \( T_2 = 33.5 \text{ cm} \)
- 13.5 cm, poorly graded gravel
- Compacted soil \( t_3 = 50 \text{ cm} \)

Soil subgrade \( [CBR = 4.38\%] \)

3) Thickness of pavement required above compacted soil \( [CBR = 6.1\%] \)

\[ T_2 = \sqrt{\frac{1.75 \times 4500}{6.0} - \frac{642.86}{\pi}} \]

\[ T_2 = 33.28 \approx 33.5 \text{ cm} \]

Thickness of compacted soil required

\[ T_1 - T_2 = 40 - 33.5 = 6.5 \text{ cm} \]

Total thickness of pavement required above poorly graded gravel \( [CBR 13.0\%] \)
\[ T_3 = \sqrt{\frac{1.75 \times 4500}{13} - \frac{642.86}{20}} = 20.03 \cong 20 \text{cm} \]

thickness of poorly graded gravel

\[ = T_2 - T_3 \]
\[ = 33.50 - 20 = 13.5 \text{cm} \]

thickness of well graded gravel

\[ = T_3 - 4 \text{cm} \]
\[ = 20 - 4 = 16 \text{cm} \]

3) California R-value Method

\( \text{California Resistance Value Method} \)

1) thickness of pavement required

\[ T = \frac{K \cdot (F \cdot T I) \cdot (30 - R)}{C \cdot V^5} \]

where

\( K = \text{constant} = 0.166 \)

\( T I = \text{Traffic Index} \)

\[ = 1.35 \cdot (EWL)^{0.11} \]

\( R = \text{Streblodomete R-value} \)

\( C = \text{Cohesionometer C-value} \)

\( EWL = \text{Yearly Value of Equivalent Wheel Load} \)
Total EWL Value = 330V_1 + 1070V_2 + 2460V_3 + 4620V_4 + 3040V_5

Thickness of pavement

T = 0.166 \times 1.35 (EWL)^{0.11} (90 - R)

\frac{c}{V_5}

T \approx 0.22 (EWL)^{0.11} (90 - R)

\frac{C^{0.20}}{C^{0.20}}

For two equivalent layers

\frac{T_1}{T_2} = \left( \frac{C_2}{C_1} \right)^{1/5}

Presently all values equal
Calculate 10 years EWL and traffic index value using following data:

<table>
<thead>
<tr>
<th>Nos. of Axle</th>
<th>AADT (Volume)</th>
<th>EWL (Constant)</th>
<th>Yearly Annual EWL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3750</td>
<td>330</td>
<td>1237500</td>
</tr>
<tr>
<td>3</td>
<td>410</td>
<td>1070</td>
<td>502900</td>
</tr>
<tr>
<td>4</td>
<td>320</td>
<td>2460</td>
<td>787200</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>4620</td>
<td>551400</td>
</tr>
</tbody>
</table>

Sum = 3082000

After 10 years: \( 1.60 \times 3082000 \)

\( = 4931200 \)

Average value (yearly value):

\( = \frac{3082000 + 4931200}{2} \)

\( = 4006600 \)
Ewe for 10 years period = 10 x 400,6600

= 400,6600

Traffic index

\[ TI = 1.35 \times (E_{we})^{0.11} = 1.35 \times (400,6600)^{0.11} \]

TI = 9.26

Thickness

\[ T = \frac{0.32 \times (TI) (30 - R_0)}{C^{0.20}} \]

\[ C = 0.22 \times 9 - 260 \times \zeta \]

\[ T = \frac{K \times (TI) (30 - R)}{C^{1.5}} \]

\[ T = \frac{0.166 \times 9.26 \times (90 - 48)}{(16)^{1.5}} \]

= 37.08 cm

To calculate the equivalent C-value of a three layer pavement having bituminous pavement

<table>
<thead>
<tr>
<th>Thickness</th>
<th>C-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 cm</td>
<td>62</td>
</tr>
</tbody>
</table>

Well graded gravel

<table>
<thead>
<tr>
<th>Thickness</th>
<th>C-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0 cm</td>
<td>180</td>
</tr>
</tbody>
</table>

Cement treated base

<table>
<thead>
<tr>
<th>Thickness</th>
<th>C-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.0 cm</td>
<td>25</td>
</tr>
</tbody>
</table>
Let us find equivalent thickness of each layer in terms of well graded gravel.

(1) Bituminous

\[ T_b = 12.5 \quad c_b = 0.2 \]
\[ T_w = \quad c_w = 2.5 \]

\[ \frac{T_b}{T_w} = \left( \frac{c_w}{c_b} \right)^{\frac{1}{5}} \Rightarrow T_w = T_b \times \left( \frac{c_b}{c_w} \right)^{\frac{1}{5}} \]

\[ T_{w1} = 12.5 \times \left( \frac{0.2}{2.5} \right)^{\frac{1}{5}} = 14.53 \text{ cm} \]

(2) Cement

\[ T_c = 25.0 \quad c_c = 1.80 \]
\[ T_w = 2 \quad c_w = 2.5 \]

\[ T_{w2} = T_c \times \left( \frac{c_c}{c_w} \right)^{\frac{1}{5}} = 25 \times \left( \frac{1.80}{2.5} \right)^{\frac{1}{5}} = 57.10 \text{ cm} \]

(3) Well graded gravel = 20.0 cm = \( T_{w3} \)

Total thickness of pavement in terms of well graded:

\[ T_w = T_{w1} + T_{w2} + T_{w3} = 14.53 + 57.10 + 20 = 72.03 \text{ cm} \]
Equivalent C-value = 25

\[ T_w = 72.00 \text{cm}, \quad C_w = 25 \quad \text{for total pavement} \]

\[ T_p = 57.50 \text{cm}, \quad C_p = ? \]

Actual thickness

\[ \frac{T_w}{T_p} = \left( \frac{C_p}{C_w} \right)^{\frac{1}{5}} \Rightarrow \frac{C_p}{C_w} = \left( \frac{T_w}{T_p} \right)^{5} \]

\[ C_p = C_w \times \left( \frac{T_w}{T_p} \right)^{5} = 25 \times \left( \frac{72.00}{57.50} \right)^{5} \]

\[ C_p = 77.4 \quad \text{Am}^{1} \]

---

Design procedure based on California R-value

Method 5

- For design of pavement, it is required to satisfy three criteria.
  1. Design based on R-value
  2. Design based on Expansion pressure
  3. Design based on Exudation pressure

- Exudation pressure is the value of pressure required to force out water from a soil.
Step 1) Thickness based on R-value.

Thickness of pavement calculated as:

\[ T_R = \frac{K_0 \cdot (T_L) \cdot (90 - R)}{0.16 \times 1 + 35 (E_{100})^{0.4}} \]

Step 2) Thickness based on Expansion pressure

Thickness of pavement is:

\[ T_e = \frac{\text{Expansion pressure (}cm^2\text{)}}{\text{Density of soil}} \]

\[ \rho [\text{g/cm}^3] = 0.002 \text{ g/cm}^3 \]

\[ T_e = \frac{\text{Expansion pressure}}{0.002} \text{ cm} \]

Step 3) Plot \( T_R \) vs \( T_e \)

![Graph showing the plot of \( T_R \) vs \( T_e \)]
Thickness of pavement required where

\[ T_R = T_e = T_1 + T_2 \text{ cm} \]

By drawing a line at 45° and above

Step 4: Plot \( T_R / \text{Exudation Pressure} \)

\[ \text{Exudation Pressure} \]

\[ \text{Exudation Pressure} \]

Thickness of pavement at 281.5 kg/cm² Exudation Pressure is found = T₂ cm.

Step 5: Thickness of pavement required

\[ = \text{Max} \text{ of } T_1 \text{ and } T_2 \]

Design a flexible pavement using WBM base course [c-value = 15] + 7.5 cm thick bituminous surface [c-value = 62] by California R-value method.

The soil subgrade has following data:

\[ \text{Traction mean } = 9.5 \text{ psi} \]
Moisture content | R-value | Expansion pressure | Exudation pressure | Tr | Te
--- | --- | --- | --- | --- | ---
15.1 | 56 | 0.135 | 36.5 | 31.20 | 64.30
18.1 | 44 | 0.099 | 26.5 | 42.20 | 47.14
21.1 | 25 | 0.055 | 18.0 | 53.60 | 26.20
24.1 | 14 | 0.034 | 15.0 | 69.73 | 16.20

**Step 1**
Thickness of pavement in terms of WBM value

(c = 15 value)

Thickness based on R-value

\[
Tr = \frac{K \cdot TE \cdot (g0 - R)}{c^{15}} = \frac{0.166 \times 5.50 \times (30 + 7)}{(15)^{15}}
\]

\[
Tr = 0.9175 \times (30 - R)
\]

\[
Tr(56) = 31.20 \text{ cm}
\]

\[
Tr(44) = 42.20 \text{ cm}
\]

\[
Tr(25) = 53.60 \text{ cm}
\]

\[
Tr(40) = 69.73 \text{ cm}
\]

**Step 2**
Thickness based on Expansion Pressure

\[
Te = \left( \frac{\text{Expansion Pressure}}{0.0021} \right)
\]

\[
Te(15.1) = \frac{0.135}{0.0021} = 64.30 \text{ cm}
\]

\[
Te(18.1) = \frac{0.099}{0.0021} = 47.14 \text{ cm}
\]
\[ T_{c}(212) = \frac{0.055}{0.0021} = 2620 \]

\[ T_{c}(441) = \frac{0.034}{0.0021} = 1620 \]

**Steps**

Plot \( T_R \) vs. Exudation pressure

\[ T_2 = 38 \text{ cm} \]

\( \eta \approx 28 \text{ kg/cm}^2 \)

Exudation pressure

**Thickness**

Say \( T_1 = 44 \text{ cm} \)
Step 5: Thickness of pavement

\[ T = 44 \text{cm of WBM layers} \]  
\[ T = 7.5 \text{cm Bitumen} \]

\[ T_B = 7.5 \text{cm} \]
\[ c_B = 6.2 \]
\[ T_B = T_B \left( \frac{E}{c_B} \right)^{1/5} \]
\[ T_B = 7.5 \left( \frac{62}{15} \right)^{1/5} = 3.6 \text{cm} \]

Say = 10 cm

Remaining thickness of WBM

\[ \text{Layer required} = 44 - 10 = 34 \text{cm} \]

(T) Triaxial Method:

- This method based on E-value

Thickness of:

- Young Modulus of Elasticity of different layers

\[ E_p > E_s \]

This is called a two-layer system

- \( E_p \) is pavement
- \( E_s \) is soil subgrade

- \( E_p > E_s \) because in pavement good material is provided
Thickness of pavement required for a two layers system:

\[ T_P = \left[ \left( \frac{3p \times Q \times Y}{2\pi E_s d} \right)^2 - Q^2 \right] \times \left( \frac{E_s}{E_p} \right)^{1/3} \]

where

- \( p \) = wheel load in kg
- \( x \) = Traffic Coefficient
- \( y \) = Rainfall Coefficient
- \( E_s \) = Young's Modulus of solid subgrade \( (P_a/cm^2) \)
- \( E_p \) = Young's Modulus of pavement \( (P_a/cm^2) \)
- \( \Delta \) = design deflection \( (0.25\,cm) \) \( (0.25\,cm) \)
- \( a \) = radius of contact area \( (cm) \)

The design a pavement section, by tri-axial method, using following data:

- Wheel load = 1000 kg
- Radius of contact area = 15 cm
- Traffic coefficient = 1.6
- Rainfall coefficient = 0.7
- Design deflection = 0.25 cm

Pavement consists of two layers over each other.
1. Base course, $E_B = 360$ kPa/cm²
2. Bituminous surfacing of 6 cm of, $E_{Bit} = 1200$ kPa/cm²

Soil subgrade = $E_s = 120$ kPa/cm²

Let us design pavement using base course material.

$E_p = 360$ kPa/cm²
$E_s = 120$ kPa/cm²

Thickness

$$ T = \frac{\sqrt{3 \pi y}}{2 \pi E_p} \cdot q^2 \cdot \left(\frac{E_s}{E_p}\right)^{\frac{1}{3}} $$

$$ T = \sqrt{\left(\frac{3 \times 1000 \times 1.6 \times 10^{-7}}{2 \times \pi \times 120 \times 0.25}\right)^2 \times \left(\frac{120}{360}\right)^{\frac{1}{3}}} $$

$$ T = 1.83 \text{ cm (say)} $$

$T_{Base} = 6 \text{ cm}$
$E_{Base} = 310$ kPa/cm²

$T_{Base} = 2$ cm
$E_{Base} = 310$ kPa/cm²
\[
\frac{T_{\text{bid}}}{T_{\text{base}}} = \left( \frac{T_{\text{base}}}{E_{\text{bid}}} \right)^{1/3} \approx 1.42
\]

\[
T_{\text{base}} = T_{\text{bid}} \times \left( \frac{E_{\text{bid}}}{E_{\text{base}}} \right)^{1/3} = 6 \times \left( \frac{1200}{360} \right)^{1/3} \approx 8.9 \text{ cm}
\]

- Remaining thickness of base course material:
  \[
  = 43.0 - 3 \text{ cm} = 40 \text{ cm}
  \]

- Total thickness of pavement is provided as:
  \[
  = 40 + 6 = 46 \text{ cm}
  \]

(3) Beamstress Method:

In this method, Young's Modulus of Elasticity \((E\text{-value})\) is used for design.

- Better quality materials are used in upper layers.
  \[
  E_1 > E_2 > E_3 > E_4
  \]
For rigid plates:

When in case of plate load test done over pavement or over soft subgrade:

\[ \Delta = 1.18 \frac{P \cdot a}{E_s} \cdot F_2 \]

Where:

- \( P \) = tyre pressure due to wheelload (Pressure due to load over plate)
- \( a \) = radius of contact area as radius of plate
- \( F_2 \) = Factor, constant
- \( \Delta \) = Diesim deflection (cm)

The plate bearing test was conducted with 30cm diameter plate on a soft subgrade yielded a pressure of 1kg/cm² at 5mm deflection.

The test carried out over 18cm basecourse yielded a pressure of 5kg/cm² at 5mm deflection.

Design the pavement section for wheel load of 10ton with a tyre pressure at 6kg/cm².
1) Plate bearing test on soft subgrade

- Diameter of plate = 30 cm
- Radius of plate = 15 cm
- Using rigid plate formula

$$\Delta = 1.18 \frac{p \cdot a}{E_s} \cdot F_2$$

where $$\Delta =$$ deflection = 5 mm = 0.5 cm

- $$p = 1000 \text{ kN/cm}^2$$
- $$a = 15 \text{ cm}$$
- $$F_2 = 1$$ (because single layer system)

$$0.5 = 1.18 \times \frac{1000 \times 15}{E_s} \times 1$$

$$E_s = 38.4 \text{ kN/cm}^2$$

2) Plate bearing test over 18 cm thick base course

- This is two layers system
- Using rigid plate formula

$$\Delta = 1.18 \frac{b \cdot q}{E_s} \cdot F_2$$

$$0.5 = \Delta$$

- $$E_s = 34.4 \text{ kN/cm}^2$$
- $$b = 51.24 \text{ cm}^2$$
- $$h = 18 \text{ cm}$$
- $$q = 150 \text{ kN}$$
In an experiment as shown in figure, Buzzminster shows that stresses are reduced by providing a layer. This is called reinforcing action of a layer.

Two values are important:

1. Ratio \( \left( \frac{h}{a} \right) = 1.5 \)

2. Ratio \( \left( \frac{E_s}{E_p} \right) = \frac{1}{100} \)

Buzzminster has suggested a factor \( F_2 \) for \( \frac{h}{a} \) and \( \frac{E_s}{E_p} \) ratio.
For a single layered system (when there is no cement)

\[ \delta = 0 \]

For \( E_s \) and \( E_p \) values of \( F_2 = 1.0 \)

**Replacement relationship**

- **Flexible plate**

A wheeled load is acting over a road surface, a flexible plate is to be considered.

Replacement

\[ A = 1.5 \cdot \frac{p \cdot a}{E_s} \cdot F_2 \]
\[ F_2 = 0.9 \]

From graph (given question)

\[ \frac{E_s}{E_p} = \frac{1}{100} \]

\[ E_p = 35.4 \times 100 = 3540 \text{ kg/cm}^2 \]

3) wheel over pavement
   (Design of pavement)

So that consider flexible pavement

\[ \Delta = 1.5 \cdot \frac{p \cdot q}{E_s} \cdot F_2 \]

\[ p = 4100 \text{ kg} \]
\[ q = 6 \text{ kg/cm}^2 \]
\[ \Delta = 5 \text{ mm} = 0.5 \text{ cm} \]
\[ E_s = 34.5 \text{ kg/cm}^2 \]

\[ 0.5 = 1.5 \times \frac{5 \times 14.75}{34.5} \cdot F_2 \]

\[ F_2 = 0.1333 \]

Using these values

\[ \frac{E_s}{E_p} = \frac{1}{100}, \quad F_2 = 0.1333 \]

From figure, \( \frac{h}{q} = 1.90 \text{ say} \)

\[ h = 1.90 \times 14.75 = 28.025 \text{ cm} \]

Thickness of pavement
Design of rigid pavement

Important terms:

- Modulus of subgrade reaction \( K \)

The value of pressure required for unit deflection (deformation) is called modulus of subgrade reaction:

\[
K = \frac{P}{\delta}
\]

\[\text{kPa/cm}^3, \quad \text{kg/cm}^3\]

[Apply pressure than \& deflection]

Radius of relative stiffness \( W \):

\[
d = \left[ \frac{E_e h^3}{12k(1-\nu^2)} \right]^{1/4}
\]

where

- \( E_e \) = Young modulus of elasticity of pavement (cement concrete slab)
- \( h \) = thickness of slab
- \( k \) = modulus of subgrade reaction
- \( \nu \) = Poisson's ratio = 0.15

Equivalent radius of resisting section \( r \)

The area effective for taking \( B \) or \( B^0 \).
(1) \( a < 1.724 \, h \)

\[
b = \sqrt{1.6a^2 + h^2} - 0.675 \, h
\]

(2) \( a > 1.724 \, h \)

\[
b = a
\]

Where

- \( a \) = radius of contact area (cm)
- \( h \) = thickness of slab (cm)
- then \( b = \text{cm} \)

The stresses developed in a concrete slab:

\[ \rightarrow \text{There are three stresses developed} \]

1. Load stresses (due to load)
2. Temperature stresses
   a. warping stress
   b. friction stress.

Load stresses: [Westergaards Method]

Westergaards stress equations

1. Interior stress

\[
S_I = \frac{0.316 \, P}{h^2} \left[ y \log_{10} \left( \frac{t}{b} \right) + 1.069 \right]
\]
Edge stresses

\[ Se = \frac{0.572}{h^2} \left[ 4 \log_{10} \left( \frac{a}{b} \right) + 0.359 \right] \]

Corner stresses

\[ Sc = \frac{3P}{h^2} \left[ 1 - \left( \frac{c_{52}}{a} \right)^{0.6} \right] \]

Here

- \( P \): wheel load \( m \) (kg)
- \( h \): slab thickness \( m \) (cm)
- \( a \): radius of relative stiffness (cm)
- \( b \): \( R \): radius of resisting section (cm)
- \( A \): radius of contact area

in interior case/edge

\( \Theta \) at corner

Tension: give

Compression: give
To calculate the stresses at interior, edge and corner region of a cement concrete pavement using Westergaard's stress equations, using following data:

wheel load value: \( p = 4100 \) kg

\( E_c = 3.3 \times 10^5 \) kg/cm²

\( h = 18 \) cm, \( m = 0.15 \), \( k = 25 \) kPa/cm², \( q = 12 \) cm

so

1. Radius of relative stiffness

\[ d = \left[ \frac{E h^3}{12 k (1 - m^2)} \right]^{1/4} \]

\[ d = \left[ \frac{3.3 \times 10^5 \times 18^3}{12 \times 25 \times (1 - 0.15^2)} \right]^{1/4} \]

\[ d = 50.61 \text{ cm} \]

2. Equivalent radius of resisting section

\( a = 12 \) cm, \( h = 18 \) cm

\( a < 1.72 h \)

\[ b = \sqrt{1.69^2 + h^2} = 0.675 h \]

\[ b = \sqrt{1.69^2 + 18^2} = 11.4 \text{ cm} \]

3. Stresses

a. Interior stress

\[ s_1 = \frac{0.316 p}{h^2} \left[ \text{Ungauged} \frac{4}{b} + 1.065 \right] \]
\[ S_t = \frac{0.316 \times 4100}{18^2} \left[ 4 \ln \left( \frac{50.61}{11.40} \right) + 1.069 \right] \]

\[ S_t = 14.63 \text{ kN/cm}^2 \]

\( \beta \text{ edge stresses} \)

\[ S_{\beta} = \frac{0.572 \times P}{h^2} \left[ 4 \ln \left( \frac{50.61}{11.40} \right) \frac{h}{b} + 0.359 \right] \]

\[ S_{\beta} = 0.522 \times 4100 \left[ 4 \ln \left( \frac{50.61}{11.40} \right) + 0.359 \right] \]

\[ S_{\beta} = 31.34 \text{ kN/cm}^2 \]

\( \gamma \text{ corner stresses} \)

\[ S_{\gamma} = \frac{3 \times P}{h^2} \left[ 1 - \left( \frac{9.52}{19} \right)^{0.6} \right] \]

\[ S_{\gamma} = 3 \times 4100 \left[ 1 - \left( \frac{12 \times 52}{50.61} \right)^{0.6} \right] \]

\[ S_{\gamma} = 18.25 \text{ kN/cm}^2 \]

1) Temperature stress \( \sigma_t \)

2) Warping stress \( \sigma_w \)

Due to variation of temperature during day/night.
During day:

- Expansion

During night:

- Max stresses occur due to warping.

(2) Frictional stresses:

(Due to seasonal temperature variation)

(a) During summer:

- Friction due to soil

(b) Winter season:

- Increase towards downstream

Stress diagram:

- Tensile due to pore pressure
- Compressive due to confinement
- GW water

 Throughout

Creeping Stresses

Torsion Stress

\[ \sigma_t = \frac{E \cdot r \cdot T}{2} \left( \frac{C_x + \mu y \cdot C_y}{1 - \mu^2} \right) \]

Edge Stresses

\[ \sigma_e = \frac{C_x \cdot E \cdot r \cdot T}{2} \]

or

\[ \sigma_e = \frac{C_y \cdot E \cdot r \cdot T}{2} \]

Corner Stresses

\[ \sigma_c = \frac{E \cdot r \cdot T}{2 (1 - \mu^2)} \left[ \frac{a}{y} \right] \]

\[ E = \text{Young Modulus of Elasticity of Cement Concrete} \]

\[ \mu = \text{Coefficient of Thermal Expansion} \]

\[ \frac{L_y}{y} = \text{Temperature Variation between Day and Night} \]

\[ \mu = \text{Poisson Ratio} \]

\[ \frac{L_y}{y} = \text{Coefficient based on} \]

\[ \frac{L_y}{y} = \text{Coefficient based on} \]
\[ L_y \]

\[ L_x \]

\( u = \text{Radius of Relative Stiffness} \)

\( a = \text{Radius of Contact Area} \)

Value of \( C_x \) and \( C_y \)

\[ \begin{array}{c|c|c}
\frac{L_x}{\varphi} & \frac{L_y}{\varphi} & C_x \text{ or } C_y \\
2 & 3 & 0.2 \\
4 & 5 & 0.6 \\
8 & 9 & 1.1 \\
12 & 13 & 1.02 \\
\end{array} \]
Fictional stresses

Due to seasonal temperature variation

Tensile stress developed, this stress is equal to the stress developed during winter.

\[ F = f \cdot R \]

During winter, slab try to contract, and contraction is prevented by frictional force \[ F = f \cdot R \]

\[ R = wL \text{ of half portion of slab.} \]

Frictional force

\[ F = f \cdot R \]

For half portion of shaded area:

\[ R = \frac{M_0}{S_{RFBD}} = \left( \frac{1}{2} X B \right) h x \]

Resisting force \( F \) in act at center on shaded area, \( f \) max tensile stress.

Then:

\[ F = S_f \times A \times f = S_f \times X B \times h \]
A pavement slab 22 cm thick is constructed over a granular subbase having $k = 18$ kN/cm³ spacing between joint. Longitudinal joint = 5.0 cm.

Des. wheel load = 4500 kg

Max. difference of temperature = 20°C

Radius of contact area = 15 cm

$Ec = 3 \times 10^5$ kN/cm²

$\alpha = 0.15, \quad \Delta = 12 \times 10^{-6}/^\circ C, \quad f = 1.50$

Find out best combination of stresses.
Ly = B = 4.2 cm, L = Lx = 55 cm
H = 22 cm, P = 4500 kg, T = 20°C, a = 15 cm.

1) Load stresses.

2) Radius of relative stiffness

\[ d = \left( \frac{Eh^3}{12K(1-\nu^2)} \right)^{\frac{3}{2}} \]

\[ d = \left( \frac{3 \times 10^5 \times 22^3}{12 \times 18 \times (1-0.15^2)} \right)^{\frac{3}{2}} = 62.37 \text{ cm} \]

4) Equivalent radius of resisting section

\[ a = 15, \ h = 22 \quad (a < 1.724h) \]

\[ b = \sqrt{1.6a^2 + h^2} - 0.675h \]

\[ b = \sqrt{1.6 \times 15^2 + 22^2} - 0.675 \times 22 = 14.20 \text{ cm} \]

5) Interior stresses

\[ S_i = \frac{0.316 P}{h^2} \left[ y \log_{10} \left( \frac{d}{b} \right) + 1.069 \right] \]

\[ S_i = \frac{0.316 \times 4500}{22} \left[ y \log_{10} \left( \frac{62.37}{14.20} \right) + 1.069 \right] = 10.69 \text{ kg/cm}^2 \]
(1) Edge stresses

\[ S_e = \frac{0.572 \cdot P}{h^3} \left[ \log_{10} \left( \frac{y}{b} \right) + 0.359 \right] \]

\[ = \frac{0.572 \times 4500}{22^2} \left[ \log_{10} \left( \frac{62.37}{14.20} \right) + 0.359 \right] \]

\[ = 15.58 \text{ kN/cm}^2 \]

(2) Corner stresses

\[ S_c = \frac{3 \cdot P}{h^3} \left[ 1 - \left( \frac{a}{l_1} \right)^{0.6} \right] \]

\[ S_c = \frac{3 \times 4500}{22^3} \left[ 1 - \left( \frac{15.52}{62.37} \right)^{0.6} \right] \]

\[ S_c = 13.28 \text{ kN/cm}^2 \]

(3) Temperature stresses

(a) Warping stresses

(i) Interface

\[ S_{w} = \frac{E_{w}}{2} \left[ -C_{xy} \right] \]

Value of \( C_{x} \) and \( C_{y} \)

\[ \frac{L_x}{y} = \frac{550}{62.37} = 8.82 \]

\[ C_x = 1.10 - \frac{1.10 + 0.32}{4} \times 0.82 \]

\[ = 1.07 \]
\[ \frac{\varphi_1}{\varphi} = \frac{q_{2\theta}}{0.237} = 6.73 \]

\[ C_\mu = 0.6 + \frac{1.1-0.6}{\varphi} \times 2.73 = 0.94 \]

\[ i = \frac{3 \times 10^5 \times 12 \times 10^6 \times 20}{2} \left[ \frac{1.08 + 0.15 \times 0.94}{1 - 0.15^2} \right] \]

\[ i = 441.91 \text{ K}\text{e}/\text{cm}^2 \]

**Edge stresses**

\[ \sigma_{te} = \frac{C_\mu \cdot E \cdot t}{2} \quad \text{or} \quad \frac{C_\mu \cdot E \cdot t}{2} \]

\[ C_\mu > C_\sigma \]

\[ \sigma_{te} = \frac{C_\mu \cdot E \cdot t}{2} = \frac{1.08 \times 3 \times 10^5 \times 12 \times 10^6 \times 20}{2} \]

\[ = 38,888 \text{ K}\text{e}/\text{cm}^2 \]

**Other stresses**

\[ \sigma_{te} = \frac{E \cdot t}{3(1-\mu)} \left[ \frac{Q}{t} \right] \]

\[ = \frac{3 \times 10^5 \times 12 \times 10^6 \times 20}{3 \times (1 - 0.15)} \left[ \frac{15}{6237} \right] \]

\[ \sigma_{te} = 13.88 \text{ K}\text{e}/\text{cm}^2 \]
3. Frictional Stress

\[ S_f = \frac{f \cdot L \cdot W}{2 \times 10^4} \]

\[ S_f = \frac{1.5 \times 5.50 \times 2500}{2 \times 10^4} = 1.03 \text{ kPa/cm}^2 \]

Worst Combination

At Mioch = \( S_i + S_{st} + S_f = 10.69 + 10.37 + 1.03 = 56.09 \text{ kPa/cm}^2 \)

At Edge = \( S_e + S_{st} + S_f = 15.58 + 38.38 + 1.03 = 55.47 \text{ kPa/cm}^2 \)

Worst Case at Corner, at top = \( S_t + S_{st} + S_f \)

\[ = 15.28 + 13.84 + 1.03 = 28.15 \]

*Worst Combination* for interior or edge.

![Diagram of stress types: load stress, warping, tension, frictional stress.]

At Interior = \( S_i + S_{st1} + S_f \) (At bottom)

At Edge = \( S_e + S_{st} + S_f \) (At bottom)
wast case at corners.

\[
\begin{array}{c}
\text{Load Stresses} \\
T \oplus \\
C \ominus
\end{array}
\quad
\begin{array}{c}
\text{Warping Stresses} \\
T \oplus \\
C \ominus
\end{array}
\quad
\begin{array}{c}
\text{Frictional Stresses} \\
\oplus T
\end{array}
\]

\[\text{At top } = \text{St + Stc + Stu} \]

→ worst combination of stresses (Table)

<table>
<thead>
<tr>
<th></th>
<th>Load Stresses</th>
<th>Warping Stress</th>
<th>Frictional Stresses</th>
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<tr>
<td></td>
<td></td>
<td>Day</td>
<td>Night</td>
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<tr>
<td>Interior stresses</td>
<td>Top</td>
<td>C ⊕</td>
<td>C</td>
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<tr>
<td></td>
<td>Bottom</td>
<td>T ⊕</td>
<td>T</td>
</tr>
<tr>
<td>Edge stresses</td>
<td>Top</td>
<td>C ⊕</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>T ⊕</td>
<td>T</td>
</tr>
<tr>
<td>Corner stresses</td>
<td>Top</td>
<td>C ⊕</td>
<td>T</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>C ⊕</td>
<td>T</td>
</tr>
</tbody>
</table>

Worst combination: In Edge and Interior stresses

→ At bottom during day during winter

corner → at top during night during winter
Design of joints

1. Expansion Joints:
   - A clear gap of 5 width is provided at expansion joints.
   - To allow expansion of slab, due to temperature increase.
   - Max. spacing b/w joints = 140 m.

2. Contraction Joints:
   - To allow contraction of slab due to decrease of temperature.
   - Paper thick joint are provided.
   - Max. spacing = 4.5 m.
Design of Expansion Joints:

If $s$ is width of gap provided

Maxim expansions allowed in the slab $p_s = \frac{s}{2}$

So that the half of the gap is still vacant.

\[
\frac{s}{2} = \frac{L}{2} \cdot (T_2 - T_1)
\]

Spacing of Expansion Joints

\[
L = \frac{s}{2 \cdot a \cdot (T_2 - T_1)}
\]

Design of contraction joint:

Case (i) Slab without reinforcement.

F = F'
Tensile stress developed at centre

\[ S_f = \frac{WLF}{2 \times 10^4} \]

\[ \text{W: } 1 \text{ cm}^2 \]

Spacing of contraction joint

\[ L = \frac{2 \times 10^4 \cdot S_f}{W \cdot f} \]

All above formula is used when reinforcement has been provided in case 2. When reinforcement are prov. resist tensile stresses.
In this case all tensile stresses are taken by steel alone; concrete is free.

\[ \text{Total tensile force of tension} = A_{st} \sigma_{st} - 1 \]

\[ \text{Force of friction} = F = f \cdot R \]

\[ F = f \left( \frac{L}{2} \times b \times h \times w \right) \]  —— 2

Equate 1 and 2

\[ A_{st} \sigma_{st} = f \frac{L}{2} \times b \times h \times w \]

Spacing of contraction joints

\[ L = \frac{2A_{st} \sigma_{st}}{f \cdot b \cdot h \cdot w} \]

Due to the expected increase in temperature of 26°C for a c.c. pavement, calculate spacing of expansion joint if gap of expansion joint is 2.5 cm.

\[ A_{st} = \left( \frac{B}{h} \right) \times \frac{\pi}{4} \times \phi^2 \]

\[ d' = 15 \times 10^{-6} \text{/°C} \]

Unit wt. of concrete = 2400 kg/m³
Max. expansion allowed = \( s_l \)

\[ s_l = \frac{3.5}{2} = 1.75 \text{ cm} \]

\[ L = 1.25 \]

\[ L = 32.05 \text{ m} \]

A cement concrete pavement has 4.5 m width and thickness of 25 cm. Design contraction joints spacing for

(i) If no reinforcement is given

\[ \text{Max. permissible stress of concrete in tension} = 0.8 \text{ kN/cm}^2 \]

(ii) If reinforcement of 12 mm \( @300 \text{ mm} \) are used. Mild steel used. \( \sigma_{st} = 1400 \text{ kN/cm}^2 \)

Coefficient of friction \( f = 1.5 \)

\[ \text{Solution:} \quad \text{(i) PCC (No steel used)} \]

\[ F = \text{F.R.} \]
\[ F = SF \cdot (B \cdot h) \]
\[ f \cdot \frac{1}{2} \cdot B \cdot h \cdot W = SF \cdot B \cdot h \]
\[ SF = \frac{fLW}{2} \quad \text{f} = \text{m}^2 \]
\[ SF = \frac{fLW}{2 \times 10^4} \quad \text{f} = \text{cm}^2 \]

\[ L = \frac{2 \times 10^4 \cdot SF}{f \cdot W} = \frac{2 \times 10^4 \cdot 0.8}{1.5 \times 2400} = 4.44 \text{m} \]

Steel is used. \[ \text{RCC} \]

\[ F = f \cdot R = A_{sd} \cdot \sigma_{sd} \]
\[ f \cdot \frac{1}{2} \cdot B \cdot h \cdot W = A_{sd} \cdot \sigma_{sd} \]
\[ L = \frac{2 \cdot A_{sd} \cdot \sigma_{sd}}{f \cdot B \cdot h \cdot W} \]

at centre
12\text{mm} 
800 \text{ C1C1}
- \[ A_{sd} = \left( \frac{P}{h} \right) \frac{\pi}{4} \times d^2 \]

\[ = \left( \frac{4500}{300} \right) \times \frac{\pi}{4} \times 1.2^2 \times \frac{1}{100} \]

\[ A_{sd} = 16.9646 \text{ cm}^2 \]

\[ L = \frac{2 \times 16.9646 \times 1400}{1.5 \times 4.50 \times 0.25 \times 2500} = 11.25 \text{ m} \]

- Design of the bar:

![Diagram of design](image)

- Consider 1 m length:

\[ = 1000 \text{ m}^3 \]

Longitudinal joint

Projection beam reinforced steel beam
Force of friction

\[ F = f \cdot R = f \cdot [\text{weight of half portion of girder}] \]

\[ F = f \cdot \frac{[(B \times 1) \times h \times w]}{\text{volume}} \]  \[ \text{[w, unit wt. of pavement]} \]

\[ w = 2 = y \]

Force of resistance by steel

\[ = A_{sd} \cdot \sigma_{sd} \]  \[ \text{Equations 1 and 2} \]

\[ f \cdot B \cdot h \cdot w = A_{sd} \cdot \sigma_{sd} \]

Area of steel required (for 1m width)

\[ A_{sd} = \frac{f \cdot B \cdot h \cdot w}{\sigma_{sd}} \]

\[ \text{Panel of reinforce moment} \]

\[ = \frac{1000}{A_{sd}} \cdot \frac{\pi}{4} \times D^2 \]

Length of tie bars (d)

\[ \text{Force of resistance} = \text{strength in bend} \]

\[ A_{sd} \cdot \sigma_{sd} = (\pi D) \times \frac{d}{2} \times \epsilon_{bd} \]

\[ \frac{\pi D}{4} \cdot \sigma_{sd} = \frac{\pi D \cdot d}{2} \cdot \epsilon_{bd} \]
Length of tie bar is equal to development length \( L_d \).

\[
L_d = \frac{P_d}{x} \cdot \frac{1}{n}
\]

A cement concrete pavement has a thickness of 0.24 m and has two lanes of total width 7.2 m. Design the dimensions and spacing of the tie bar using the following data:

- Allowable stress in steel in tension = 1400 kN/m²
- Unit weight of concrete = 2400 kN/m³
- Coefficient of friction = \( f = 1.5 \)
- Allowable bond stress in concrete = 24.6 kN/cm²
Total width of slab = 7.20 m
Half width = B = 3.60 m
Consider 1 m length of slab
h = 24 cm = 0.24 m

Area of steel

\[ A_{st} = \frac{f \cdot B \cdot h \cdot w}{\sigma_{st}} \]

\[ A_{st} = \frac{1.5 \times 3.6 \times 0.24 \times 2400}{1400} = 157.14 \text{ mm}^2 \]

Using 10 mm Ø bars
Spacing = \[ \frac{1000}{221.17} \times \frac{11}{4} \times 10^{-2} = 353.5 \text{ mm} \]

Using 8 mm = \[ \frac{353.3 \times 8^2}{10^2} = 226 \text{ mm} \]

Provide 8 mm @ 226 mm C/C

Length of tie bars:

\[ u = \frac{2d}{u \times 2b} \]

\[ u = \frac{2 \times 8}{20 \times 24.6} = 22.76 \text{ cm} \]

\[ d = 23 \text{ cm} \]
-x Dowel bars:

- provided at Expansion joints

\[ s_1 \]

- differential deflection = \( s_1 \)

- Dowel bars

- differential deflection = \( s_2 - s_3 \)

- At Expansion joint

- Dowel bars is fixed one side of the pavement and provided other side a gap. Because Dowel bar provided at Expansion joint so that Expansion of the joint is allowed so that provide gap.

- When gap not provide than Expansion is not allowed.
Design of Dowel bars:

- Dowel bars are designed based on Bradbury analysis \( S^- \) (As per IRC)

1) Load carrying capacity of a single dowel bar is minimum of following:

a) Strength in shear

\[
p' = \frac{\pi d^2 f_s}{4}
\]

b) Strength in bending

\[
p' = \frac{2d^3 f_t}{L_d + 8.88}
\]

c) Strength in bearing

\[
p' = \frac{L_d^2 d - f_b}{12.5 \left( L_d + 1.588 \right)}
\]

- Development length \( L_d \)

\[
L_d = 5d \sqrt{\left[ \frac{f_t}{f_b} \times \frac{L_d + 10.58}{L_d + 8.88} \right]}
\]

- Solve by trial and error.

where

- \( d = \) Dia of bar (cm)
- \( s = \) gap or expansion joint width in (cm)
Design steps:

1. Length of doweled bar
   \[ L = (L_0 + s) \]

2. Load capacity of doweled group system
   \[ = 0.90 \times \text{of wheel load} \]

3. Required load capacity factors
   \[ = \frac{\text{Load capacity of doweled group}}{\text{Load capacity of single doweled bar}} \]
   \[ = 0.40 \times \frac{P}{P_1} \]

4. Capacity factor of doweled bars
   \[ \text{just below load} = 1.0 \]
   \[ \text{at } 1.80 \text{ ft distance} = 0 \]

Now total capacity factor is calculated

\[ = 1.0 + \left( \frac{1.80l - s}{1.80l} \right) + \left( \frac{1.80l - 2s}{1.80l} \right) + \ldots \]

\[ \times \frac{K_{0.40l}}{P_1} \]
Spacing should be selected such that the above condition is satisfied.

\( d \) = radius of the relative stiffness.

We design a dowel bar system for pavement thickness = 2.5 cm.

Radius of relative stiffness = 80 cm

Gross wheel load = 5100 kg

Joint width = 2.4 cm

Permissible stresses:

- Shear = 1200 kg/cm² = \( f_s \)
- Flexure = 1400 kg/cm² = \( f_f \)
- Bearing = 120 kg/cm² = \( f_b \)

Use diameter of dowel bar = 20 mm

Steel development length required:

\[
L_d = 5d \left[ \frac{f_f}{f_b} \times \frac{L_d + 1.5d}{L_d + 8.8d} \right]^{1/2}
\]

\[
= 5 \times 20 \left[ \frac{1400}{120} \times \frac{L_d + 1.5 \times 20}{L_d + 8.8 \times 20} \right]^{1/2}
\]

\[
L_d^2 \left[ \frac{L_d + 81.2}{L_d + 3.6} \right] = 1166.67
\]

by trial and error.
1. Length of base = \( L + 5 + 1 = 27.27 + 2.41 = 30 \) cm
   
   Say = 30 cm

2. Load capacity of single dowel bars

   (i) In shear
   \[
   F_s = \frac{\pi d^2 f_y}{4} = \frac{\pi (2)^2}{4} \times 1200 = 3769.9 \text{ kg}
   \]

   (ii) In bearing
   \[
   F_b = \frac{120 \times 27.27^2 \times 2.0}{12.5 \left( 27.27 + 1.5 \times 2.4 \right)}
   \]
   \[
   = 469.50 \text{ kg}
   \]

3. Strength in flexure or bending
   \[
   F_f = \frac{f_y \times 2d^3}{L_d + 8.5d} = \frac{1400 \times 2 \times 2^3}{(27.27 + 8.5 \times 2.4)}
   \]
   \[
   = 469.90 \text{ kg}
   \]
Strength of single dowel bar

\[ P' = 462.50 \text{ kg} \]

2) Load capacity of dowel groups systems

\[ = 0.40 \times 5100 = 2040 \text{ kg} \]

Required

3) Load capacity factor

\[ = \frac{\text{load capacity of group}}{\text{load capacity of single dowel bar}} \]

\[ = \frac{2040}{462.50} = 4.41 \]

Assume spacing

\[ 1.80 \times 8 = 1.20 \times 80 = 144 \]

Capacity factor of group

\[ 1 + \frac{144 - 3.0 \times 1}{144} + \frac{144 - 23.30}{144} \times 1 + \frac{144 - 3.30}{144} \times 1 \]
Introduction:-

- Earth is an oblate spheroid.
  - Polar Axis = 12,713.80 km
  - Equatorial Axis = 12,756.75 km
  - Difference = 42.95 km

- Average Radius = 6,370 km

Plain Surveying:
- Earth curvature is not considered.

Geodetic Survey:
- Earth curvature is considered for large area.

Example:

1. $12 km + 1.5^\circ$

2. For a 12 km long

\[ \text{diff} = 1.0 \text{ cm only} \]

Area $= 158 \text{ km}^2$
Assume spacing = 20 cm

Capacity factor:

\[
\text{capacity factor} = \frac{144 \times 8 - [30 + 60 + 36 + 120]}{144} = 0.11
\]

Spacing = 18 cm

\[
\text{Spacing} = \frac{144 \times 8 - (18 + 36 + 54 + 72 + 90 + 108 + 126)}{144} = 0.50 > 0.45 \text{ OK}
\]
\[ (\theta A' + \theta B' + \theta C') - (\theta A + \theta B + \theta C) = 1 \text{ second.} \]

= 0° 0' 1"  θ 0° 0' 1"

**Principle of Surveying:**

1. Location of a point by measurement from two reference points.

A, B → Reference point

Chains Survey

Compass Surveying

Traversing

Chains Survey

**Chains Survey (Offset Method):**

First major control points are fixed and measured with higher accuracy. Minor details can be taken later.
Even with worse precision, error involved in minor details will not be reflected in major measurement.

* Accuracy and Error *

1. **Precision**:
   - Degree of perfection used in measurement is called precision.
   [Using correct instruments, correct manner of reading]

2. **Accuracy**:
   - Degree of perfection obtained in measurement is called accuracy.

3. **True Error**:
   - Difference between the exact true value of a quantity and measured error is called true error.

4. **Discrepancy**:
   - Difference between two measured value of the same quantity is called discrepancy.
Theory of probability [For Accidental Errors]

Accidental Errors follow a definite rule. It is called Law of Probability.

As per this law:

1. Small errors are more frequent than large errors (because frequency large in -0.1 to +0.1).
2. Positive and negative errors of same size has equal frequency so they are equally probable.

Principal of least square:

The most probable value (MPV) is one for which sum of square of all errors is minimum.
The value of a quantity which has more chance of being the correct value of a quantity is called most probable value.

Errors:

Types

1. Instrumental Error → due to faulty instrument
2. Personal Error → due to wrong reading of a measurement
3. Natural Error → due to temperature, wind, humidity, local attraction, magnetic declination.

Kind:

1. Accumulative Error → [Systematic Error]
   → Always occurs in same direction.
2. Compensating Error → [Random Errors / Accidental Errors]
   → Occurs some time in one direction and some time in other direction
   → Value occurs Give and Offer Errors.
   → Give and Offer Errors will compensate each other.
case-0 \( x_1, x_2, x_3 \ldots \) in are measurement

with unit weight. (Means one value occurs at one time)

if \( x \) is most probable value

errors \( = (x-x_1), (x-x_2), \ldots (x-x_n) \)

can be principle of least square

sum of squares of errors = least

\( y = (x-x_1)^2 + (x-x_2)^2 + (x-x_3)^2 + \ldots \)

for \( y \) minimum

\( \frac{dy}{dx} = 0 = 2(x-x_1) + 2(x-x_2) + \ldots = 0 \)

\( nx = [x_1 + x_2 + x_3 + \ldots + x_n] = 0 \)

\[ x = \frac{x_1 + x_2 + x_3 + \ldots + x_n}{n} \]

most probable value is the average value of

all measurement.

\[ \alpha = \alpha \]

having different weightage

<table>
<thead>
<tr>
<th>( x_1 )</th>
<th>( \omega_1 )</th>
<th>MPV</th>
<th>Errors</th>
<th>Square of Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_2 )</td>
<td>( \omega_2 )</td>
<td>( (x-x_1) )</td>
<td>( (x-x_1)^2 \omega_1 )</td>
<td></td>
</tr>
<tr>
<td>( x_3 )</td>
<td>( \omega_3 )</td>
<td>( (x-x_2) )</td>
<td>( (x-x_2)^2 \omega_2 )</td>
<td></td>
</tr>
<tr>
<td>\vdots</td>
<td>\vdots</td>
<td>( (x-x_{n-1}) )</td>
<td>( (x-x_{n-1})^2 \omega_{n-1} )</td>
<td></td>
</tr>
</tbody>
</table>
As per principle of least square

\[ y = \omega_1 (x-x_1)^2 + \omega_2 (x-x_2)^2 + \cdots \]

\[ \frac{dy}{dx} = 2\omega_1 (x-x_1) + 2\omega_2 (x-x_2) + \cdots = 0 \]

\[ x(\omega_1 + \omega_2 + \omega_3 + \cdots) = \omega_1 x_1 + \omega_2 x_2 + \cdots \]

\[ x = \frac{\omega_1 x_1 + \omega_2 x_2 + \cdots + \omega_n x_n}{\omega_1 + \omega_2 + \cdots + \omega_n} \]

\[ \rightarrow \text{called weighted average.} \]

\[ \text{This is most probable value} \]

\[ \text{Probable Error of Single Observation} = \]

\[ Es = \pm 0.6745 \sqrt{\frac{\sum v^2}{(n-1)}} \]

where

\[ v = (x-x_1) \]
\[ (x-x_2) \]
\[ (x-x_3) \]

\[ \text{difference bw} \ any \ single \ measurement \ and \ mean \ of \ the \ set \ of \ measurements. \]

\[ \text{Probable Error of Single Observation (unit LCF weighted data)} \]

\[ Es = \pm 0.6745 \sqrt{\frac{\sum wv^2}{(n-1)}} \]
**Probable Error of Mean of the Series:**

\[ E_m = \pm 0.6745 \sqrt{\frac{\sum u^2}{n(n-1)}} \]

\[ E_m = \frac{E_3}{\sqrt{n}} \]

**Significant Figure in a Measurement:**

- 6.147
- 6.14

If there are \( n \) figures in a measurement, \((n-1)\) figures are called certain figures. Last figure is called uncertain figure.

Chances of Errors are in uncertain figure.

\[ \begin{array}{c|c|c|c|c|c}
5 & 6.10 & 6.20 & 6.30 & 6.40 & 8m \\
\end{array} \]

\[ \Rightarrow \text{read } 6.3 \]
\[ \text{Maxm Error} = 0.05 \text{m} \]
\[ \text{Probable Error} = 0.025 \text{ m} \]

\[ 6 \text{m} \]
\[ 6.10 \quad 6.20 \quad 6.30 \quad 6.40 \]

\[ \text{Reading} = 6.26 \]
\[ \text{Maxm Error} = 0.005 \text{m} \]
\[ \text{Probable Error} = 0.0025 \text{ m} \]

3. The probable error of weighted arithmetic mean is:

\[ E_s = \pm 0.6745 \sqrt{\frac{\sum (wv^2)}{(\sum w)(n-1)}} \]

\[ \text{Probable error of any observation of weighted} \]
\[ w \]
\[ = \frac{E_s}{\sqrt{w}} = \pm 0.6745 \sqrt{\frac{\sum wv^2}{w(n-1)}} \]
Errors in computed results

Significant figure

If a measurement has n digits:

Initial (n-1) figures = certain figure
Last figure = uncertain figure

For this measurement:

1. Max\(^n\) Error = 0.005 m
   [Half of least count]

2. Probable Error = Half of Max\(^n\) Error
   = 0.0025 m

Summation of Errors:

Max\(^n\) Error, sum is simple algebra:

\[ \sigma_\text{total} = \sigma_1 + \sigma_2 + \sigma_3 + \cdots \]

Probable Error: In this case, accumulation is root mean square.
ε_t = \sqrt{e_1^2 + e_2^2 + e_3^2 + \ldots}

1. Sum for \( s \): 
   \[ S = x + y \]
   \[ ds = 1 \cdot dx + 1 \cdot dy \]

   For Max\(^M\) Error:
   \[ \text{Max\(^M\) Error in } x = \delta x \]
   \[ \text{Max\(^M\) Error in } y = \delta y \]
   \[ \text{Max\(^M\) Error in } S = \delta s \]

   \[ \delta s = \delta x + \delta y \] \( \text{---(1)} \)

2. Probable Error:
   \[ \text{Probable Error in } x = e_x \]
   \[ \text{Probable Error in } y = e_y \]
   \[ \text{Probable Error in } S = e_s \]

   \[ e_s = \sqrt{e_x^2 + e_y^2} \] \( \text{---(2)} \)

3. Deduction:
   \[ S = x - y \]
\[ \frac{E_s}{S} = \sqrt{\left(\frac{E_x}{x}\right)^2 + \left(\frac{E_y}{y}\right)^2} \]

**Que:** If \( S = x + y \), \( x = 3.4 \), \( y = 6.26 \)

Find out maximum and probable errors in computed value of \( S \).

**Soln**

\( x = 3.4 \)

\( S_x = 0.05 \) \( \text{Max Error} \text{ Half of least count} \)

\( E_x = 0.025 \) \( \text{Probable Error} \text{ [Half of Max Error]} \)

\( y = 6.26 \)

\( S_y = 0.005 \) \( \text{Max Error} \)

\( E_y = 0.0025 \) \( \text{Probable Error} \)

\( S = x + y \)

\( \delta S = \delta x + \delta y \)

**For Max Probable Error for \( S \)**

\( \delta S = \delta x + \delta y \)

\( \delta S = 0.05 + 0.005 \)

\( \delta S = 0.055 \)

**Probable Error for \( S \)**

\[ E_S = \sqrt{E_x^2 + E_y^2} \]

\[ E_S = \sqrt{0.025^2 + 0.0025^2} \]

\[ E_S = 0.02515 \]

**Range of Probable Value for \( S \)**
\[ ds = \left(-\frac{1}{y^2}\right)dx - \left(\frac{x}{y^2}\right)dy \]

1) For Max Error

\[ \text{In } x = \text{ex, for } \delta = \frac{1}{y} \cdot \delta x \]

\[ \text{In } y = \text{ey, for } \delta = \left(\frac{x}{y^2}\right) \cdot \delta y \]

Max Error \( s = \delta s \)

\[ \delta s = \frac{1}{y} \cdot \delta x + \frac{x}{y^2} \cdot \delta y \]

2) Probable Error

\[ \text{In } x = \text{ex, for } \delta = \left(\frac{1}{y} \cdot \text{ex}\right) \]

\[ \text{In } y = \text{ey, for } s = \left(\frac{x}{y^2}\right) \cdot \text{ey} \]

Probable Error for \( s = \delta s \)

\[ \delta s = \sqrt{\left(\frac{1}{y} \cdot \text{ex}\right)^2 + \left(\frac{x}{y^2} \cdot \text{ey}\right)^2} \]

\[ \text{In } x = \text{ex, for } \delta = \frac{x}{y} \cdot \delta y \]

\[ \text{In } y = \text{ey, for } s = \frac{y}{x} \cdot \text{ey} \]

\[ \text{Probable Error for } s = \delta s \]

\[ \delta s = s \sqrt{\left(\frac{\text{ex}}{x}\right)^2 + \left(\frac{\text{ey}}{y}\right)^2} \]
\[ ds = dx - dy \]
\[ ds = x \cdot dx + (-1) \cdot dy \]

1. **Max Error**
   \[ \text{Max Error in } s = \delta s = \delta x + \delta y \]
   \[ \delta s = \delta x + \delta y \]

2. **Probable Error in } s = \delta s = \sqrt{\delta x^2 + \delta y^2} \]

3. **Multiplication**
   \[ s = xy \]
   \[ ds = x \cdot dy + y \cdot dx \]

4. **Max Error**
   \[ \text{Max Error in } x = \delta x \]
   \[ \text{Max Error in } y = \delta y \]
   \[ \text{Max Error in } s = \delta s \]
   \[ \delta s = y \cdot \delta x + x \cdot \delta y \]

5. For \( s \)
   \[ y \cdot \delta x \]
   \[ x \cdot \delta y \]
probable Error

probable Error in \( x = e_x \)
probable Error in \( y = e_y \)
probable Error in \( s = e_s \)

\[
es_s = \sqrt{(y \cdot e_x)^2 + (x \cdot e_y)^2}
\]

\[
es_s = xy \sqrt{\left(\frac{y \cdot e_x}{x \cdot y}\right)^2 + \left(\frac{x \cdot e_y}{x \cdot y}\right)^2}
\]

\[
es_s = s \sqrt{\left(\frac{e_x}{x}\right)^2 + \left(\frac{e_y}{y}\right)^2}
\]

\[
es_s \quad \frac{e_s}{s} = \sqrt{\left(\frac{e_x}{x}\right)^2 + \left(\frac{e_y}{y}\right)^2}
\]

**Division**

\( s = \frac{x}{y} \)

\( ds = y dx - x dy \quad \frac{dy}{y^2} \)
Q. The following are the observed values of an angle and their weights:

<table>
<thead>
<tr>
<th>Angle</th>
<th>Weightage</th>
</tr>
</thead>
<tbody>
<tr>
<td>30° 29' 20&quot;</td>
<td>2</td>
</tr>
<tr>
<td>30° 29' 18&quot;</td>
<td>2</td>
</tr>
<tr>
<td>30° 29' 19&quot;</td>
<td>3</td>
</tr>
</tbody>
</table>

Find

1. Probable error of single observation of unit weight.
2. Probable error of weighted arithmetic mean.
3. Probable error of single observation of weight 3.

\[
\begin{align*}
n &= \text{no. of measurement} = 3 \\
\text{Average value be} & = \bar{x} \\
\bar{x} &= \frac{\sum w_i x_i}{\sum w_i} \\
\end{align*}
\]

\[
\begin{align*}
\text{Probable error of single observation} & = \pm 0.6745 \sqrt{\frac{\sum w_i x_i}{(n-1)}} \\
\end{align*}
\]
(2) Probable error of weighted arithmetic mean:

\[ E_s = \pm 0.6745 \sqrt{\frac{3\omega \cdot \nu^2}{(\omega)(n-1)}} \]

\[ = \pm 0.6745 \sqrt{\frac{4}{7(3-1)}} \]

\[ = \pm 0.6745 \sqrt{\frac{4}{14}} \]

\[ = \pm 0.3605 \]

(3) Probable error of single observation of weight \( \omega \), \( \omega \) = \omega + \text{given} = 3

\[ E_s = \pm 0.6745 \sqrt{\frac{3\omega \cdot \nu^2}{\omega \cdot (n-1)}} \]

\[ = \pm 0.6745 \sqrt{\frac{3 \cdot 3 \cdot 3}{3(3-1)}} \]

\[ = \pm 0.6745 \sqrt{\frac{27}{6}} \]

\[ = \pm 0.5507 \]
\[ S = S_0 + S_e = 9.66 + 0.025 \text{ kg} = 9.685 \text{ kg} \]

To \[ S - S_e = 9.66 - 0.025 \text{ kg} = 9.635 \text{ kg} \]

\[ \frac{x^2}{y^2} \text{ if } S = \frac{96.83}{y^2} = \frac{x}{y} \]

\[ x = 96.83 \quad y = u.g \]

\[ S_x = 0.005 \quad S_y = 0.05 \]

\[ \varepsilon_x = 0.0025 \quad \varepsilon_y = 0.025 \]

Max. Error

For \( S \):

\[ x = \left( \frac{1}{y} \right) \text{ dx} \]

\[ y = \left( \frac{x}{y^2} \cdot 8y \right) \]

\[ \delta S = \frac{1}{y} \cdot S_x + \frac{x}{y^2} \cdot S_y \]

\[ S_0 = \frac{1}{4.9} \left( 0.005 \right) + \frac{96.83 \times 0.05}{4.9} \]

\[ S_0 = 0.20267 \]

Max. Range for \( S \)

\[ S = \frac{96.83}{4.9} = 19.7642 \]
\[
S + \delta S = 19.761 + 0.20367 = 19.964
\]
\[
S - \delta S = 19.761 - 0.20367 = 19.558
\]

\[\delta \text{ probable Error} \]
\[
\frac{\delta S}{S} = \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2}
\]
\[
\delta S = S \sqrt{\left(\frac{0.0525}{36.83}\right)^2 + \left(\frac{0.025}{4.0}\right)^2}
\]
\[
\delta S = 19.761
\]
\[
\delta S = \pm 0.1008
\]

Range of \(\delta\)
\[
S + \delta S = 19.761 + 0.1008 = 19.862
\]
\[
S - \delta S = 19.761 - 0.1008 = 19.6604
\]
Line

Linear Measurement

1) Scale:

- Scale is the ratio of map distance to ground distance.

\[
\text{Scale} = \frac{\text{Map distance}}{\text{Ground distance}}
\]

- Example scale: 1 cm = 500 m

\[
\text{Ratio} = \frac{1 \text{ cm}}{500 \times 100 \text{ cm}} = \frac{1}{50,000}
\]

- Scale: (1 : 50,000) ← R of R

   ▼

   Representative Fraction

Types:

1) Plain Scale:

- Measure upto two dimensions only.

   ▼

   Let us make scale 1 cm = 4 m

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 m</td>
<td>10 m</td>
<td>30 m</td>
</tr>
</tbody>
</table>
Scale 1 cm = 1 m

Take 10 cm along line

In this case, read two dimensions

1. decameters (10 m)
2. meters

Diagram

→ Measure up to three dimensions.

In this case, measure three dimensions

1. 10 m → decameters
2. meter → meters
3. 0.1 meter (10 cm) → decimeter
Vernier scale:

Also read three dimensions.

(i) Direct vernier scale

(ii) Vernier scale is in same direction as that of main scale.

(iii) 

(n-1) divisions of main scale is divided into n division of vernier scale.

\[(n-1)s = n \cdot v\]

Least count:

Smallest measurement that can be read by the scale.

\[= s - v\]  \( (s > v) \)
Least count = \( \frac{s}{\eta} \)

In this case read, 3 dimensions, say = 6.67

\( 6.67 \times \frac{1}{10} \) of mm.

\( 6 \) cm

3. Retrograde vernier:

1. Vernier scale moves in opposite direction to main scale.
2. \((n+1)\) division of main scale is equal to \(n\)th division of vernier scale.
If the drawing has shrunk, the scale of the drawing will change.

\[
\text{shrunk scale} = \left[ \frac{\text{shrinkage factor} \times (\text{original scale})}{\text{original length}} \right]
\]

where

\[
\text{shrinkage factor} = \frac{\text{shrunk length}}{\text{original length}}
\]

Example:

If a 10 cm long line on the drawing has shrunk to 9.5 cm:

\[
\text{shrinkage factor} = S\cdot F = \frac{\text{shrunk length}}{\text{original length}} = \frac{9.5}{10}
\]

\[S\cdot F = 0.95\]

\[
\text{shrunk scale} = \text{original scale} \times S\cdot F = \frac{1}{5000} \times 0.95
\]

\[= \frac{1}{5263.16}\]

New scale

\[
1 \text{ cm} = 5263.16 \text{ cm} \\
1 \text{ cm} = 5.26316 \text{ m}
\]
\[ - (n+1)s = n \cdot v \]

\[ v = \left( \frac{n+1}{n} \right) s \]

Least count = \( v - s \) \((v > s)\)

\[ = \left( \frac{n+1}{n} \right) s - s \]

\[ = \frac{s}{n} \]

Least count = \( \frac{s}{n} \)

* Shrink scale:

\[ 9.5 \text{ cm} = 50 \times 10 = 500 \text{ m} \]

Scale 1 cm = \( \frac{500}{9.5} = 52.6316 \text{ cm} \)
If an area of 250 cm² is measured on drawing. How much is represented on ground:

\[ A = 250 \times (52.6316)^2 \]

\[ A = 692521.33 \text{ m}^2 \]

Error due to incorrect length of chain/tape:

\[ L = \text{designated length of tape} \]

\[ L' = \text{wrong length of tape (actual)} \]

\[ L'' = \text{length of line measured} \]

\[ L = \text{true length of line} \]

\[ \text{True} \times \text{True} = \text{Wrong} \times \text{Wrong} \]

\[ L \times L = L' \times L'' \]

True length of line:

\[ L' = \frac{L' \times L''}{L} = \frac{L'}{L} \times L'' \]
Ex: \[ u = \frac{30 \cdot 10}{30} \times 600 = 602 \text{m} \]

For area
\[ A = \left( \frac{L'}{L} \right)^3 \times A' \]

For volume
\[ V = \left( \frac{L'}{L} \right)^3 \times V' \]

* Measured value = 600m
  
  Correction = +2m
  
  Corrected value = 602m
  
  \[ \Rightarrow \text{Error is Negative} \]

Actual Length
Measured value
Corrected value

Error
Correction

More

Less

Give

Give
(2) Correction due to slope:

Let $A$ and $B$ be the points of interest.

Correction due to slope

$$C_s = AB - AC$$

$$= l - \sqrt{l^2 - h^2}$$

$$= l - l \left[1 - \left(\frac{h}{l}\right)^2\right] \sqrt{2}$$

$$= \frac{h^2}{2l}$$

Correction due to slope $= \frac{h^2}{2L}$

This correction always gives.

(3) Correction due to alignment:

Let $A$ and $B$ be the points of interest.

Correction due to alignment

$$CaR = l - \sqrt{l^2 - h^2}$$

$$CaR = \frac{h^2}{2L}$$

Correction always gives.
Tape corrections:\n\[ c_a = \left( \frac{c}{L} \right) \times L' \]

L = designated length of tape
L' = incorrect length of line measured

L = 30 m, L' = 30.10 m, W = 600 m

Correction required per chain length
\[ c = L' - L = 30.10 - 30 = 0.10 \text{ m} \]

Total correction
\[ c_a = \left( \frac{0.10}{30} \right) \times 600 = 2.0 \text{ m} \]

Corrected length of line
\[ = W + \text{correction} = 600 + 2.0 = 602 \text{ m} \]
Connection due to Temperature:

\[ C_1 = l' \cdot \alpha (T_m - T_0) \]

\( l' \) = length of line measured
\( \alpha \) = Correction for thermal expansion
\( T_m \) = Temperature at the time of measurement
\( T_0 \) = Temperature at the time of standardization of tape

\[ C_0 = \frac{(P_m - P_0)}{AE} \cdot l \]

\( P_m \) = Pull at the time of measurement
\( P_0 \) = Pull at the time of standardization
\( l \) = length of line
\( A \) = cross-sectional area of tape
\( E \) = Young modulus of tape/chain
Sag correction:

\[ S_g = \left( \frac{w \cdot l}{2G \cdot P_m^2} \right)^2 \cdot l \]

\[ S_g = \frac{w \cdot l}{2G \cdot P_m^2} \]

- \( w \): weight of tape
- \( l \): length of line
- \( P_m \): pull at the time of measurement.