HAND WRITTEN NOTES:
OF
CIVIL ENGINEERING

SUBJECT:
HIGHWAY ENGINEERING
Important Years:

1. Jankatam Tree
   - Named in: Nov 1927
   - Submitted report: 1928

2. Central Road Fund: 1928

3. Indian Road Congress: 1934


5. First 20 Year Plan: 1943-63
   - Nagpur Road Plan

6. CRRRI (Central Road Research Institute): 1950

7. 2nd 20 Year Plan: 1961-81
   - Bombay Road Plan

8. 3rd 20 Year Plan: 1981-2001
   - Lucknow Road Plan

Jaykay Committee Recommendation

In 1928 Jaykay Committee submitted its reports with the following recommendations:

1. Road development should be considered as a matter of national interest.

2. An extra tax on petrol should be levied 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

<table>
<thead>
<tr>
<th>Year</th>
<th>Target</th>
<th>Area</th>
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<tbody>
<tr>
<td>1943-63</td>
<td>16 KM/100 sq km</td>
<td></td>
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<tr>
<td>1961-81</td>
<td>32 KM/100 sq km</td>
<td></td>
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<tr>
<td>1981-2001</td>
<td>82 KM/100 sq km</td>
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<table>
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<tr>
<th>Total Road Length Target</th>
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<tr>
<td>5.25 Lakh KM</td>
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</table>
5. Target Expenditure

44.8 crore
5200 crores

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

   Added
   1. 1600 km/h
   2. 5% allowance for future development

   Classification
   1. Primary
   2. Expressway
   3. Secondary
   4. SH
   5. MDR
   6. Tertiary
   7. ODR
   8. VR

* Different road pattern:

1. Rectangular and block pattern:

2. Star and block pattern:
(a) Star and circular

(b) Star and grid pattern

Indian road have been developed on star and grid pattern
Hexagonal
Geometrical design

1. Terrain classification:

   Types: cross slope of terrain

   steep terrain: \( > 60 \cdot \text{°} \)

   mountainous terrain: 25 to 60 \( \cdot \text{°} \)

   rolling terrain: 10 to 25 \( \cdot \text{°} \)

   plain terrain: \( < 10 \cdot \text{°} \)

   cross slope is max slope of ground available in that area.

2. Design vehicle:

   Max width = 9.44 m (3.510 m)

   Max height:

   1) single deck = 3.80 m

   2) double deck = 4.70 m

   1) Max length:

   1) single unit with two axles = 10.7 m
3) Single unit > 2 axle = 12.2 m

4) Tractor + Trailer = 18.3 m

5) Carriageway width

   Single lane road = 3.75 m
   Two lane road = 7.00 m
3. Pavement surface characteristics:

1. Friction:
   
   There are two types:

   a. Longitudinal coefficient of friction

   \[ \mu_l = f = 0.35 \]

   Applicable to limiting application of brakes.

   b. Lateral coefficient of friction

   \[ \mu_l = f = 0.15 \]

   In lateral direction movement of vehicles (e.g., in case of superelevation) or curves

   Skid: when brakes are applied

   \[ \text{Diagram:} \]

   Slip: when accelerating

   \[ \text{Diagram:} \]

   c. Uneven 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]

(3) Camber : central portion of road w.r.t. edge

Purpose → to drain off water from road surface

Type of pavement  Light rainfall  Heavy rainfall

1. Cement concrete  1.7 - (in 60)
   High bituminous  1.7 - (in 60)

2. Thin Bituminous  2.5 - (in 60)

3. WBM/Gavel  2.5 - (in 60)

4. Earth Road  3.5 - (in 33.3)

Design Speed :-

NH 8 SH
plain    rolling   mount   steep
up    up    R    M    R    M    R    M
0    00    80    65    50    40    40    30

Pavement design done for rolling speed.

Sight distance:

As per IRC sight distance requirement:

on horizontal curve:

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]
lag distance:

Distance travelled for total reaction time

$$= V \cdot t_R = 0.278V \cdot t_R$$ \[ V=\text{mph} \]

Reaction time: 0.5 sec to 5 sec.

Generally: 2.5 to 3 sec. considered

PIEV Theory:

1. P → Perception:
   Time to send sensation from eyes to brain.

2. I → Intellaction:
   Time to rearrange different thoughts, analysing the situation by brain.

3. E → Emotion:
   Time elapsed in emotional sensation.

4. V → Voulition:
   Time for final decision.

Braking distances:
Assumptions:

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

\[ KE_{\text{lost}} = \text{work done} \]

\[ \frac{1}{2}mv^2 = (\text{force of resistance}) \times s \]

\[ = (Mg\sin\theta + F) \times s \]

\[ = (Mg\sin\theta + F\cdot mg\cos\theta) \times s \]

\[ s = \text{distance} = 2 \]

\[ F = f \]

\[ R = mg\cos\theta \]

\[ \text{breaking distance} \]

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

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

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

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

when movement is downward

\[ v = 0 \]

\[ \text{In this case} \]

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

\[ \text{(downward)} \]

\[ \text{Total stopping sight distance} \]

\[ SSD = 0.278 v \cdot t_r + \left( \frac{0.278 v}{2g \left( f - s \cdot v \right)} \right)^3 \]
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) = \( v_n \)
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.

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

\( t_r \) = Reaction time. (2.5 to 3.08 sec)

\[ \text{Distance } d_2 \]

Distance travelled by A in overtaking B.

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

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

Minimum clearance required

\[ s = 0.7 \cdot v_B + \frac{1}{2} a \]

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

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

\[ s = 0.20 v_B + 6 \]

Minimum clearance required between two vehicles

\[ d = \text{length of vehicle} \]

\[ 0.7 \text{ reaction time} \]

\[ v_B \text{ = distance} \]
Where 0.7 sec = reaction time for vehicles moving back to back.

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

Equating (2) and (3)

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

\[ T = \frac{\sqrt{4s}}{a} \]

(4)

(3) Distance (d3) is:

Distance travelled by opposite side vehicle c

\[ d_3 = 0.278 V_c \cdot T \]

(5)

Total overtaking sight distance

\[ OSD = d_1 + d_2 + d_3 \]

(6)

Value of acceleration:

\[ \text{Speed} \] \hspace{1cm} \text{a} \hspace{1cm} \text{OSD}
\begin{align*}
25 & \quad 1.41 & \quad 90 \\
30 & \quad 1.3 & \quad 165 \\
40 & \quad 1.24 & \quad 235 \\
50 & \quad 1.11 & \quad 340 \\
65 & \quad 0.73 & \quad 470 \\
80 & \quad 0.53 & \\
109 & \quad \quad & \\
\end{align*}

(7)

(depend on the speed)
Super-elevation is provided on curve to counteract the effect of centrifugal force.

\[
mg - \text{ weight} \\
\frac{mv^2}{R} = \text{ centrifugal force} \\
\text{force of friction}
\]

\[
F = fR = f\left(mg \cos \theta + \frac{mv^2}{R} \sin \theta \right)
\]

Equating all forces along the surface of road

\[
mg \sin \theta + F = \frac{mv^2}{R} \cos \theta
\]

\[
mg \sin \theta + f\left(mg \cos \theta + \frac{mv^2}{R} \sin \theta \right) = \frac{mv^2}{R} \cos \theta
\]

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

Put \( \tan \theta = e \), super-elevation (S = E)

\[ g (f+e) = \frac{v^2}{R} (1-f \cdot e) \]  \hspace{1cm} (21)

\[ \frac{f+e}{1-fe} = \frac{v^2}{gr} = \frac{(0.078v)^2}{9.81R} = \frac{v^2}{127R} \]

\[ \frac{e+f}{1-fe} = \frac{v^2}{127R} \]  \hspace{1cm} (A)

Max. value of \( e \) is 0.07, and \( f \) = 0.15, so \( ef \) value is small, so \( (1-e+f) \) term is neglected or \( = 1 \)

So super-elevation

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

Design steps:

1. Max. super-elevation is allowed:
   - On plain and rolling terrain = 0.07 (7%)  
   - On hilly road = 0.10 (10%)  
   - On urban road with frequent intersection = 0.04 (4%)
Min. super-elevation = camber slope

Steps:

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

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

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

2. If \( e \) calculated above is less than \( \max \) permissible super-elevation, hence it's O.K.

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

Provide \( e \) value calculated

3. If \( e_{\text{cal}} > e_{\max} \)

Limit value to \( e_{\max} \)
And check value of \( f \) considering full design speed.

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

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

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

4. If \( f \) calculated \( > \) \( f_{\text{max}} \) (0.15)
   then limit the speed (restricted max speed)
   \[ e_{\text{max}} + f_{\text{max}} = \frac{v_{\text{max}}^2}{127R} \]

5. \( V_{\text{max \ (allowed)}} = \sqrt{127R (e_{\text{max}} + f_{\text{max}})} \)

5. Special case:

If no superelevation is provided, max speed on a curve

\[ v_{\text{max}} = \sqrt{127R f_{\text{max}}} \]

Minimum radius of curve

\[ R_{\text{min}} = \frac{v_{\text{max}}^2}{127 (e_{\text{max}} + f_{\text{max}})} \] \[ \text{[At max speed]} \]

\[ R_{\text{min}} = \frac{v^2}{127 (e + f)} \] \[ \text{[At rolling speed]} \]
Extra widening:

Extra widening is required on curve purposes:

- Mechanical widening
- Psychological widening

**Mechanical widening:**

In triangle OAB,

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

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

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

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

If \( n \) = number of lanes

\[ E_w = \frac{nu^2}{2R} \]  \( \Box \)  \( \text{(1)} \)

(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, spiral is used.

\( a \) cubic paraboloidal

\[ y = \frac{x^3}{201} \]

\( b \) spiral

\[ y = \frac{r^3}{6RL} \]
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
\[ x = (W + Ew) \tan \theta \]

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

If pavement is rotated about centre

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

Length of Transition Curve
\[ T.C. = N \cdot x \]

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:

\[ S = \frac{L^3}{24R} \]

Set back distance:

Set back distance is minimum clearance required from centre of road at any obstruction on inner side of curve, so that full sight distance (CSSD, OSSD or ISSD) is available.
Through 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 (Lc > c)

\[
\frac{S}{L_c} = \frac{2\pi R}{360} \quad d = \frac{360 \cdot S}{2\pi R} \quad \Rightarrow \quad \frac{d}{2} = \frac{180S}{2\pi R}
\]
set back distance

\[ m = CD = OC - OD \]

\[ m = R - R\cos \frac{\theta}{2} \]

---

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

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

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

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

set back distance \((m)\)

\[ m = EF + FI + \phi DI \]
\[ m = \left( R - R \cos \left( \frac{\theta}{2} \right) \right) + \left( \frac{S - Lc}{2} \right) \sin \left( \frac{\theta}{2} \right) \]

**Case-3**  
Two lane road \((Lc > S)\)

- Set back distance from centre of road
- Radius \(R\) from centre of road
- Radius \(OA = (R - d)\).
- \(d = \) half of one lane
- Sight distance
  - Measured along centre line of inner lane.

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

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

**set back distance**

$$m = CE$$

$$= OC - OE$$

$$m = R - (R-d) \cos \frac{1}{2}$$

**case (i) Two lane road ($L_c < s$)**

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

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

$$\frac{d^2}{2} = \frac{180L_c}{2\pi (R-d)}$$
set back distance

\[ m = \frac{EH}{E_h} = E_u + G_H - (O_E - O_H) + DJ \]

\[ m = \left[ R - (R - d) \cos \frac{\pi}{2} \right] + \frac{s - S_c}{\frac{1}{2}} \sin^2 \frac{\pi}{2} \]

design of vertical alignment -

different gradients

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

1) Plain gradient
   1 in 30

2) Mountainous
   1 in 50

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 situations, when there is no option for a regular gradient, the gradient is called Exceptional gradient:

Plain and Falling:
- 1 in 15
- 1 in 14.3
- 1 in 12.5

Minimum gradient:

\[ \text{1 in 500} \] is required to drain of water in concrete drain.

\[ \text{1 in 200} \] on interior surface.

Lever resistance:

A curved track tractive force available

\[ = T \cos \theta \]

The direction of movement.

Curve resistance:

\[ = (T - T \cos \theta) \]
Reduction of grade at the location of curve

Grade compensation

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

Ex. For a mountainous region at the location of a curve, if \( R = 130 \text{ m} \), what maxm. ruling gradient can be provided.

Sol. Ruling gradient = 1 in 20 = 0.05

[For mountainous]

Grade compensation

\[ \frac{30 + R}{R} = \frac{30 + 130}{130} = \frac{160}{130} \]

\[ \text{Maxm. } \frac{75}{R} = \frac{75}{130} \text{ %} = 0.57 \text{ %} \]

\[ = 0.57 \times 10^{-3} = 5.7 \times 10^{-4} \]

Compensated gradient

\[ = 0.05 - 5.7 \times 10^{-3} = 0.04375 \]

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

\[ \frac{15}{20} \text{ m} \]

\[ \frac{1}{1} \text{ m} \]

\[ \frac{1}{2} \text{ m} \]

\[ \frac{1}{3} \text{ m} \]
elliptical curve

0) summit curve
1) valley curve

range in gradient: \( -\theta \)

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

General formula

\[
N = \frac{1}{20} - \frac{1}{15} = 0.1666\bar{6}
\]

Summit curve: (simple parabola)

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

\[
H = 1.20\overline{n}
\]

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:

\[ L_s = \frac{V^3}{C R} \]

Radius of T to C at junction:

\[ R = \frac{L_s}{N} \]

\[ L_s = \frac{V^3}{C} \left( \frac{L_s}{N} \right) = \frac{N V^3}{C L_s} \]

\[ L_s = \frac{N V^3}{C} \]

\[ L_s = \sqrt{\frac{N V^3}{C}} = \left( \frac{N V^3}{C} \right)^{1/2} \]

Total length of T to C:

\[ L = 2 L_s = 2 \left( \frac{N V^3}{C} \right)^{1/2} \]

Length of valley curve:

\[ L = 2 \left( \frac{N V^3}{C} \right)^{1/2} \]

\[ N = \text{total change in radius} \]

\[ V = \text{mile per second} \]

\[ C = \text{mile per second}^3 \]
Head sight sight distance.

Equation of parabola

\[ y = ax^2 \]

\[ = \left( \frac{N}{2l} \right) x^2 \]

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

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 (SSD / OSD / FSD) in meters
- \( h_1 \) = Height of head sight above road surface

\[ h_1 = 0.75 \quad \text{if not given} \]

\[ \beta = \text{Angle at head sight} \]

\[ \beta = 1^\circ \quad \text{if not given} \]
If length $L < s$

Length of valley curve

$$L = 2s - \frac{2(ch + 8\tan B)}{N}$$
The driver of a vehicle travelling 60 km/h up a gradient required some less to stop this vehicle after he applies the brakes, than drives down at same speed down the same gradient \( f = 0.4 \), what is the \( \gamma \) gradient.

\[
\theta = \sin^{-1} \left( \frac{v}{s} \right)
\]

\[
S_1 = S_2 - g
\]

\[
S_1 = \frac{v^2}{2\gamma(f+s)}
\]

\[
S_2 = \frac{v^2}{2\gamma(f-s)}
\]

\[
S_2 - S_1 = g
\]

\[
\frac{v^2}{2\gamma(f-s)} - \frac{v^2}{2\gamma(f+s)} = g
\]

\[
(0.278 \times 60)^2 = \frac{(0.278 \times 60)^2}{2 \times 9.81 \times (0.4 \times 5)} = g
\]

\[
\frac{1}{0.4 - 8} = \frac{1}{0.4 + 5} - \frac{9}{14.18}
\]
Length of curve required to fulfill IRC condition

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

\[
L = \frac{NS^2}{\left(\sqrt{2x_{1.2}} + \sqrt{2x_{0.15}}\right)^2}
\]

For SSD

\[
L = \frac{NS^2}{u - y}
\]

For OSD or BSDs

Length of curve

\[
L = \frac{NS^2}{\left(\sqrt{2x_{1.2}} + \sqrt{2x_{1.2}}\right)^2} = \frac{NS^2}{9.6}
\]

\[
L = \frac{NS^2}{9.6}
\]
we have \( f \left( L \right) \neq 8 \) \( \quad \boxed{42} \)

length of curve \( = 2S - \frac{(\sqrt{2H} + H)^3}{N} \)

For SSD \( \quad L = 2S - \frac{4.4}{N} \)

For Osd \( \quad L = 2S - \frac{3.6}{N} \)

valley curve \( \text{cubic parabola} \) is used for highway valley curve

Two criteria\( \:\:

1) Comfort condition
2) Head light sight distance

Comfort condition\( \:\:

\[ \theta = \pi, \quad L = \text{Total Length} - L \]

\[ R = 8 \]

\[ N = \text{(Total Change)} \] in gradient
\[
\begin{align*}
8.4 + 8 \quad &- \quad 0.4 + 8 = 0.63467 \\
(0.4 - 8) (0.4 + 8) \\
28 &\quad = \quad 0.4^2 - s^2 \\
o.63467
\end{align*}
\]
\[
3.15 \quad s = \quad 0.16 - s^2
\]
\[s^2 + 3.15, 8 - 0.16 = 0\]
\[s = 0.049 = 0.05 \quad \text{(in 20.4 kmph)} \quad \text{shape}\]

\text{speed of overtaking and overtaken vehicles are 80 kmph and 60 kmph,} \\
a = 2.5 \text{ kmph/sec.}

\text{calculate safe passing distance.}

(1) \text{ Single lane one way traffic (d_1 + d_2)}

(2) \text{ Three lane both way traffic (d_1 + d_2 + d_3)}

\[\text{reaction time 2 sec}\]

\text{**when speed of opposite side not given then take (V_A = V_c)}

\[\text{A} \quad \rightarrow \quad \text{B} \quad \rightarrow \quad \text{C} \quad \rightarrow \quad \text{D} \quad \rightarrow \quad \text{E} \quad \rightarrow \quad \text{F} \quad \rightarrow \quad \text{G} \quad \rightarrow \quad \text{H} \quad \rightarrow \quad \text{I} \]

\[\text{I} \quad \rightarrow \quad \text{J} \quad \rightarrow \quad \text{K} \quad \rightarrow \quad \text{L} \quad \rightarrow \quad \text{M} \quad \rightarrow \quad \text{N} \quad \rightarrow \quad \text{O} \quad \rightarrow \quad \text{P} \quad \rightarrow \quad \text{Q} \quad \rightarrow \quad \text{R} \quad \rightarrow \quad \text{S} \quad \rightarrow \quad \text{T} \quad \rightarrow \quad \text{U} \quad \rightarrow \quad \text{V} \quad \rightarrow \quad \text{W} \quad \rightarrow \quad \text{X} \quad \rightarrow \quad \text{Y} \quad \rightarrow \quad \text{Z}\]
Distance \( d_1 = 0.278 V_B \cdot T \cdot \phi \)

\[ = 0.278 \times 60 \times 9 = 33.36 \text{ m} \]

Distance \( d_2 \)

Min. distance btw two vehicles

\[ s = 0.2 V_B + 6 \]

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

Time \( T \) = \[ \sqrt{\frac{us}{a}} = \sqrt{\frac{u \times 18}{0.278 \times 9.5}} \]

\[ = 10.18 \text{ sec.} \]

Distance

\[ d_2 = 2s + b = 2 \times 18 + 0.278 \times V_B \cdot T = 80.8 \text{ m} \]

Distance \( d_3 \)

\[ = 0.278 \times V_C \cdot T = 0.278 \times 80 \times 10 = 226.4 \text{ m} \]

\[ V_C \text{ not give fike } V_A = V_C \]

For lane 1 (one way)

\[ O \cdot S \cdot D = d_1 + d_2 = 33.36 + 80.8 = 233.16 \text{ m} \]

Three lane two way traffic

\[ O \cdot S \cdot D = d_1 + d_2 + d_3 = 33.36 + 80.8 + 226.4 \]

\[ = 440.56 \text{ m} \]
For total OS = 466M

Min length of overtaking zone = 3 × OS = 3 × 466 = 1398 M

Desirable length = 5 × OS = 5 × 466 = 2330

Overtaking zone (3 × OS)

Homework

1. 1992, while designing a highway in a built-up area, it was necessary to provide a horizontal curve of radius 325 m. Design the following geometrical features:

  0 SE  
  0 Ew  
  0 Length of T - C  

Desired speed = 65 km/h
Length of wheel base = 6.1 m
Pavement width = 10.5 m
\[ R = 325 \text{ m} \]
\[ V = 65 \text{ km/h} \]
\[ u = 6 \text{ km/h} \]
\[ w = 10.5 \text{ m} \]
\[ \text{no. of lane} = \frac{10.5}{3.5} = n = 3 \]

1. **Super-elevation**
   2. **Design for** 75% of design speed
   
   \[ e = \left( \frac{0.75V}{127R} \right)^2 = \left( \frac{0.75 \times 65}{127 \times 325} \right)^2 = 0.0575 \]

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

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

3. **Check the value of f**
   
   for full design speed

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

   \[ f = \frac{65^2}{127 \times 325} = 0.0575 \]

   \[ 8.5 < 5.75 \]

4. **Extra widening**

   \[ E_w = \frac{nud^2}{2R} + \frac{V}{9.51R} = \frac{3 \times 6.12}{2 \times 325} + \frac{65}{9.5 \times 325} \]

   \[ = 0.55 \text{ m} \]
Total width of road
= W + Ew = 10.5 + 0.55 = 11.05 m

3. Length of transition curve

a. Rate of change of radial acceleration

L = \frac{v^2}{cR}
\frac{c}{75 + v} = \frac{80}{75 + v}
L = (0.218 \times 65)^2
= 0.57 \times 325
L = 31.85 m

b. As per rate of change of super-elevation

Total cause of outer edge (Assume)

\chi = (W + Ew) e = (11.05) \frac{5.75}{100} = 0.635 m

L = 100 \times \chi = 100 \times 0.6354 = 63.54 m

C. Empirical formula

L = 2.7 \frac{v^2}{R} = \frac{2.7 \times 65^2}{325} = 35.1 m
6. A truck with c.n. at $x = 1.4m$ and $y = 6.7m$ is travelling on a curve road of radius $200m$ and $e = 0.05$. Determine max. safe speed to avoid both slipping and overturning. Coefficient of side friction = 0.15. Sketch, explain, and derive the expression.

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

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

\[ \tan \theta + \left( f \tan \theta + f \frac{v^2}{R} \tan \theta \right) = \frac{v^2}{R} \]

\[ \frac{e+f}{1-e+f} = \frac{v^2}{g \times R} \]

Max speed.

\[ -v = \sqrt{\frac{gR(e+f)}{1-(e+f)}} = \sqrt{9.81 \times 300 \times (0.05+0.15)} \]

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

(2) For overturning

Vehicle may overturn about point B.

Equating moment of all forces about B

\[ \frac{mv^2}{R} \cos \theta \times y = m g \sin \theta \times y + C \times \frac{mv^2}{R} \cos \theta + \frac{2mv^2}{R} \sin \theta \times y \]

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

\[ \frac{v^2}{R} \times y = g \times e \times y + d \times x + \frac{v^2}{R} \times e \times x \]
\[ \frac{v^2}{\partial R} = \frac{x+ey}{y-ex} \]

\[ v_n = \sqrt{\frac{(x+ey)}{(y-ex)}} \times g \times \frac{R}{R} \]

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

\[ v_{\text{max}} = 142.97 \text{ m/sec} = 520.05 \text{ kmph} \]

The speed will be allowed to take a minimum

\[ v_{\text{max}} = 71.52 \text{ kmph} \]

6. A rectangular bridge span of length \( l \) and width \( w \), is used on a horizontal curve. If the road is 8m wide, and minimum clearance of 1m is desired from the edge of pavement and bridge rail, show that minimum radius of curvature

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

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

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

**Quest:** A vertical parabolic curve is to be used under a grade separation structure. The minus grade left the right is 4.1%, and plus grade is 3%. Intersection of two grades is at 435 m and at an elevation of 251.8 m. The curve passes through a fixed point of a chainage of 460 m and R lot of 260 m. Find the length of curve.

**Soln:**

Equation of parabolic curve

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

\[ h = \text{distance from first tangent} \]
(1) For point $A (h_1)$

- Point $P$: $P = 260 m$
- Point $Q$: $Q = P + 410 - CT$
  
$$CT = 460 - 485 = 25 m$$

$$h_1 = PQ = 260 - 250 \cdot 48 = 9.52 m = k \cdot x^2$$

(2) For point $B$

$$h_2 = BS + SR = 0.03x + 0.04x = 0.07x = k \cdot x^2$$
\[ h_2 = \frac{1}{x^2} = \frac{1}{(24)^2} = 0.0077 \]

For point B = (x = 24)

\[ r = \frac{0.0077}{u^2} \]

From (1) and (2)

\[ \left( \frac{0.0077}{u^2} \right)(u^2 + 25)^2 = 9.52 \]

\[ u^2 + 50u + 625 = \frac{9.52 \times u}{0.0077} \times u \]

\[ u^2 - 4944u + 625 = 0 \]

\[ u = 492.89, 492.73 \]

Total length of curve = \( 8u \) = 985.46 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.

[Diagram of summit curves]
\[ N = \left| \frac{1}{n_1} - \frac{1}{n_2} \right| \]

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

Assuming wongnat curve \((\text{le} > \text{s})\)

\[ L = \frac{\frac{11}{300} \times (18\text{C})^2}{4 \times 4} = 270\text{m} \]

\[ L > S \text{, so assumption is correct, hence(o.k)} \]

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 fulfil both comfort condition and head light signal distance condition.

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

Design speed = 80 kmph.

Comfort condition

\[ L = L_s \quad | \quad L_s \]

\[ L = L_s \]
Length of curve

\[ L = 2L_5 = 2 \times \left( \frac{N \cdot V^3}{C} \right)^{1/2} \]

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

\[ N = \left( \frac{1}{N_1} - \frac{1}{N_2} \right) = \left( -\frac{1}{20} - \frac{1}{30} \right) = \frac{50}{600} \]

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

\[ L = 7.82 \text{ m} \]

2) Headlight side distance

Since \( s = 0 \) because half upward and half downward gradient.

Assuming \( L_c > s \)

\[ s = \text{stopping signal distance} \]

\[ s = 0.278 \cdot V \cdot t_r + (0.278 N)^2 \]

\[ = \frac{2J (t \pm s_y)}{2J} \]

\[ s = 0.278 \times 80 \times 1.5 + (0.278 \times 80)^2 \]

\[ = 2 \times 81 (0.35 + s_h) \]
SSD (cs) = 127.63 m

\[ L = \frac{N S^2}{2 (n_1 + n_2 \beta)} = \frac{\frac{50}{800} \times 127.63^2}{2 \left( 0.75 + 127.63 \tan 70^\circ \right)} \]

\[ S_{90} = 228 m \]

228 m > s

\[ \text{Hence O.K.} \]

Assumption is correct.

Provide length of curve = 228 m. (Provide max. length) is both conditions.
Traffic Engg.

Topic to discussion

Traffic characteristics
  - Road user characteristic
  - Vehicular characteristic
  - Booking characteristic

Traffic studies
  - Traffic volume
  - Traffic density
  - Speed study
  - O & D study
  - Traffic flow study
  - Traffic capacity
  - Parking study
  - Accident study

3) Traffic operation and control

  - Traffic regulations
  - Traffic control devices
  - Traffic signs
    - Regulatory sign
    - Warning sign
    - Information sign
    - Traffic signal
  - Traffic island
Braking Characteristics

Assumptions:
1. After application of brakes, brakes are fully jammed.
2. The vehicle is just skidding over road surface.
3. Brake efficiency = 100%
4. Friction coefficient of friction (f) is utilised.
5. In case brake efficiency is less than 100%.
\[
\text{observed} \times 100 = \text{Brake efficiency in } \% \\
\]

If a vehicle travels a distance after application of brakes

\[ \text{KE loss} = \text{Work done} \]

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

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

\[ v^2 = 2 g f \cdot s \]

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

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

If time taken = t sec.

retardation = a

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

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

[\[ v = u + a \cdot t \]

\[ v^2 = u^2 + 2 a s \]
\[ v^2 = 2as \]

\[ f = \frac{a}{g} \]

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

\[ s = ut + \frac{1}{2} at^2 \]

\[ = vt - \frac{1}{2} \left( \frac{v}{t} \right) t^2 \]

\[ = vt - \frac{1}{2} vt \]

\[ s = \frac{vt}{2} \]

**Question:** A vehicle is 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 the retardation.

1. Time taken
2. Retardation
\[ V = 6.5 \text{ km/h} \]

\[ s = 25.5 \text{ m} \]

\[ V = 85.5 \text{ m/s} \]

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

Average skid resistance

\[ f = \frac{V^2}{2gy} \]

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

Brake efficiency

\[ = \frac{0.6526 \times 100}{0.70} \]

\[ = 93.5 \% \]

Time taken

\[ S = \frac{VT}{2} \Rightarrow t = \frac{2S}{V} \]

\[ = \frac{2 \times 25.5}{18.07} \]

\[ = 2.82 \text{ sec} \]

Retardation

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

\[ a = \frac{V}{t} = \frac{18.07}{2.82} = 6.40 \text{ m/sec}^2 \]
0.3. If a vehicle takes 4.5 sec to stop and skid marks observed are 46 M. Calculate:

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

\[ t = 4.5 \text{sec} \]

1. \[ S = 46 \text{M} \]
2. \[ f = 4.5 \text{sec} \]

1. Initial speed \( (v) \)

\[ s = \frac{vt}{2} \]

\[ v = \frac{2s}{vt} = \frac{2 \times 46}{4.5} = 20.444 \text{ m/sec} \]

\[ v = 73.54 \text{ m/sec}, \text{ km/h} \]

2. \[ f = \frac{v^2}{2s} \]

\[ = \frac{(20.444)^2}{2 \times 46} = 0.463 \]

3. Retardation

\[ a = g f \]

\[ = 9.81 \times 0.463 = 4.54 \text{ m/sec}^2 \]
Traffic study:

Traffic Volume:

Number of vehicles passing from a road section one unit 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) for different types of vehicles:

1. Passenger car, tempo, tractor, auto Rickshaw
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   1050  Exerience period

(2) Variation charts:-
    showing variation of volume.

(4) Traffic flow maps:-
    on different routes.

(5) 30th highest hourly volume

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

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

speed of vehicle = \( \text{km/hr} \)

Relation btw Volume, Density, Speed:

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

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

\[ v = 4.76 - 0.22k \]

where \( v \) = speed in \( 	ext{km/hr} \)

and \( k \) = density in \( \text{veh/km} \)
Find the capacity of road.

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

soh

\[
    u = 42.76 - 0.22k
\]

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 \( C = 0 \)

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

\[
    k(42.76 - 0.22k) = 0
\]

\[
    k = 0
\]

\[
    C = 42.76 - 0.22k = 19.43 \text{ vehicles/km}
\]

\[\text{Flow} \quad P \quad (C)\]

\[\text{2018 vehicles/yr}\]

Epistemic Equation (from parabolic equation)
For \( k \) to be \( \max \)

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

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

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

\( \max \)

\[
c = 42.76 \times 97.18 = 4166 \times 97.18
\]

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

Important Values:

1. Volume is zero at zero density.
2. Volume increases if density is increasing and shall be \( \max \) at \( k = 97.18 \text{ veh/km} \).
3. After this value, volume is reduced and again becomes zero at \( k = 194.36 \text{ veh/km} \).

\( \max \) flow observed

\[
= 2.78 \text{ km/hr}
\]
1. Origin and destination study (O and D study)
2. Roadside interview
3. License plate method
4. Return post card method
5. Tag on car method
6. Home interview method
7. Work spot interview method

Presentation:
- Desire lines are prepared
- Thickness of desired lines
- 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

I. 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:

3) As per velocity and distance, maintained below two vehicle.

\[ V \text{ km} = \frac{1000 \times V \text{ (m)}}{s} \]

\( V \text{ km} \) distance travel in 1 hour.

Theoretical max. capacity:

\[ C_{\text{max}} = \frac{1000 \times V}{s} \text{ (veh/hr)} \]

\( V = \text{Speed in kmph} \)

\( s = \text{Minimum distance between two vehicles} \)

\[ = (0.7V + d) \]

\[ = (0.7V + c) \]

\[ = (0.2V + c) \]

0.7 sec = perception reaction time
Q. Estimate maximum theoretical capacity of a highway for one way one lane traffic moving at 65 kmph. Speed consider average length of vehicle = 5.2 m. and time head way blow two vehicles = 2.5 sec.

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

\( t_h \) = Time head way

1. As per speed
   - Minimum clearance \( s = (0.7v + \varphi) = (0.2v + \varphi) \)
   - \( s = 0.2 \times 65 + 52 = 18.20 \)

Theoretical capacity (max)

\[
C_{\text{max}} = \frac{1000v}{s} = \frac{1000 \times 65}{18.20} = 3571 \text{ veh/hr}
\]

2. As per time headway = 2.5 sec
   - \( C_{\text{max}} = \frac{3600}{t_h} = \frac{3600}{2.5} = 1440 \text{ veh/hr} \)

---

6. Accident study:

- Type 1:
  1. A moving vehicles hit a parked vehicle
  2. Two vehicle moving at slight 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 = \((v_B' - v_A')\)

Newtonian Law of Collision:

As per this law, velocity of separation bears a constant ratio with velocity of approach. This ratio is called a 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]

1) Perfectly elastic collision

\[ e = 1.0 \]

\[ e = \frac{v_{B'} - v_{A'}}{v_A - v_B} = 1.0 \]
K.E. lost = work done

Brake efficiency = 100%

Total movement of vehicle when brake are applied

\[
F_{mg} = \frac{m-g}{m} \cdot V_A \cdot V_B = m \cdot V_A + m \cdot V_B
\]

Total momentum after collision

\[
\text{momentum equation}\]

Total momentum before collision

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

\[
v_A' = v_B
\]

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

Perfectly plastic collision

\[
(v_B - v_A) = (v_A - v_B)
\]
\[ \frac{1}{2} m v_1^2 - \frac{1}{2} m v_2^2 = F x s \]
\[ = f \cdot m g \cdot s \]

\[ v_1^2 - v_2^2 = 2 g f \cdot s \]

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

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

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

Assumption:

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

Better collision:

For vehicle A:

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

2. Momentum Equation:

Total momentum just before collision = Total momentum just after collision

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

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

3. After collision:

For vehicle A and B.

\[ v_3^2 - v_2^2 = 2gf \cdot s_2 \]

\[ v_3^2 = 2gf \cdot s_2 \]

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

Steps:

Given values: 1. \( s_1 \) 2. \( s_2 \) 3. \( m_A \) 4. \( m_B \) 5. \( f \)

- Calculate \( v_3 \) from Eq(3)
- Calculate \( v_2 \) from Eq(1)
- Calculate \( v_1 \) from Equation (1)
A vehicle apply brakes and skid through a distance $s_1 = u_0 m$ before colliding another parked vehicle, the weight of which is 60% of former. From fundamental principles, calculate initial speed of moving vehicles if distance which both vehicles skid is 18 m. $f = 0.60$. Show the various step and assumptions made each step.

After collision:

For vehicle $A + B$

$V_3^2 = 2g f \cdot s_2$

$V_3 = \sqrt{2 \times 9.81 \times 0.60 \times 12}$

$V_3 = 11.88 \text{ m/sec}$
Momentum Equation

\[ m_A \cdot v_{A2} + m_B \cdot 0 = (m_A + m_B) \cdot v_3 \]

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

\[ = \frac{m_A + 0.60m_A}{m_A} \times 11.80 = 19.017 \]

(2) Better Collision for A

\[ v_1^2 - v_{A2}^2 = 2\Delta f \cdot s_1 \]

\[ v_1 = \sqrt{v_{A2}^2 + 2 \cdot \Delta f \cdot s_1} \]

\[ v_1 = \sqrt{(19.017)^2 + 2 \times 0.81 \times 0.60 \times 40} \]

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

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

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

![Diagram](image-url)
Given values
- $S_{A1}, S_{A2}, S_{B1}, S_{B2}, s, MA, MB$

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

After collision case $\circ$

For $A$

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

$$V_{A3} = \sqrt{2g \cdot f \cdot S_{A2}}$$

--- (1)

For $B$

$$V_{B3} = \sqrt{2g \cdot f \cdot S_{B2}}$$

--- (2)

Momentum equation $\circ$

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

$$MA \cdot V_{A2} + MB \cdot S_{B} = MA \cdot V_{A3} \cdot \cos \theta_A + MB \cdot V_{B3} \cdot \sin \theta_B$$

$$V_{A2} = V_{A3} \cdot \cos \theta_A + \left(\frac{MB}{MA}\right) V_{B3} \cdot \sin \theta_B$$

--- (3)

Total moment in the $y$ direction for $A$

$$MA \cdot S_{O} + MB \cdot V_{B2} = MA \cdot V_{A2} \cdot \sin \theta_A + MB \cdot V_{B2} \cdot \cos \theta_B$$

$$V_{B2} = \left(\frac{MA}{MB}\right) V_{A2} \cdot \sin \theta_A + V_{B2} \cdot \cos \theta_B$$

--- (4)
Before Collision

For A

\[ v_{A1}^2 - v_{A2}^2 = 2g f \cdot S_{A1} \]

\[ v_{A1} = \sqrt{v_{A2}^2 + 2g f S_{A1}} \]  \hspace{1cm} (5)

For B

\[ v_{B1}^2 - v_{B2}^2 = 2g f \cdot S_{B1} \]

\[ v_{B1} = \sqrt{v_{B2}^2 + 2g f S_{B1}} \]  \hspace{1cm} (6)

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

\[ \text{Initial skid direction before collision} \quad 50^\circ \text{ N of W} \]

\[ \text{Initial skid distance before collision} \quad 35 \text{ m} \]

\[ \text{Initial skid distance after collision} \quad 15 \text{ m} \]

\[ \text{Weight} \quad 0.75 \text{ t for A} \quad 6 \text{ t for B} \]

\[ f = 0.55 \]

Calculate initial speed of two vehicles.
After Collision:

For A:
$$v_{A3}^2 = v_{A2}^2 + 2g \Delta h_{A2}$$
$$v_{A3} = \sqrt{2 \times 9.81 \times 0.55 \times 15} = 12.722 \text{ m/sec.}$$

For B:
$$v_{B3} = \sqrt{2 \times 9.81 \times 0.55 \times 36} = 19.71 \text{ m/sec.}$$

Momentum Equation

$$\theta_A = 130^\circ, \quad \theta_B = 60^\circ$$

In the direction of the problem:

$$M_A \cdot v_{A2} + M_B \cdot v_{B2} = M_A \cdot v_{A3} \cos \theta_A + M_B \cdot v_{B3} \sin \theta_B$$

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

$$v_{A2} = 12.722 \times \cos 130^\circ + \frac{1}{0.75} \times 19.71 \times \sin 60^\circ$$

$$v_{A2} = 14.58 \text{ m/sec.}$$
2. Before collision, in the direct(b), y-direction

\[ MA_0 + MB \cdot v_{B2} = m_A \cdot v_{A_2} \cdot \sin \theta_A + MB \cdot v_{B3} \cdot \cos \theta_B \]

\[ v_{B2} = \frac{M_A}{M_B} \cdot v_{A_3} \cdot \sin \theta_A + V_{B3} \cdot \cos \theta_B \]

\[ v_{B2} = 0.75 \times 12.722 \times \sin 30^\circ + 11.31 \times \cos 60^\circ \]

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

Before collision

\[ v_{A1} = \sqrt{v_{A_2}^2 + 2g \cdot s_{A1}} \]

\[ v_{A1} = \sqrt{(14.58)^2 + 2 \times 9.8 \times 0.55 \times 35} = 24.295 \text{ m/sec} \]

\[ v_{A1} = 87.35 \text{ km/h}. \]

For B

\[ v_{B1} = \sqrt{v_{B_2}^2 + 2g \cdot s_{B1}} = \sqrt{(17.16)^2 + 2 \times 9.8 \times 0.55 \times 30} \]

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

Design of signal timing

General principle of signal design

**Types**

1. Two-phase system

\[ \text{Signal} \]

\[ \text{PH} \]

\[ \text{PH-1} \]

\[ \text{PH-2} \]

\[ \text{PH-Phase} \]
Types of Four Phase System:

For Two Phase System:

Properties:

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

\[ R_A = V_{IB} + A_B \]
\[ R_B = V_{IA} + A_A \]
(5) Unseen time on two roads is decided as per traffic volume on two roads.

\[ \frac{u_{1A}}{u_{1B}} = \frac{\eta_A}{\eta_B} \]

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

These are two purposes:

- \( l \) = length of vehicle
- \( t \) = traffic time
- \( W \) = SSD
- \( 1.1 \) = Traffic signal

(4) Two allow the vehicle approaching the intersection to stop before intersection.

For vehicle (1):

- At design speed \( v \) = \( v_{\text{design}} \)
- Retardation = \( a \)
- \( -a = \frac{v - v}{t} \)
- \( t = \frac{v}{a} \)

Minimum time required to stop the vehicle (Amber time required)

- \( t_r \) = perception reaction time
- \( t_i \) = total time
- \( t_i = t_r + \frac{v}{a} \)
To allow all these vehicles that are in danger area (within SSD zone) to go.

Max time required to cross (say vehicle no@)

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

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

Amber time should be \text{max} of \( t_1 \) and \( t_2 \)

Methods for design signal timing:

D) Tricyclic method:

- In this case traffic volume per minute is used.

If 15 minute 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
\[ x_A = \frac{\eta_A}{15 \times 60} \times T \]

\[ x_B = \frac{\eta_B}{15 \times 60} \times T \]

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

→ Green time required on two roads

\[
\frac{v_{1A}}{v_{1A}} = x_A \times t_n \]

\[
\frac{v_{1B}}{v_{1B}} = x_B \times t_n \]

\[
\begin{array}{c|c|c}
\hline
v_{1A} & A_A & R_A \\
\hline
R_B & v_{1B} & A_B \\
\hline
\end{array}
\]

→ Total cycle time

\[ T_1 = (v_{1A} + A_A) + (v_{1B} + A_B) \]

→ Calculated cycle time \((T_1)\) should be equal to assumed cycle time \(T\) (sec.)

→ If not, assume another cycle time and repeat the process.
It is min traffic count on two roads at 150 and 120 vehicles per lane. If amber time on two roads 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

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

Total cycle time

\[ = (t_{1A} + t_h) + (t_{1B} + t_h) \]
\[ = (25 + 5) + (20 + 5) = 55 \text{ sec} \]
2nd Method

\[ T = u_n + A_n + \sum_{\beta} A_{\beta} \]

\[ = (x_1 x_{\theta_1}) + A_n + (x_2 x_{\theta_2}) + A_{\beta} \]

\[ = \left( \frac{n_n}{15 \times 60} x_T x_{\theta_n} \right) + 5 + \frac{n_B}{900} x_T x_{\theta_B} + 5 \]

\[ = \frac{150}{900} x_T x_{\theta_n} + 10 + \frac{120}{900} x_T x_{\theta_B} \]

\[ T = \frac{10}{(1 - 0.416 - 0.333)} = 35.88 \text{ sec.} \]

Say 40 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.

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

\( t_{pa} \) (initial walk period)

\[ L = 1.2 \text{ m/s} = \text{speed of pedestrian} \]

Minimum Red Time on Two Roads

\[ R_A = t_{pa} \]

\[ R_B = t_{pb} \]

Minimum Green Time Required on Two Roads (for traffic)

\[ R_A = t_{pa} + A_B \] \( \Rightarrow \) \[ t_{pa} = R_A - A_B \]

\[ R_B = t_{pb} + A_B \] \( \Rightarrow \) \[ t_{pa} = R_B - A_B \]
Consider any one green time \( t_{GA} \) or \( t_{GB} \) as calculated above and another is found using traffic volume on two roads.

\[
\frac{\eta_{GA}}{\eta_{GB}} = \frac{\eta_A}{\eta_B}
\]

If \( \eta_{GB} \) is considered than \( \eta_{GA} \) calculate

\[
\eta_{GA} = \frac{\eta_A}{\eta_B} \times \eta_{GB}
\]

(9)

(5) Total cycle time

\[
T = (t_{GA} + t_{AN}) + (t_{GB} + t_{BN})
\]

---

Traffic

---

\( T_A \)

\( T_B \)

\( T \)

---

\( P_A \)

\( P_B \)

---

Pedestrian for

\( w_{GA} \)

\( w_{GB} \)

\( w_{GA} \) and \( w_{GB} \)

---

Green

\( W_{GA} \)

\( W_{GB} \)

---

Walk

\( G_{GA} \)

\( G_{GB} \)

---

Walk

\( W_{GA} \)

\( W_{GB} \)
2) \[ RA = v_{1A} t_{1A} + A_{1A} \]
\[ RB = v_{1B} t_{1B} + A_{1B} \]

3) Do not walk period [pedestrian signal]
\[ Dw_{1A} = v_{1A} t_{1A} + A_{1A} \]
\[ Dw_{1B} = v_{1B} t_{1B} + A_{1B} \]

8) Clearance interval
\[ CIA = \frac{WA}{1.2} \]
\[ CIB = \frac{WB}{1.8} \]

7) Walk period on two roads
\[ WA = RA - CIA \]
\[ WB = RB - CIB \]

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

- Width of road
  - Road A: 18 m
  - Road B: 7.5 m
- Traffic volume (total)/hr
  - Road A: 900 vehicles/hr
  - Road B: 350 vehicles/hr
- Amber time on two roads
  - 5 sec
- No. of lane
  - 1 lane
  - 2 lanes
Design roundabout on two roads

\[ \eta_A = 500 \text{ v/hr/kane} \]

\[ \eta_B = 350 \text{ v/hr/kane} \]

Step 1: Minimum for pedestrian

\[ \frac{WA}{1.2} = 7.0 + \frac{18}{1.2} = 29.33 \text{ sec.} \]

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

Step 2: Minimum on traffic

22.8 sec.
14.8 sec.

Step 3: Minimum on traffic

\[ 14 - 5 = 8 \text{ sec.} \]

\[ 17 \text{ sec.} \]
Let us consider max:

\[ \eta_B = 1.2 \text{sec.} \]

\[ \eta_B = \frac{315}{250} = \frac{315}{\eta_B} \]

if \( \eta_B \) is considered

\[ \eta_B = 0.75 \]

\[ \eta_B = \frac{175}{\eta_B} \times 0.75 = \frac{315}{250} \times 0.75 = 2.2 \text{sec.} \]

Total cycle time

\[ \frac{1}{T} = (\eta_A + \eta_B) + (\eta_B + \eta_B) \]

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

\[ = 47 \text{sec.} \]

\[ T = \frac{1}{47} \approx 2.17 \text{sec.} \]

\[ \eta_B = 0.75 \]

\[ \eta_B = 28.8 \text{sec.} \]

\[ P_B = 27 \text{sec.} \quad U_B = 1.8 \text{sec.} \quad \eta_B = 580 \]

\[ D_B = 27 \text{sec.} \quad V_B = C_F \quad \eta_B = -15 \]

\[ W_B = 89 \text{sec.} \quad \eta_B = 7 \quad \eta_B = 82 \text{sec.} \]

\[ P_B \]
\( R_A = \text{q}_{\text{in A}} = 115 = 22 \)  \[\text{9a}\]
\( R_B = \text{q}_{\text{in B}} = 42.5 = 27 \)  \[\text{9b}\]

4. Pedestrian walk period
\( \text{DW}_{\text{A}} = \text{C}_{\text{in A}} + A_A = 27 \)
\( \text{DW}_{\text{B}} = \text{C}_{\text{in B}} + A_B = 22 \)

5. Clearance time for
\[ \text{C}_{\text{FA}} = \frac{\text{WA}}{12} = \frac{18}{12} = 1.5 \text{sec} \]
\[ \text{C}_{\text{FB}} = \frac{\text{WA}}{12} = \frac{7.5}{12} = 0.625 \approx 1 \text{sec} \]

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

7. Webster's method

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

If there are two roads
- Normal flow (design value)
  - Road A = 94
  - Road B = 98
- Saturation flow values are
  - Road A = 5A
  - Road B = 5B
(saturation flow)

\[ s = \begin{array}{cccc} 
3.0 & 3.5 & 4.0 & 4.5 & 5.0 \\
1850 & 1750 & 1650 & 2250 & 2550 
\end{array} \]

**Steps**

1. \( y_A = \frac{q_A}{s_A} \)
2. \( y_B = \frac{q_B}{s_B} \)
3. \( Y = y_A + y_B \)
4. Total class time
   \[ L = 2n + R \]
   where:
   - \( n \): Number of phases
   - \( R \): All red time (168 sec)
5. Optimum cycle time
   \[ c_0 = \frac{1.5L + 5}{1 - Y} \text{ sec} \]
6. Green time required on two road
   - \( G_{\text{A}} = \frac{y_A}{Y} (c_0 - L) \)
   - \( G_{\text{B}} = \frac{y_B}{Y} (c_0 - L) \)
Due to the design, signal timing for two roads (A) and (B), the traffic volume of these two roads are:

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

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

If the red time is 15 sec, use the Webster method and design for a two-phase system.

Normal Flow:
- \( Q_A = 465 \text{ veh/hr/lane} \) [Max. for traffic (A)]
- \( Q_B = 350 \text{ veh/hr/lane} \) [Max. for traffic (B)]

Saturation Flow:
- Consider half of total width of road A for saturation flow
- Road A: For 7.50 width (from table)
  - \( S_A = 52.5 \times 7.50 = 393.75 \text{ veh/hr} \) [For two lane]
  - \( S_A \text{ per lane} = \frac{393.75}{2} = 196.875 \text{ veh/hr/lane} \)
Road (b) per road width = 0.5 (one lane)

$S_B = 1950 \text{ veh/hr/km}$

3) $Y_A = \frac{Q_A}{S_A} = \frac{465}{1950} = 0.236$

$Y_B = \frac{Q_B}{S_B} = \frac{350}{1950} = 0.18$

$Y = 0.416$

C) Total loss time

$L = a+h+k$; no at phase-9

$L = 2 \times 2 + 15 = 19 \text{ sec.}$

D) Optimum cycle time

$C_0 = \frac{1.5L + 5}{1 - Y} = \frac{1.5 \times 19 + 5}{1 - 0.416} = 57.36$

$C_0 = \frac{58 - 19}{0.416}$

Green time

$\tau_A = \frac{Y_A(C_0 - L)}{Y} = \frac{0.236}{0.416} [58 - 19]$

$\tau_A = 22.125 \text{ sec}$

$\tau_B = \frac{Y_B (C_0 - L)}{Y} = \frac{0.18}{0.416} [58 - 19] = 16.81$ sec

Total cycle time $= \tau_A + \tau_B + \tau_A + \tau_B = 22.125 + 16.81 = 38.94$ sec
IRC Method

1. Combination of approximate and exact method
2. Calculate signal cycle time using approximate method.

\[ T_{sec} = (T_A + T_{app}) + (T_B + T_{app}) \]

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

No. of vehicles accumulated on two roads in one cycle time

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

Minimum green time:

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

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

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

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

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

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

Road A
- Width of road: 9.4 m
- No. of lane: 6
- Traffic volume in one direction: 1850
- Other direction: 1360
- Amber time: 5 sec.

Road B
- Width of road: 7.5 m
- No. of lane: 2
- Traffic volume in one direction: 350
- Other direction: 290
- Amber time: 5 sec.

3. Design volume on two roads:

\[ n_A = \frac{1850}{2} = 925 \approx 925 \text{ veh/hr/lane} \]

\[ n_B = \frac{350}{1} = 350 \text{ veh/hr/lane} \]
1. Use approximate method

1. M/M unfront time required for pedestrian signal

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

\[ \eta_{PB} = 7.8 \text{ sec} + \frac{W_B}{1.2} = 7 + \frac{7.5}{1.2} = 13.25 \approx 14 \text{ sec} \]

2. Unfront time for traffic signal

\[ RA = \eta_{PA} = 27.8 \text{ sec} \]

\[ RB = \eta_{PB} = 14 \text{ sec} \]

Unfront time

\[ \eta_{A} = RB - AA = 14 - 5 = 9 \text{ sec} \]

\[ \eta_{B} = RA - AB = 27 - 5 = 22 \text{ sec} \]

3. Consider

\[ \eta_{B} = 22.8 \text{ sec} \] (Max value in \( \eta_A \) and \( \eta_B \))

\[ \frac{\eta_A}{\eta_B} = \frac{7}{3} = \frac{21}{2} \]

\[ \eta_A = \frac{617}{350} \times 22 = 38.78 \approx 39 \text{ sec} \]

4. Total cycle time

\[ T = (\eta_A + AA) + (\eta_B + AB) \]

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

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

5. Number of vehicle accumulated on two rear

6. One cycle time
\[x_A = \frac{617}{60 \times 60} \times 71 = 12.17 = 13 \text{ sec. Nos.}\]

Green time required

\[G_{1,2,3} = 6 + (13 - 1) \times 2 = 30 \text{ sec.} < 35 \text{ sec.}\]

Hence O.K.

Similarly on Road B

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

Red time required

\[G_{1,2,3} = 6 + (7 - 1) \times 2 = 18 \text{ sec} < 22 \text{ sec.}\]

Hence O.K.

Webb's method

\[Q_A = 617 \text{ veh/hr/ lane}\]

\[Q_B = 350 \text{ veh/hr/lane}\]

Saturation flow value

[Saturation flow value calculate for half party of roads]

\[S_A = \text{for } 12 \text{ m width}\]

\[= \frac{529 \times 12}{3} = 6300 \text{ veh/hr/ lane}\]

\[= \frac{6300}{3} = 2100 \text{ veh/hr/lane}\]

\[S_B = \text{for } 3.75 \text{ m wide road}\]

\[= \frac{1890 + 1950}{2} = 1920 \text{ veh/hr/lane}\]
\[ y_n = \frac{q_n}{s_n} = \frac{617}{2100} = 0.294 \]

\[ y_B = \frac{q_B}{s_B} = \frac{350}{1920} = 0.182 \]

\[ y = y_n + y_B = 0.294 + 0.182 = 0.476 \]

Total processing time

\[ L = 2n + A \]

\[ = 2 \times 3 + 16 = 20.8 \text{ sec.} \]

Optimum cycle time

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

\[ c_{1A} = \frac{y_n}{y} \left( C_0 - L \right) = \frac{0.294}{0.476} \left( 67 - 20 \right) = 25.8 \text{ sec.} \]

\[ \text{Hence, } c_{1A} = 25.8 < c_a \]

\[ c_{1B} = \frac{y_B}{y} \left( C_0 - L \right) = \frac{0.182}{0.476} \left( 67 - 20 \right) = 18.8 \text{ sec} < 22.8 \text{ sec.} \]

\[ \text{Hence, } c_{1B} \text{ is } \text{O.K.} \]

\[ c_{1n} = 27 \text{ sec.} \]

\[ c_{1A} = 25.8 \text{ sec.} \]

\[ c_{1B} = 18.8 \text{ sec.} \]

\[ c_{1n} = 27 \text{ sec.} \]

\[ \text{Hence, } c_{1A} \text{ and } c_{1B} \text{ are } \text{O.K.} \]

\[ T_A = 27 \]

\[ T_B = 27 \]

\[ P_B \text{ (pedestrian B)} \]

\[ P_A \text{ (pedestrian A)} \]
Red Time = Wb + Ab = 22 + 5 = 27 sec.

\( R_B = W_A + A_B = 35 + 5 = 40 \) sec.

Donat walk period

\( D_{wA} = W_A + A_A = 44 \) sec.

\( D_{wB} = W_B + A_B = 27 \) sec.

Clearance interval

\( C_{IA} = \frac{24}{1.2} = 20 \) sec.

\( C_{IB} = \frac{7.5}{1.2} = 6.25 \approx 7 \) sec.

Walk period

\( W_A = R_A - C_{IA} = 27 - 20 = 7 \) sec.

\( W_B = W_B - 7 = 37 \) sec.

15 a. A driver travelling at speed limit of 50 mph as cited for crossing an intersection the claimed it duration of amber display was improper and consequently a claudia zone existed at that location using following data determine whether claim was correct

- Amber duration = 0.5 sec.
- Comfortable deceleration = 3 m/s²
- Car length = 4.6m
- Perception Reaction Time \( t_r = 1.5 \) 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 (for vehicle 0):
   \[ t = \frac{v}{a} \]
   \[ t = 1.5 + \frac{0.278 \times 50}{3} = 6.13 \text{ sec} \times 2.5 \text{ sec} \]
   Amber time provided.

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

   \[ SSD = 0.278 \times v \times t + \left( 0.278 \times v \right)^2 \]
   \[ 2a (t)^2 \]
   \[ SSD = 0.278 \times 50 \times 1.5 + \left( 0.278 \times 50 \right)^2 \]
   \[ 2 \times 0.5 \times 0.35 + 0 \]
   \[ SSD = 20.85 + 28.14 = 48.99 \text{ say } 49 \text{ m}. \]
Total time required to cross
\[
\frac{s + d + w + f}{0.278\, V} = \frac{4.8 + 15 + 4.6}{0.278\, V} = 4.935\, \text{sec.}
\]
\[
\geq 4.50\, \text{sec.}
\]
Yes, driver claim is correct.

1.1.4.
Design of rotary intersection.

1.2.
Examples:

1. Circular rotary.

2. Elliptical rotary.
3. Turbine Rotary

4. Tangential Rotary

2. Design Speed:
   - Rural Area = 40 kmph
   - Urban Area = 30 kmph

3. Radius of Rotary [Minimum Radius of Traffic Island]
   No super-elevation is provided [Camber slope is provided to drain off water]
   \[ e = 0 \]

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

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

here value of \( f = 0.13 \) → Rural Area [40 kmph]

\( f = 0.47 \) → Urban Area [30 kmph]
4) As per IRC,
   Radius of entry (\( R_{entry} \))

   Rural area = 20 to 35 m (40 kmph)
   Urban area = 15 to 25 m (60 kmph)

   Minimum radius of central island
   \[ R_{min} = 1.35 \times R_{entry} \]

5) Width of carriageway

   1) At entry \( e_1 \)
      Minimum = 5.0 m
      As per approximate road width
      7.0 m
      10.5 m
      14.0 m
      \[ 6.5 \text{ m} \]
      \[ 7.0 \text{ m} \]
      \[ 8.0 \text{ m} \]
(2) \[ w = \text{wearing section (e_2)} = e_1 \text{ if no value suggested or given} \]

(3) \[ w = \left[ \frac{e_1 + e_2}{2} + 3.5 \right] \]

(4) Length of weaving section
\[ L = 4.0 \cdot w = 4 \times \text{width of weaving section} \]

Value not given than recommended value

- 60 kmph \rightarrow 6.5 \text{ to 7.0m}
- 30 kmph \rightarrow 3.0 \text{ to 6.0m}

(5) Capacity of rotary:

\[ Q_p = \frac{2800 w \left( 1 + \frac{e}{w} \right) \left( 1 - \frac{p}{3} \right)}{(1 + \frac{w}{L})} \]

where

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

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

\[ L = \text{length of weaving section} \]

\[ p = \text{weaving ratio} \]

\[ p = \frac{\text{total weaving traffic}}{\text{total traffic}} \]
In a weaving section 4 type of movement of traffic can occur which is a, b, c, and d.

- **Weaving Ratio:**
  \[ p = \frac{b + c}{a + b + c + d} \]

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)

  - leg 1: 45
  - leg 3: 122
  - leg 4: 54
  - leg 5: 18
  - leg 6: 116
  - leg 7: 15
  - leg 8: 460
  - leg 9: 182
  - leg 10: 132
  - leg 11: 651
Find the weaving ratio between leg 1 and 0. What is the use of this value? Draw a sketch showing traffic volume between 0 and 5.

\[ a = V_{12} = 37 \]
\[ b = V_{13} + V_{14} + V_{15} = 303 + 64 + 52 = 419 \]
\[ c = V_{32} + V_{13} + V_{52} = 122 + 34 + 132 = 308 \]
\[ d = V_{53} + V_{52} + V_{54} \\
   = 18 + 62 + 15 = 95 \]
\[ p = \frac{b + c}{a + b + c + d} = \frac{37 + 419}{37 + 419 + 308 + 95} = 0.846 \]
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.
Weaving ratio between different legs

1. N-E

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

Weaving ratio

\[ \frac{b + c}{a + b + c + d} \]
\[ = \frac{950 + 725}{415 + 950 + 725 + 200} \]
\[ = 0.70 \]

2. E-S

\[ a = 300 \]
\[ b = 550 + 250 = 800 \]
\[ c = 650 + 300 = 950 \]
\[ d = 300 \]

Weaving ratio

\[ \frac{b + c}{a + b + c + d} \]
\[ = \frac{800 + 950}{300 + 800 + 950 + 300} \]
\[ = 0.745 \]

3. S-W

\[ a = 350 \]
\[ b = 400 + 225 = 625 \]
\[ c = 550 + 300 = 850 \]
\[ d = 250 \]

Weaving ratio

\[ \frac{b + c}{a + b + c + d} \]
\[ = \frac{625 + 850}{350 + 625 + 850 + 250} \]
\[ = 0.71 \]

4. W-N

\[ a = 400 \]
\[ b = 500 + 300 = 800 \]
\[ c = 400 + 225 = 625 \]
\[ d = 225 \]

Capacity

\[ Q_p = 280w \left( 1 - \frac{p}{w} \right) \left( 1 - \frac{2}{3} \right) \]
\[ \frac{1.5}{1 + \frac{w}{l}} \]
value of $t = 0.745$ & width of road

Entry width $e_1 = 6.5 + (\frac{15.5}{2} = 7.5)$

take $e_1 = 7.50 m$

width of non weaving section $e_2 = e_1 = 7.50 m$

$e = \frac{e_1 + e_2}{2} = 7.50 m$

weaving portion width

$w = \frac{e_1 + e_2}{2} + 3.5 = 7.50 + 3.50 = 11.00 m$

Length of weaving portion $= 4w = 4 \times 11 = 44 m$

Capacity $Q_p = \frac{280 \times 11 \left(1 + \frac{7.5}{11}\right) \times \left[1 - \frac{745}{3}ight]}{\left(1 + \frac{11}{44}\right)}$

$Q_p = 3114.9 = 3115 \text{ veh/h}$

Road width $= 15 m$

\[ e_1 = 7.0 m \quad 6.5 m \quad 10.5 m \quad 7.0 m \quad 14.0 m \quad 8.0 m \]
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. Subgrade

   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 bow.)

**Rigid Pavement**

Rigid pavement are constructed by using cement concrete [PCC, RCC, PSC]

- consists of generally three layers.
  1. Pavement (Cement concrete)
  2. Lean concrete (Base course 1:5:10)
  3. Soft subgrade

- Load transfer is by slab action.

- Soil. 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.

**Semi-Rigid Pavement**

- It binder material of better quality like solid cement, lime, Pozzolanic cement are
used with stone 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. Maximum legal axle load as per IRC
   
   \[ \text{Max. Legal Axle Load} = 8170 \text{ kg} \]

2. Equivalent single wheel load (ESWL)
   
   \[ \text{Equivalent Single Wheel Load} = 4085 \text{ kg} \]

3. Stress at a depth point at z depth due to load from a wheel.
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

Boussineq's Equation
\[
\sigma_z = p \left[ 1 - \frac{z^3}{(a^2 + z^2)^{3/2}} \right]
\]

1) 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 $120^\circ$ and $128^\circ$ ESWL values can be interpolated on a log scale.

Due: Calculate ESWL value for a dual wheel assembly carrying 20,500 kg each for pavement thicknesses of 15, 20 and 25 cm. If centre to centre distance between tyre is $s = 30$ cm, clear distance between wall $d = 12$ cm.
<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>EWL</th>
<th>log₁₀(EWL)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.778</td>
<td>2.050</td>
<td>3.311</td>
<td></td>
</tr>
<tr>
<td>1.176</td>
<td>2.699</td>
<td>3.431</td>
<td>$= 3.311 + \frac{3.31 - 3.31}{1.17 - 0.778}$</td>
</tr>
<tr>
<td>1.301</td>
<td>3.144</td>
<td>4.469</td>
<td>$= 3.311 + \frac{0.302}{1} (1.301 - 0.778)$</td>
</tr>
<tr>
<td>1.398</td>
<td>3.149</td>
<td>3.498</td>
<td>$= 3.311 + \frac{0.302}{1} (1.398 - 0.778)$</td>
</tr>
<tr>
<td>1.778</td>
<td>3.613</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing EWL data points and calculations.](image-url)
Methods for design of flexible pavements:

1. Group index method $\gamma = (u_1 - \gamma) / \gamma$

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

- Group index value

$$u_1 - \gamma = 0.2a + 0.005ac + 0.01bd$$

Here:

- $a = P - 35 \, \mu_0$
- $b = P - 15 \, \mu_0$
- $c = w_l - 40 \, \%$
- $d = I_p - 10 \, \%$

Here:

- $P = \%$ of fine soil particles passing 0.074 mm sieve.
- $w_l = \text{liquid limit}$
- $I_p = \text{plasticity index}$
- $I_p = w_l - w_p$
- $w_p = \text{plastic limit}$

A value of group index may be 0 to 5.

- High group index is a poor soil.
The thickness of pavement is found as per the given index value, using tables and graphs.

**Table:**

Total thickness of pavement required over a soil having bit value as:

<table>
<thead>
<tr>
<th>Bit Value</th>
<th>Base + Surface $(T_1)$</th>
<th>Subbase $(T_2)$</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>

**Limitations:**

The for all type of material used in pavement, the thickness suggested same. Thickness does not depend upon quality of material.
A soil subgrade has following data:

(a) soil passing from 0.074 mm sieve = 60%
(b) \( W_L = 45.1\), \( W_P = 25.1\).

calculate thickness of pavement required above the soil subgrade using ungroup index method. use table as shown above.

\[ p = 60\% \]
\[ W_L = 45.1 \]
\[ W_P = 25.1 \]
\[ I_p = W_L - W_P = 45.1 - 25.1 = 20.0 \]

\[ q = p - 35 = 60 - 35 = 25 < 40 \text{ OK} \]
\[ b = p - 15 = 60 - 15 = 45 \text{ too high, take } 40 \]
\[ c = w_L - u_0 = 45 - 40 = 5 < 20 \text{ OK} \]
\[ d = I_p - 10 = 20 - 10 = 10 < 10 \text{ OK} \]

Ungroup index:
\[ 0.7a + 0.005a + 0.01b = 0.7 \times 25 + 0.005 \times 40 + 0.01 	imes 40 \]
\[ = 17.5 + 2 + 4 = 23.5 \text{ OK} \]

Total thickness of pavement:

1. Surface + base = 30 cm
2. Sub base = 30 cm

Total = \( T = 30 + 30 = 60 \text{ cm} \)
CBR Method
(california bearing ratio method)

- CBR Value

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

The value of load required for 0.5 mm penetration and 5.0 mm penetration are compared with standard load values.

Standard load value are load required for 0.5 mm and 5.0 mm penetration over standard aggregate.
Standard load values are

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

4. CBR values

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

For 2.5mm

\[ CBR_1 = \frac{P_1}{1370} \times 100 \]

For 5.0mm

\[ CBR_2 = \frac{P_2}{2055} \times 100 \]

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

6. If 5.0mm CBR value is higher,

In this case, test is repeated and if same results is obtained again, this same CBR value (Chirnse value) is accepted as CBR value.

7. Draw blow load and penetration curve - 1) Normal curve, \( P_1 \) and \( P_2 \) taken for 2.05 and 5.0mm penetration.

8. False shear strength reading or initial concavity due to the soil compacted by hand not properly mixed.
If these are a frictional coefficient in the graph.

This is due to the settlement of soil at the end point of this tangent line.

The straight line of the tangent and origin is shifted.

Point and PI are read using shifted scale.

Design of pavement based on CBR values.

\[ T = \frac{P}{CBR} \]

\[ P = 1.15 \frac{A}{h} \]
\[
T = \frac{1.75p}{\text{CBR}} - \frac{\pi \times p}{\pi \times p}
\]

\[
T = \frac{1.75p}{\text{CBR}} - \frac{p}{\pi \times p}
\]

\[
T = \int \left( \frac{1.75}{\text{CBR}} - \frac{1}{\pi \times p} \right)
\]

**where**

- \(p\) = wheel load (kN)
- \(p\) = tyre pressure (kPa/cm²)
- \(A = \frac{p}{p} = \text{contact area} \text{ (cm}^2\text{)}\)
- \(\text{CBR} = \text{CBR value in } \%\)

**Diagram:**

- Load acting on the circular area
- Plan view of the pavement
- Soil or granular material

---

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Quality of material used in pavement is not considered.

Thickness can be found for a limited CBR value only. \[ t = \sqrt{\frac{1.25}{C_{BR}} \frac{R}{C_{BR}}} \]  

CBR test was conducted for subgrade and following results were obtained:

<table>
<thead>
<tr>
<th>Depth (cm)</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>
<tbody>
<tr>
<td>Value</td>
<td>4.0</td>
<td>6.0</td>
<td>8.0</td>
<td>10.0</td>
<td>12.0</td>
<td>14.0</td>
<td>16.0</td>
<td>18.0</td>
<td>20.0</td>
<td>22.0</td>
</tr>
</tbody>
</table>

Above this soil subgrade following material 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 layer thickness:
   - Wheel load = 4500 kg
   - Tyre pressure = 315 kPa

Calculate thickness of different layer of pavement using CBR method.

- Graph load and penetration
- CBR value of soil subgrade.
P₁ = 60 kg
P₂ = 83 kg

\[ \text{CBR}(2.5) = \frac{60}{1370} \times 100 = 4.38 \% \]

\[ \text{CBR}(8.0) = \frac{83}{2025} \times 100 = 4.10 \% \]

CBR value = 4.38 \%

CBR value of soil subgrade = 4.38 \%

Wheel load \ p = 4500 kg

Tyre pressure \ p = 715 \text{ kN/m}²

Contact area \ A = \frac{p}{\text{p}} = \frac{4500}{715} = 6.328 \text{ cm}²
Total thickness of pavement required over soil subgrade (CBR = 4.38%)

\[ T_1 = \frac{1.75 P}{CBR} - \frac{A}{\pi} = \frac{1075 \times 4500}{4.38} - \frac{642.86}{\pi} \]

\[ T_1 = 33.01 \text{ cm} \approx 40 \text{ cm} \]

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

Soil subgrade [CBR = 4.38%]

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

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

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

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%)

\[ T_3 = 30 \text{ cm} \]
\[ T_3 = \sqrt{\frac{1.75 \times 4500}{13} - \frac{642.86}{20}} = 20.03 \approx 20 \text{ cm} \]

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:
(California Resistance Value Method)

1. Thickness of pavement required
\[ T = \frac{K \cdot (T_I) \cdot (90 - R)}{C \cdot V_s} \]

where
\[ K = \text{constant} = 0.166 \]
\[ T_I = \text{Traffic Index} \]
\[ = 1.35 (EWL)^{0.11} \]
\[ R = \text{Rutability R-value} \]
\[ C = \text{Cone penetrometer C-value} \]
\[ EWL = \text{Yearly value of Equivalent wheel load} \]
Total Ewl value = 330V₁ + 1070V₂ + 2460V₃ + 4620V₄ + 3040V₅

Thickness of pavement:

\[ T = 0.166 \times \frac{1.35 \text{ (Ewl)}^{0.11} (90-R)}{C/V_5} \]

\[ T = 0.22 \text{(Ewl)}^{0.11} (90-R) \]

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

For two equivalent layers:

- If other values fail
To calculate 10 years EWL and traffic index value using following data:

<table>
<thead>
<tr>
<th>No. of AXLE</th>
<th>AADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3750</td>
</tr>
<tr>
<td>3</td>
<td>470</td>
</tr>
<tr>
<td>4</td>
<td>320</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
</tr>
</tbody>
</table>

Assume 60% increase in traffic in the next 10 years period. Calculate thickness of pavemen required, if R-value = 48, c = 16.

**Yearly Value of EWL (w present year)**

<table>
<thead>
<tr>
<th>No. 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>470</td>
<td>1070</td>
<td>502500</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>556400</td>
</tr>
<tr>
<td>SUM</td>
<td></td>
<td></td>
<td>3082000</td>
</tr>
</tbody>
</table>

After 10 years = 1.60 x 3082000

= 4931200

Average value (yearly value) = \( \frac{3082000 + 4931200}{2} \)

= 4006600
EWC for 10 years period = $10 \times 400,000 = 4,000,000$

Traffic Index

$TI = 1.35 \times (EWC)^{0.11} = 1.35 \times (4,000,000)^{0.11}$

$TI = 9.26$

Thickness

$T = \frac{0.32(TI)(30-R)}{C^{0.20}}$

$T = \frac{K \cdot (TI) \cdot (30-R)}{C^{1/5}}$

$T = \frac{0.166 \times 3.26 \times (90-48)}{(16)^{1/5}} = 37.08 \text{ cm}$

- Calculate the equivalent $c$-value of
- Three layer pavement having

<table>
<thead>
<tr>
<th>Bituminous pavement</th>
<th>Thickness</th>
<th>$c$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 cm</td>
<td>62</td>
<td></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

\[ T_b = 12.5 \quad C_b = 0.2 \]
\[ T_{w1} = \frac{2.5}{C_w} \]
\[ T_{w1} = 12.5 \times \left( \frac{\text{C}_{w}}{\text{C}_b} \right)^{1/5} = 14.52 \text{ cm} \]

2. Cement

\[ T_c = 25.0 \quad C_c = 1.80 \]
\[ T_{w2} = 25 \times \left( \frac{\text{C}_c}{\text{C}_w} \right)^{1/5} = 57.10 \text{ cm} \]

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

Total thickness of pavement in terms of well graded
\[ T_w = T_{w1} + T_{w2} + T_{w3} = 14.52 + 57.10 + 20 \]
\[ T_w = 91.62 \text{ cm} \]
Equivalent c-value = 25

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

\[ T_p = 57.50 \text{cm}, \quad c_p = 2 \]

Actual thickness

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

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

\[ c_p = 77.4 \]

- 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 value of pressure required to force our water from a soil.
Step 1: Thickness based on R-value.

Thickness of pavement calculated as:

\[ T_R = \frac{K_0 (T_L) (S_0-K)}{0.164 x + 35 (E_{wL})^{0.7}} \]

Step 2: Thickness based on expansion pressure.

Thickness of pavement is:

\[ T_e = \frac{\text{Expansion pressure (F/cm²)}}{\text{Avg. density of soil}} \]

\[ \rho = \frac{\text{Expansion pressure (F/cm²)}}{0.0021} \]

\[ T_e = \frac{\text{Expansion pressure}}{0.0021} \text{ cm} \]

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

![Graph showing the relationship between \( T_R \) and \( T_e \)]
Thickness of pavement required where
\[ T_R = T_e = \frac{T_1}{10} \text{ cm} \]

By drawing a line at 45° angle.

Step 4: Plot \( T_R \) vs. Exudation Pressure

Thickness of pavement at 28150 kN/m² Exudation Pressure is found = \( T_2 \) cm.

Step 5: Thickness of pavement required
\[ = \max \{ T_1 \text{ and } T_2 \} \]


The subgrade has the following data:

Traffic factor \( = 9.5 \text{ cm} \)
Moisture content | R-value | Expansion pressure | Exudation pressure | Tr : Te
---|---|---|---|---
15.4 | 56 | 0.135 | 36.5 | 31.20 | 64.30
18.4 | 44 | 0.099 | 26.5 | 42.20 | 47.14
21.4 | 25 | 0.055 | 18.0 | 53.60 | 26.20
24.4 | 14 | 0.034 | 15.0 | 69.73 | 16.20

so 1st \( \text{Step} \) Thickness of pavement in terms of WBM Value

\( C = 15 \text{ value} \)

Thickness based on R-value

\[ Tr = \frac{K \cdot TIC (50-R)}{\text{c}^{15}} = \frac{0.166 \cdot 5.50 \times (50-R)}{(15)^{1/5}} \]

\[ Tr = 0.9175 (50-R) \]

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

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

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

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

\( \text{step(2) Thickness based on Expansion pressure} \)

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

\[ Te(15.4) = \frac{0.135}{0.0021} = 64.30 \text{ cm} \]

\[ Te(18.4) = \frac{0.099}{0.0021} = 47.14 \text{ cm} \]
\[
T_e(24^\circ) = \frac{0.034}{0.0021} = 16.20
\]

Steps:

1. \[T_e = 13.5\]
2. \[T_1 = 40.2 \text{ cm}\]

Step 4: Plot \(T_e\) vs. vaporization pressure

\[T_2 = 38.0 \text{ cm}\]

\[p = 28.831 \text{ cm}^2\]

Exudation pressure
Step 5. Thickness of pavement

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

- **Step:**
  - 10 cm
  - 44 cm (wBM)
  - 34 cm
  - 7.5 cm Bitumenesity
  - 3 cm (WBM)
  - 9.5 cm

\[ T_B = 7.5 \text{ cm} \]
\[ c_B = 6.2 \]
\[ T_w = 2 \]
\[ c_w = 15 \]
\[ T_w = T_B \left( \frac{c_e}{c_B} \right)^{1/5} \]
\[ = 7.5 \left( \frac{6.2}{15} \right)^{1/5} = 3.6 \text{ cm} \]

\[ s_{a_y} = 10 \text{ cm} \]

Remaining thickness of WBM

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

(4) Triaxial Method

- This method based on \( E \) - value

  Thickness of

  \[ E_p > E_s \]

  This is called a two layers system

  - \( E_p > E_s \) b/c as in pavement good material is placed
Thickness of pavement required for a two layered system:

\[ T_p = \left[ \sqrt{\left( \frac{3F \times Y}{2\pi E_s \Delta} \right)^2 - q^2} \right] \times \left( \frac{E_s}{E_p} \right)^{1/3} \]

where

- \( F \) = wheel load in kg
- \( Y \) = Traffic coefficient
- \( E_s \) = Young's Modulus of solid subgrade (\( \text{Pa} \/ \text{cm}^2 \))
- \( E_p \) = Young's Modulus of pavement (\( \text{Pa} \/ \text{cm}^2 \))
- \( \Delta \) = design deflection (0.25 cm)
- \( q \) = radius of contact area (cm)

\[ \frac{T_1}{T_2} = \left( \frac{E_2}{E_1} \right)^{1/3} \]

---

For 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 subgrade.
Let us design pavement using base course material.

\[ \text{Ep} = 360 \text{ kN/m}^2 \]
\[ \text{Es} = 120 \text{ kN/m}^2 \]

\[
T = \left[ \frac{3 \pi y}{2 \pi \varepsilon} \right]^2 - q^2 \times \left( \frac{\text{Es}}{\text{Ep}} \right)^{1/2}
\]

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

\[
T = 1.80 \text{ cm} \quad (8\text{ ay})
\]

- Base course, \( E_b = 360 \text{ kN/cm}^2 \)
- Bituminous surfacing of 6 cm of, \( E_{bit} = 1200 \text{ kN/cm}^2 \)
- Boil subgrade = \( E_{ss} = 120 \text{ kN/cm}^2 \)
\[ \frac{T_{\text{bid}}}{T_{\text{base}}} = \left( \frac{T_{\text{base}}}{E_{\text{bid}}} \right)^n \]

\[ T_{\text{base}} = T_{\text{bid}} \times \left( \frac{E_{\text{bid}}}{E_{\text{base}}} \right)^n = 6 \times \left( \frac{1200}{360} \right)^n = 8.96 \text{cm} \]

- Remaining thickness of base course material
  \[ = 90 - 3 \text{cm} = 87 \text{cm} \]

- Total thickness of pavement is provided
  \[ = 4 \text{cm} \]

\[ = 40 + 6 = 46 \text{cm} \]

(5) Bazingstee's Method

- In this method, Young Modulus of Elasticity (E-value) is used for design.

\[ \text{Surface} \quad E_1 \]

\[ \text{Base} \quad E_2 \]

\[ \text{Sub-base} \quad E_3 \]

\[ \text{Solid subgrade} \quad E_4 \]

- Better quality materials are used in upper layers.

\[ E_1 > E_2 > E_3 > E_4 \]
For rigid plates:

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

Where:

- \( p \) = tyre pressure due to wheelload
- \( q \) = pressure due to load over plate
- \( a \) = radius of contact area as radius of plate
- \( F_2 \) = factor, constant
- \( \Delta \) = design deflection (cm)

A plate bearing test was conducted with 30cm diameter plate on a soft subgrade yielded a pressure of 5kN/m² at 5mm deflection.

The test carried out over 18cm basecourse yielded a pressure of 5kN/m² at 5mm deflection.

Design the pavement section for wheel load of 100kN with a tyre pressure of 6kg/cm² and
1) Plate bearing test on soft subgrade

- Dia. 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 \( \Delta = \text{deflection} = 5 \text{mm} = 0.5 \text{cm} \)

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

\[ 0.5 = 1.18 \times 1 \times 15 \times \frac{1}{E_s} \times 1 \]

\[ E_s = 38.4 \text{ kPa/cm}^2 \]

2) Plate bearing test over 18 cm thick base course

This is two layers system

- Using rigid plate formula

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

\[ 0.5 = \Delta \]

- \( b = 5 \text{cm}^2 \)
- \( h = 18 \text{cm}, q = 15 \text{kPa} \)

\[ E_s = 34.4 \text{ kPa/cm}^2 \]
In an experiments as shown in figure - Busminster show 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 \( \left( \frac{E_s}{E_p} \right) = \frac{1}{100} \)

Busminster has suggested a factor \( F_2 \) is \( \frac{h}{a} \) and \( \frac{E_s}{E_p} \) ratio.
For a single layered system (when there is no cement)
\[ n = 0 \]

Value of \( F_2 = 1.0 \)

Displacement relationship:

- Flexible plate:

On wheely loads is acting over a road surface, flexible plate is to be considered.

Displacement:

\[ A = 1.5 \frac{p_a}{E_s} \cdot F_2 \]
\[ 0.5 = 1.18 \times \frac{5 \times 15}{35.4} \times F_2 \]

\[ F_2 = 0.47 \]

From graph (given question)

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

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

\[ \frac{h}{t} = \frac{18}{15} = 1.2 \]

\[ F_2 \]

\[ \frac{h}{t} = 1.2 \]

\[ F_2 = 0.1333 \]

\[ \frac{E_s}{E_p} = \frac{1}{100}, \quad F_2 = 1.333 \]

Whee over pavement (design of pavement)

So that consider flexible pavement

\[ A = 1.5 \times \frac{p \times d}{E_s} \]

\[ p = 4100 \text{ kg} \]

\[ d = 6 \text{ kg/cm}^2 \]

\[ A = 5 \text{ mm} = 0.5 \text{ cm}^2 \]

\[ E_s = 34.5 \text{ kg/cm}^2 \]

\[ 0.5 = 1.5 \times \frac{6 \times 14.75}{34.5} \times F_2 \]

\[ \frac{h}{t} = 1.5 \]

\[ 1.5 \times 14.75 = 28.025 \text{ cm} \]

Thickness of pavement

\[ h = 1.5 \times 14.75 = 28.025 \text{ cm} \]
Design of rigid pavement -

Important terms -

1. Modulus of subgrade reaction (K)

The value of pressure required for unit deflection (deformation) is called modulus of subgrade reaction.

\[ K = \frac{P}{\delta} \] \( \text{K} \text{cm}^3/\text{cm} \)

[Apply pressure then \& deflect]

2. Radius of relative stiffness (ω) -

\[ d = \left[ \frac{E_c h^3}{l_k (1-\mu^2)} \right]^{\frac{1}{3 \varphi}} \]

where

- \( E_c \) → Young modulus of elasticity of pavement (cement concrete slab)
- \( h \) → Thickness of slab
- \( K \) → Modulus of subgrade reaction
- \( \mu \) → Poisson's ratio = 0.15

Equivalent radius of resisting section \( (b) \)

The area effective for taking \( B\text{Mo} \).
1. \( a < 1.724 \, h \)

2. \( a > 1.724 \, h \)

\[
b = \sqrt{1.6a^2 + h^2} - 0.675 \, h
\]

Where

- \( a \) = radius of contact area (cm)
- \( h \) = thickness of slab (cm)

Then \( b = \text{cm} \)

The stresses developed in a concrete slab:

- There are three stresses developed:
  1. Load stresses (due to load)
  2. Temperature stresses
     1. warping stress
     2. friction stress

3. Load stresses. [Westergaard's Method]

   - Westergaard's stress equations

4. Interior stress

\[
S_i = \frac{0.316 \, P}{h^2} \left[ 1 + \log_{10} \left( \frac{h}{b} \right) + 1.069 \right]
\]
Edge Stresses

$$S_e = \frac{0.572 P}{h^2} \left[4 \log_{10} \left(\frac{d}{b}\right) + 0.359\right]$$

Corner Stresses

$$S_c = \frac{3P}{h^2} \left[1 - \left(\frac{0.52}{d}\right)^{0.6}\right]$$

Here:

- $P$ = wheel load in (Kg)
- $h$ = slab thickness in (cm)
- $d$ = radius of relative stiffness (cm)
- $b$ = radius of resisting section (cm)
- $a$ = radius of contact area

In interior case/edge:

- Tension: Give
- Compress: Give

At corner:

- Tension: Give
- Compress: Give
In 1987 due 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 \( p = 4100 \text{ kg} \)

\( E_c = 3.3 \times 10^5 \text{ kg/cm}^2 \)

\( h = 18 \text{ cm}, \ \mu = 0.15, \ \kappa = 25 \text{ kPa/cm}, \ q = 12 \text{ cm} \)

So:

1. **Radius of Relative Stiffness**

\[
\rho = \left[ \frac{Eh^3}{12\kappa(1-\mu^2)} \right]^{\frac{1}{3}}
\]

\[
\rho = \left[ \frac{3.3 \times 10^5 \times 18^3}{12 \times 25(1-0.15^2)} \right]^{\frac{1}{3}}
\]

\( \rho = 50.61 \text{ cm} \)

2. **Equivalent Radius of Resisting Section**

\( a = 12 \text{ cm}, \ h = 18 \text{ cm} \)

\( a < 1.724h \)

\[
b = \sqrt{1.69^2 + h^2} = 0.675h
\]

\[
b = \sqrt{1.69^2 + 18^2} - 0.675 \times 18 = 11.4 \text{ cm}
\]

3. **Stresses**

4. **Interia Stress**

\[
\sigma_I = \frac{0.316p}{h^2} \left[ \tan \gamma_{10} \frac{4}{b} + 1.067 \right]
\]
\[ Si = \frac{0.316 \times 4100}{18^2} \left[ 4 \log_{10} \left( \frac{50.61}{11.40} \right) + 1.069 \right] \]

\[ Si = 14.63 \text{ kN/cm}^2 \]

3) Bending Stresses

\[ Su = \frac{0.572 \times P}{h^2} \left[ 4 \log_{10} \left( \frac{Y}{h} \right) + 0.35g \right] \]

\[ Su = \frac{0.822 \times 4100}{18^2} \left[ 4 \log_{10} \left( \frac{50.61}{11.40} \right) + 0.35g \right] \]

\[ Su = 21.34 \text{ kN/cm}^2 \]

4) Corner Stresses

\[ Sc = \frac{3 \times P}{h^2} \left[ 1 - \left( \frac{9.52}{9} \right)^{0.6} \right] \]

\[ Sc = \frac{3 \times 4100}{18^2} \left[ 1 - \left( \frac{12 \times 52}{50.61} \right)^{0.6} \right] \]

\[ Sc = 18.25 \text{ kN/cm}^2 \]

1) Temperature Stress \( \sigma_t \)

2) Warping Stress \( \sigma_w \)

Due to variation of temperature during day/night.
(o) During day:

- Max stresses occur due to warping.

(2) Frictional stresses:

- [Due to seasonal temperature variation]

(a) During summer:

- Friction due to soil resistance.

(b) Winter season:

- Shear stress increases towards a point at a certain temperature.

- Temperature throughout.
Fanning Stresses

Italics stress

\[ s_{fi} = \frac{E \cdot t}{2} \left( \frac{C_x + \mu C_y}{1 - \mu^2} \right) \]

Edge Stresses

\[ s_{te} = \frac{C_x \cdot E \cdot t}{2} \]

or

\[ s_{te} = \frac{C_y \cdot E \cdot t}{2} \]

Corner Stresses

\[ s_{tc} = \frac{E \cdot t}{2} \left( \left[ \frac{a}{a + b} \right] \right) \]

**E**

Young Modulus of Elasticity of Concrete Concrete

Pavement (kPa/cm²)

**\( C_x \)**

Coefficient of Thermal Expansion

**\( C_y \)**

Temperature Variation Between Day and Night

**\( \mu \)**

Poisson Ratio

\[ \text{Coefficient based on } \left( \frac{L_y}{L} \right) \]

\[ \text{Coefficient based on } \left( \frac{L_y}{H} \right) \]
\( u = \text{Radius of Relative Stiffness} \)

\( a = \text{Radius of Contact Area} \)

Value of \( C_x \) and \( C_y \)

\[ \begin{array}{c|c|c}
\frac{L_x}{\varphi} & \frac{L_y}{\varphi} & C_x \text{ or } C_y \\
2 & & 0.2 \\
4 & & 0.6 \\
8 & & 1.1 \\
12 & & 1.02 \\
\end{array} \]

Diagram:
- \( L_x \) and \( L_y \) with \( C_x \) and \( C_y \)
- \( \frac{L_x}{\varphi} \) and \( \frac{L_y}{\varphi} \)
- \( C_x \) or \( C_y \) values for different \( \varphi \) values
- Horizontal axis: \( \varphi \) values
- Vertical axis: \( C_x \) or \( C_y \) values

Legend:
- Day
- Night
- \( L_x \)
- \( L_y \)
3. Frictional Stresses -

Due to seasonal temperature variation, tensile stress develops, which is resisted by frictional forces. During winter, the slab tends to contract, and if not prevented, it can lead to cracks.

\[ F = f \cdot R \]

\[ R = \frac{W}{L} \]

For the upper portion of the slab:

\[ R = \frac{M}{I} = \frac{M}{I_{\text{area}}} = \frac{M}{I_{\text{cross}}} \]

Resisting force acts at the center of the shaded area. If the tensile stress is \( f \), then:

\[ F = S \times f \times A = S \times f \times L \times B \times h \]
\[ F = f \cdot \left( \frac{L}{2} \times B \right) \times h \times w \] —— (1)

Resisting force = Stress
\[ S_f = \frac{f \cdot L \cdot w}{2} \] —— (2)

Equating (1) and (2)
\[ f \cdot \frac{L}{2} \times h \times w = S_f \cdot B \cdot h \]

\[ S_f = \frac{f \cdot L \cdot w}{2 \times 10^4} \]  
\[ f = \frac{k \cdot M^2}{m^2} \]
\[ w = \text{unit wt of pavement material} \]
\[ w = 24, 25 \text{ kN/m}^3 \]
\[ w = 2400 \text{ kPa/m}^3 \]
\[ w = 2500 \text{ kPa/m}^3 \]

A pavement slab 22 cm thick is constructed over a granular subbase having \( k = 18 \text{ kPa/cm}^3 \) spacing between joint. i.e., transverse joint = 550 cm

Longitudinal joint = 4.2 m.

Design wheel load = 4500 kg

Max. difference of temperature = 20°C

Radius of contact area = 15 cm

\( E_c = 3 \times 10^5 \text{ kPa/cm}^2 \)

\( \Delta t = 0.15 \), \( a = 12 \times 10^{-6} / \text{°C} \), \( f = 1.50 \)

Find out best combination of stresses.
Load Stresses 

Radius of Relative Stiffness

\[ \lambda = \sqrt{\frac{Eh^3}{12K(1-\nu^2)}} \]

\[ \lambda = \sqrt{\left[ \frac{3 \times 10^5 \times 22^3}{12 \times 18 \times (1-0.15^2)} \right]} = 62.37 \text{ cm} \]

Equivalent Radius of Resisting Section

\[ a = 15, \quad h = 22 \quad (a < 1.724h) \]

\[ b = \sqrt{1.6a^2 + h^2} - 0.675h \]

\[ b = \sqrt{1.6 \times 15^2 + 22^2} - 0.675 \times 22 = 14.20 \text{ cm} \]

Internal Stresses

\[ S_i = \frac{0.316 P}{h^2} \left[ h \log_{10} \left( \frac{y}{b} \right) + 1.069 \right] \]

\[ S_i = \frac{0.316 \times 4500}{22^2} \left[ h \log_{10} \left( \frac{62.37}{14.20} \right) + 1.069 \right] = 10.69 \text{ kN/cm}^2 \]
(a) Edge Stresses

\[ \sigma_e = \frac{0.572 \cdot P}{h^3} \left[ \ln_{10} \left( \frac{d}{b} \right) + 0.359 \right] \]

\[ = \frac{0.572 \times 4500}{22.2} \left[ \ln_{10} \frac{62.37}{14.20} + 0.359 \right] \]

\[ = 15.58 \text{ KPa/cm}^2 \]

(b) Corner Stresses

\[ \sigma_c = \frac{3 \cdot P}{h^3} \left[ \ln \left( \frac{a_1 - \left( \frac{a_5}{a_1} \right)^{0.6} \right) \right] \]

\[ \sigma_c = \frac{3 \times 4500}{22.3^3} \left[ 1 - \left( \frac{15.52}{16.37} \right)^{0.6} \right] \]

\[ \sigma_c = 13.28 \text{ KPa/cm}^2 \]

(c) Temperature Stresses

(i) Warping Stresses

(ii) Interrogation

\[ \sigma_i = \frac{E \alpha_i}{2} \left[ \frac{C_{x_{1y_{1y}}}}{1 - v_{x_{1y}}} \right] \]

Value of \( C_x \) and \( C_y \)

\[ \frac{L_x}{y} = \frac{550}{62.37} = 8.82 \]

\[ C_x = 1.10 - \frac{1.10 - 0.82}{4} \times 0.82 \]
\[
\frac{\gamma_{20}}{0.237} = 6.73
\]

\[
c_y = 0.6 + \frac{1.1 - 0.6}{\gamma} \times 2.73 = 0.94
\]

\[
\tau = \frac{3 \times 10^5 \times 12 \times 10^6 \times 20}{2} \left[ \frac{1.08 + 0.15 \times 0.94}{1 - 0.15^2} \right]
\]

\[
\tau = 441.97 \text{ kN/cm}^2
\]

**Edge stresses**

\[
\sigma_{te} = \frac{c_x \cdot E \cdot T}{2}
\]

\[
\sigma_{te} = \frac{c_y \cdot E \cdot T}{2}
\]

\[
c_x > c_y
\]

\[
\sigma_{te} = \frac{c_x \cdot E \cdot T}{2} = \frac{1.08 \times 3 \times 10^5 \times 12 \times 10^6 \times 20}{2}
\]

\[
= 38.88 \text{ kN/cm}^2
\]

**Other stresses**

\[
\sigma_{te} = \frac{E \cdot T}{3(1 - \mu)} \left[ \frac{Q}{x} \right]
\]

\[
= \frac{3 \times 10^5 \times 12 \times 10^6 \times 20}{3 \times (1 - 0.15)} \left[ \frac{15}{6237} \right]
\]

\[
\tau_{te} = 13.88 \text{ kN/cm}^2
\]
(3) Frictional Stress

\[ S_\text{f} = \frac{f \cdot L \cdot W}{2 \times 10^4} \]

\[ S_\text{f} = \frac{1.5 \times 5.50 \times 2500}{2 \times 10^4} = 1.03 \text{ kPa/cm}^2 \]

Worst Combination
- At interior = \( S_\text{i} + S_\text{t} + S_\text{f} \)
- At edge = \( S_\text{e} + S_\text{et} + S_\text{f} \)

Worst case at corner:
- At top = \( S_\text{ct} + S_\text{et} + S_\text{f} \)
- = 13.28 + 13.84 + 10.3 = 27.42

# Worst Combination
- For interior or edge.

[Diagram showing different stress components: load stress, warping, tensile, and frictional stress.]

\[ A + \text{interior} = S_\text{i} + S_\text{t} + S_\text{f} \] (At bottom)

\[ A + \text{edge} = S_\text{e} + S_\text{et} + S_\text{f} \] (At bottom)
Worst case at corners.

- Load stresses
- Warping stresses (night)
- Frictional stresses (winter)

\[ \Delta t_{top} = \Delta c + \Delta t_{ct} + \Delta t \]

Worst combination of stresses (Table):

<table>
<thead>
<tr>
<th></th>
<th>Load stresses</th>
<th>Warping stress</th>
<th>Frictional stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>day</td>
<td>night</td>
</tr>
<tr>
<td>Interior stresses top</td>
<td>c ( \bigotimes )</td>
<td>c</td>
<td>t</td>
</tr>
<tr>
<td>Interior stresses bottom</td>
<td>t ( \bigoplus )</td>
<td>t</td>
<td>c</td>
</tr>
<tr>
<td>Edge stresses top</td>
<td>c ( \bigotimes )</td>
<td>c</td>
<td>t</td>
</tr>
<tr>
<td>Edge stresses bottom</td>
<td>t ( \bigoplus )</td>
<td>t</td>
<td>c</td>
</tr>
<tr>
<td>Corner stresses top</td>
<td>t ( \bigoplus )</td>
<td>c</td>
<td>t</td>
</tr>
<tr>
<td>Corner stresses bottom</td>
<td>c ( \bigotimes )</td>
<td>t</td>
<td>c</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 8 width is provided at Expansion Joints.
   - To allow expansion of slab due to temperature increase.
   - Max spacing between 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

Max. Expansion allowed in the slab $\frac{s}{2} = \frac{L - x}{2} \cdot (T_2 - T_1)$

Spacing of Expansion Joints

$L = \frac{s}{2 \cdot a \cdot (T_2 - T_1)}$

Design of contraction joint -

Case 1: Slab without reinforcement.

FEM stiffness ($S_1$)
Tensile stress developed at centre

\[ S_f = \frac{WLF}{2 \times 10^4} \]

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.

If area of steel $A_{st} = A_{st}$

Max. permissible stress in tension for steel = $\sigma_{st}$

Total tensile force of tension = $A_{st} \times \sigma_{st}$ — (1)

Force of friction = $F = f \times r$

$F = f \left( \frac{L \times B \times h \times W}{2} \right)$ — (2)

Equating (1) and (2)

$A_{st} \times \sigma_{st} = f \frac{L}{2} \times B \times h \times W$

Spacing of contraction joints

$$L = \frac{2A_{st} \times \sigma_{st}}{f - B \times h \times W}$$

Given

$$A_{st} = \left( \frac{B}{h} \right) \times \frac{\pi}{4} \times \Phi^2$$

Due to the max. expected increase in temperature is 26°C for a c.c. pavement, calculate spacing of expansion joint if gap of expansion joint is 2.5 cm.

$$d = 15 \times 10^{-6} / \circ C$$

Unit wt. of concrete = 2400 kg/m³
Maxim Expansion allowed = \(8/2\)

\[= \frac{9.50}{3} = 1.25 \text{ cm}\]

\[L - \alpha _{.T} = \frac{8}{2}\]

\[L = 1.25\]

\[15 \times 10^6 \times 26^0 \times 100\]

\[L = 8.05 \text{ m}\]

**Question:** A cement concrete pavement has u.5 m width and thickness of 25 cm. Design contraction joints spacing for

(i) if no reinforcement is given

Maxim permissible stress of concrete in tension

\[= 0.8 \text{ kN/cm}^2\]

(ii) if reinforcement of 12 mm @ 300 mm IG. are used. Mild steel used. \(\sigma_{stt} = 1400 \text{ kN/cm}^2\)

Coefficient of friction \(f = 1.5\)

\[\text{Solution: (i) PCC (No steel used)}\]

\[F = F \cdot R\]

\[S_u\]
- \[ F = S_t \cdot (B \cdot h) \]
- \[ f \cdot \frac{1}{2} \cdot B \cdot h \cdot w = S_t \cdot B \cdot h \]
- \[ S_t = \frac{fLw}{2} \quad \text{[kN/m}^2\text{]} \]
- \[ S_t = \frac{fLw}{2 \times 10^4} \quad \text{[kN/cm}^2\text{]} \]
- \[ L = \frac{2 \times 10^4 \cdot S_t}{f \cdot w} = \frac{2 \times 10^4 \times 0.8}{1.5 \times 2400} = 0.44 \text{m} \]

Steel is used. [RCC]

Diagram:
- Load at centre
- 12 mm fixed at 800 c/c
\[ A_{sf} = \left( \frac{B}{h} \right) \frac{\pi}{4} \times \phi^2 \]
\[ = \left( \frac{4500}{300} \right) \times \frac{\pi}{4} \times 1.2^2 \times \frac{1}{100} \]
\[ A_{sf} = 16.8646 \text{ cm}^2 \]

\[ L = \frac{2 \times 16.8646 \times 1400}{1.5 \times 4.50 \times 0.25 \times 3500} = 11.25 \text{ m} \]

L = 11.25 m

* Design of the bar *

Consider 1 m length

= 1000 mm

Longitudinal joint

Projection beam reinforced small length

F = f.R.
Force of friction

\[ F = f \cdot R = f \cdot \text{[weight of half portion of slab]} \]

\[ F = f \cdot \left( \frac{8B \times L \times W}{4} \right) \quad \text{(1)} \]

\[ w = \text{unit wt. of pavement} \]

\[ w = 3 \rightarrow y \]

Force of resistance by steel

\[ = \text{Asd} \cdot \sigma_{st} \quad \text{(2)} \]

Equations (1) and (2)

\[ f \cdot B \cdot h \cdot w = \text{Asd} \cdot \sigma_{st} \]

Area of steel required (for lm width)

\[ \text{Asd} = \frac{f \cdot B \cdot h \cdot w}{\sigma_{st}} \quad \text{(A)} \]

Sizing of reinforcement moment

\[ = \frac{1000 \cdot \frac{\pi}{4} \cdot D^2}{\text{Asd}} \]

Length of tie bars (d) =

Force of resistance = strength in b.d.

\[ \text{Asd} \cdot \sigma_{st} = (\text{fc}) \times \frac{d}{2} \times \epsilon_{bd} \]

\[ = \frac{\pi}{4} \cdot (D)^2 \cdot \sigma_{st} = \frac{\pi}{4} \cdot D \cdot \epsilon_{bd} \]
\[
\begin{align*}
\phi &= 2 \tan^{-1} \left( \frac{W \cdot \phi \cdot \sigma}{Ld \cdot \rho} \right) \\
Ld &= \frac{\phi \cdot \sigma}{\rho \cdot h}
\end{align*}
\]

Length of ties bar is equal to development length (Ld)

One cement concrete pavement has a thickness of 24 cm and has two lanes of total width 7.2 m with a longitudinal joints. Design the dimensions and spacing of the base using the following data:

- Allowable stress in steel in tension = 1400 KPa
- Unit weight of concrete = 2400 KPa/m³
- Coefficient of friction = \( f = 1.5 \)
- Allowable bond stress in concrete = 24.6 KPa/cm²

Diagram: A diagram showing the dimensions and layout of the pavement with a length of 23 cm, width of 3.6 m, and spacing of 7.20 m.
Total width of slab = 7.20m
Half width = $B = 3.60m$
Consider 1m length of slab
$h = 24cm = 0.24m$

Area of steel

$$A_{st} = \frac{f \cdot B \cdot h \cdot W}{\sigma_{st}}$$

$$A_{st} = \frac{1.5 \times 3.60 \times 0.24 \times 2400}{1400} = 1.31cm^2$$

Using 10mm Ø bars

Spacing = \frac{1000}{232.17} \times \frac{(0.5)}{4} \times 10^{-2} = 353.5 mm

Using 8mm = \frac{353.5 \times 8^2}{10^2} = 226 mm

Provide 8mm @ a = 226 mm c/c

Length of tie bars

$$u = \frac{2 \phi_{st}}{u \times 2b}$$

$$u = 2 \times \frac{0.8 \times 1400}{u \times 24.6} = 22.76cm$$

$u = 23 cm$
Dowel bars are provided at expansion joints.

Differential deflection = $\delta_2 - \delta_3$

Dowel bars are fixed on one side of the pavement and provided on the other side a gap. Because a 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 (As per IRC)

1) Load carrying capacity of a single dowel bar is given by following:

1. Strength in shear

\[ P' = \frac{\pi}{4} \times d^2 \times f_s \]

2. Strength in bending

\[ P' = \frac{2d^3 \times f_t}{L_d + 8.88} \]

3. Strength in bearing

\[ P' = \frac{L_d^2 \times d \times f_b}{12.5 \left( L_d + 1.58 \right)} \]

Development length \( L_d \)

\[ L_d = 5d \left[ \frac{f_t}{f_b} \times \left( \frac{L_d + 1.58}{L_d + 8.88} \right) \right]^{1/2} \]

→ solve by trail and error.

where

- \( d \) = dia of bar (cm)
- \( s \) = gap or expansion joint width in (cm)
- \( f_{fs} = \) max\(^{m}\) permissible stresses in shear
- \( f_{tt} = \) max\(^{m}\) permissible stresses in bending
- \( f_{tb} = \) max\(^{m}\) permissible stresses in bearing

**Design steps:**

1. **Length of dowel bars**
   \[ L_{d} = (L_{d} + s) \]

2. **Load capacity of dowel group system**
   \[ W = \text{load of wheel load} \]

3. **Required load capacity factor**
   \[ \frac{W}{\text{Load capacity of single dowel bar}} \]
   \[ \text{Load capacity of dowel group} \]
   \[ = 0.40xP \]
   \[ = \frac{0.40xP}{P'} \]

4. **Capacity factor of dowel bars just below load**
   \[ K_{0.40P} \]

Now total capacity factor is calculated:

\[ = 1.0 + \left( \frac{1.80d - s}{1.80d} \right) + \frac{(1.80d - 2s)}{1.80} \times K_{0.40P} \]
Spacing should be selected such that above condition is satisfied.

\[ d = \text{radius of the relative stiffness.} \]

Design a dowel bar system for pavement thickness = 2.5 cm.

Radius of relative stiffness = 8.0 cm

Team wheel load = 5100 kg

Joint width = 2.4 cm

Permissible stresses:

- in shear = \(1200 \text{ kg/cm}^2 = f_s\)
- flexure = \(1400 \text{ kg/cm}^2 = f_f\)
- Bearing = \(120 \text{ kg/cm}^2 = f_b\)

Use diameter of dowel bar = 20 mm

Nominal development length required

\[ L_d = 5d \left[ \frac{f_f}{f_b} \times \frac{L_d + 1.5d}{L_d + 8.8d} \right]^{1/2} \]

\[ = 5 \times 2.0 \left[ \frac{1400}{120} \times \frac{L_d + 12.5 \times 3.4}{L_d + 38 \times 3.4} \right]^{1/2} \]

\[ L_d^2 \left[ \frac{L_d + 31.12}{L_d + 3.4} \right] = 1166.67 \]

by trial and error
\[ l_d = 27.27 \text{ cm} \]

Total length of base \[ = L_d + s = 27.27 + 2.47 = 30 \text{ cm} \] (say)

(\text{Load capacity of single dower bar})

(1) In shear

\[ F_s = \frac{\pi d^3 f_s}{4} = \frac{\pi}{4} (2.2)^3 \times 1200 = 3760.9 \text{ kg} \]

(2) In bearing

\[ F_b = \frac{f_b \cdot L_d^3 \cdot d}{12.5 \left[ L_d + 1.5 \right]} \]

\[ F_b = \frac{120 \times 27.27^2 \times 2.2}{12.5 \left[ 27.27 + 1.5 \times 2.2 \right]} \]

\[ = 462.5 \text{ kg} \]

(2) Strength in flexure or bending

\[ F_f = \frac{f_f \times 2d^3}{L_d + 8.3d} = \frac{1900 \times 2 \times 2^3}{(27.27 + 8.8 \times 2.4)} \]

\[ = 469 \text{ kg} \]
Strength of single dowel bar

\[ \rho = 462.5 \text{ kg} \]

1) Load capacity of dowel groups systems

\[ = \text{no. of wheel load} \]

\[ = 0.40 \times 500 = 200 \text{ kg} \]

2) Load capacity factor

\[ \text{Load capacity of group} \]

\[ \text{Load capacity of single dowel bar} \]

\[ = \frac{200}{462.5} = 0.43 \]

Assume spacing

\[ 1.80s = 1.20 \times 80 = 144 \]

Capacity factor of group

\[ = 1 + \frac{144 - 30}{144} \times 1 + \frac{144 - 30 \times 30}{144} \times 1 + \frac{144 - 30 \times 30}{144} \times 1 + \frac{144 - 30 \times 30}{144} \times 1 \]
SURVEYING

Introduction:

- Earth is an oblate spheroid.
  - Polar axis = 12713.80 km
  - Equatorial axis = 12756.75 km
  - Difference = 42.95 km
- Average radius = 6370 km

> Plain surveying:
  - Earth curvature is not considered.

> Geodetic survey:
  - Earth curvature is considered for large area.

Examples:

1. [Diagram 1]
   - For a 12 km curve
   - Curve
   - Diff = 0.04 km only

2. [Diagram 2]
   - For a sphere
   - Area = 185 km²
\[ \text{Spacing} = 18 \text{ cm} \]

\[ \frac{144 \times 8 - (18 + 36 + 54 + 72 + 90 + 108 + 126)}{144} = 1.50 \geq 1.1 \text{ min. OK} \]

\[ 144 \times 5 - \left[ 30 + 60 + 90 + 120 \right] \]

\[ 144 \]

\[ \text{Assume Spacing} = 20 \text{ cm} \]

\[ \text{Capacity factor} = \]

\[ \frac{144 \times 8 - \left[ 30 + 40 + 60 + 80 + 100 + 120 + 140 \right]}{144} \]

\[ 1.11 \]

\[ \text{Spacing} = 18 \text{ cm} \]

\[ \frac{144 \times 8 - (18 + 36 + 54 + 72 + 90 + 108 + 126)}{144} = 1.50 \geq 1.1 \text{ min. OK} \]
\[
(\theta A' + \theta B' + \theta C') - (\theta A + \theta B + \theta C) = 1 \text{ second.}
\]

\[= 0^\circ 0' 1'' \text{ or } 0^\circ 0' 1''\]

**Principle of surveying:**

1. **Location of a point by measurement from two reference points.**

   ![Diagram of chain survey](image)

   **Chain survey**

   **Revealing**

   **Working whole to part ->**

2. **First major control points are fixed and measured with higher accuracy, minor details can be taken later.**
Even with worst 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 values 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 
   for 0 to 0.1 and 0.9 to 1].
2. Positive and negative errors of same size have 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.
Most probable value (MPV):
The value of a quantity which has more chance of being the correct value of a quantity is called most probable value.

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 occur in some direction.
2. Compensating Error [Random Errors / Accidental Errors]
   -> Occurs some time in one direction and some time in other direction
   -> Value occur +ive and -ive errors.
   -> +ive and -ive errors will compensate each other.
Case-1: \( x_1, x_2, x_3 \ldots \) are measurements with unit weight. (Means one value occurs at one time)

If \( x \) is most probable value

\[ \text{Errors} = (x-x_1), (x-x_2), (x-x_n) \]

By the principle of least square

\[ \text{Sum of squares of errors} = \text{Least} \]

\[ y = (x-x_1)^2 + (x-x_2)^2 + (x-x_3)^2 + \ldots \]

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 measurements.

Case-2:

\[ \text{having different weightage} \]

\[ \begin{array}{cccc}
\text{MPV} & \text{Errors} & \text{Square of Errors} \\
(x-x_1) & (x-x_1)^2 \times w_1 \\
(x-x_2) & (x-x_2)^2 \times w_2 \\
(x-x_3) & (x-x_3)^2 \times w_3 \\
\end{array} \]
As per principle of least squares

\[ y = \omega_1 (x-x_1)^2 + \omega_2 (x-x_2)^2 + \ldots \]

\[ \frac{dy}{dx} = 2\omega_1 (x-x_1) + \omega_2 (x-x_2) + \cdots = 0 \]

\[ x(\omega_1 + \omega_2 + \omega_3 + \cdots) = \omega_1 x_1 + \omega_2 x_2 + \cdots + \omega_n x_n \]

\[ x = \frac{\omega_1 x_1 + \omega_2 x_2 + \cdots + \omega_n x_n}{\omega_1 + \omega_2 + \cdots + \omega_n} \]

Called weighted average.

This is most probable value.

\[ \text{probable error of single observation} = \frac{\sum v^2}{n-1} \]

where

\[ v = (x-x_1), \quad (x-x_2), \quad (x-x_3), \quad \ldots \]

\[ \text{difference bet. any single measurement and mean of the series.} \]

\[ \text{probable error of single observation (unit wt. is not given)} \]

\[ Es = \pm 0.6745 \sqrt{\frac{\sum wv^2}{n-1}} \]
1. **Probable Error of Mean of the Series**

\[
Em = \pm 0.6745 \sqrt{\frac{\sum u^2}{n(n-1)}}
\]

\[Em = \frac{E_5}{\sqrt{n}}\]

2. **Significant Figure in a Measurement**

- 6.147
- 6.14

3. If there are \( n \)-figures in a measurement, \((n-1)\) figures are called certain figures. Last figure is called uncertain figure.

4. Chance of errors are in uncertain figure.

[Diagram with measurements: 6.10, 6.20, 6.30, 6.40, 8.0

\[\Rightarrow \text{read } 6.3\]
Maxm Error = 0.05 m

Probable Error = 0.025 m (\frac{\text{Maxm Error}}{2})

Reading = 6.26

Maxm Error = 0.005 m

Probable Error = 0.0025 m

9. The probable error of weighted arithmetic mean:

\[ E_s = \pm 0.6745 \sqrt{\frac{\sum wv^2}{(\sum w)(n-1)}} \]

2. Probable error of any observation of weighted

\[ = \frac{E_s}{\sqrt{w}} = \pm 0.6745 \sqrt{\frac{\sum wv^2}{w(n-1)}} \]
Significant Figures

If a measurement has \( n \) digits:
- Initial \((n-1)\) figures = certain figures
- Last figure = uncertain figure

\( 6.24 \text{m} \)

For this measurement:
1. Maximum Error = 0.005m
   [Half of least count]

2. Probable Error = Half of Maximum Error
   = 0.0025m

Summation of Errors:
- Maximum Error - sum is simple algebra:
  \[ e = e_1 + e_2 + e_3 + \ldots \]
- Probable Error - in this case accumulation is root mean square
\[ \frac{e_s}{s} = \sqrt{\left(\frac{e_x}{x}\right)^2 + \left(\frac{e_y}{y}\right)^2} \]

**Qn:** If \( s = x + y \), \( x = 3.4 \), \( y = 6.26 \)

Find out maximum and probable errors in computed value of \( s \).

**Sol:**

\[ x = 3.4 \]

\[ s_x = 0.05 \quad \text{maximum error} = \text{half of least count} \]

\[ e_x = 0.025 \quad \text{probable error} = \text{half of max error} \]

\[ y = 6.26 \]

\[ s_y = 0.005 \quad \text{maximum error} \]

\[ e_y = 0.0025 \quad \text{probable error} \]

For maximum probable error for \( s \):

\[ s_{max} = s + s_x + s_y \]

\[ s = 3.4 + 0.05 + 0.005 = 3.455 \]

For probable error for \( s \):

\[ e_s = \sqrt{e_x^2 + e_y^2} \]

\[ e_s = \sqrt{0.025^2 + 0.0025^2} = 0.025124 \]

Range of probable value for \( s \):
\[ ds = \left(\frac{1}{y}\right) dx - \left(\frac{x}{y^2}\right) dy \]

1. For Max Error

\[ m \ x \ = \ 6 \ \ \ \ \ for \ \ \ \ \ \ \ \ 0 \ = \ \frac{1}{y} \ \cdot \ \delta x \]
\[ m \ y \ = \ dy \ \ \ \ for \ \ \ \ \ \ \ \ 0 \ = \ \left(-\frac{x}{y^4}\right) \cdot (\delta y) = \frac{x}{y^2} \ \cdot \ \delta y \]

Max Error \[ s = \delta s \]

\[ \delta s = \frac{1}{y} \ \cdot \ dx + \frac{x}{y^2} \ \cdot \ \delta y \]

2. Probable Error

\[ m \ x \ = \ ex \ \ \ \ for \ \ \ \ \ \ \ \ 0 = \ \left(\frac{1}{y} \cdot e_x\right) \]
\[ m \ y \ = \ ey \ \ \ \ for \ \ \ \ \ \ \ \ 0 = \ \left(-\frac{x}{y^2}\right) \cdot e_y \]

Probable Error for \[ s = e_s \]

\[ e_s = \sqrt{\left(\frac{1}{y} \cdot e_x\right)^2 + \left(\frac{x}{y^2} \cdot e_y\right)^2} \]

\[ e_s = \frac{x}{y} \ \sqrt{\left(\frac{y}{x} \cdot \frac{1}{y} \cdot e_x\right)^2 + \left(\frac{y}{x} \frac{x}{y^2} \cdot e_y\right)^2} \]

\[ e_s = s \ \sqrt{(\frac{e_x}{x})^2 + (\frac{e_y}{y})^2} \]
3) ** probable Error

- probable Error in \( y = e^x \) for \( y \cdot e^x \)
- probable Error in \( y = e^y \) for \( x \cdot e^y \)
- probable Error in \( y = e^s \) for \( y \cdot es \)

\[
es = \sqrt{(y \cdot e_x)^2 + (x \cdot e_y)^2}
\]

\[
es = \sqrt{[(y \cdot e_x)^2 + (x \cdot e_y)^2] \frac{x^2y^2}{x^2y^2}}
\]

\[
es = xy \sqrt{(\frac{y \cdot e_x}{x \cdot y})^2 + (\frac{x \cdot e_y}{xy})^2}
\]

\[
es = \frac{es}{s} \sqrt{(\frac{e_x}{x})^2 + (\frac{e_y}{y})^2}
\]

4) ** Division:

- \( s = \frac{x}{y} \)
- \( ds = \frac{y \cdot dx - x \cdot dy}{y^2} \)
1. Following are the observed values of an angle and their weightage.

\[
\begin{array}{|c|c|}
\hline
\text{Angle} & \text{Weightage} \\
30^\circ 20' 20'' & 2 \\
30^\circ 20' 18'' & 2 \\
30^\circ 20' 19'' & 3 \\
\hline
\end{array}
\]

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.

\[
\text{\{Given\}}
\]

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Angle} & \text{Diff.} & \text{\(w^1\)} & \text{\(w^2\)} \\
\hline
30^\circ 20' 20'' & 20'' & 2 & 40'' \\
30^\circ 20' 18'' & 18'' & 2 & 36'' \\
30^\circ 20' 19'' & 19'' & 3 & 57'' \\
\hline
\text{Total} & & & 133'' \\
\text{n = no. of measurements} & & & 4 \\
\hline
\end{array}
\]

\[
\text{Average value be}
\]

\[
\bar{x} = \frac{133''}{4} = 33''
\]

\[
\text{Probable error of single observation}
\]

\[
\pm 0.6745 \left( \frac{2 \cdot 40''}{9} \right) = \pm 4.6''
\]
2. Probable error of weighted arithmetic mean.

\[ E_s = \pm 0.6745 \sqrt{\frac{\sum w_i v_i^2}{(\sum w_i)(n-1)}} \]

\[ = \pm 0.6745 \sqrt{\frac{4}{7(3-1)}} \]

\[ = \pm 0.3605 \]

3. Probable error of single observation of weight \( \frac{1}{3} \), where \( w = \frac{1}{n} \) given \( n = 3 \)

\[ = \pm 0.6745 \sqrt{\frac{\sum w_i v_i^2}{(\sum w_i)(n-1)}} \]

\[ = \pm 0.6745 \sqrt{\frac{4}{3(3-1)}} \]

\[ = 0.5507 \]
\[ S + e_S = 9.66 + 0.025124 = 9.685 \]

\[ S - e_S = 9.66 - 0.025124 = 9.635 \]

\[ \frac{x}{y} = \frac{96.83}{u.g} \]

\[ x = 96.83, \quad y = u.g \]

\[ \sigma_x = 0.0005, \quad \sigma_y = 0.0025 \]

Max. Error

For \( S \)

\[ x = \left( \frac{1}{y} \right) dx, \quad y = \left( \frac{x}{y^2} + \sigma_y \right) \]

\[ \delta_S = \frac{1}{2} \delta x + \frac{x}{y^2} \delta y \]

\[ \delta_S = \frac{1}{u.g} \left( 0.0005 \right) + \frac{96.83}{u.g^2} \times 0.0025 \]

\[ \delta_S = 0.20267 \]

Max. Range for \( S \)

\[ S = \frac{96.83}{u.g} = 13.7612 \]
\[ s + e_s = 19.761 + 0.1008 = 19.862 \]
\[ s - e_s = 19.761 - 0.1008 = 19.6604 \]

**Possible Error**

\[ \frac{e_s}{s} = \sqrt{\left(\frac{e_x}{x}\right)^2 + \left(\frac{e_y}{y}\right)^2} \]

\[ e_s = s \sqrt{\left(\frac{0.025}{36.83}\right)^2 + \left(\frac{0.025}{4.9}\right)^2} \]

\[ e_s = \pm 0.1008 \]

**Range of Error**

\[ s + e_s = 19.761 + 0.1008 = 19.862 \]
\[ s - e_s = 19.761 - 0.1008 = 19.6604 \]
Linear Measurement

m) scales:

> 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. F.

\[\downarrow\]

Representative fraction

Types:

1) Plain scales:

Measure (onto two dimensions only).

Set us make scale 1 cm = 4 m.

<table>
<thead>
<tr>
<th>26 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 m</td>
</tr>
<tr>
<td>30 m</td>
</tr>
</tbody>
</table>
Scale 1 cm = 4 mm

Take 10 cm along line

In this case, read two dimension

1. decameter (10 m)
2. meter

3. Diagonal vertical scale:

=> Measure upto three dimensions

In this case, measure three dimensions

1. 10 m → decameter
2. meter → meter
3. 0.1 meter (10 cm) → decimeter
7. Vernier scale is in the same direction as that of main scale.

8. \((n-1)\) divisions of main scale is divided into \(n\) division of vernier scale.

\[(n-1)S = nV\]

\[V = \left(\frac{n-1}{n}\right)S\]

Least count:

Smallest measurement that can be read by the scale:

\[= S - V\]

\((S > V)\)
\[ \leq s - \left( \frac{n-1}{\eta} \right) \leq \frac{s+sH-sH}{\eta} \]

Least count = \( \frac{s}{\eta} \)

In this case read, 3 dimensions, say = 6.67

6.7 \text{ cm} \Rightarrow 6.67 \text{ mm}

5. Retrograde verniers:

1. Vernier scale moves in opposite direction to main scale.
2. (n+1) division of main scale is equal to ndivision of vernier scale.
If drawing has shrunk, the scale of the drawing will change.

\[ \text{shrunk scale} = \left( \frac{\text{original scale}}{\text{new scale}} \right) \]

where

\[ \text{shrinkage factor} = \frac{\text{shrunk length}}{\text{original length}} \]

Example:
- A 10 cm long line on a drawing has shrunk to 9.5 cm.
- Shrinkage factor = S.F. = \( \frac{\text{shrunk length}}{\text{original length}} \)
  \[ \frac{9.5}{10} = 0.95 \]
- Shrinked scale = original scale \times S.F.
  \[ \frac{1}{5000} \times 0.95 = \frac{1}{5263.16} \]

New scale
- 1 cm = 5263.16 cm
- 1 cm = 52.6316 m
\[ - (n+1)s = \eta - v \]

\[ v = \left(\frac{n+1}{\eta}\right)s \]

**Least count**

\[ v = \left(\frac{n+1}{\eta}\right)s - s \]

\[ = \frac{s}{\eta} \]

**Least count**

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**Shrunken scale**

Now scale

\[ 9.5 \text{ cm} = 50 \times 10 = 500 \text{ m} \]

**Scale 1 cm**

\[ = \frac{500}{9.5 \times 50} = 52.631 \text{ cm} \text{ or } \text{m} \]
If an area of 250 cm² is measured on a drawing, how much is represented on ground:

\[ A = 250 \times (52 - 6316)^2 \]

\[ A = 632521.33 \text{ m}^2 \]

* Error due to incorrect length of chain/tape:

- \( L \) = designated length of tape
  - [True length should be] \( 30 \text{ m} \)
- \( L' \) = wrong length of tape (actual)
  - \( 30.1 \text{ m} \)

- \( L'' \) = length of line measured
  - \( 600 \text{ m} \)
- \( L \) = True length of wire line

\[ \text{True} \times \text{True} = \text{wrong} \times \text{wrong} \]

\[ L \times L = L' \times L'' \]

True length of line

\[ \ell = \frac{L' \times L''}{L} = \frac{L'}{L} \times \ell'' \]
Ex: \( u = \frac{30 \times 10}{30} \times 600 = 602\text{m} \)

For area
\[
A = \left(\frac{L'}{L}\right)^3 \times A'
\]

For volume
\[
V = \left(\frac{L'}{L}\right)^3 \times V'
\]

* Measured value = 600 m
  correction = + 2 m
  corrected value = 602 m

\(\Rightarrow\) Error is Negative

Actual Length
环绕

Measured Value

Corrected Value

\(\Rightarrow\) Give

Less
30 m

Less
29-50 m

\(\Rightarrow\) Give
2. Correction due to slope:

\[ C_s = A B - A C \]
\[ = d - \sqrt{d^2 - h^2} \]
\[ = d - d \left[ 1 - \left(\frac{h}{d}\right)^2 \right] \frac{1}{2} \]
\[ = \frac{h^2}{2d} \]
\[ C_s = \frac{h^2}{2L} \]

Correction due to slope always gives.

3. Correction due to alignment:

\[ C_{al} = d - \sqrt{d^2 - h^2} \]
\[ C_{al} = \frac{h^2}{2L} \]

Correction always gives.
Tape corrections:

1. Correction due to standard length of tape/chain = \( c \)

   Correction required per chain length = \( c \)

   Total correction required for \( L' \) length measured

2. \( c_a = \left( \frac{c}{L} \right) \times L' \)

   \( L = \) designated length of tape

   \( L' = \) incorrect length of line measured

3. \( L = 30 \text{ m}, \ L' = 30.10 \text{ m}, \ L' = 600 \text{ m} \)

4. Correction required per chain length

   \( c = L' - L = 30.10 - 30 = (+) \ 0.10 \text{ m} \)

5. Total correction

   \[ \frac{c}{L} \times L' = \frac{0.10}{30} \times 600 = +2.00 \text{ m} \]

6. Corrected length of line

   \( = L' + \text{ correction} \)

   \( = 600 + 2.0 \)

   \( = 602 \text{ m} \)
(c) Correction due to temperature:

\[ C_1 = \ell' \alpha (T_m - T_0) \]

\[ \ell' = \text{length of line measured} \]
\[ \alpha = \text{Correction of thermal expansion} \]

\[ T_m = \text{Temperature at the time of measurement} \]
\[ T_0 = \text{Temperature at the time of standardization of tape} \]

\[ \delta_1 = \text{Correction due to pull} \]

\[ \delta_1 = \frac{(P_m - P_0) \ell}{AE} \]

\[ P_m = \text{Pull at the time of measurement} \]
\[ P_0 = \text{Pull at the time of standardization} \]
\[ \ell = \text{length of line} \]
\[ A = \text{cross-sectional area of tape} \]
\[ E = \text{Young's modulus of tape/chain} \]
(6) Sog Correction:

\[ S_g = \frac{\frac{(w \cdot l)^2}{24 \cdot P_m^2}}{\frac{w^2 \cdot d}{84 - P_m^2}} \]

\( P_m \) = pull at the time of measurement

\( P_m \) = pull at the time of measurement