Hand Written Notes:

of

Civil Engineering

Subject:

Transportation
Introduction

(1) Cross section of a Railway Track

- Bed
- Fixtures
- Rail
- Fastener
- Collar
- Shoulder
- Rails
- Sleeper
- Earl Subgrade

(2) Gauges In India:

- BG (Broad gauge) -> 1.676 m
- MG (Meter gauge) -> 1.0 m
- NG (Narrow gauge) -> 0.9144 m
- LG (Light gauge) -> 0.61 m

- Gauge is distance between inner face of rails (Running faces)

(4) Coning of wheels:

Theory -> A slope of about 1 in 20 is provided to wheel in a cone shape. The same slope is provided to the top surface of rails. This slope provided to wheel is called coning of wheel.

The wheel assembly (one axle) moves out, rail rests in neutral position such that axle neutral.
on two rails are always equal. Whenever the train moves sideways in any direction, diameter of wheel over one rail increases and it decreases over another. Due to different of dia & distance travelled over one wheel increases that result in automatic direction of wheel assembly in its original central position.

Purpose:
1. To keep train just in central position during movement.
2. To reduce wear & tear of flange and rails.
3. Over curve track, distance required to be travelled on outer rail is more than that of an inner rail. Due to centripetal force, the wheel assembly is pulled outward a distance travelled on two rails are adjusted automatically.
Welded Rails:

Long welded rails:

- Gaps are provided generally for allowing expansion due to an increase in temperature. For gaps a large no. of joints are required.
- To avoid joints, rails are welded.
- In long welded rails, rails are not allowing to expand, due to which the stresses are developed in rail section. This stress is arrested by fixturing & sleepers.

\[ \text{IF } L = \text{length of welded rail} \]
\[ \text{Due to } T \text{ temperature increase} \]
\[ \text{Increase in length } = L \cdot T \]

Then

\[ \text{Strain developed in rail } = \frac{DL}{L} = \frac{L \cdot T}{I} \]

\[ = \sigma T \]

\[ \text{Stress developed (IF above 'Strain is not allowed)} \]

\[ p = E_s \times \sigma \]

\[ p = ES \times T \]

\[ p = A \times \frac{ES}{I} \]

Stress developed in rail section

\[ p = A 	imes \frac{ES}{I} \]

If one sleeper is provided, R resistance.
No. of sleepers required to resist p force:

\[ n = \frac{P}{R} \]  

\( R = 800 \text{kg} \)

Min. length of long welded rail required:

\[ L_{\text{min}} = (n-1)S \]

Min. length of rail required so that central portion of rails does not move:

= 2.1m

Problem:

Determine the min. theoretical length of LWZ by which the central portion of 52 kg rail would not be subjected to sagittal moment due to 30°C temperature variation.

Use following data:

1. Rail (52 kg) rail section
2. C/S: A = 66.15 \( \text{mm}^2 \)
3. So. = 2.18 \( \times 10^6 \) \( \text{N/mm}^2 \)
4. I = 11.5 \( \times 10^6 \) \( \text{cm}^4 \)

Solution:

\[ S = 60 \text{ cm} \]

\[ R = 800 \text{kg} \]

Due to 30°C temperature increase:

Increase in length = 1.5 ft
Stress = $\sigma$

Force developed in rail section if no moment is allowed

\[ P = A_s \times E_s \times X_T \]

\[ P = 66.15 \times 2.1 \times 10^6 \times 115 \times 10^{-6} \times 30 \, \text{cm}^2 \, \text{kg/} \text{cm}^2 \]

\[ P = 47925.67 \, \text{kg} \]

Minimum no. of sleeper are required = \( \frac{P}{P} = \frac{47925.67}{300} \approx 159.75 \) (60 nos)

Minimum length of rail on one side required = \((n-1) \times 8\) cm

\[ L_{min} = (160-1) \times 0.60 \]

\[ L_{min} = 95.4 \, \text{m} \]

Min. Total length required (for no movement of centre position) = \( 2 \times 95.4 \)

= 190.8 m

\[ \text{Diagram:} \]

\[ \text{190.8m} - \]

\[ L_{min} - L_{min} \]
7. Sleepers:

7.1 Composite Sleeper Index:

(about wooden sleeper)

This is an index to find out the suitability of a particular timber to be used as wooden sleeper.

C.S.I. = \( \frac{S + 10H}{20} \)

- \( S \) = Strength Index at 12% moisture content
- \( H \) = Hardness

Minimum Value of C.S.I:

(a) Break sleeper = 78.3
(b) Crossing " = 1852
(c) Bridge " = 1455

7.2 Slepper Density:

No. of sleeper are required for one rail is called sleeper density. It is denoted by \((n+x)\).

Generally, value is \((n+x)\) to \((n+6)\)

- \( n = \) length of one rail in meter

If B.G. track, \( n = 12.8 \) m, \( x = 13 \) m

Sleeper density = \((n+5)\)

No. of Sleeper provided = \( n+5 \)

= 13 + 5

= 18 Nos
Minimum Depth of Ballast: \( \Rightarrow \)

\[
\begin{align*}
&\text{run depth} \quad \text{Ballast} \\
&K-w \\
\end{align*}
\]

If

\[ S = \text{Spacing of Sleepers} \]
\[ W = \text{Width of Sleepers} \]

Run depth of Ballast curve required.

\[ D_{\text{min}} = \frac{S-W}{2} \]

Geometrical Design: \( \Rightarrow \)

1. Speed of Train: \( \Rightarrow \) Design speed is decided as per following:
   1. Max. Speed decided by Indian Railways.
   2. Safe Speed from Martin's Formula on Curve.
   3. Max. Speed as per Cont. provided.
   4. As per length of Transition Curve.

\( \Rightarrow \) Safe Speed on Curve (Martin's Formula): \( \Rightarrow \)

2. On Transition Curve: \( \Rightarrow \)

For Safe Speed:
   1. For 0.7 & 0.9

\( V_{\text{max}} = 4.35 \sqrt{R-67} \)
1. For N0 track:

\[ V_{\text{max}} = 3.65 \sqrt{R/6} \]

2. For high speed trains:

\[ V_{\text{max}} = 4.58 \sqrt{R} \]

6. On non-transitioned curved:

7. On B01 & N01 track:

\[ V_{\text{max}} = 80\% \text{ for transition curve} \]

\[ V_{\text{max}} = 0.8 \times 3.65 \sqrt{R/6} \]

8. On N01 track:

\[ V_{\text{max}} = 0.8 \times 3.65 \sqrt{R} \]

9. For high speed & train:

\[ V_{\text{max}} = 4.58 \sqrt{R} \]

4. Degree of curve:

- Angle formed at centre by one chain length of curve is called degree of curve.
(1) For 30 m chain length

\[
\frac{30}{D'} = \frac{2\pi R}{360} \\
\Rightarrow D' = \frac{30 \times 360}{2\pi R} \\
\Rightarrow \frac{D'}{R} = \frac{1730.9}{R}
\]

\[
R = \frac{1730}{D'}
\]

<table>
<thead>
<tr>
<th>D'</th>
<th>1'</th>
<th>2'</th>
<th>3'</th>
<th>4'</th>
<th>5'</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>1720</td>
<td>860</td>
<td>573</td>
<td>480</td>
<td>344</td>
</tr>
</tbody>
</table>

(2) For 20 m chain length

\[
\frac{20}{D'} = \frac{2\pi R}{360} \\
\Rightarrow D' = \frac{30 \times 360}{2\pi R} \\
\Rightarrow \frac{D'}{R} = \frac{1146}{R}
\]

\[
R = \frac{1146}{D'}
\]

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<td>573</td>
<td>382</td>
<td>289</td>
<td>194</td>
</tr>
</tbody>
</table>

meter
If $AB = 1$

For a chord length $AB$, versine of curve is length $CD$

Using properties of circle

$\Rightarrow AD \times DB = CD \times DE$

$\frac{1}{2} \times \frac{1}{2} = V(2R - v)$

Hence $(2R - v) = 2R$

$\frac{1}{2} = V \cdot 2R$

$V = \frac{1}{2R}$
Super elevation and Cant:

To counteract the effect of centrifugal force, outer rail is raised w.r.t. inner rail, this rate is called super elevation and Cant.

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

Equating forces along the surface of two rails:

\[ \tan \theta = \frac{v^2}{Rg} \]

Super elevation or Cant

\[ e = G(0.785) \]

\[ e = \frac{Gv^2(0.785)^2}{9.81R} \]

\[ e = \frac{Gv^2}{127R} \]

\[ e = \frac{1.676v^2}{127R} \]

Ex. for BR Track
Different trains with different speed are moving on a track. Actual cant provided is kept for an average speed, called equilibrium speed. Actual provided is called equilibrium cant.

Equilibrium Speed

1. When sanctioned speed is > 50 kmph
   Equilibrium speed will be minimum of:
   (i) \( v_{av} = \frac{3}{4} v_{max} \)
   (ii) Safe speed calculated from maxima formula.

2. When sanctioned speed < 50 kmph
   Minimum of:
   (i) \( v_{av} = v_{max} \)
   (ii) Safe speed from maxima formula

3. Weighted average speed:
   \( n_1 \) no. of train \( \rightarrow v_1 \) speed
   \( n_2 \) " " " \( \rightarrow v_2 \) " "
   Weighted average speed = \( \frac{n_1 v_1 + n_2 v_2}{n_1 + n_2} \)

\[ v_{	ext{average}} = \frac{\sum n v}{\sum n} \]
Cont provided = actual Cont

\[ \frac{67.6 \times 75^2}{127 \times 5.73} \]

Cont Deficiency:

Max speed on track (BG) = 100 kmph
Equilibrium speed = 75 kmph
R = 5.73 m
Actual Cont provided

\[ \frac{6n \times v^2}{127 \times 5.73} = \frac{1.676 \times 75^2}{127 \times 5.73} \]

= 0.1295 m
= 12.95 cm

Cont required for max speed at 100 kmph

\[ \frac{6n \times v^2}{127 \times 5.73} = \frac{1.676 \times 100^2}{127 \times 5.73} \]

= 23.03 cm

Cont deficiency

For a high speed train, total Cont required is less than that actually provided for equilibrium speed. The deficiency of Cont for a high speed train is called Cont deficiency. A train is allowed to move with a certain max. value of Cont deficiency.
<table>
<thead>
<tr>
<th>Types of Track</th>
<th>Actual Cant provided</th>
<th>Cant deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) BG</td>
<td>Speed ( \leq 120 \text{ kmph} ) = 165 cm</td>
<td>Speed ( \leq 100 \text{ kmph} ) = 7.60 cm</td>
</tr>
<tr>
<td></td>
<td>Speed ( \geq 120 \text{ kmph} ) = 180 cm</td>
<td>Speed ( \geq 100 \text{ kmph} ) = 16.0 cm</td>
</tr>
<tr>
<td>(2) M01</td>
<td>( \leq 100 \text{ kmph} ) = 100 cm</td>
<td>5.10 cm</td>
</tr>
<tr>
<td>(3) N01</td>
<td>7.6 cm</td>
<td>3.80 cm</td>
</tr>
</tbody>
</table>

Problem: Equilibrium cant is provided for a speed of 80 kmph on a 4' curve (BG track).

(i) What is the value of actual cant provided?
(ii) What max. speed can be allowed on this track.

Solution: \( v_{uu} = 80 \text{ kmph} \)

4' curve

Radius of curve \( R = \frac{17.20}{4} \)

\( R = 430 \text{ m} \)

(i) Actual cant required

\( e = \frac{Gv^2}{127R} = \frac{1.696 \times 80^2}{127 \times 430} \)

\( e = 0.1964 \text{ m} \)

\( e = 19.64 \text{ cm} \)

Max. Limit of \( e = 16.50 \text{ cm} \)

Actual cant provided = 16.50 cm
(ii) After allowing max cant deficiency = 7.6 cm

Theoretical cant:

\[ e_{th} = e_{act} + d = 16.750 + 7.6 \]
\[ = 24.6 \text{ cm} \]

Max. Speed:

\[ \frac{C_1 v_{max}^2}{127-R} = \left( \frac{24.6}{100} \right) = e_{th} \]

\[ v_{max} = \sqrt{\frac{127R \cdot e_{th}}{C_1}} \]

\[ v_{max} = \sqrt{\frac{127 \times 480 \times 0.36}{1.676}} \]

\[ v_{max} = 88.6 \text{ km/h} \]

(+) Negative Super-elevation:

→ If outer track of a curve is provided at a lower level than the inner rail, it is called a negative super-elevation.
For example, if a branch curve track is diverted in opposite direction from main curved track (+)ve SE, provided for main track shall become a (-)ve SE for branch track.

If max. speed allowed on main track

\[ V_{\text{max}}(\text{main}) \]

\[ \begin{align*}
\text{Max. speed} & \rightarrow e_{th} \\
\text{average speed} & \rightarrow e_{act} \\
e_{th} & = e_{act} + \delta \\
e_{act} & = e_{th} - \delta
\end{align*} \]

Theoretical cant on main track = \[ C_{\text{th}}(\frac{V_{\text{max}}(\text{main})}{RT}) = e_{th}(m) \]

\[ C_{\text{act}}(m) = e_{th}(m) - \delta \]
\[ e_\text{c} = -e_{\text{act}(m)} \]  

Theoretical cant for branch: \( e_{\text{th}}(B) = e_8 + \pi \)  

Max speed allowed on branch track:  

\[ V_{\text{max}}(B) = \sqrt{\frac{127 \cdot E_{\text{h}}(a) \cdot R}{G_7}} \]

**Problem:** A branch track of 6° curve is diverting from a 3° main curve in opposite direction (i.e., track). If max. speed allowed on main track is 65 km/hr, calculated actual cant provided for main/branch track. What max. speed allowed from the branch track?

**Solution:**

Radius of main track (3° curve)  

\[ R_m = \frac{1720}{3} = 573.33 \text{ cm} \]

Radius of branch track (6° curve)  

\[ R_B = \frac{1720}{6} = 286.67 \text{ m} \]
Max speed allowed on main track

\[ V_{m\text{ (max)}} = 65 \text{ kmph} \]

Theoretical cant for main track

\[ c_{th\text{ (m)}} = \frac{6s \cdot 9^3}{127 \cdot \rho_m} = \frac{1.636 \times 65^2}{127 \times 573} \]

\[ c_{th\text{ (m)}} = 0.097m \]

\[ c_{th\text{ (m)}} = 9.73 \text{ cm} \]

Actual cant provided

\[ c_{act\text{ (m)}} = c_{th\text{ (m)}} - D \]

\[ c_{act\text{ (m)}} = 9.73 - 7.60 \]

\[ c_{act\text{ (m)}} = 2.13 \text{ cm} \]

(+) use S.E. for main track

Actual cant available for branch track

\[ c_{act\text{ (b)}} = -c_{act\text{ (m)}} = -2.13 \text{ cm} \]
Purpose: A parabolic curve is introduced by two straight and curve track to serve the following purposes:

(i) To provide super elevation (cont) in a gradual manner (from toe)

(ii) To reduce the radius of curve gradually (from $R=$ at straight junction to $R=R$ at curve junction)

(iii) To reduce the effect sudden part due to centrifugal force.

Requirements of an Ideal Transition Curve:

(i) The Curve should be perfectly tangential to its junction points at straight junction $R=\infty$ at curved junction $R=R$

(ii) Rate of change of curvature should same as rate of change of super elevation so that full S.E. can be provided within length of transition curve.
For Railway's Transition curve, cubic parabola is preferred.

All these three curve are almost same up to a deflection angle of 3.205°.

Path followed by these 3 curve are almost same with 9° deflection.

Cubic parabola used in railways is also called 'Freud's curve'.

Cubic parabola:
General eq. for a cubic parabola

\[ y = ax^3 + bx^2 + cx + d \] → Deflection eq.

At \( x=0, y=0 \)

\[ d = 0 \]

Differentiate:

\[ \frac{dy}{dx} = 3ax^2 + 2bx + c \] → Slope eq.

At \( x=0 \)

\[ \frac{dy}{dx} = 0 \]

\[ \Rightarrow c = 0 \]

\[ \frac{d^2y}{dx^2} = 6ax + 2b \] → Curvature eq.

At \( x=0 \), \( \frac{d^2y}{dx^2} = 0 \)

\[ \frac{1}{d} = \frac{1}{b} = 0 \]

\[ \Rightarrow b = 0 \]

At end point

\[ x = l \]

\[ \frac{d^2y}{dx^2} = \frac{1}{d} = 6al \]

\[ \Rightarrow \frac{1}{d} = 6al \]

\[ \Rightarrow a = \frac{1}{6RL} \]
for cubic parabola.

1. Deflection: $\gamma = \alpha x^3 = \frac{x^3}{6RL}$

2. Slope: $\frac{dy}{dx} = 6ax^2 = \frac{3x^2}{6RL} = \frac{2x^2}{2RL}$

3. Curvature: $\frac{d^2y}{dx^2} = 6ax = \frac{6x}{6RL} = \frac{x}{RL}$

4. Slope at end

   at $x = t$,

   $\frac{dy}{dx} = \frac{2x^2}{2RL} = \frac{L^2}{2RL} = \frac{L}{2R}$

5. Spinal angle ($\phi$): It is the slope of tangent at any point on the curve.

   $\Rightarrow \phi = \tan \phi$

   $\Rightarrow \tan \phi = \frac{dy}{dx} = \frac{x^2}{2RL}$

   $\Rightarrow \phi_{\text{max}} \text{ at } (x = t)$

   $\frac{L^2}{2RL} = \frac{1}{2R}$

6. Deflection angle ($\alpha$): $\Rightarrow$

   $\alpha = \tan \alpha = \frac{4}{x}$

   $\Rightarrow \frac{4}{x} = \frac{x^3}{6RL} = \frac{x^2}{6RL}$

   $\Rightarrow \alpha = \frac{x^3}{6RL} = \frac{x^3}{3x^2RL} = \frac{\phi}{3}$
\( y_{\text{max}} = \frac{4}{16} R \)

- Transition Curve on a Railway

Transition curve is provided as shown in Fig.

IF \( R \) = Radius of curve

\( S \) = Shift of curve due to transition curve

\( P_1 \) = First tangent point

\( P_2 \) = Last tangent point

\( \angle O A B = \frac{41 R}{L} = \frac{L}{2R} = \phi \) Splay angle

So \( \angle A O B = (\Delta - 2\phi) \)

\( \angle \text{change of point} \ Y \) = Given

The value of shift \( S = \frac{L^2}{24R} \)

Radius = \((R+s)\)

Tangent length

\( PV = (R+s) \tan \Delta/2 \)
Total tangent length,
\[ T_{uv} = u_2 + p_u = (R+s) \tan \frac{u}{2} + u_2 \]

Change to \( T_i \),
\[ \text{chainage} \ V - V_T, \]
\[ \text{chainage of} \ A \]
\[ \text{chainage of} \ T_i + l \]

Length of simple curve
\[ L = \frac{2\pi R \times (\Delta - 2\theta)}{360} \]
\[ \text{chainage of} \ B \]
\[ \text{chainage of} \ A + l \]
\[ \text{chainage} \ P_R = \text{change of} \ B + l \]

Shift \( PR = P_R - RS \)
\[ = Y - (OR - OS) \]
\[ = Y - (R - R\cos\theta) \]
\[ = Y - R(1 - \cos\theta) \]
\[ = Y - R \times \sin^2\theta / 2 \]
length of Transition Curve:

There are two approaches:

1. Perpendicular Approach
2. Parallel Approach

Where:

- \( L \) = Length in m
- \( L = 3 \text{ m} \)
- \( \theta \) = Central deflection in cm
- \( v \) = Speed in km/h

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

\[
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\]

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\]

\[
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\]

\[
S = \frac{L^2}{24R}
\]
(iii) \( L = 0.0733 \cdot V_{\text{max}} \)

3. Length of Transition curve:
   (i) \( L = 4.47\sqrt{R} \) \( \forall R = \text{Radius in meter} \)
   \( L = \text{Length in meter} \)
   (ii) \( L = 3.6e \) \( \forall e = 6 \text{ cm} \)
   \( L = m \)

3. Based on rate of change of radial acceleration:
   \( L = \frac{3.29V^3}{R} \) \( \forall V = \text{Speed in m/sec} \)
   \( R = m \)
   \( L = m \)

\[ R = \infty \]
\[ \tan \frac{V^2}{R} = 0 \]

→ Radial acceleration = \( \frac{V^2}{R} \)

at Straight section: \( R = \infty \)

\[ \frac{V^2}{R} = 0 \]

at Curved section: \( = \frac{V^2}{R} \)

Radial acceleration changes from 0 to \( \frac{V^2}{R} \)

If train takes \( T \) sec to make the change

Time \( T = \frac{L}{V} \)

Rate of change of radial acceleration = \( a_c \)

\[ a_c = \frac{V^3}{R} \]
Problem: Equilibrium cant is provided on a BC track of 4" curve for an equilibrium speed of 80 kmph.

Total deflection angle $\delta = 45^\circ$.

(i) Calculate value of actual cant provided.
(ii) What max. speed can be allowed on this track.
(iii) Calculate length of transition curve required.
(iv) If change of intersection point is 80.52 m, calculate change of important points on the curve with transition curve.
(v) Plot out the transition curve of every 10 m distance.

Solution: Pad of curve $R = 1720/40 = 43.0 m$

Equilibrium speed $V_{eq} = 80$ kmph

(i) Equilibrium cant (actual cant) provided

$$e = \frac{6x^3}{R^2 R} = \frac{1.676 \times 80^3}{127 \times 430}$$

$$e = 0.196 = 19.6 \text{ cm}$$
$$C_{\text{max}} = 16.50 \text{ cm}$$

Provided $C = 16.50 \text{ cm}$

(ii) Max Speed

6. Const + Const efficiency

Const $C = 16.50$

Allow max. and deficiency = 7.60

Total (Theoretical) Const = 24.1 cm

$$V_{\text{max}} = \sqrt{\frac{127.3 \text{ REOh}}{61}}$$

$$V_{\text{max}} = \sqrt{\frac{127 \times 480 \times 0.241}{1.676}}$$

$$V_{\text{max}} = 88.6 \text{ kmph}$$

6. Max. Safe Speed on curve by Martin Annual

$$V_{\text{max}} = 4.35 \sqrt{R - 67}$$

$$V_{\text{max}} = 4.35 \sqrt{480 - 67}$$

$$V_{\text{max}} = 83.0 \text{ to } 83 \text{ kmph}$$

Max. Speed allowed = 83 kmph

(iii) Length of transition curve

6. $L = 4.41\sqrt{R} = 4.4 \sqrt{480} = 91.24 \text{ m}$

6. $L = 3.6C = 3.6 \times 16.50 = 59.4 \text{ m}$

6. $L = \frac{3.38 v^2}{P} = \frac{3.38 \times (0.278 V_{\text{max}})^3}{480}$

$$= 3.38 \times (0.278 \times 88)^3 / 480$$

$$= 93.96 \text{ m}$$
(iv) chainage of important points:

\[ \text{Chainage of } V = 8052 \text{ m} \]
\[ R = 480 \text{ m} \]

\[ s = \frac{L^2}{24R} = \frac{94^2}{2\times480} \]
\[ = 0.86 \text{ m} \]

Total tangent length

\[ VT_1 = TP + PV \]
\[ VT_1 = \frac{L}{2} + (R+s) \tan \frac{\delta}{2} \]
\[ VT_1 = \frac{94}{2} + (480 + 0.86) \tan \frac{85}{2} \]
\[ VT_1 = 4411.81 \]

Chainage AB = 4411.81 = Chainage of V - VT_1
\[ = 8052 - 4411.81 \]
\[ = 7640.19 \text{ m} \]
Length $AB = l = \frac{2\pi R}{360} \times (\theta - 2\beta)
= \frac{2\pi \times 430}{360} (85 - 2 \times 6' 15' 45'\) \\
= 543.92 \text{ m}

Point $P_1 = 7610.19 \text{ m}$

$L = 94$

Change $A = 7904.19 \text{ m}$

$TA = 543.92 \text{ m}$

$L = 94$

Change = 8342.11 \text{ m}

of $P_2$

(V) Setting out of transition curve

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Equation of curve

$y = \frac{x^3}{6PL} = \frac{x^3}{6 \times 430 \times 94}$

$y = \frac{x^8}{4Y3520}$
Problem: Determine the length of transition curve & offsets at every 15m distance for a 30 curved track having curvature & cant of 120m. Max permissible speed on the curved is 85 kmph.

Solution:

(i) Max Speed

(a) Cant Formula

Theoretical cant = Actual cant + Cant distance

\[ \text{Theoretical cant} = 19.60 \, \text{cm} \]

\[ = 0.196 \, \text{m} \]

\[ V = \sqrt{\frac{127 R_{\text{eth}}}{67}} \]

\[ V = \sqrt{\frac{127 - 430 \times 0.97}{1.676}} \]

\[ V = 79.90 \, \text{m} \]

(b) Safe speed on curve by marshall's formula

\[ V_{\text{max}} = 4.85 \sqrt{R \cdot 67} \]

\[ V_{\text{max}} = 4.35 \sqrt{430 \cdot 67} \]

\[ V_{\text{max}} = 82.87 \, \text{kmph} \]

(c) Max. Speed permissible = 85 kmph

Max. allowable speed = 79.90 kmph

80 kmph
(i) \( L = 7.20 \times 12 = 86.4 \text{ m} \)

(ii) \( L = 0.073 \cdot e^y \max = 0.73 \times 12 \times 80 = 70.08 \text{ m} \)

(iii) \( L = 0.073 \cdot 40 \cdot 0.76 \times 80 = 44.38 \text{ m} \)

\[ h = 86.4 \text{ m} \geq 87 \text{ m} \]

(d) Setting out the transition curve

\[ y = \frac{x^3}{6RL} = \frac{x^3}{6 \times 480 \times 87} \]

\[ y = \frac{x^3}{220460} \]

<table>
<thead>
<tr>
<th>( x \text{m} )</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>87</th>
</tr>
</thead>
<tbody>
<tr>
<td>( y \text{m} )</td>
<td>0</td>
<td>0.015</td>
<td>0.13</td>
<td>0.406</td>
<td>0.962</td>
<td>1.899</td>
<td>1.92</td>
</tr>
</tbody>
</table>
Problem: 4° curve, cant = 12 cm, max. design speed = 100 kmph, cant deficiency = 7.60 cm. Determine length of transition curve = 9 & offset sets at every 15 m.

B) Problem (C)

Problem: Define cant & cant deficiency. Calculate length of transition curve for a 601 curved track having 5° deflection & a cant of 14 cm max. permissible speed = 80 kmph.

Solution: 5° curve

Radius = \( \frac{1730}{5} \) = 346 m

Max. Speed

@ Cant Formula

Theoretical cant = \( c_{th} = c + d \)

= 14 + 7.60

= 21.60 cm

= 0.216 m

\[ V_{max} = \sqrt{\frac{12T R e a t h}{G}} \]

\[ V_{max} = \sqrt{\frac{12 \times 344 \times 276}{1.696}} \]

\[ V_{max} = 75.03 \] kmph

Safe Speed on curve by martins formula:

\[ V_{max} = 4.35 \sqrt{R - G} \]

\[ V_{max} = 4.35 \sqrt{344 - 67} \]

\[ V_{max} = 72.39 \] kmph

Max. permissible speed = 80 kmph

Allowable speed \( V_{max} = 72.39 \) mm 72 kmph
Length of transition curve

1. \[ L = 4.4\sqrt{R} = 4.4\sqrt{3441} = 81.6 \text{ m} \]

2. \[ L = 3.86e = 3.86 \times 14 = 54.04 \text{ m} \]

3. \[ \frac{3.28 \times (0.2782x)^3}{R} \]

\[ L = \frac{3.28 \times (0.2782 \times 72)^3}{3441} \]

\[ L = 76.4 \text{ m} \]

\[ \text{So } h = 81.6 \text{ m} \]

Problem: on a transitional curve on BG Track speed

railway, board formula \( V = 4.35\sqrt{R-67} \pm 1.35 \)

times speed obtained by cant formula allowing

cant deficiency of 9.60cm. IF actual cant is

provided for 80 length speed, calculated

(i) Radius of curve:

(ii) Max. speed allowed on the track.

(iii) Actual value of cant provided.

Solution:

\[ V = 4.35\sqrt{R-67} \] — (1)

If Radius = \( R \),

Actual cant \( e = \frac{6142}{127R} = \frac{1.676 \times 80^2}{127 \times R} \)

\[ e = \frac{844}{R} \]

Theoretical cant \( e' = e + h \)

\[ e' = \frac{844}{R} + \frac{9.60}{100} \]

\[ e' = \frac{844}{R} + 0.096 \]
Speed by cant formula

\[ V_{max} = V_2 = \sqrt{\frac{129 \times 1535}{1.676}} \]

\[ V_2 = \sqrt{\frac{129 \times R \times (84.4 + 0.076)}{1.676}} \]

\[ V_1 = 1.85 \times V_2 \]

\[ 4.35 \times \sqrt{R - 69} = 1.85 \times \sqrt{129 \times R \times (84.4 + 0.076)} \]

Square on both sides

\[ 10.38 \times (R - 69) = \frac{R^2}{1.676} \times (84.4 + 0.076 \times R) \]

\[ 10.38 \times R - 695.64 = 6395.46 + 5.76 \times R \]

\[ R = 1534.84 \text{ m} \]

\[ \therefore 1535 \text{ m} \]

(6) Max. Speed

For cant formula

\[ V_{max} = V_2 = \sqrt{\frac{129 \times 1535 \times (84.4 + 0.076)}{1.676}} \]

\[ V_2 = 1284.3 \text{ kmph} \]

(7) Actual cant

\[ e = 84.4 \times R \]

\[ e = \frac{84.4}{1535} \]

\[ e = 0.055 \text{ m} \]

\[ e = 5.5 \text{ cm} \]
Problem: Calculate max. speed allowed on a curve for a B&H track for given particulars.

A) = q. curve.

B = max. speed allowed by railway = 140 kmph

C = length of transition curve = 120 m

Solution: curve \( R = \frac{1720}{q} = 960 m \)

Max speed shall be min at following

1) Safe speed from Martin's formula

\[
V = 4.35 \sqrt{R - 67}
\]

\[
V = 4.35 \sqrt{860 - 67}
\]

\[
V = 122 \text{ kmph}
\]

Use formula for high speed trains

\[
V = 4.58 \sqrt{R}
\]

\[
V = 4.58 \sqrt{860}
\]

\[
V = 134.3 \text{ kmph}
\]

2) Cant formula

Theoretical formula \( \frac{6V^2}{127R} \)

\[
= \frac{1.676 \times 84^2}{127 \times 860}
\]

\[
= 27.55
\]

Use max. actual cant = 18.50 cm

4) Cant deficiency \( z = 10 \text{ cm} \)

Total cant = 28.50 cm

\[
V_{\text{max}} = \sqrt{\frac{127 \times R \times z}{6}} = \sqrt{\frac{127 \times 860 \times 28.5}{1.676}}
\]

\[
V_{\text{max}} = 186.29 \text{ kmph}
\]
As per length of transition curve

Max. speed for speed up to 100 kmph

\[ V_{\text{max}} = \frac{184L}{e}, \quad L = \text{length (m)} \]

\[ V_{\text{max}} = \frac{184L}{\varepsilon} \quad \varepsilon = \text{const (mm)} \]

Max. speed for speed > 100 kmph

\[ V_{\text{max}} = \frac{196L}{e} \]

\[ V_{\text{max}} = \frac{196L}{\varepsilon} = \frac{198 \times 12}{185} \]

\[ V_{\text{max}} = 128.41 \text{ kmph} \]

2) Max. speed allowed = 145

So max. speed = 128 kmph

(i) Max. speed

\[ V_{\text{max}} \rightarrow \text{constant} \rightarrow \text{max. allowed} \rightarrow \text{transition curve} \rightarrow \text{max.} \]

(ii) Length of transition curve

\[ \rightarrow \text{use} \quad V_{\text{max}} \quad \text{consider max. length} \]

(iii) \[ e_{\text{max}} = e + d \]

\[ \downarrow \]

\[ \text{max. avg. speed} \]

\[ \text{Speed} \]

\[ L \]
Extra widening on curve

\[ d = \frac{(B+L)^2}{R} \text{ cm} \]

- \( B = \) Rigid wheel base (in m)
  - 6.0 m (for 8.67 track)
  - 4.88 m (for 9.57 track)

- \( R = \) Radius of curve (in m)

- \( L = \) Lap of flange (in m)

\[ L = 0.02 \sqrt{h^2 + 2Dh} \text{ m} \]

- \( h = \) Depth of wheel flange below top level of rail (in m)

- \( D = \) Diameter of wheel (in cm)
Problem: For a 50t track, wheel base is 15 cm. Dia of wheel is 1.52 m. Determine extra width required if depth of flange below top of rail is 3.5 cm. Radius of curve = 180 m.

Solution: Lap of flange $L = 0.02 \sqrt{h^2 + Dh}$

$L = 0.02 \sqrt{3.15^2 + 15 \times 3.15}$

$L = 0.44 \text{ cm}$

d = $\frac{13 (B+L)^2}{R}$

d = $\frac{13 (6+0.44)^2}{480}$

$d = 1.25 \text{ cm}$
Vertial Curve

(1) Rolling Gradient: The max. gradient that can be provided in most general conditions is called Rolling Gradient.

For plains: \(1 \text{ in } 150 \text{ to } 1 \text{ in } 200\)

For hills: \(1 \text{ in } 100 \text{ to } 1 \text{ in } 150\)

No gradient should be more than rolling gradient in general conditions.

(2) Momentum Gradient: When an upgradient is met a down gradient as shown in fig. in case of a valley curve.

Then train get momentum during downward movement, that is used for upward movement. So we can provided the gradient slightly more than, rolling gradient. The gradient provided is called momentum gradient.

(3) Higher Gradient: In very extraordinary situation new gradient can be provided more steep than rolling gradient. In this case, extra locomotive is required to pull the train.
Gradient of 1 in 9.5 to 1 in 100 will require one extra locomotive.

4) Gradient in station yards: A mild slope is required just for drawing purpose. High gradient should be avoided to avoid automatic movement of drawbar.

Max. Gradient in station yards = 1 in 400
Min. Gradient for drainage = 1 in 1900

5) Grade compensation on curves: Due to curve, train has to resist some resistance, so max. gradient provided should be reduced at the location of curve.

<table>
<thead>
<tr>
<th>Track</th>
<th>Grade compensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) B.G.T. Track</td>
<td>0.04% per degree of curve</td>
</tr>
<tr>
<td>(ii) M.G. Track</td>
<td>0.03% &quot; &quot; &quot; &quot;</td>
</tr>
<tr>
<td>(iii) N.G. Track</td>
<td>0.02% &quot; &quot; &quot; &quot;</td>
</tr>
</tbody>
</table>

If rolling gradient = 1 in 150

Ex.: If a curve of 1 in 150 is there, on a B.G.T. track, what will be grade compensation and compensated gradient?

Sol.: Grade compensation = \[
\frac{0.04}{100} \times 150 = 0.06\%
\]

\[
\text{Compensated Gradient} = \frac{1}{150 - 0.625} = \frac{1}{149.375} = 0.0067
\]
Vertical Curve

1. Summit Curve
   - +91.7° + 2.7°
   - +91.7°

2. Valley Curve
   - -91.7° - 2.7°
A general case

Summit curve:

\[ BD = DE \]

Two gradient arc: 
- \( g_1 \rightarrow \) up gradient 
- \( g_2 \rightarrow \) Down gradient

Rate of change of gradient per chain length

Total length of Summit (valley) curve

\[ l = \frac{g_1 - g_2}{\gamma} = 2 \pi n \text{ chains} \]

Total chain is equally divided into two parts from point of intersection.

IF length of chain = 1

1. Chainage of B = known
2. Chainage of A = chainage of B + \( n \times 1 \)
3. Chainage of C = chainage of B + \( n \times 1 \)
Reduced level

1. RL of B = Given
2. RL of A = RL of B - \frac{H_1 NL}{100}
3. RL of C = RL of B - \frac{H_2 NL}{100}
4. RL of E = \frac{RL(A) + RL(W)}{2}
5. RL of D = \frac{RL(B) + RL(E)}{2}

Equation of paraboli curve (Summit)
(Simple paraboli curve is used)

\[ y = ax^2 + bx + c \] — (1)

at A
\[ x = 0 \]
\[ y = 0 + 0 + c = c \]

Slope Eq.
\[ \frac{dy}{dx} = 2ax + b \]

Slope (1) \( x = 0 \)
\[ \frac{dy}{dx} = + b \]
\[ b = 6 \]

Equation
\[ y = ax^2 + \frac{6}{2}x + c \] — (2)

\( P(x, y) \) is point on the curve to get RL of LP
RC of O = RL of A + \frac{6}{2}m \cdot x
RL of P = PL of O - 100

Value of \( P0(h) \)

\[ P0(h) = RO - PR \]

\[ = (c + g_1 x) - y \]

\[ = (c + g_1 x) - (ax^2 + g_1 x + c) \]

\[ = -ax^2 \]

\[ = kx^2 \]

Value of \( h \) for last point of curve

\[ Fc = f_{01} + g_{1e} \]

\[ Fc = g_1 \frac{nl}{100} + g_2 \frac{nl}{100} \]

\( e_1 = \text{rise/fall per chain length} \)

\[ e_1 = g_1 \frac{x}{100} \]

\[ e_2 = g_2 \frac{x}{100} \]

\[ h = e_1 n + e_2 n \]

General eq.

\[ h^2 \cdot n (e_1 - e_2) \]

\[ k x^2 \cdot n (e_1 - e_2) \]

\[ k (2n)^2 = n (e_1 - e_2) \]

\[ k n^2 = n (e_1 - e_2) \]

\[ k = \frac{(e_1 - e_2)}{2n} \]

Note: Value of \( x \) for end point = 2 chain.
Eq. For \( h = k \cdot e^{2} \)  
\[ \left( \frac{e_{1} - e_{2}}{4n} \right) \cdot e^{2} \]  
Here value of \( x = \) No. of chains  
\[ = 1, 2, 3, 4 \]  
RL of point \( P \) = RL of \( O \) - \( PO \)  
\[ = \text{RL of} \ O - k \]

**Problem:** A summit curve has two gradient + 0.85% & -0.85%. Rate of change of gradient per chain length is 0.15%. If RL & change of point of intersection B is 350, 50 m & 2500 m respectively, calculated RL & change of different point of the summit curve we 50 m chain.

**Solution:**
\( \theta_1 = 40^\circ 65^\prime \)
\( \theta_2 = -0^\circ 85^\prime \)
\( \tau = 0.15 \text{ per chain length} \)

**Length of curve**

\[
L = \frac{\theta_1 - \theta_2}{\tau} \times 2
\]

\[
L = \frac{40^\circ 65^\prime - (-0^\circ 85^\prime)}{0.15} \times 2
\]

\[
L = 101.105
\]

\[
L = 20
\]

**Chamfer of point A = chamage of B + \( \theta_1 \)**

\[
= 2500 - 5 \times 10
\]

\[
= 2350 \text{ m}
\]

**Chamfer of point C = chamage of B + \( \theta_1 \)**

\[
= 2500 + 150
\]

\[
= 2650 \text{ m}
\]

**RL of A = RL of B - \( \frac{\theta_1}{100} \)**

\[
= 350.50 - \frac{0.65 \times 5 \times 30}{100}
\]

\[
= 349.525 \text{ m}
\]

**RL of C = 350 - 50 - \( \frac{0.85 \times 5 \times 30}{100} \)**

\[
= 349.225 \text{ m}
\]

**RL of E = \( \frac{RL of A + RL of C}{2} \)**

\[
= \frac{349.525 + 349.225}{2}
\]

\[
= 349.375 \text{ m}
\]
$$RL_{OF D} = RL_{OF B} + RL_{OF E}$$

\[ = \frac{350.50 + 349.375}{2} \]

= 349.9375 m

Value of \( n = k x^2 \)

\[ = \left( \frac{e_1 - e_2}{4n} \right) x^2 \]

\[ V \geq e_1 = + \frac{9}{100} = 0.09 \]

\[ e_1 = 0.095 \]

\[ e_2 = - \frac{9.21}{100} = -0.0921 \]

\[ e_2 = 0.255 \]

\[ k = \left( \frac{e_1 - e_2}{4n} \right) = \frac{0.195 - 0.255}{100} \]

\[ A = 0.0225 \]

\[ h = 0.225 x^2 \]
<table>
<thead>
<tr>
<th>Point</th>
<th>Change</th>
<th>RL of 1st tangent</th>
<th>h = kx^2</th>
<th>RL of point on curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2350</td>
<td>349.525</td>
<td>0</td>
<td>349.525</td>
</tr>
<tr>
<td>1</td>
<td>2580</td>
<td>349.720</td>
<td>0.0225</td>
<td>349.525</td>
</tr>
<tr>
<td>2</td>
<td>2410</td>
<td>349.915</td>
<td>0.09</td>
<td>349.825</td>
</tr>
<tr>
<td>3</td>
<td>2340</td>
<td>350.110</td>
<td>0.2045</td>
<td>349.9075</td>
</tr>
<tr>
<td>4</td>
<td>2490</td>
<td>350.305</td>
<td>0.36</td>
<td>[349.945]</td>
</tr>
<tr>
<td>5</td>
<td>2530</td>
<td>350.500</td>
<td>0.5625</td>
<td>349.9875</td>
</tr>
<tr>
<td>6</td>
<td>2570</td>
<td>350.695</td>
<td>0.81</td>
<td>349.885</td>
</tr>
<tr>
<td>7</td>
<td>2660</td>
<td>350.890</td>
<td>1.1025</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2590</td>
<td>351.085</td>
<td>1.44</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2620</td>
<td>351.280</td>
<td>1.8225</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2650</td>
<td>351.475</td>
<td>2.25</td>
<td>349.225</td>
</tr>
</tbody>
</table>

Valley Curve:

RL of P = RL of 0 + h
(on first tangent)
Problem:

Point and crossing:

0 Turnout:

→ Point or Switch

Trailing Point direction

Trailing direction

Pavement is a combination of point and crossing, it is used to direct the train from one track to another, so that flexibility of movement can be obtained in a different track.

There are the weakest location of railway tracks, so proper design, strong material and proper maintenance is nee

(stick, rail)

(heel block)

(stick, rail)

(heel block)

(Cross Section at heel of the Switch)
(i) Heel Clearance (Heel Clearance): It is the distance by running of Stock rail and tongue rail measured at the need of the switch.

In India:
- On Track: 13.7 cm to 13.3 cm
- M on Track: 13.1 cm to 11.7 cm
- N on Track: 9.8 cm to

(ii) Flangeway Clearance: It is the distance of adjacent faces of Stock rail and tongue rail at heel of the switch.

Value for 1 m 12 crossing = 6.0 cm + 0.3 cm = 6.3 cm (For wear)

Indian Railway:
- For 1 in 8 crossing = 6.0 + 0.6 cm = 6.6 cm

(iii) Flangeway Depth: Depth from top of rail to top of heel block is called flangeway depth.

(iv) Throw of Switch: The distance by which the toe of tongue rail moves sideways is called throw of switch.

\[ b_{th} = 9.5 \text{ cm} \]
\[ m_{th} = 8.9 \text{ cm} \] (in India)

(v) Switch Angle: Angle with Stock rail and tongue rail, when tongue rail is touching the Stock rail is called angle of switch.
$B = \text{Switch angle}$

$\sin\theta = \frac{h}{S_2}$  --- (1)

$\sin\beta = \frac{h}{S_2} = \frac{h-t}{S_1}$  --- (2)

$\beta = \sin^{-1} \left( \frac{h}{S_2} \right) = \sin^{-1} \left( \frac{h-t}{S_1} \right)$

Crossing:

- Trailing direction
- Leading direction
- Facing direction
- Right hand wing rail
- Left hand wing rail
- Cross angle
- Gape
- Plane
- TNC
- ANC
- Home
(i) Crossing should be rigid enough to sustain heavy impact loading from wheel.

(ii) Special type of steel (high manganese steel) is used for point and crossing.

(iii) Crossing should be as long as possible.

Important terms:

(i) FNCL and TNC: Due to blunt nose, actual position of nose is called FNCL (actual nose of crossing). Theoretical nose of crossing is possible only if thickness of nose is zero.

(ii) Number of crossing (Angle of crossing) :=

\[ \text{Number of Crossing} = \frac{\text{Spread of leg of crossing}}{\text{length of rail from TNC}} \]

(iii) Goela's method (Right Angle method) := (use for Indian Railway)

In this method spread is measured on perpendicular length on one rail.

Angle of crossing = \( \alpha \)

Number of crossing = 1 in \( n \)

\[ \text{Hand} = \frac{1}{n} \]
No. of crossing \[ \cot \theta = N \] \[ \text{(A)} \]

Angle of crossing \[ \theta = \cot^{-1} N \] \[ \text{(B)} \]

Different number of crossing used

1. In 6 \rightarrow used in symmetrical split \( \theta = 9^\circ 27' 44'' \)

2. In 8\1/2 \rightarrow used in station yards where space is restricted on sharp turnout \( \theta = 6^\circ 43' 35'' \)

3. In 12 \rightarrow used in station yards of main line \( \theta = 4^\circ 45' 79'' \)

4. In 16 \rightarrow used in high speed turn out on BG/M.G. Track \( \theta = 3^\circ 34' 35'' \)

Example: No. of crossing \( 1 \text{ in } 12 \)

\[ N = 12 \]

\[ \cot \theta = \frac{N}{\text{rise}} \]

\[ \cot \theta = \frac{12}{\text{rise}} \]

\[ \theta = \cot^{-1} \left( \frac{12}{\text{rise}} \right) \]

\[ \text{rise} = 4^\circ 45' 49.1'' \]

1
(a) Central Line Method:

\[ \tan \frac{\gamma}{2} = \frac{R}{N} = \frac{1}{2N} \]

\[ \cot \frac{\gamma}{2} = 2N \]

\[ \theta_{y/2} = \cot^{-1} 2N \]

Number of crossings:
\[ N = \frac{1}{2} \cot \frac{\gamma}{2} \]

(b) Isosceles Traingle Method:

\[ \cot \frac{\gamma}{2} \times \frac{y/2}{N} = \frac{1}{2N} \]

\[ \csc \frac{\gamma}{2} = 2N \]

\[ \frac{\gamma}{2} = \cot^{-1} (2N) \]

\[ q = 2 \cot^{-1} (2N) \]

\[ 2N = \frac{1}{2} \csc \gamma_{y/2} \]
Design calculation of a Turn Out:

1. Curved Lead (CL): Distance from toe of Switch to T1 along Straight track.
2. Switch Lead (SL): Distance from toe of Switch to heel of Switch along Straight track.
3. Crossing Lead (CL): Distance from heel of Switch and toe along Straight track.

\[ CL = SL + L \]  \[ R = Ro - \frac{g}{2} \]

4. Outer Radius Curve (Ro) \[ R = Ro - \frac{g}{2} \]
5. Centre Radius Curve (R) \[ R = Ro - \frac{g}{2} \]
6. Angle of Switch (A)
7. Angle of Crossing (A) / No. of Crossing
8. Flex of Rail (A) / Gauge (G)
9. Check other.Track (A) / Gauge (G)
(a) Design calculations:

1. Method 1: In this case, curve is starting from toe of slab and end at TNC.

2. Given Value:
   - $l_t$: gauge
   - $n$: roof crossing

3. Curve end (CL):$
ewline\Rightarrow CL = B_T$
\Rightarrow CL = BE + ET
\Rightarrow CL = GC = + EC
\Rightarrow CL = G \cot \theta + G \cos \theta$
\Rightarrow CL = G \sin N + G \sqrt{1 + \cos^2 \theta}$
\Rightarrow CL = G \sin N + G \sqrt{1 + N^2}$
\Rightarrow CL = G (N + \sqrt{1 + N^2}) = G \sin N + G \sin N + G \cos N$
\Rightarrow CL = 2GN

\[ CL = 2GN \]
(2) \[
\tan \frac{\theta}{2} = \frac{G_2}{CL}
\]
\[
CL = G_7 \cot \frac{\theta}{2}
\]

Using property of circle:
\[
CL^2 = G_7(2R_0 - G_7)
\]
\[
CL^2 = G_7 R_0
\]
\[
CL = \sqrt{2G_7 R_0}
\]

(3) Radius \(R_0\)
\[
\Rightarrow R_0 = \frac{G_7}{2} + DT
\]
\[
\Rightarrow R_0 = CL \cot \frac{\theta}{2} + G_7
\]
\[
\Rightarrow R_0 = 2G_7 N^2 + G_7
\]
\[
\Rightarrow R_0 = G_7 + 2G_7 N^2
\]

As per Indian Army Code:
\[
R_0 = 1.5G_7 + 2G_7 N^2
\]

\[
R = R_0 - \frac{G_7}{2}
\] \(\Rightarrow \) control radius.

(3) Shear load \(SC\) \(\Rightarrow\)

using property of circle
\[
SC \times SC = h(2R_0 - h)
\]
\[
SC^2 = 2hR_0
\]
\[
SC = \sqrt{2hR_0}
\] (this very very less as compared to \(R_0\))
(c) Lead or crossing lead:

\[ L = CL - SL \]

(i) Heel divergence:

\[ h = \frac{SL}{2R_0} \]

Problem: Calculate angle of switch and heel divergence at tongue rail.

- Length of tongue rail = 5.10 m
- Thickness of toe of tongue rail = 0.65 cm, Actual length of tongue tongue rail = 4.90 m

Solution:

\[ \begin{align*}
  s_1 & = 4.90 \text{m} \\
  s_2 & = 5.10 \text{m} \\
  t & = 0.65 \text{cm} = 0.0065 \text{m} \\

\end{align*} \]

In triangle ABE:

\[ \sin B = \frac{h}{s_2} \quad (7) \]

In triangle ABC:

\[ \sin B = \frac{h + t}{s_1} \quad (8) \]

\[ \sin B = \frac{h}{s_2} = \frac{h + t}{s_1} \]

\[ \Rightarrow \frac{h}{510} = \frac{h - 0.065}{490} \]

\[ \Rightarrow h_{BE} = 510h - 0.65 \times 510 \]
\[ h = \frac{331.5}{(510 - 490)} \]
\[ h = 11.05 \text{ cm} \]

\[ \cos B = \frac{h}{L} = \frac{11.05}{510} \]
\[ B = \cos^{-1} \left( \frac{11.05}{510} \right) \]
\[ B = 1.14' 29.42'' \]

**Problem:** Calculate necessary elements to set out a ten-turner taking from a straight BM track.

- No. of Crossing = 11712
- Heel Divergence = 12.0 cm
- Curve is starting from toe of quarter and passes through the tangent.

**Solution:**

1. **Current Load**
   \[ C_L = 2 G/N \]
   \[ C_L = 2 \times 1.676 \times 12 \]
   \[ C_L = 410.24 \text{ N} \]

2. **Radius \( R_0 \)**
   \[ R_0 = 1.5G + 2G/N^2 \]
   \[ R_0 = 1.5 \times 1.676 + 2 \times 1.676 \times 12^2 \]
   \[ R_0 = 485.8 \text{ cm} \]
   \[ R = R_0 \left( \frac{L}{C_L} \right) = \frac{485.8 \times 12}{410.24} \approx 138 \text{ cm} \]
3. Switch lead (SL): 

\[ SL = \sqrt{2 \times 85 \times 0.12} \]

\[ SL = 10.79 \text{ m} \]

4. Crossing lead (L):

\[ L = CL - SL \]

\[ L = 40.234 - 10.79 \]

\[ L = 29.434 \text{ m} \]

**Method - III:** In this case, we have to calculate the angle of crossing from heel of the switch and ends at TMC. We have

(a) only crossing lead (L)

(b) Radius

\[ \text{Angle of crossing} = \alpha \]

\[ \text{Angle of Switch} = \beta \]
0 Crossing load:

\[ L = (c_7 \cdot h - x \cdot \sin \theta) \cot \left( \frac{3\pi}{2} \right) + x \cdot \sin \theta \]

0 Podium:

\[ h_0 = \frac{(c_7 - h - x \cdot \sin \theta)}{(\cos B - \cos \theta)} \]

Problem:

Calculate the necessary elements to set out a 1 in 8 \( {1/8} \) turnout taking from a straight 801 Track with 136 mm gauge starting from heel of the switch and ending at a distance 860 mm from TMC. Given that:

- Heel divergence = 136 mm
- Switch angle = 1° 30' 27"

Make a free hand sketch showing value of calculated elements.

Solution:

No. of crossing

\[ N = \frac{b}{2} = 8.5 \]
\[ N = c_7 + q = 8.5 \]
\[ \alpha = \tan^{-1} \left( \frac{136}{8.5} \right) \]
\[ q = 6' 43' 35.4" \]

Switch angle \( \beta = 1' 30' 27" \)

- \( h = 136 \text{ mm} \)
- \( h = 0.136 \text{ m} \)

Straight length \( (x) \) before TMC:

\[ x = 860 \text{ mm} \]
\[ c_7 = 1.676 \text{ m} \]

- Crossing load

\[ L = (c_7 - h - x \cdot \sin \theta) \cot \left( \frac{3\pi}{2} \right) + x \cdot \sin \theta \]
\[ L = \left( 1.676 - 0.136 - 0.864 \times \sin 6.42' 35.4'' \right) \\
\cos \left( \frac{6.42' 35.4'' + 1.36' 27''}{2} \right) \\
+ 0.864 \times \cos 6.42' 35.4'' \]

\[ L = 30.73 \text{ m} \]

2. Radius \( R = \frac{G \cdot (1 - h - x \sin \alpha)}{\cos B - \cos \gamma} \)

\[ R = \frac{1.676 - 0.136 - 0.864 \sin 6.42' 35.4''}{\cos 1.36' 27'' - \cos 6.42' 35.4''} \]

\[ R = 232.3 \text{ m} \]
\[ \angle CF B = (a - B) \]
\[ \angle F B I = \angle F K I = \frac{a - B}{2} \]
\[ \angle K B S = a - \left( \frac{a - B}{2} \right) = \frac{3a - B}{2} \]
\[ \angle K B S = \left( \frac{a + B}{2} \right) \]

(1) Crossing lead (L):

In triangle \( BKJ \):

\[ \tan \left( \frac{a + B}{2} \right) = \frac{KJ}{BJ} \]
\[ \tan \left( \frac{a + B}{2} \right) = \frac{C_1 - h}{2} \]
\[ L = (C_1 - h) \cot \left( \frac{a + B}{2} \right) \]

(2) Radius \( R_o \):

In triangle \( B I O \):

\[ \sin \left( \frac{a - B}{2} \right) = \frac{BI}{OB} \]
\[ OB = R_o = \frac{BI}{\sin \left( \frac{a - B}{2} \right)} \]

In triangle \( B K J \):

\[ \sin \left( \frac{a + B}{2} \right) = \frac{KJ}{BK} \]
\[ BK = \frac{(C_1 - h)}{\sin \left( \frac{a + B}{2} \right)} \]
\[ BK = 2BI \]
\[ R = \frac{(G_n - h)}{2 \sin \left( \frac{\theta}{2} \right)} \]

Put \( G_n \) in eq.(1)

\[ R_0 = \frac{(G_n - h)}{2 \sin \left( \frac{\theta}{2} \right) \sin \left( \frac{\phi}{2} \right)} \]

\[ R_0 = \frac{(G_n - h)}{\cos \phi - \cos \phi} \]

\[ \text{Method - III:} \]

\[ \text{In this case, a straight length is provided just before the curve. Also, a curve is started from the heel of the curve and ends at the starting point of the straight length before the curve.} \]

We need:

1. Crossing head (H)
2. Radius

(This method is used in Indian Railways)
A Cross Over:

- Combination of two turnout mounted at two parallel tracks to divert the train from one track to another is called cross over.

Case A:

- With an intermediate straight portion like two turnouts.

\[ A \]

\[ B \]

\[ C \]

\[ D \]

\[ E \]

\[ F \]

\[ G \]

\[ H \]

\[ I \]

\[ J \]

\[ K \]

\[ CL = 2G \]

\[ K \text{— Overall length of cross over.} \]

- Length of turnout = Curve lead

\[ CL = 2G \]

- Straight length of cross over by two turnout

\[ LH = S \]

If \( D \) = Distance b/w c/e of two tracks.

In triangle \( \triangle BCE \):

\[ EC = G \sec \alpha \]

\[ EL = (D-G) - G \sec \alpha \]

In triangle \( \triangle ELH \):
\[ \tan \theta = \frac{EL}{LH} \]

\[ LH = EL \cot \theta \]

\[ LH = \left[ (D-G)G_1 \right] \cot \theta \]

\[ LH = (D-G)N - G_1 \sqrt{1 + \tan^2 \theta} \]

\[ LH = 5 \]

\[ S = (D-G)N - G_1 \sqrt{1 + \tan^2 \theta} \]

\[ S = (D-G)N - G_1 \sqrt{1 + \tan^2 \theta} \]

Overall length of crossover

\[ = 4G_1N + S \]

\[ = 4G_1N + (D-G_1)N - G_1 \sqrt{1 + \tan^2 \theta} \]

---

**Case (b):**

Without any straight portion two tee-turnout 中间部分也弯曲。 (No Straight Portion)
\[
\text{Given values:} \\
\text{GNI:} \quad R_0, \quad R, \quad G, \quad N_1, \quad N_2 \\
\text{No. of crossing} \quad N_1, \quad \text{and} \quad N_2 \\
\text{Equation:} \\
O \cdot A = \sqrt{(R_1 + R_2)^2 - (R_1 - R_2)^2} \\
\text{Length on and O}_2 \\
A \cdot A = R_1 + R_2 \\
O_1O_2 = R_1 + R_2 \\
O_1O_2 = R_0 - G/2 \\
R_2 = R_0 - G/2 \\
10^3 \text{ coax } \\
R_1 = 1.5G + 2G N_1 N_2 \\
\text{}\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}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A Diamond Crossing:

\[ \text{Given:} \ N = \cot(q) \]

- \( q = \cot^{-1}(N) \)

Components:
1. Length \( AB = BC = CD = DA = G_1 \cos q \cdot y \)
2. Length \( BE = DF = G_1 \cot q \)

\[
\begin{align*}
\text{In triangle } DEF: \\
\tan q &= \frac{G_1}{DF} \\
DF &= G_1 \cot q
\end{align*}
\]

3. Diagonal \( AC \)

- In triangle \( ACF \)
  \[ \sin q_2 = \frac{G_1}{AC} = \frac{y}{A} \]
  \[ AC = G_1 \cos q_2 \]

4. Diagonal \( BD = 2DH \)

- In triangle \( ABD \)
  \[ \tan q_2 = \frac{DH}{AH} \]
\[ DH = AH \tan \frac{\theta}{2} \]
\[ DH = \frac{1}{2} AC \tan \frac{\theta}{2} \]
\[ DH = \frac{1}{2} \left( E \cos \frac{\theta}{2} \cdot \text{cosec} \frac{\theta}{2} \right) \]
\[ DH = \frac{1}{2} \left( E \sin \frac{\theta}{2} \cdot \frac{\sin \frac{\theta}{2}}{\cos \frac{\theta}{2}} \right) \]
\[ DH = \frac{1}{2} \left( E \sin \frac{\theta}{2} \right) \]

\[ BN = 2 DH \]
\[ BN = 2 \times \frac{1}{2} E \sin \frac{\theta}{2} \]
\[ BN = E \sin \frac{\theta}{2} \]

**Problem:** A crossover occurs with two parallel lines. Mark of Problem: A crossover occurs with two parallel lines. A part of it is shown in the diagram. The length of the crossover portion is 8 km. Find the overall length of the crossover.

**Solution:**

```
C = 8 km
```

Diagram showing the crossover and the calculation of the length.
\[ CL = 26N \]
\[ CL = 27 \times 1.676 \times 8.5 \]
\[ CL = 28.492 \text{ m} \]

\[ CF = 2 \times 6.7 \]
\[ CF = 5 \times 1.676 \]
\[ CF = 3.334 \]

\[ CF = \frac{G \cdot 32\pi}{L} \]
\[ CF = 1.676 \sqrt{1 + \frac{1}{N^2}} \]
\[ CF = 1.676 \sqrt{1 + \frac{1}{8.5^2}} \]
\[ CF = 1.687 \]

\[ FL = 3.334 - 1.687 \]
\[ FL = 1.636 \]

\[ L = FL \cdot C_0 \cdot L_0 \]
\[ L = 1.636 \times 8.5 \]
\[ L = 13.91 \]

**Overall length of C/0**

\[ = 49N + 5 \]
\[ = 27 \times 28.492 + 13.91 \]
\[ = 70.89 \text{ m ±0.1} \]
To understand this topic, three important points are:

1. **Tractive effort (Te)**: The power generated by the engine and transferred to the driving wheels for movement of the train is called tractive effort. This tractive effort should be sufficient to overcome all resistances.

2. **Hauling capacity**: Hauling capacity is the force of friction available on the rail surface on the driving wheels, which is the value of hauling capacity. It should be more than total resistance offered by the train.

   \[ F = \mu R = \mu Wd \]

   \[ Hc = \mu L \cdot Wd \]

   If \( n \) = No. of pair of driving wheel.

   \( Wd \) = total weight of one pair of driving wheel.

   The train will not move if hauling capacity is less than total resistance.

3. **Total resistance**: Resistance offered by the train due to various reasons for movement of train.

   \[ \text{Total resistance} < \text{Te} \]
Steam Engine Cylinder

Let us consider a steam engine for which:

- \( A \) = area of piston/cylinder
- \( P \) = pressure difference
- \( L \) = length of stroke
- \( h \) = no. of cylinder
- \( D \) = dia of wheel
- \( d \) = dia of eq piston

\[ \Rightarrow \text{Power generated} = \text{work done on wheel} \]

\[ \Rightarrow np.\frac{DL}{2} = \pi DT \]

\[ \Rightarrow np.\frac{\pi D^3}{8} = \pi DT \]

\[ \Rightarrow Te = \frac{n\pi Dd^2}{2} \]

- Tractive effort.

\[ Te \propto \frac{1}{D} \]

So a there should be a balance, so that sufficient speed is obtained with out reducing the tractive effort.
(2) **Hauling Capacity:**

Hauling capacity depends upon weight on driving wheel. It is the force of friction that can be developed between rail and driving wheel.

\[ Hc = \mu \cdot n \cdot Wd \]

If \( Wd \) = wt. of one driving wheel.

\( \mu \) = Coefficient of friction.

\[ = 0.10 \text{ to } 0.30 \]

Note: 0.10 → at high speed

0.30 → at low speed

Generally, \( \mu = 0.20 \) may be considered.

\[ \frac{1}{6} = 0.167 \]

(As per old book)

**Driving wheels:**

(1) **incometric:**

For a 4-6-2 locomotive, no. of pairs of driving wheel

1. \( 4 + 6 + 2 = 4/2 = 3 \)
2. \( 4 - 6 + 2 = 6/2 = 3 \)

the value of \( \mu \) at low speed = \( \mu \) is less.

at high speed = \( \mu \) is less.

**Hauling Capacity = Total Resistance**
5. Total Resistance:

- Train Resistance:
  (i) Resistance independent of speed (Rolling Resistance): \( R_{R1} \)
  \[ R_{R1} = 0.0016 \cdot \omega_0 \rightarrow \text{Rolling Resistance} \]
  \( \omega_0 = \text{wt. of train in tonnes} \)

- Due to:
  (i) Journal friction: a function of locomotive, wagon's etc.
  (ii) Function of wheel and rail.

- Worn action of rail. (Note: the train moves in this direction)

- Internal resistance.

\[ R_{R1} = 0.0016 \cdot \omega_0 \rightarrow \text{Rolling Resistance} \]

- Train resistance depends on speed (\( R_{R2} \)):
  \[ R_{R2} = 0.00006 \cdot \omega_0 \cdot V \]

- \( V = \text{speed in kmph} \)

- Atmospheric resistance (\( R_{R3} \)):
  \[ R_{R3} = 0.0000006 \cdot \omega_0 \cdot V^2 \]

- Total rail resistance:
  \[ R_T = R_{R1} + R_{R2} + R_{R3} \]
\[ R_T = 0.0016 \theta + 0.00008 \theta \gamma + 0.000006 \theta \gamma^2 \]

\[ R_f = 0.0016 \theta \gamma \]

(1) Resistance due to Block Profile:

(1) Due to Gradient:

\[ R_g = w \tan \theta \]

\[ R_g = w \sin \theta \]

(for small \( \theta \), \( \sin \theta = \tan \theta \))

(2) Due to Curve (Curve Resistance):

\[ R_c = 0.004 + 0.01 \theta \]

\[ R_c = 0.0004 \theta \] for \( C \theta \)

\[ R_c = 0.0003 \theta \] for \( M \theta \)

\[ R_c = 0.0002 \theta \] for \( N \theta \)
Due to starting and acceleration:

\[ v = v_0 + \frac{0.15 + \frac{0.05 v_0}{w_{\text{wagon}}}}{v_{\text{locomotive}}} \]

\[ v = v_0 + w_{\text{locomotive}} \]

\[ W_2 = w_{\text{wagon}} \]

Due to acceleration:

\[ a = \left( \frac{v_2 - v_1}{t} \right) \]

\[ R_{ac} = 0.0286 + a \]

\[ R_{ac} = 0.0296 \left( \frac{v_2 - v_1}{t} \right) \text{ kmph/see.} \]

If \( v_1 \) and \( v_2 \) are in kmph.

\( t = \text{sec.} \)

\( w = \text{tonnes} \)

Wind resistance:

\[ R_W = 0.000017 \cdot a \cdot v_{10}^2 \]

\( a = \text{Exposed area in m}^2 \)

\( v_{10} = \text{wind velocity in kmph} \)

For movement:

\[ H.C > \text{Total Resistance} \]

\[ T.e > \text{Total Resistance} \]
For solving question:

\[ F_e = h.c. = \text{Total Resistance} \]

In normal case, total resistance = \( R_{T1} + R_{T2} + R_{T3} \)

**Problem:** Determine the max permissible train load that can be pulled by a locomotive having 4 pairs of driving wheels, carrying an actual load of \( 4t \) each. The train has to run at a speed of 80 kmph on a straight level on a track. Also determine the reduction in speed of the train has to climb a gradient of 1 in 100.

**Solution:**

Locomotive \( \Rightarrow \) no. of pairs of driving wheel

\( n = 4 \)

Weight on each part (axle)

\( c_u = 24t \)

Hauling capacity

\[ h.c. = d - 0.090d \]

\[ h.c. = 6.20 \times 4 \times 24 \]

\[ h.c. = 19.2 t \]

**Case 1:**

Train loading \( c_o \) = \( 0 \)

\[ h.c. = \text{Total Resistance} \]

\[ 19.2 = R_{T1} + R_{T2} + R_{T3} \]

\[ 19.2 = 0.0016 c_o + 0.00003 c_o \cdot k + 0.000006 c_o \cdot k^2 \]

\[ 19.2 = 0.0016 \cdot 0 + 0.00003 \cdot 80 + 0.000006 \cdot 80^2 \]

\[ 19.2 = 101 \]

\[ c_o = 1921.62 \ t \]
Case II: On a Gradient 1 in 200 is there

\[ H = R + R_2 + R_3 - w \cdot \tan \theta \]

\[ \Rightarrow 19.2 = w (0.0018 + 0.0000008v + 0.0000006v^2) + w \cdot \tan \theta \]

\[ \Rightarrow 19.2 = \]

\[ \Rightarrow \theta \approx 3.295 \quad \text{(82)} \]

\[ v = \]

\[ \Rightarrow v = 48.26 \text{ km} \]

**Problem:** A train having 20 wagen weighing 19.6 each is to run at a speed of 50 kmph. The train is to move on a 1 in 200 gradient. The total weight of locomotive with 235 t load on each driving axle is 15 t. The dy of locomotive is 420 tonne. Axle load is 15 t. The rolling resistance of wagen and locomotive are 2.5 ft/lb and 8.5 ft/lb respectively. The resistance which depends upon speed is 3.65 ft/lb. Find out the stages gradient for conditions.

**Solution:**

\[ \text{Locomotive} \quad \text{wagon 2000 - 19.6 t each} \]

\[ \text{Weight of wagons} = 20 \times 19.6 \]

\[ = 392 \text{ t} \]

\[ \text{Weight of locomotive} = 120 \text{ t} \]

\[ \text{Weight of train} w = 480 \text{ t total} \]
Locomotive = 2-8-2

- No of pairs of driving wheel = 9
- Weight of each pair of driving wheel = 22.5 t

Hauling capacity = \( \text{d} \times \text{w} \)
\[ = 0.20 \times 4 \times 22.5 \]
\[ = 19.5 \text{ t} \]

The maximum force exerted = \( 7e = 15 \text{ t} \)

So this train can move with the force of 15 t only.

Train load = 480 t
Speed = 50 kmph

Maximum gradient = \( \tan \theta = 2 \)

\[ H.o \text{ or } Te = \text{Total Resistance} \]
\[ = R_{T1} + R_{T2} + R_{T3} + \text{load} \cdot \tan \theta \]
\[ \Rightarrow R_{T1} = \frac{24.5 \times 1.5 \times 380}{980} + \frac{24.5 \times 1.5 \times 1.5 \times 380}{980} \text{ locomotive} \]
\[ \Rightarrow R_{T1} = 1320 \text{ kg} \]
\[ \Rightarrow R_{T1} = 1.320 \text{ t} \]

\[ R_{T2} = \text{Resistance, dependent on speed} \]
\[ R_{T2} = 8.65 \text{ t} \]
\[ \Rightarrow R_{T3} = 0.000000 \text{ 6.80} \times \text{w}^2 \]
\[ \Rightarrow R_{T3} = 0.000000 \text{ 6.480} \times \text{50}^3 \]
\[ \Rightarrow R_{T3} = 0.72 \text{ t} \]
Problem: Determine the maximum effect developed by a two cylinder engine from the following data:

1. Wield load on driving wheels = 5.80 t.
2. Difference of pressure in cylinder = 0.75 kg/cm²
3. Dia of piston = 32 cm
4. Length of stroke = 42 cm
5. Dia of wheel = 153 cm

State whether working of engine is satisfactory.

Solution:

\[ W_d = 5.80 \text{ t} \]
\[ P = 0.75 \text{ kg/cm}^2 \]
\[ d' = 32 \text{ cm} \]
\[ L = 42 \text{ cm} \]
\[ D = 153 \text{ cm} \]

Maximum effect developed by engine

\[ P_e = \frac{n P L d'^2}{2.71} \]
\[ P_e = \frac{2 \times 0.75 \times 42 \times 32^2}{2.71} \]
\[ P_e = \frac{2 \times 78153}{2.71} \]
\[ P_e = 743 \text{ kg} \]
\[ P_e = 0.743 \text{ Tonnes} \]
\[ H_c \cdot M = 0.20 \times 5.80. \]
\[ H_c = 1.16 \text{ t} \]

**Tractive effort < Hc.**

So engine is not satisfactory.

**Solution:**

(a) Hauling capacity:

- Pairs of drawing wheels: \( n = 8 \)
- Weight on each pair: \( w = 22 \text{ t} \)

\[ H_c = \frac{M \cdot w}{1.16} = \frac{0.20 \times 22}{1.16} = 13.2 \text{ t} \]

(b) On a straight & level track:

\[ H_c = \text{Train Resistance} \]

\[ H_c = 0.00016 t + 0.00008 \frac{v}{100} + 0.0002 w + 0.25 \]

\[ 13.2 = 0.0016 + 0.0002 \times 22 + 0.25 \]

\[ v = 1308.73 \text{ t} \]
when track goes on a gradient \( 110^\circ 180^\prime \)

\[ \text{H.C.} = 0.0018 \omega + 0.00008 \omega v + 0.000006 \omega v^2 + \text{etc.} \]

\[ \Rightarrow 13.2 = 0.0016 \times 1202.73 + 0.00008 \times 1202.73 \times v + 0.000006 \times 1202.73 \times v^2 + 1202.73 \times \text{etc.} \]

\[ \Rightarrow 13.2 = 1925 + 0.097 v + 0.00096 v^2 + 6.68 \]

\[ \Rightarrow 4.597 = 0.097 v + 0.00096 v^2 \]

\[ \Rightarrow v = 37.8 \text{ kmph} \]

Reduction in speed = 75 - 37.3 = 37.7 \text{ kmph}

(\(\square\)) when it is a curve of \(2^\prime\)

\[ \text{H.C.} = \frac{0.0004 \times 2}{12} + 0.00001 \times 1202.73 \times v \]

\[ \Rightarrow \text{H.C.} = 10.962 \]

\[ \Rightarrow v = \]

(\(\square\)) when gradient and curve

\[ \text{H.C.} = \frac{1202.73 + 0.962}{190} \]

\[ \Rightarrow v = \]
(1) **Highway Egg:**

- **Introduction:**
- **Important events:**

1. Jaykaran Committee recommendation
   - For 1927
   - Submitted report in 1928

2. Central Road Fund → 1929
3. Indian Road Congress → 1934
4. Motor Vehicles Act → 1939
5. 1st 20-year road plan → 1943 (Nagpur)
6. CRRI → Central Road Research Institute → 1950
7. 2nd 20-year road plan → 1961 (Bombay road plan)
8. 3rd 20-year road plan → 1961 (Ludhiana)

(2) **Jaykaran Committee recommendation:**

1. Road development is a national interest should be considered as such.
2. Any tax on petrol should be used for road development.
3. Result: Central Road Fund (1929)
4. Semi-official Government body should be formed for road development planning.
   - Result: Indian Road Congress → 1934
- Fire Search Institute should be named for research & development work.

Result: CRRS → 1950

<table>
<thead>
<tr>
<th>Feed development plane</th>
<th>First</th>
<th>Second</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Venue</td>
<td>Naqbar</td>
<td>Bombay</td>
<td>Lucknow</td>
</tr>
<tr>
<td>2. Target</td>
<td>16 km</td>
<td>32 km</td>
<td>62 km</td>
</tr>
<tr>
<td></td>
<td>100 sq km</td>
<td>100 sq km</td>
<td>100 sq km</td>
</tr>
<tr>
<td>3. Classification</td>
<td>Express</td>
<td>Express way</td>
<td>Primary</td>
</tr>
<tr>
<td></td>
<td>NH</td>
<td>NH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SH</td>
<td></td>
<td>Secondary</td>
</tr>
<tr>
<td></td>
<td>MIDR</td>
<td>SH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ODR</td>
<td>MIDR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VR</td>
<td>ODR</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VR</td>
<td></td>
</tr>
</tbody>
</table>
Roman Roads:

1. Zero slope
2. Basque construction
3. Macadum:

Macadum: Macadum was first who used small sized stones for bottom layers.
- Stress at bottom layers are less than stress at top layers — this theory was introduced by Macadum.
- Slope at top & bottom layers.
- Side drains.
Geometrical Design:

1. Cross-section elements:
2. Friction:
   - Longitudinal coefficient of friction
     \[ \mu = 0.35 \text{ to } 0.5 \]
   - Laterally coefficient of friction
     \[ \mu = 0.8 \]

Skid:
- When brakes are applied
  \[ \xrightarrow{\text{longitudinal movement}} \text{circumferential moment} \]

Skid:
- When vehicle is being accelerated
  \[ \xrightarrow{\text{circum. moment}} \text{longitudinal movement} \]

Comber:
- To drain off water from road surface

1. Straight
2. Parabolic
3. Semi-parabolic
<table>
<thead>
<tr>
<th>Type of Pavement</th>
<th>Light Rainfall</th>
<th>Heavy Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cement concrete pavement or High quality Bituminous</td>
<td>1.7%</td>
<td>20% (1 in 50)</td>
</tr>
<tr>
<td>2. Simple Bituminous or WBN</td>
<td>2.0%</td>
<td>2.5% (1 in 40)</td>
</tr>
<tr>
<td>3. Gravel road</td>
<td>2.5%</td>
<td>3.0% (1 in 33.3)</td>
</tr>
<tr>
<td>4. Earth road</td>
<td>3.0%</td>
<td>4.0% (1 in 25)</td>
</tr>
</tbody>
</table>

**Side Distance:**

1. Stopping sight distance: As per IRC

[Diagram of horizontal and vertical curves]
Stopping sight distance: 

\[ = \text{lag distance} + \text{braking distance} \]

\( \text{lag distance} \rightarrow \) Distance travelled by the vehicle during reaction time of driver.

PIEVT theory:

P \rightarrow \text{Perception} \rightarrow \text{Time taken to send signal from eye of brain.}

I \rightarrow \text{Inference} \rightarrow \text{Time taken to understand a station, rearranging different thoughts.}

E \rightarrow \text{Emotion} \rightarrow \text{Extra time taken due to emotions.}

V \rightarrow \text{Valuation} \rightarrow \text{Time for final action.}

Total time taken = Reaction time

\text{Vary from (0.5 to 5 sec.)}

Generally, \( t_R = 3.5 \text{ to } 3.8 \text{ sec.} \)

\[ \text{lag distance} = \text{Speed} \times \text{Reaction Time} \]

\[ \text{lag distance} = V \times t_R \]

\[ = 0.278 \times V \times t_R \]

\( \text{braking distance} \rightarrow \)

[Diagram of braking applied showing forces and distances]
After application of brake, vehicle moves a distance.

1. Full brake efficiency (1.07) is to be considered as:
   after brake, wheels are fully jammed.

   \[ \text{Kinetic energy} = \text{work done loss} \]

   \[ \Rightarrow \frac{mu^2}{2} = (F\dot{a} \times S) \]

   \[ \Rightarrow \frac{mu^2}{2} = (mg \sin \theta + \mu R) S \]

   \[ \Rightarrow \frac{mu^2}{2} = (mg \sin \theta + F \dot{a} \cos \theta) S \]

   **Stopping sight distance**

   \[ \Rightarrow S = \frac{\text{V}^2}{2g (\sin \theta + F \dot{a} \cos \theta)} \]

   \[ \Rightarrow S = \frac{\text{V}^2}{2g (\text{tan} \theta + F)} \]

   \[ \Rightarrow S = \frac{\text{V}^2}{2g (F + S \dot{a})} \]

   **Pedal stopping sight distance**

   = (log distance + stopping distance)

   \[ = (0.278 \text{ V.e}) + \left( \frac{0.278 \text{ V.e}}{2g (F + S \dot{a})} \right) \]

   \[ (\pm) \text{ue for upward slope} \]

   \[ (\pm) \text{ue for downward slope} \]
1. One way traffic/one lane road  → SSD
2. Two lane road
two way traffic → SSD
3. One lane road/two way traffic
   → ISD → Intermediate sight distance
   \[= 2 \cdot SSD\]
4. Head light-sight
   distance  → SSD

Head light-sight
distance
Overtaking eight distance:

A → Overtaking vehicle (Speed $V_A$)
B → Overtaking vehicle (" $V_B$)
C → " from opposite side (Speed $V_C$)

1. Distance $d_1$:
   
   $d_1 = \text{distance travelled by } A \text{ in reaction time}$

   $d_1 = 0.248 \times V_B \times T_R$  \(1\)

   (A = B forced to move with same speed, that of B
   Speed of just before $B = V_B$

2. Distance $d_2$:

   If $T_{see} = $ total time required from A to move for

   $2 \times 0.5$

   $d_2 = V_B \cdot T + \frac{1}{2} a T^2$

   \[ d_2 = 0.248 \times V_B \times T + \frac{1}{2} a T^2 \]  \(2\)

   According to vehicle (B)
\[ d_2 = b + 25 \]
\[ d_2 = 0.298V_B + 25 \]

\[ S = \frac{at^2}{2} \]
\[ T = \sqrt{\frac{2S}{a}} \]

\[ a = \text{acceleration of vehicle} \]
\[ S = \text{num. distance to be maintained btw two vehicles} \]
\[ S = 0.7 \times V_B + 1 \]
\[ S = 0.7 \times 0.278V_B + 6 \]
\[ S = 0.2V_B + 6 \]

\[ 0.7 \text{ see reaction time} \]
\[ 1 \text{ length of vehicle} \]

(3) Distance \( d_3 \):

\[ d_3 = 0.278V_c \cdot T \]

Total overtaking &de distance = \( d_1 + d_2 + d_3 \)
Problem: The driver of a vehicle travelling to text up a gradient accelerates 9 m/s less to stop after applying the brakes than a driver travelling with same speed down the same gradient. What is the gradient?

Solution:

\[ s_2 - s_1 = 9 \text{ m} \]

Moment up the gradient:

\[ s_1 = \frac{v^2}{2g(F + s_f)} \]

\[ s_1 = \frac{(0.278 \times 60)^2}{2 \times 9.81 (0.40 + 5)} \]

\[ s_1 = 14.18 \text{ m} \]

Down the gradient:

\[ s_2 = \frac{(0.278 \times 60)^2}{2 \times 9.81 (5 - F)} = \frac{14.18}{0.40 - 5} \]

\[ s_2 = s_1 = 9 \]
Problem: On a two way road, the speed of overtaking &
over taken vehicles are 65 & 40 kmph respectively.

Determine:
1. Safe overtaking Safe distance.
2. Min. length of overtaking Zone. & Show the details
   of overtaking Zone by a neat Sketch.

\[ \frac{14.18}{0.9} - \frac{14.18}{0.4} = 9 \]
\[ \frac{6.05 \pm 0.001 \pm 5}{0.4 - 5^2} = 9 \]
\[ \frac{2S}{0.16 - 5^2} = \frac{9}{14.18} \]
\[ 0.16 - 5^2 = 1.57565 \]
\[ S^2 + 1.57565 - 0.16 = 0 \]
\[ S = 0.05 \sqrt{20} \text{ Ans.} \]

\[ a = 0.92 \, \text{m/sec}^2 \]

Solution: 

\[ V_A = 65 \, \text{kmph} \]
\[ V_0 = 40 \, \text{kmph} \]
(i) Distance $d_1$
\[ d_1 = 0.278 \times v_0 \times T \]
\[ d_1 = 0.278 \times 40 \times 2.5 \]
\[ d_1 = 27.8 \text{ m} \]

(ii) Distance $d_2$:
\[ d_2 = 0.278 \times v_B \times T + \frac{1}{2} a t^2 \]
\[ S_{\text{tot}} = 0.2 \times v_B + 6 \]
\[ \Rightarrow S = 0.2 \times 40 + 6 \]
\[ S = 14 \text{ m} \]
\[ T = \sqrt{\frac{2S}{a}} = \sqrt{\frac{4 \times 14}{0.92}} \]
\[ T = 7.8 \text{ sec} \]
\[ d_2 = 0.278 \times 40 \times 7.8 + \frac{1}{2} \times 0.92 \times (7.8)^2 \]
\[ d_2 = 114.72 \text{ m} \]

(iii) Distance $d_3$:
\[ d_3 = 0.278 \times v_2 \times T \]
\[ d_3 = 0.278 \times 65 \times 7.8 \]
\[ d_3 = 140.95 \text{ m} \]

Total LSD = $d_1 + d_2 + d_3$
\[ = 27.8 + 114.72 + 140.95 \]
\[ = 283.47 \text{ m} \]
Overtaking Zone →

\[ \text{Min. length} = 3 \times \text{OSD} \]
\[ = 3 \times 283.47 \]
\[ = 850.41\text{m} \]

2. Desirable length of Overtaking: →
\[ = 5 \times \text{OSD} \]
\[ = 5 \times 283.47 \]
\[ = 1417.35\text{m} \]

\( S_p_1 \rightarrow \) Overtaking Zone ahead.
\( S_p_2 \rightarrow \) end of Overtaking Zone.

Value of acceleration
Value of acceleration & OSD:

<table>
<thead>
<tr>
<th>Speed</th>
<th>$a\text{ m/s}^2$</th>
<th>OSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1.30</td>
<td>90 m</td>
</tr>
<tr>
<td>40</td>
<td>1.24</td>
<td>165 m</td>
</tr>
<tr>
<td>50</td>
<td>1.11</td>
<td>235 m</td>
</tr>
<tr>
<td>65</td>
<td>0.92</td>
<td>340 m</td>
</tr>
<tr>
<td>80</td>
<td>0.72</td>
<td>490 m</td>
</tr>
<tr>
<td>100</td>
<td>0.53</td>
<td>640 m</td>
</tr>
</tbody>
</table>

Super elevation:

- Provided on curve to counteract the effect of centrifugal force

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

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

Equating all force along surface of road.
\[ mg \sin \theta + F = \frac{mu^2 \cos \theta}{R} \]
\[ mg \sin \theta + F (mg \cos \theta + \frac{mu^2 \sin \theta}{R}) = \frac{mu^2 \cos \theta}{R} \]
\[ g \tan \theta + Fg + \frac{Fmu^2 \tan \theta}{R} = \frac{v^2}{R} \]

\text{Super elevation}
\[ \text{put} \quad \tan \theta = e \]
\[ g e + Fg = \frac{v^2}{R} (1 - ef) \]
\[ g (ef + F) = \frac{v^2}{R} (1 - ef) \]
\[ \frac{(e + F)}{(1 - ef)} = \frac{v^2}{gR} \]

\[ 1 - ef \approx 1.00 \]

then
\[ efF = \left(0.278v\right)^2 \]
\[ g \]
\[ e + F = \frac{v^2}{1279R} \]
\[ e = \frac{v^2 - F}{1279R} \]

\[ \text{Erosion force} \]
(4) **Max Value of Super-elevation:**

1. On plain or rolling road = \( T_1 = 0.07 \)
2. On fully road = \( T_2 = 0.10 \)
3. On urban road (with = 4\( T_3 \) = 0.04 frequent intersection)

(5) **Design Steps:**

1. If design speed = \( V \) kmph
   
   Super-elevation is calculated for 75 kmph for design speed
   
   \( \text{Value of } F \text{ is not considered} \)
   
   \[ e = \frac{(0.75V)^2}{127R} \]

   \[ e = \frac{V^2}{226R} \]

2. If value calculated above is less than max feasible value, then S.E. calculated is provided

   \[ e \leq e_{\max} \]

3. If \( e > e_{\max} \)

   Then check value of \( F \) considering full design speed

   Using \( e_{\max} \) value.

   \[ e + F = \frac{V}{127R} \]

   \[ F = \frac{V^2}{127R} - e_{\max} < 0.15 \]
If $V < 0.15$ OK

Provide $E_{max}$.  

\[ E_{max} = \frac{V^2}{127 + R} \]

**Example:** If S.E. is to be designed for a design speed of 110 kmph on a road in plain area for a curve of radius $R = 120$ m, what should be the value of S.E. provided. Check max. allowed speed.

**Solution:**

\[ V = 110 \text{ kmph} \]

1. **Super-elevation**

\[ e = \frac{0.75 \times V^2}{127 + R} = \frac{0.75 \times 110^2}{127 + 120} = 0.127 \]

\[ e_{max} = 0.07 \times e \]

\[ E_{max} = 0.07 \]

\[ \text{Check:} \quad E_{max} + F = \frac{V^2}{127 + R} = \frac{110^2}{127 + 120} = 0.07 + F = \frac{110^2}{127 + 120} \]
\( F = 0.1568 > 0.15 \)

8. Max. Speed allowed

\[ \Rightarrow E_{\text{max}} + F_{\text{max}} = \frac{V_{\text{max}}^2}{127R} \]

\[ \Rightarrow V_{\text{max}} = \sqrt{\frac{127R(E_{\text{max}} + F_{\text{max}})}{127R}} \]

\[ \Rightarrow V_{\text{max}} = \sqrt{127 \times 420 (0.07 + 0.15)} \]

\[ \Rightarrow V_{\text{max}} = \text{108.2 kmph} \]

Ans

\[ \text{Min. radius of curve} \Rightarrow \]

\[ \Rightarrow E_{\text{max}} + F_{\text{max}} = \frac{V^2}{127R} \]

\[ \Rightarrow R_{\text{min}} = \frac{V^2}{127(E_{\text{max}} + F_{\text{max}})} \]

\[ \Rightarrow R_{\text{min}} = \]
Extra widening:

\[ E_w = \text{Extra width required} \]

\[ R = \text{Outer radius of road} \]

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

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

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

\[ \Rightarrow \text{Extra width} \]

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

\[ E_w = \frac{d^2}{2R} \quad (2R + E_w < 2R) \]

If \( n = \text{Total no. of lanes} \)

\[ E_w = \frac{nd^2}{2R} \]
1. \[ C_0 = \frac{h_2^2}{2R} \]  
   \( \text{mechanical widening.} \)

2. \[ \text{Psychological widening:} \quad \frac{V}{9.5\sqrt{R}} \]

Total extra widening required: \[ \frac{h_2^2}{2R} + \frac{V}{9.5\sqrt{R}} \]

3. \( \text{Transition Curve:} \Rightarrow \)
   
   \( \Rightarrow \text{Length of Transition curve:} \Rightarrow \)

   1. As per rate of change of radial acceleration (C)
      
      \[ \text{Length of Transition curve} = \frac{V^3}{CR} \]
      
      \[ = \frac{(0.278V)^3}{CR} \]

   \[ C = \left( \frac{80}{V+75} \right) \]
   
   \[ C = [0.50 \leq C \leq 0.80] \]

3. As rate of change of super elevation: \( \Rightarrow \)
   
   Calculate super elevation \( \frac{V^3}{225R} \)

4. If pavement is rotated about inner edge
Raise of pavement edge

\[ x = (w + E_w) e \]

(2) If pavement is rotated about centre

Raise of pavement edge

\[ x = \left(\frac{w + E_w}{2}\right) e \]

Length of transition curve as per depth elevation

- \(150 \times e \rightarrow \) for plan region
- \(100 \times e \rightarrow \) for built-up area
- \(60 \times e \rightarrow \) for holly area

(3) As per empirical formula,

For plain 2 loading

\[ L = \frac{2.340 V^2}{p} \]
\[ V = \text{kmph} \]
\[ R = \text{m} \]

(2) for mountainous & steep terrain

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

(1) Terrain classification:

1. Steep terrain: \( \geq \) cross slope > 60°.
2. Mountainous region: 25 to 60°.
3. Rolling terrain: 10 to 25°.

(4) Set back distance:

Case (a) One lane road (\( L > SSD \))

Set back distance is min clearance required from one line of the road to any obstruction, such that sight distance is available through the length of road.
Set back distance \( CD = m \)
Distance \( ACB = SB = S \)

\[
\frac{8SD}{2\pi R} = \frac{S}{360}
\]

\[\Rightarrow \theta = \frac{180S}{\pi R}\]

\[\Rightarrow \frac{\theta}{2} = \frac{180S}{2\pi R}\]

Set back distance \( CD = m \)

\[
m = OC - OD
\]

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

\[
m = R \left( 1 - \cos \frac{\theta}{2} \right)
\]

Case 2: One lane road \( (L < SD) \)
Length \( AC = \frac{SD- Lc}{2} \)
\[ = \frac{(S-Lc)}{2} \]

Sight distance = \( ACEDB = S \)

Length of curve = \( CED = Lc \)

\[ Lc < S \]

\[ \Rightarrow \frac{Lc}{2\pi R} = \frac{\chi}{360} \]

\[ \Rightarrow \chi = \frac{180 Lc}{\pi R} \]

\[ \Rightarrow \frac{\chi}{2} = \frac{180 Lc}{2\pi R} \]

Set back distance

\( m = EG = EF + FG \)

\( m = (OE - OF) + CH \)

\[ m = (R - R \cos \alpha/2) + \left( \frac{S-Lc}{2} \right) \sin \alpha/2 \]
Case 3: Two lane road \( (L > S) \)

\[ ADB = 5 \]

\[ \text{Radius is measured from centre of road (total width)} \]

\[ OA = (R-d) \]

\[ d = \text{half of inner lane} \]

\[ \text{Setback distance is measured from centre line of total width of road.} \]

\[ m = CE \text{ distance} \]

\[ \Rightarrow S = \frac{d}{2\pi(R-d)} \]

\[ \Rightarrow \phi = \frac{180 \times S}{\pi(R-d)} \]
\[ \gamma_1 = \frac{180 S}{2\pi(R-d)} \]

Set back distance

\[ m = CE = OC - OE \]

\[ m = R - (R-d) \cos \frac{\phi_2}{2} \]

Case 2: Two lane road if length of curve:

\[ \Rightarrow A_C = \frac{S - L_c}{2} \]

\[ \Rightarrow \frac{L_c}{2\pi(R-d)} = \frac{\phi}{360} \]

\[ \Rightarrow \phi_1 = \frac{180 L_c}{\pi(R-d)} \]

\[ \Rightarrow \gamma_1 = \frac{180 L_c}{2\pi(R-d)} \]
Set back distance:

\[ m = EH \]
\[ m = EG + GH \]
\[ m = (OG - OD) + CI \]
\[ m = R - (R-d) \cos \theta/2 + \left( \frac{S-Lc}{2} \right) \sin \theta/2 \]

Design of vertical alignment:

1. Gradient:
2. Fulling Gradient: max gradient that can be provided in general conditions
   
   As per plan & rolling: 1 in 30
   IRC: mountainous: 1 in 20
   Steep region: 1 in 16.7

3. Limiting Gradient: Due to cost factor & topographical condition gradient can be increased up to limiting gradient
   
   plan & rolling: 1 in 20
   mountainous: 1 in 16.7
   steep region: 1 in 14.3

4. Extra ordinary Condition: Exceptional gradient can be provided
   
   plan & rolling: 1 in 15
   mountainous: 1 in 14.3
   steep region: 1 in 12.5
Case (i) \( L > (SSD \text{ or } OSR) \)

\[
1.20 = h + 0.15m
\]

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

- \( H \): height of driver eye = 1.20 m
- \( h \): height of obstruction = 0.15 m
- \( N \): total change in gradient
  \( N = |N_1 - N_2| \)
- \( S \): Stopping Sight distance

\[
\Rightarrow L = \frac{NS^2}{(\sqrt{2\times1.2 + \sqrt{2\times0.15^2}})^2} = \frac{NS^2}{4.4^2}
\]

(2) For overtaking sight distance \( h = H = 1.20 \) m

\[
\Rightarrow L = \frac{NS^2}{(\sqrt{5h + 5h})^2} = \frac{NS^2}{(\sqrt{2\times1.2 + \sqrt{2\times1.2}})^2}
\]
Case (5) if $L < SSD$ or $OSD$

$$L = \frac{2S - (\sqrt{2h} + \sqrt{2h})^2}{N}$$

For SSD

$$L = 2S - \frac{4.41}{N}$$

For OSD

$$L = 2S - \frac{9.6}{N}$$

**Valley Curve:**

Length is calculated.

**Comfort Condition:** Based on rate of change of radial acceleration ($C$)

In this case, two transition curves are provided back-to-back to complete the total length of valley curve.
Length of Transition Curve: \[ L_c = \frac{V^3}{CR} \]

In this case, radius at section \[ R = \frac{L_c}{N} \]

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

\[ L_c^2 = \frac{N V^3}{C} \]

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

Total Length of valley curve

\[ L = 2 \times L_c \]

\[ L = 2 \times \sqrt{\frac{N V^3}{C}} \]

(2) As per head light sight distance: \[ \heartsuit \]
\[ h_1 + S \tan B = aS^2 \]

\[ h_1 + S \tan B = \left( \frac{N}{\pi L} \right) S^2 \]

Length of curve

\[ L = \frac{NS^2}{2(h_1 + S \tan B)} \quad \text{if } (L > S) \]

\[ L = 2S - 2 \frac{h_1 + S \tan B}{N} \quad \text{if } (L < S) \]

Generally

\[ h_1 = \text{height of headlight above ground} \]

\[ = 1.20 \text{ m} \]

\[ \beta = \text{beam angle} \]

\[ \beta = 1^\circ \]
Problem: A national highway in hilly area has a curve of radius equal to minimum ruling radius. Design all geometrical features of this curve. Calculate set back distance also stopping sight distance if road is of two lane.

Solution: Design Speed

For national highway in hilly road.

\[ V = 50 \text{ kmph} \]

\[ R_{\text{min}} = \frac{V^2}{129(F + F')} \]

\[ R_{\text{min}} = \frac{50^2}{129(0.10 + 0.15)} \]

\[ R_{\text{min}} = 7.674 \text{ m} \]

Super Elevation

(1) Design for 25 kmph design speed

\[ e = \frac{0.75V^2}{129R} = \frac{(0.75 \times 50)^2}{129 \times 79} \]

\[ e = 0.14 > 0.10 \]

Provide: \[ e = 0.10 \]
Look for $F'$ for all design speed

\[ e + f = \frac{V^4}{129R} \]

\[ F = \frac{80^2}{129 \times 79} - 0.15 \]

\[ F = 0.149 < 0.15 \text{ so ok} \]

\[ E_{w} = 0.10 \]

3) Extra widening

For a two lane road

\[ \text{width} = w = 7.0 \text{ m} \]

\[ E_{w} = \frac{2 \times 6^2}{2 \times 79} + \frac{80}{9.5 \times 79} \]

\[ E_{w} = 1.05 \text{ m} \]

Total width of road = $w + E_{w}$

\[ = 7 + 1.05 \]

\[ = 8.05 \text{ m} \]

4) Transition curve

1) As per rate of change of radial curvature acceleration

\[ l_{s} = \frac{V^2}{CR} \]

\[ C = \frac{80}{75 + 4} = \frac{80}{75 + 50} = 0.64 \]

\[ 0.50 < C < 0.80 \text{ - ok} \]

\[ l_{s} = \frac{(0.278 \times 50)^3}{0.64 \times 79} = 53 \text{ m} \]
ii) As per code of change of SE.
Assume pavement is rotated outer edge

\[ 0 = \omega + \omega_c \]

\[ x = (0 + \omega_c) \cdot e \]

\[ x = 0.35 \times 0.10 = 0.035 \text{ m} \]

Length of P. curve = 60 \times x

\[ = 60 \times 0.035 \]

\[ = 2.1 \text{ m} \]

(iii) As per empirical formula

\[ L_S = \frac{v^2}{R} = \frac{50^2}{79} = 31.64 \text{ m} \]

Length of transition curve = 53.10 m

5) Set back distance
Assume length of curve > S.S.D

\[ L > S.S.D \]

Stopping Sight distance

\[ S.S.D = 0.278 \cdot v \cdot d + \frac{(0.278 \cdot v)^2}{2g(F - S)} \]

\[ = 0.278 \times 50 \times 2.5 + \frac{(0.278 \times 50)^2}{2 \times 9.81 \times (0.35 + 0)} \]

\[ S.S.D = 63.44 \text{ m}. \]
\[ d = \frac{\omega + \varepsilon \omega}{4} = \frac{8.05}{4} = 2.01 \text{ m} \]

\[ \Rightarrow \frac{q}{360} = \frac{S}{2\pi (R-d)} \]

\[ \Rightarrow \frac{q}{2\pi} = \frac{180}{\pi} \frac{S}{(R-d)} = \frac{180 \times 62.90}{2\pi (79 - 2.01)} \]

\[ \Rightarrow q = 23.405 \]

Set back distance

\[ m = R - (R-d) \cos \frac{q}{2} \]

\[ m = 79 - (79 - 2.01) \cos 23.405 \]

\[ \Rightarrow m = 8.34 \text{ m} \]
Problem: As ascending gradient 1:60 meet a descending gradient 1 in 50. Find the length of summit curve for SSD = 180 m

Solution: \[ N = |N_1 - N_2| = \frac{1}{50} - (\frac{1}{60}) = \frac{1}{50} + \frac{1}{60} = \frac{1}{27.27} \]

Length of summit curve

Assuming \( L > 4.8\) m

\[ L = \frac{N S^3}{(\sqrt{2h + (kh)^2})^2} \]

\[ L = \frac{1}{27.27} \times 180^2 \]

\[ L = \frac{1}{27.27} \times 180^2 \]

\[ L = 270 \text{ m} \]

\( L > 55.0 \text{ (Assumption is correct)}\)

\[ L = 270 \text{ m} \]
Problem: A valley curve of a S.H is formed by a descending gradient of 1 in 30 meeting an up gradient of 1 in 300.

Design the length of valley curve for

(i) Comfort condition
(ii) Head light sight distance condition

Design Speed = 80 kmph
\[ c = 0.60 \text{ m/sec}^2 \]
Reaction time \( t_r = 2.5 \text{ sec} \)
\[ F = 0.35 \text{ m} \]

Solution:

(i) Comfort condition

Based on rate of change of radial acceleration
\[ c = 0.60 \text{ m/sec}^2 \]

Total length of curve
\[ L = 2L_3 = 2\sqrt{\frac{c}{g}} \]
\[ L = 2\sqrt{\frac{10}{0.278 \times 80^3}} \]
\[ L = 28.17 \text{ m} \]

(ii) Head light sight distance condition

\[ H.S.D. = S.S.D. = 0.278 V^2 + \frac{(0.278V)^2}{2g(F \pm 0.5)} \]
\[ = 0.278 \times 80^2 + \frac{0.278^2 \times 80^2}{2 \times 9.8 (1 \pm 0.5)} \]
Assuming 
\[(L > S)\]

\[L = \frac{N s^2}{2(l_4 + 3\tan B)}\]

\[L = \frac{\frac{1}{2} \times 127.6^2}{2(0.75 + 127.6 \cdot \tan 1)}\]

\[L = 227.8 m > S = (127.6)\]

\[(L > S)\] Assumption is Correct

\[L = 227.8 m\]

\[\text{length of valley curve provided}\]

\[\text{max of above}\]

\[= 227.8 m\]
A Vertical parabola curve is to be used under a grade separation structure. The min grade left to right is 4% & plus grade is 8%. The intersection of two grade is at 485 m & at an elevation of 251.48 m. The curve passes through its fixed point of change of 460 m & RL of 360 m. Find the length of curve.

**Solution:**

**Assume length of curve = 2L**

**RL of B = 251.48 m**

**RL of C = RL of B - 251.48 \times 2 / 100**

**= 251.48 - 251.48 \times 1 / 100**

**= 250.48 m**

**h value for point P**

**h = 0 = RL of P - RL of C**

**= (260 - 250.48)**
\[ h = 9.52 \text{ m} \]

\[ A_r c = 9.52 \text{ m} \]

Value of \( x \) for point \( P = (A + 25) \)
\[ k (A + 25) = 9.52 \text{ m} \] \[(i)\]

Value of \( h \) for last point \( C \)
\[ x_C = 2 \]
\[ \Rightarrow h = 34 \cdot 0FL + 41 \cdot OFL \]
\[ \Rightarrow h = 0.031 + 0.041 \]
\[ \Rightarrow h = 0.087 \]

\[ h = k x^2 = k \cdot (21)^2 \]
\[ k \times 0.41^2 = 0.071 \]

\[ \Rightarrow k = \frac{0.071}{0.16} = 0.443 \]

\[ \Rightarrow k = \frac{0.071}{0.16} = 0.443 \] \[(ii)\]

Put in eq. (i)
\[ \Rightarrow 0.0175 (A + 25)^3 = 9.52 \]
\[ \Rightarrow A^3 + 501 + 625 = 544 \]
\[ \Rightarrow A^3 - 494 = 0 \]
\[ \Rightarrow A = 49.4 \text{ m} \]

Total length of curve \( 15 \times 2d = 2 \times 49.4 = 98.8 \text{ m} \)
Traffic Engineering

1. Traffic Engineering can be divided into

   a. Traffic characteristics:
      - Road user behaviour
      - Vehicle characteristics
      - Breaking characteristics

2. Traffic studies:
   - Traffic volume
   - Speed study
   - ODD study
   - Delay study
   - Capacity
   - Parking study
   - Pedestrian study

3. Traffic operation:
   a. Traffic regulation
      - Traffic control devices
      - Warning
      - Inspector of traffic separators
      - Regulatory

4. Traffic sign:
5. Road marking
6. Traffic island: Pedestrian
7. Parking & lighting
Breaking characteristics:

\[ R = mg \]

Assumption:

1. 100% brake efficiency if there after application of brake: Brake are fully applied when it is rammed vehicle is not sliding over the road surface.

\[ V = \text{mass of vehicle} \]

\[ k = \text{coefficient of friction} \]

\[ \Delta mu^2 = F \times S \]

\[ \Delta v = F \times m \times g \times S \]

\[ V^2 = 2g + S \]

Distance travelled

\[ S = \frac{V^2}{2gf} \]

If retardation = a
4. **Capacity**:

- **Basic Capacity**: In most ideal condition, the maximum volume that can be accommodated on a road is called basic capacity.

- **Possible Capacity**: In general condition of traffic, traffic volume varies in different conditions.

**Inexact Condition**: 0

**In Most Ideal Condition**: Basic Capacity

(It may be zero to basic capacity)

3. **Practical Capacity**: In general condition of traffic, volume generally found on the road is called practical capacity.

4. **Theoretical Capacity**:

\[
\text{Theoretical capacity} = \frac{100V}{S} \text{ (vehicle/hour)}
\]

If \( S \) = The min clearance required, then:

\[
S = (0.7 \times V + 1)
\]
\[ S = (0.2V + 6) \]

Theoretical capacity := if time headway less than vehicle = 4.5 sec.

Theoretical capacity \( = \frac{60 \times 60}{4.5} \) cars/hr.

Problem: \( \Rightarrow \) Estimate theoretical capacity of highway with one-way traffic flow at 55 mph speed for one lane. Assume average length of vehicle = 5.2 m, time headway = 4.5 sec.

Solution: Base on speed

Theoretical capacity \( = 100V / s \) for \( S = 0.2V + 1 \)

\[ S = 0.2 \times 55 + 5.2 = 16.2 \text{ m} \]

Capacity \( C = \frac{100 \times 55}{16.2} \)

\( C = 3395 \text{ veh./hr.} \)

\( \Theta \) based on time headway

\[ C = \frac{3600}{1.5} = 2400 \text{ veh./hr.} \]
**Accident Analysis**

**Types:**

1. A moving vehicle hits a parked vehicle.
2. Two vehicles moving towards each other at a crossroad at an intersection.

![Diagram]

3. A moving vehicle collides with an object.
4. Head on collision.

⇒ **Assumptions:**

⇒ Analysis of Accident:

1. After application of brakes, wheels are fully jammed: 100% brake capacity.
2. Collision of two vehicles is considered plastic collision.

⇒ collision of two bodies:

![Diagram]

A & B are two bodies collided at a point.

- Before collision: Speed of \(A\) = \(v_A\)
- Speed of \(B\) = \(v_B\)
for collision \[ V_A > V_B \]

Velocity of approach = \((V_A - V_B)\)

After collision
Velocity of \( A + B = V_A' + V_B' \)

For separation \( V_B' > V_A' \)
Velocity of Separation = \((V_B' - V_A')\)

Newton's Law of collision: \(
\text{As per Newton's Law}\)
Velocity of separation has a constant ratio with velocity of approach. The constant is called coefficient of restitution denoted by 'e'.

\[
e = \frac{\text{Velocity of Separation}}{\text{Velocity of approach}} = \frac{V_B' - V_A'}{V_A - V_B}
\]

Value of e is between 0 to 1

0) For perfectly elastic collision: \(
\text{Value of } e = 1.0
\)

\[
\Rightarrow \frac{V_B' - V_A'}{V_A - V_B} = 1.0
\]

\[
\Rightarrow (V_B' - V_A') = (V_A - V_B)
\]

0) For perfectly plastic collision
Value of e = 0
\[ \frac{v_B' - v_A'}{v_A - v_B} = 0 \]

\[ v_B' - v_A' = 0 \]

Both bodies move together.

Analysis:
Analysis of a vehicle applied brakes.

\[ F = F_m g \]

\[ v_1 \]

\[ v_2 \]

Applied Break

\[ v_1 - v_2 = 2gF \cdot s_1 \]

\[ v_2^2 - 0 = 2gF \cdot s_2 \]

\[ v_2^2 = 2gF \cdot s_2 \]

Case 0: Accident of a moving vehicle with a parked vehicle.

\[ v_1 \]

\[ v_3 \]

\[ v_{R0} \]

\[ v_0 \]

Before collision

After collision
(1) Before collision:

For vehicle A

\[ v_1^2 - v_2^2 = -2gFS \]  \hspace{1cm} \text{(1)}

(2) Momentum equation:

Total momentum = Total momentum just after collision

\[ m_A v_2 + m_B v_0 = (m_A + m_B) v_3 \]

\[ v_2 = \left( \frac{m_A + m_B}{m_B} \right) v_3 \]  \hspace{1cm} \text{(2)}

(3) After collision:

\[ v_3^2 = 0 = 2gFS_2 \]

(for combined vehicle A & B)

\[ v_3^2 = 2gFS_2 \]

\[ v_3 = \sqrt{2gFS_2} \]  \hspace{1cm} \text{(3)}

Step (1) Find \( v_3 \)

- (2) Calculate \( v_3 \) from momentum eq.
- (3) Calculate \( v_1 \) from before collision eq.
Problem: A vehicle applied brakes and skid through a distance of 40m before colliding another parked vehicle, the weight of which is 60% of former. From fundamental principle of momentum, find the initial speed of moving vehicle which both vehicles skid after collision is 12m.

\[ F = 0.60 \]

Solution:

1. After collision
   - For vehicle A + B
   \[ v_A^2 = \sqrt{2gF_s} = \sqrt{2 \times 9.8 \times 0.60 \times 12} \]
   \[ v_A = 11.89 \text{ m/s} \]
2. Momentum eq.
   \[ v_2 = \left( \frac{m_A + m_B}{m_A} \right) v_3 \]

   Weight of parked vehicle = 60% weight of moving vehicle
   \[ m_B = 0.60 m_A \]
   \[ m_B = 0.60 m_A \]

   \[ v_2 = \left( \frac{m_A + 0.60 m_A}{m_A} \right) v_3 \]
   \[ v_2 = 1.60 v_3 \]
   \[ v_2 = 19.02 \text{ m/s} \]
3. Before collision:

For vehicle A:

\[ v_t^2 - v_o^2 = 2gF s_1 \]

\[ v_t = \sqrt{v_o^2 + 2gF s_1} \]

\[ v_t = \sqrt{(19.02)^2 + 2 \times 9.81 \times 0.60 \times 40} \]

\[ v_t = 28.85 \text{ m/s} \]

\[ v_t = 103.78 \text{ mph} \]

Case 2: Two vehicles approaching from right angle collision at an intersection:

\[ \text{Known:} \]

\[ s_{A1}, s_{B1}, s_{A2}, s_{B2} \]

\[ \text{Unknowns:} \]

\[ v_{A1}, v_{B1}, v_{A2}, v_{B2} \]

\[ v_{A3}, v_{B3} \]

\[ \text{Towards collision:} \]

\[ \text{For } A: \] \[ v_{A1}^2 - v_{A2}^2 = 2gF s_{A1} \]

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

\[ \text{For } B: \] \[ v_{B1}^2 - v_{B2}^2 = 2gF s_{B1} \]

\[ v_{B1} = \sqrt{v_{B2}^2 + 2gF s_{B1}} \]
Momentum equation:

\[ m_A \cdot v_{A1} + m_B \cdot v_{B1} = m_A v_{A3} \cos \alpha + m_B v_{B3} \sin \theta \]

\[ v_{A2} = \frac{1}{m_A} \left( m_A v_{A3} \cos \alpha + m_B v_{B3} \sin \theta \right) \]

\[ \text{In the direction of } v_{B1} \]

\[ m_A \cdot v_{A1} + m_B \cdot v_{B2} = m_A v_{A3} \sin \alpha + m_B v_{B3} \cos \theta \]

\[ v_{B2} = \frac{1}{m_B} \left( m_A v_{A3} \sin \alpha + m_B v_{B3} \cos \theta \right) \]

After collision:

\[ v_{A3} = \sqrt{2gFS_{A2}} \]

\[ v_{B3} = \sqrt{2gFS_{B2}} \]

**Problem:**

Two vehicles A and B approaching at right angle. A from west, B from south.

Vehicle A

- Before collision
  - From west
  - \( S_{A1} = 25 \text{ m} \)
- After collision
  - \( 50 \text{ } \text{NofW} \)
  - \( S_{A2} = 15 \text{ m} \)

Vehicle B

- Before collision
  - From south
  - \( S_{B1} = 20 \text{ m} \)
- After collision
  - \( 60 \text{ } \text{EofN} \)
  - \( S_{B2} = 36 \text{ m} \)

Vehicle C

- Initial speed
  - \( 75 \text{ } \text{ofC} \)

- Change in speed
  - \( 6 \text{ } \text{ft} \)

- Friction
  - \( F = 0.55 \)
Solution:

1. After collision:

   For A: \( V_{A_3} = 2gfF A_2 \)
   \[ V_{A_3} = \sqrt{2 \times 9.8 \times 0.55 \times 15} \]
   \[ V_{A_3} = 12.72 \text{ m/sec} \]

   For B: \( V_{B_3} = \sqrt{2gfF B_2} \)
   \[ V_{B_3} = \sqrt{2 \times 9.8 \times 0.55 \times 86} \]
   \[ V_{B_3} = 19.71 \text{ m/sec} \]

2. Momentum equation

   \( \angle A = 150 - 30 = 120^\circ \)
   \( \angle B = 60^\circ \)

   \[ V_{A_2} = \frac{1}{M_A} \left( M_A V_{A_3} \cos \theta + M_B V_{B_3} \sin \theta \right) \]

   \[ V_{A_2} = \frac{12.72 \times \cos 120^\circ + \frac{1}{0.75} 19.71 \sin 60^\circ}{61.9} \]
VA₂ = 14.58 m/sec

Indirection of B

\[ M_B \cdot V_B₂ = M_A \cdot V_A₃ \cdot \cos 30° + M_B \cdot V_B₃ \cdot \cos 0° \]

\[ V_B₂ = \frac{M_A}{M_B} \cdot V_A₃ \cdot \cos 30° + V_B₃ \cdot \cos 0° \]

\[ V_B₂ = 0.75 \times 12.72 \times \sin 130° + 19.71 \times \cos 60° \]

\[ V_B₂ = 19.16 \text{ m/sec} \]

3. Before collision

\[ \Rightarrow \quad V_A₁ = \sqrt{V_A₂² + 2\cdot g \cdot F_S A₁} \]

\[ V_A₁ = \sqrt{14.58² + 2 \times 9.8 \times 0.55 \times 35} \]

\[ V_A₁ = 24.295 \text{ m/sec} \]

\[ V_A₁ = 87.34 \text{ km/h} \]

\[ \Rightarrow \quad V_B₂ = \sqrt{V_B₂² + 2 \cdot g \cdot F_S A₂} \]

\[ V_B₂ = \sqrt{17.16 + 2 \times 9.8 \times 0.55 \times 20} \]

\[ V_B₂ = 22.58 \text{ m/sec} \]

\[ V_B₂ = 81.6 \text{ km/h} \]
Signal design:

[Diagram of a complex traffic signal design with multiple lanes and directional arrows.]
for a Two phase Signal System:

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

\[ W_{S1} = \sqrt{\frac{PA}{PB}} \]

\[ PA = GB + AB \]  \( \text{(1)} \)

\[ PB = GA + AB \]  \( \text{(2)} \)

2) Green time: when vehicles are allowed to go. The Green time is calculated based on traffic volume on two roads.

3) Amber time: Amber time or yellow time is provided to serve following purpose.

(i) All the vehicles that have entered into danger zone (within 300 distance from intersection) should be allowed to cross the intersection.
Total distance required to travelled for crossing vehicles = \( (SSD + w + l) \)

\[ t_1 = \frac{(SSD + w + l)}{v} \]

\( t_1 \) = min amber time for crossing vehicle

(ii) To allowed sufficient time to stop the vehicle approaching the intersection for vehicle beyond SSD line

Min time required

\[ t_2 = Reaction\ time + Breaking\ time \]

\[ t_2 = t_r + \left( \frac{v}{a} \right) \]

\( t_r \) = reaction time
\( \frac{v}{a} \) = retardation

(iii) Red amber time is also provided sometime at the end of "red time". But it is part of red time only

\[ \begin{array}{c|c|c|c}
\text{G.A} & AP & PN & STP \\
\hline
\end{array} \]
Design of Signal Timings:

1. Proportional Cycle Method.
2. Approximate Method.
3. Webster's Method.
4. IRC Method.

1. Proportional Cycle Method: [Two phase signal system:--]

Step
1. Assume a cycle time = T See
2. Number of vehicles accumulated on two roads in one cycle time

\[ x_A = \frac{n_A}{15 \times 60} \times T \]

\[ x_B = \frac{n_B}{900} \times T \]

2. Minutes required
   (WA time headway = 34 seconds)

\[ G_WA = x_A \times t \]

\[ G_WB = x_B \times t \]
Total cycle time: \( T_I = (C_A + A_A) + (G_B + A_B) \)

Note: \( T_B \) should be equal.

Problem: If 15 minute traffic count on two roads are 180 & 150 vehicle per lane. If time head way is 38 sec during green phase & amber time on two roads are 4.0 sec. Design signal timings by trail cycle method.

Solution:

\( \eta_A \) in 15 min = 180 veh/lane

\( \eta_B \) in 15 min = 150 veh/lane

Let us assume cycle time = 60 sec.

In one cycle time,

No. of vehicles accumulated

\[ \Rightarrow x_A = \frac{\eta_A}{150} \times 60 \]

\[ \Rightarrow x_A = \frac{180}{150} \times 60 = 12 \]

\[ \Rightarrow x_B = \frac{150}{15} \times 60 = 150 \]

Green time required

\[ G_A = 12 \times 3 = 36 \text{ sec} \]

\[ G_B = 150 \times 3 = 30 \text{ sec} \]

Total cycle time = \( (G_A + A_A) + (G_B + A_B) \)

\[ = (36 + 9) + (30 + 4) \]

\[ = 74 \text{ sec} \]
3. Approximate Method: This method is based on pedestrian time to cross the road & traffic volume.

4. Time required for pedestrian to cross the road:
   \[ \text{Time} = \frac{\text{WA}}{\text{Speed}} = \frac{\text{WA}}{1.2 \text{ m/see}} = \text{clearance interval} \]

2. Minimum green time for pedestrian signal:
   For Road A:
   \[ t = \sqrt{\frac{4 \times \text{WA}}{1.2}} \]
   Initial walk period clearance interval

   \[ G_{PA} = t + \frac{\text{WA}}{1.2} = R_A \]
   \[ G_{PA} = t + \frac{\text{WA}}{1.2} = R_B \]

3. Red time required for traffic signal:
   \[ R_A = G_{PA} \]
   \[ R_B = G_{PB} \]
4. Min Green Time for traffic signal:

- $G_{1A} = p_B - p_A$
- $G_{1B} = p_A - p_B$

(1.49)

5. Considered any one Green time as another is calculated based on traffic volume

$$\frac{G_{2A}}{G_{1B}} = \frac{n_A}{n_B}$$

If $G_{1A}$ is considered

$$G_{1B} = \frac{n_B}{n_A} \times G_{1A}$$

6. Total cycle time:

$$T = (G_{1A} + p_A) + (G_{1B} + p_B)$$

7. Red time:

- $p_A = G_{1B} + G_{1A}$
- $p_B = G_{1A} + A_B$

8. Don't walk period:

- $DWA = G_{1A} + A_A$
- $DWA = G_{1A} + p_A + p_B$
0. Clearance Interval:
\[ CI_A = \frac{WA}{1.2} \]
\[ CI_B = \frac{WB}{1.2} \]

15. Walk Period:
\[ WA = FA - CI_A \]
\[ WB = FB - CI_B \]

9. Webster's Method:
This method is based on normal flow (traffic volume) & saturation flow on two roads.

Normal Saturation
A → na SA
B → nb SB

1. \[ \gamma_A = \frac{na}{SA} \quad \gamma_B = \frac{nb}{SB} \]

2. \[ \gamma = \gamma_A + \gamma_B = \gamma \]

3. Optimum Cycle Time
\[ C_0 = \frac{1.5L + 5}{(1 - \gamma)} \]

4. \[ T = \text{Total Lost Time per Cycle} = (2n + p) \]

n = No. of Phase.
R = All Red Time (Generally 16 sec).
4. Green time required:
\[ G_A = \frac{Y_A (Co-L)}{Y} \]
\[ G_B = \frac{Y_B (Co-L)}{Y} \]

5. IRC Method:
IRC is a combination of Approximate method, Webster method & another check suggested by IRC.

**Design Speed Step:**

1. Use approximate method:
\[ T = (G_A + AA) + (G_B + AB) \]

2. IRC check
Calculate no. of vehicles accumulated on two road in one cycle time:
\[ \text{Road A} = \frac{N_A}{60 \times 60} \times T = \text{xA} \text{ (No of Traffic/vehicles)} \]

Min Green time required to clear xA traffic
\[ = 6 \text{ sec.} + (x_A - 1) \times 2.8 \text{ sec} \]
\[ \text{for first} \]
\[ \text{Vehicle} \]
\[ \text{for remaining} \]

\[ G_A^* = \frac{Y_A}{60 \times 60} \times T \text{ sec} \]
\[ G_B^* = \frac{Y_B}{60 \times 60} \times T \text{ sec} \]
\[ (x_B) = 6 + (x_B - 1) \times 2.8 \text{ sec} \]

G_A & G_B calculated by approximate method should not be less than above values.
Check by webster method:

Saturation flow value

<table>
<thead>
<tr>
<th>Approach road width (m)</th>
<th>Saturation flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>1850</td>
</tr>
<tr>
<td>3.5</td>
<td>1890</td>
</tr>
<tr>
<td>4.0</td>
<td>1952</td>
</tr>
<tr>
<td>4.5</td>
<td>2250</td>
</tr>
<tr>
<td>5.0</td>
<td>2550</td>
</tr>
<tr>
<td>5.5</td>
<td>2990</td>
</tr>
<tr>
<td>&gt; 5.5</td>
<td>525 Veh/hour per meter width of road</td>
</tr>
</tbody>
</table>

Problem: A right angle intersection has two roads A & B

Road A

- No. of lan: 6
- Width: 19.0 m
- Value of traffic in one direction: 1360 ve/h

Road B

- No. of lan: 7
- Width: 7.5 m
- Value of traffic in one direction: 310 ve/h

Design signal timing for a two-phase traffic signal using IPA method:

- In other direction: 1280 ve/h
- Amber time: 4 sec

Solution:

Design volume per lane

For Road A: $n_A = \frac{1360}{3} = 453$ veh/hr for 3-lane road
For road $B = 810 = NB$

(1) Approximate method:

(i) Mean green time for pedestrian:

$\Rightarrow G_{PA} = 7 \text{ sec} + \frac{WA}{1.2}$

$G_{PA} = 7 + \frac{19}{1.2} = 22.83 \approx 23 \text{ sec}$

$\Rightarrow G_{PB} = 7 \text{ sec} + \frac{WB}{1.2}$

$G_{PB} = 7 + \frac{7.5}{1.2} = 13.25 \approx 14 \text{ sec}$

(ii) Mean time on traffic signal:

$PA = G_{PA} = 23 \text{ sec}$

$PB = G_{PB} = 14 \text{ sec}$

(iii) Mean green time on traffic signal:

$G_{PA} = PB - PA$

$= 14 - 23 = 10 \text{ sec}$

$G_{PB} = PA - AB = 23 - 4 = 19 \text{ sec}$
If  $G_{AB} = 10$ see  18 considered

\[
\frac{G_{AB}}{G_{AB}} = \frac{nA}{nB}
\]

\[
G_{AB} = \frac{nB}{nA} \times G_{AB}
\]

\[
G_{AB} = \frac{310}{454} \times 10 = 6.8 \text{ see} < G_{AB} \text{ (1)}
\]

then  \( G_A = 19 \text{ see} \) is considered

\[
G_A = \frac{nA}{nB} \times G_{AB}
\]

\[
G_A = \frac{454}{310} \times 19 = 24.8972 \approx 28 \text{ see}
\]

**Total cycle time**

\[
T = (G_A + AA) + (G_B + AB)
\]

\[
T = (38 + 4) + (19 + 4)
\]

\[
T = 55 \text{ see}
\]

(2) Check for IRC method.

Check for Green time required to clear traffic

- Total no. of vehicle accumulated in one cycle time
- On road A  \( x_A = \frac{nA}{60 \times 60} \times T \)

\[
x_A = \frac{454}{60 \times 60} \times 55 = 6.91 \approx 7 \text{ cars}
\]

\[
G_A = 6.8 \text{ see} + (7 - 1) \times 2
\]

\[
G_A = 18 \text{ see} < 28 \text{ see calculated}
\]

On road B  \( x_B = \frac{nB}{60 \times 60} \times 55 \)

\[
x_B = 4.76 \text{ cars}
\]
\[ G_{A} = 6 + (5-1) \times 2 \text{ sec} \]
\[ G_{A} = 14 \text{ sec} < 19 \text{ sec. modified OK.} \]

3. Webster method:

Normal flow values:
\[ n_{A} = 450 \text{ veh/hr/lane} \]
\[ n_{B} = 310 \text{ veh/hr/lane} \]

Saturation flow value:

Road A: for width = \( \frac{9.5}{2} = 9.5 \text{ m} \)
\[ S_{A} = 9.5 \times 825 = 4987.5 \text{ veh/hr/3 lanes} \]
\[ S_{A} = \frac{4987.5}{3} \text{ veh/hr/lane} \]
\[ S_{A} = 1662.5 \text{ veh/hr/lane} \]

Road B: for width = \( \frac{3.5}{2} = 3.75 \text{ m} \)
\[ S_{B} = \frac{1890 + 1950}{2} = 1920 \text{ veh/hr/5 lanes} \]

\[ y_{A} = \frac{n_{A}}{S_{A}} = \frac{450}{1662.5} = 0.27 \]
\[ y_{B} = \frac{n_{B}}{S_{B}} = \frac{310}{1920} = 0.16 \]
\[ y = y_{B} + y_{A} = 0.27 + 0.16 \]
\[ y = 0.43 \]

Total lost time \( t = 2n \times y = 2 \times 9 = 18 \text{ sec.} \)

Optimum cycle time \( T = \frac{1.5L + b}{(1-y)} \)
\[
C_0 = \frac{1.5 \times 3.0 + 5}{1 - 0.43} = 61.4 \text{ sec}
\]

\[
G_{PA} = \frac{Y_A}{4} (n_0 - L) = \frac{0.27}{0.43} (61.4 - 90)
\]

\[
G_{PA} = 56.88 < 28 \text{ sec (Provided OK)}
\]

\[
G_{PB} = \frac{Y_B}{4} (n_0 - L) = \frac{0.16}{0.43} (61.4 - 20)
\]

\[
G_{PB} = 15.4 \text{ sec} < 19 \text{ sec (Provided OK)}
\]

\[
\begin{array}{c|c|c|c}
G_{PA} & A_B & A_B & \text{PA} \\
\hline
28 & \text{(1)} & \text{(2)} & \text{(3)} \\
\end{array}
\]

\[
\begin{array}{c|c|c|c}
A_B & G_{PB} & F_B & \text{PB} \\
\hline
28 & \text{(4)} & \text{(5)} & \text{(6)} \\
\end{array}
\]

\[
\begin{array}{c|c|c|c}
F_A & \text{WA} & \text{CFA} & \text{DFA} \\
\hline
32 & \text{(7)} & \text{(8)} & \text{(9)} \\
\end{array}
\]

\[
\begin{array}{c|c|c|c}
\text{WA} & \text{CIB} & \text{DWA} & \text{PB} \\
\hline
\text{(10)} & \text{(11)} & \text{(12)} & \text{(13)} \\
\end{array}
\]

1. Red Time
   \[
P_A = G_{PB} + A_B = 19 + 4 = 23 \text{ sec}
   \]
   \[
P_B = A_B + G_{PB} = 28 + 3 = 32 \text{ sec}
   \]

2. Donot Walk Period
   \[
   \text{DWA} = G_{PA} + A_B = P_B = 32 \text{ sec}
   \]
   \[
   \text{DWA} = G_{PB} + A_B = P_A = 28 \text{ sec}
   \]

3. Clearance Interval
   \[
   CFA = \frac{\text{WA}}{1.2} = \frac{19}{1.2} = 15.83 \text{ sec}
   \]
   \[
   CIB = \frac{\text{WB}}{1.2} = \frac{28}{1.2} = 23.33 \text{ sec}
   \]
Problem: A driver travelling at the speed of 50 kmph was cited for crossing an intersection. He claimed that the duration of amber display was improper. Consequently, a dilemma zone existed at that location. Using the following data, determine whether driver's claim was correct.

- Amber time = 0.5 sec.
- Reaction time = 1.5 sec.
- Retardation = 3 m/s²
- Car length = 4.6 m
- Intersection width = 15 m

Solution:

Amber time is required for two purpose.
1. To allow the vehicle just head of danger area to cross the intersection

\[ SSD = 0.278 V^2 + \left( \frac{(0.278 V)^2}{29(F + 1.5)} \right) \]

\[ SSD = 0.278 \times 50 \times 1.5 + \left( \frac{(0.278 \times 50)^2}{2 \times 9.81 (0.35)} \right) \]

\[ = 48.98 \text{ m} \]

\[ = 50 \text{ m} \]

Total distance to be traveled to cross = SSD + 10 + L

\[ = 49 + 15 + 4.5 = 68.5 \text{ m} \]

Required time = \[ \frac{68.6}{0.278 \times 50} \approx 4.98 \text{ sec} > 4.5 \text{ sec} \]

Yes, danger zone exists for crossing vehicle.

2. For stopping vehicle

Total time required to stop = Reaction time + Braking time

Braking time = \[ \frac{V}{a} = \frac{0.278 \times 50}{3} \]

\[ = 4.63 \text{ sec} \]

Total time = 1.5 + 4.63 = 6.13 \text{ sec} > 4.5 \text{ sec} \]

So, yes, danger claim is correct.
Problem: The speed density relation ship for a particular road was found to be \( u = 42.76 - 0.22k \)

If \( u \) is speed in \( \text{km/hr} \),

\( k \) is density in \( \text{Veh/km} \).

Find the capacity of road.

Give your comment on the result. Sketch relationship between density & speed & Show an important traffic flow parameter.

Solution: Speed \( u = 42.76 - 0.22k \)

Capacity of the road = Traffic volume

\[ c = u \times k \]

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

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

If \( c = 0, k = 0 \)

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

\[ k = \frac{42.76}{0.22} = 194.36 \]

For max \( c \)

\[ \frac{dc}{dk} = 42.76 - 0.44k = 0 \]

\[ k = \frac{42.76}{0.44} = 97.18 \]

Max \( c \)

\[ c = 42.76 \times 97.18 - 0.22 \times 97.18^2 \]

\[ c = 2078 \]
Comment:

1. Relation: $b/0 = c & k = R$ probable.
2. Value of $c/b$ zero to $k = 0.2$ $b = 94.36$ veh/hr.
3. Value of capacity measure would increase in density upto 97-18 veh/hr, where $c/b$ max = 207.8 veh/hr after which capacity reduces.

- Design of Round Intersection:
  - Shapes:
    - Circular:
    - Elliptical:
  - Turbine:
  - Tangential:
2. Design Speed Values:
   - Rural area = 40 kmph
   - Urban area = 30 kmph

3. Radius of Volcano:
   - N-S-E: 18; remainder: $c = 0$
   - $R_{min} = \frac{V^2}{12T(1+c)} = \frac{V^2}{12T}$
   - Value of $F = 0.43$ \(\rightarrow\) 40 kmph
   - 0.47 \(\rightarrow\) 30 kmph

\[ e_2 = \text{width at non-weaving section} \]
\[ e_1 = \text{width of entry} \]
(i) Radius of entry curve:
\[ R_{entry} = 20 \text{ to } 35 \text{ m} \rightarrow \text{For } 40 \text{ kmph} \]
\[ = 15 \text{ to } 25 \text{ m} \rightarrow \text{For } 30 \text{ kmph} \]

(ii) Min radius of central island:
\[ = 1.33 \times R_{entry} \]

(iii) Width of entry = \( e_1 \)
Minimum = 5 m

Asphalt road width:
\[ 7.0 \text{ m} \quad 6.5 \text{ m} \]
\[ 10.5 \text{ m} \quad 7.0 \text{ m} \]
\[ 14.0 \text{ m} \quad 8.0 \text{ m} \]

(iv) Width of non-weakening Section = \( e_2 \)
If no value suggested, take \( e_2 = e_1 \)

(v) Width of weakening Section (\( W \))
\[ W = \left( \frac{e_1 + e_2}{2} + 3.5 \text{ m} \right) \]

(vi) Length of weakening section (\( l \))
\[ \leq 4 \text{ times of width of weakening section} \]
\[ l = 4W \text{ m} \]

Recommended Values:
40 kmph \( \rightarrow 45 \text{ to } 90 \text{ m} \)
30 kmph \( \rightarrow 30 \text{ to } 60 \text{ m} \)
Capacity of Arterial:

\[ C = \frac{280_w (1 + \frac{e}{w}) (1 - \frac{1}{3})}{(1 + w/L)} \]

\[ w = \text{width of weaving section} \]

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

\[ p = \text{weaving ratio} = \frac{b + c}{(d + b + c + d)} = \]

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

Weaving ratio is ratio of weaving traffic to total of traffic b/w two road. (value 0/10 0.5 to 1.0)
A road intersection has five legs designed as 1, 2, 3, 4, and 5. Leg 1 is in N-S direction and others are marked clockwise.

\[
\begin{align*}
V_{12} & \rightarrow 37 \\
V_{13} & \rightarrow 303 \\
V_{14} & \rightarrow 64 \\
V_{15} & \rightarrow 52 \\
V_{31} & \rightarrow 466^x \\
V_{32} & \rightarrow 122^x \\
V_{34} & \rightarrow 47^x \\
V_{35} & \rightarrow 687^x \\
V_{41} & \rightarrow 182^x \\
V_{42} & \rightarrow 84 \\
V_{43} & \rightarrow 185^x \\
V_{45} & \rightarrow 116^x \\
V_{51} & \rightarrow 45^x \\
V_{52} & \rightarrow 132^x \\
V_{53} & \rightarrow 62^x \\
V_{54} & \rightarrow 15^x
\end{align*}
\]

Find the weaving ratio for long 122. What is the use of this value? Draw a sketch showing the traffic volume by 122.

Solution:

For weaving ratio b/w 122:

\[
\begin{align*}
a & = V_{12} = 37 \\
b & = V_{13} + V_{14} + V_{15} \\
c & = 303 + 64 + 52 = 419 \\
d & = V_{32} + V_{42} + V_{52} \\
e & = 122 + 54 + 132 = 308
\end{align*}
\]
\[ d = V_{43} + V_{53} + V_{54} \]
\[ d = 65 + 62 + 15 = 95 \]

Weaving ratio \( p = \frac{b+c}{a+b+c+d} = \frac{39 + 419 + 398}{39 + 419 + 398 + 95} = 0.846 \]

1. Weaving ratio is ratio of weavng traffic to total traffic
2. It is used to calculate capacity of rotary

7c. 62-2007

Problem: Traffic flow in an urban area at right angle with section of two major roads, at the design year are given below. Total width of carrying way is 15 m.

Traffic Flow

<table>
<thead>
<tr>
<th>Approach</th>
<th>Left Turning</th>
<th>Straight</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>380</td>
<td>550</td>
<td>280</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 & check for practical capacity making suitable assumption as per...

Solution: Weaving ratio:

1. Between North to East (NE)
   \[ a = 45 \]
   \[ b = 650 + 300 = 950 \]
   \[ c = 300 + 225 = 725 \]
   \[ d = 95 \]
\[ P = \frac{b+c}{a+b+c+d} = \frac{9.80 + 7.25}{4.15 + 9.80 + 7.25 + 3.00} \]

\[ P = 0.70 \]

(3) Between E-S

- \( a = 3.00 \)
- \( b = 5.50 + 2.50 = 8.00 \)
- \( c = 6.50 + 3.00 = 9.50 \)
- \( d = 3.00 \)

\[ P = \frac{8.00 + 9.50}{8.00 + 3.00 + 9.50 + 3.00} = 0.745 \]

(3) Between S-W

- \( a = 3.50 \)
- \( b = 4.00 + 2.25 = 6.25 \)
- \( c = 5.50 + 3.00 = 8.50 \)
- \( d = 2.50 \)

\[ P = \frac{6.25 + 8.50}{3.50 + 6.25 + 8.50 + 2.50} = 0.71 \]
(1) Between 60-70

\[
\begin{align*}
\text{a} &= 4100 \\
\text{b} &= 800 + 300 = 800 \\
\text{c} &= 4000 + 250 = 4250 \\
\text{d} &= 22.5 \\
\end{align*}
\]

\[
\begin{align*}
p &= \frac{800 + 600}{400 + 800 + 16.10 + 22.5} = 0.698 \approx 0.70
\end{align*}
\]

we use

\[
p = 0.945
\]

capacity

\[
c = \frac{2800 \times (1 + e_1 / w) \times (1 - p / 3)}{(1 + w / L)}
\]

\[
e_1 = 6.5 \text{ m} \quad (\text{for 7.5 m})
\]

\[
e_2 = e_1
\]

\[
c = \frac{e_1 + e_2}{2} = 6.5 \text{ m}
\]

\[
w = \frac{e_1 + e_2 + 3.5}{2} = 6.5 + 3.5
\]

\[
w = 10 \text{ m}
\]

\[
L = w \times w = 40 \text{ m}
\]

\[
c = \frac{2800 \times 10 \left(1 + \frac{6.5}{10}\right) \left(1 - \frac{p / 3}{10}\right)}{(1 + w / L)}
\]

\[\text{C = ?}\]

\[
C = 2.398 \text{ veh/h/m}
\]
Pavement Design

Types:

1. Flexible Pavement: constructed by using stone aggregate with binder materials like earth, bitumen etc.
   - It consists of four layers:
     1. Surface course.
     2. Base course.
     3. Sub base course.
     4. Soil Subgrade.

   - Flexible pavement have very low flexibility strength.
   - Load transfers by grain to grain transfer.
   - Slab may be deflected to the slope of bottom layers.

2. Rigid Pavement:
   - Constructed by using PCC, RCC, (cement concrete) or prestressed concrete slab:
     - Only three layers:
       1. Pavement slab.
       2. Lean concrete.
       3. Soil/Subgrade

   - Flexural strength is high.
   - Load transfer is by slab action.
   - It can bridge over minor undulations.

Surface Course
Base Course
Sub Base Course
Soil/Subgrade

Concrete Slab
Lean Concrete (1:5:10)
Soil/ Subgrade
(8) Semi-rigid pavement:→ Semi-rigid pavement constructed by using 
soil cement soil lime mixture.
Pozzolanic cement etc.
It has comparatively high strength.

(9) Design of flexible pavement:→
Some important design parameters.
(1) Max. wheel load
As per IRC
max. legal axle load = 8170 kg
→ Max. Equivalent Single wheel load (EswL) = 40.85 kg
(2) Stress due to a wheel load below ground level:→

\[ \sigma = \frac{P}{2t} \left[ 1 - \frac{2z^3}{(a^2 + 2z^2)^{3/2}} \right] \]
→ Boussinesque's eq.
\[ p = \text{surface pressure} \]
3) ESWL – for a dual wheel assembly:

IF \( S \) = centre to centre distance b/w wheels.
\( d \) = clear distance b/w wheels
At \( \frac{d}{2} \) depth = ESWL = \( P \)
at \( 2s \) depth = ESWL = \( 2P \)
Problem: Calculate Eswl of a dual wheel assembly, each weighing 2050 kg, for pavement thickness 15, 25, 30 cm. If c/e spacing H/w type B 88 cm, distance 120 cm.

Solution:

\[ S = 88 \text{ cm} \]
\[ d = 12 \text{ cm} \]
\[ d/2 = 6 \text{ cm} \]
\[ P = 2050 \text{ kg} \]
\[ W = P = 2050 \text{ kg} \]
\[ 25 \text{ depth} = 2 \times 88 = 176 \text{ cm} \]
\[ Eswl = 2P = 4100 \text{ kg} \]

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>log(depth)</th>
<th>Eswl (kg)</th>
<th>log(Eswl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.778</td>
<td>2085</td>
<td>3.312</td>
</tr>
<tr>
<td>15</td>
<td>1.176</td>
<td>2903</td>
<td>3.482</td>
</tr>
<tr>
<td>20</td>
<td>1.301</td>
<td>2949</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1.398</td>
<td>3182</td>
<td>3.613</td>
</tr>
<tr>
<td>60</td>
<td>1.779</td>
<td>4100</td>
<td></td>
</tr>
</tbody>
</table>

\[ 3.312 + \frac{(3.613 - 3.312)}{(0.778 - 0.778)} \times (1.301 - 0.778) = 2903 \text{ kg} \]

\[ 3.312 + \frac{(3.613 - 3.312)}{(1.301 - 0.778)} = 2903 \text{ kg} \]

\[ 3.312 + (3.613 - 3.312) \times (1.301 - 0.778) = 2903 \text{ kg} \]
Rigidity factor:

- Tyre pressure is effective for top layers (surface layer only).
- Contact pressure effect on bottom layers.

<table>
<thead>
<tr>
<th></th>
<th>Case (1)</th>
<th>Case (2)</th>
<th>Case (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyre Pressure</td>
<td>7 kg/cm²</td>
<td>7 kg/cm²</td>
<td>7 kg/cm²</td>
</tr>
<tr>
<td>Contact Pressure</td>
<td>7 kg/cm²</td>
<td>Tyre Pressure</td>
<td>Tyre Pressure</td>
</tr>
<tr>
<td>R.F</td>
<td>1.0</td>
<td>&gt; 1.0</td>
<td>&lt; 1.0</td>
</tr>
</tbody>
</table>

Design method:

Group Index Method:

- This method depends upon G.I. value of soil over which pavement is to be laid.
- Total thickness of pavement is found using G.I. value.

Group Index Value

\[ G.I. = 0.2a + 0.005ac + 0.01bd \]

- \( a = P - 35 < 40 \)
- \( b = P - 15 < 10 \)
- \( c = B.o.c - 40 < 20 \)
- \( d = 10 < 20 \)
\( P \) = percent fines passing from 0.075 mm sieve.

\( W_L \) = liquid limit.

\( I_P \) = plasticity index

- G.I. Values are found below 0 to 20.
- Higher G.I. Values show poor soil.
- Thickness of pavement are found based on above G.I. values.

<table>
<thead>
<tr>
<th>G.I. Values</th>
<th>Base Course</th>
<th>Sub Base Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>5-9</td>
<td>20.5</td>
<td>20</td>
</tr>
<tr>
<td>10-20</td>
<td>30 cm</td>
<td>30 cm</td>
</tr>
</tbody>
</table>

Limitation:

- Quality of pavement is not considered. Same thickness required even better quality materials are used.
Problem: A soil subgrade has following data.

1. Soil passing = 0.074 mm sieve
   \[ P = 60\% \]

2. Liquid limit = 45\%.

3. Plastic limit = 20\%.

Find out thickness of pavement required above this soil subgrade using following data.

<table>
<thead>
<tr>
<th>G.I. Value</th>
<th>Total thickness of pavement req</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>30 cm</td>
</tr>
<tr>
<td>5</td>
<td>45 cm</td>
</tr>
<tr>
<td>10</td>
<td>62 cm</td>
</tr>
<tr>
<td>15</td>
<td>78 cm</td>
</tr>
<tr>
<td>20</td>
<td>90 cm</td>
</tr>
</tbody>
</table>

Solution:

\[ P = 60\% \]

\[ WL = 45\% \]

\[ WP = 20\% \]

Plasticity Index: \[ Ip = WL - WP = 45 - 20 = 25 \]

\[ Ip = 25\% \]

\[ a = P - 35 = 60 - 35 = 25 < 40 \text{ ok} \]

\[ b = P - 15 = 60 - 15 = 45 < 40 \text{ ok} \]

\[ c = WL - 40 = 45 - 40 = 5 < 20 \text{ ok} \]

\[ d = Ip - 10 = 25 - 10 = 15 < 20 \text{ ok} \]
Group Index:
\[ G_{I} = 0.4A + 0.005ae + 0.01bd \]
\[ = (0.2 \times 25) + (0.005 \times 25 \times 5) + (0.01 \times 40 \times 15) \]
\[ = 11.625 \]

Total thickness required
\[ = 62 + \left( \frac{78 - 62}{15 - 10} \right) \times (11.625 - 10) \]
\[ = 67.2 \text{ cm} \]

2. **CBR Method**: (California bearing ratio method)

\[ \rightarrow \text{CBR Value (CBR Test)} \]

- A soil sample is kept in a vessel, and a load is applied over the soil. Load values and corresponding penetrations are measured.
- Load values for 2.5 mm and 5.0 mm penetration are found (say \( P_1 \) and \( P_2 \)).

3. These load are compared with standard load values of 25 mm and 50 mm penetration over standard aggregate.

   Standard load values:
   - For 2.5 mm → 1394 kg
   - For 5.0 mm → 2055 kg

4. **CBR Value**
   - For 2.5 mm → \( \frac{P_1}{1394} \times 100 = \text{CBR}_{2.5} \)
   - For 5.0 mm → \( \frac{P_2}{2055} \times 100 = \text{CBR}_{5.0} \)
6. Generally a CBR value is found more. In this case, the value is accepted as CBR value.

6. If a CBR value is higher:
   - Test is repeated, & if same result are found again higher CBR value (5.0 mm) is accepted as CBR value.

7. If the curve shows an initial concavity, it is due to false set of less small sample. In this case, origin is get shifted by drawing a tangent from steepest point of curve to x-axis.

8. Design of pavement:
   - Thickness of pavement
     \[ T = \sqrt{\frac{1.95P}{CBR} - \frac{P}{nT}} \]

   \[ P = \text{wheel load (in kg)} \]
   \[ n = \text{tire pressure} = \frac{P}{A} \]
A = Contact area = 1 m²
a = radius of contact area
CBR = CBR value is 7

**Limitation:**
- Same as G.I. method.
- Quality of material of pavement is not considered.
- Thickness can be found for a limited CBR value only.

**Problem:** CBR test was conducted for a soil subgrade & following result was found:

<table>
<thead>
<tr>
<th>Penetration</th>
<th>0</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>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>0</td>
<td>50</td>
<td>20</td>
<td>32</td>
<td>43</td>
<td>49.8</td>
<td>59</td>
<td>70</td>
<td>79</td>
<td>93</td>
</tr>
</tbody>
</table>

Following materials are required to be used over this soil subgrade:

- Compressed soil (CBR = 6.7%)
- Poorly graded gravel (CBR = 12.7%)
- Well graded gravel (CBR = 60.7%)
- Bituminous surface or 40 cm thick

Design the pavement using CBR method.

If wheel load = 1160 kg

Type pressure = 7 kg/cm²

**Solution:**

\[ P_1 = 60 \text{ kg} \rightarrow \text{for } 2.5 \text{ mm} \]
\[ P_2 = 82 \text{ kg} \rightarrow \text{for } 5.0 \text{ mm} \]
$\text{CBR (2.5)} = \frac{P_1}{1370} \times 100 = \frac{60}{1370} \times 100 = 4.38\%$

$\text{CBR (5.0)} = \frac{P_2}{2055} \times 100 = \frac{82}{2055} \times 100 = 3.99\%$

(a) Total thickness of pavement above soil surface (CBR = 4.38%) 

$$T_1 = \sqrt{\frac{1.75 \times P}{\text{CBR}}} - \frac{P}{\text{PRT}} = \sqrt{\frac{1.75 \times 9100}{4.38} - \frac{9100}{7 \times 11}}$$

$$T_1 = 38.10\, \text{cm} \, \text{say} \, 39\, \text{cm}$$

(b) Total thickness required above compacted soil (CBR = 6.7%) 

$$T_2 = \sqrt{\frac{1.75 \times 9100}{6}} - \frac{9100}{7 \times 11} = 31.79\, \text{cm} \, \text{say} \, 32\, \text{cm}$$

Thickness of compacted soil req. 

$$T_1 - T_2 = 39 - 32 = 7\, \text{cm}$$
1) Total thickness required above poorly graded gravel

\[ t_3 = \sqrt{\frac{1.75 \times 2100}{12}} = \frac{4100}{7 \times 17} = 20.28 \text{ cm} \]

Thickness of poorly graded gravel

\[ t_2 - t_3 = 32 - 21 = 11 \text{ cm} \]

(3) Thickness of well graded gravel = \( t_3 - 4 \text{ cm} \)

\[ = 21 - 4 = 17 \text{ cm} \]

Method:

(3) California R-value (Resistance value) method:

This method is based on:

1. Stabilometer – R’ value
2. Cohesion meter – C value

Thickness of pavement required

\[ t (\text{cm}) = \frac{k \times T_I (90 - R)}{C \times Y} \]

If \( k \) = constant

\[ T_I = \text{Traffic Index Based on (EWL) Value} = 1.35 (EWL)^{0.11} \]

Thickness of pavement required

\[ t = \frac{0.166 \times 1.35 (EWL)^{0.11} (90 - R)}{C \times Y} \]

\[ t = \frac{0.22 (EWL)^{0.11} (90 - R)}{C \times Y} \]
Annual average of Equivalent wheel load based on 'AADT' value for different class of wheel
As per no. of axle

<table>
<thead>
<tr>
<th>No. of axle</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWL constant</td>
<td>330</td>
<td>1070</td>
<td>2460</td>
<td>4620</td>
<td>3040</td>
</tr>
</tbody>
</table>

\[
\frac{T_1}{T_2} = \left( \frac{C_2}{C_1} \right)^{Y_5} \rightarrow \text{(for equivalent thickness)}
\]

Problem: Calculate 10 year EWL & traffic index value using following data

<table>
<thead>
<tr>
<th>No. of Axle</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>3950</td>
<td>4400</td>
<td>3200</td>
<td>1200</td>
</tr>
</tbody>
</table>

Assume 60% increase in traffic in next 10 years then calculate thickness of pavement required in this case. If

\[
R\text{-value} = 418 \quad \text{use California R-value method.}
\]

\[
C\text{-value} = 16
\]

Solution: EWL of present
<table>
<thead>
<tr>
<th>Hoof Axle</th>
<th>AASHTO Volume</th>
<th>EWL Constant</th>
<th>Total EWL Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3750</td>
<td>380</td>
<td>1237500</td>
</tr>
<tr>
<td>3</td>
<td>470</td>
<td>1090</td>
<td>502900</td>
</tr>
<tr>
<td>4</td>
<td>320</td>
<td>2460</td>
<td>787200</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
<td>4620</td>
<td>554400</td>
</tr>
</tbody>
</table>

Total present EWL = 3082000

EWL of next 10 years = 1.6 x 3082000 = 4931200

Average Value = \frac{3082000 + 4931200}{2} = 4006600

Total EWL for 10 year period = 10 x 4006600 = 40066000

Traffic Index = \left( \frac{1.35}{\text{EWL}^{0.11}} \right) = 1.35 \left( \frac{40066000}{0.11} \right)

TI = 9.26

Thickness of pavement

\[ T = \frac{K \cdot TI \cdot (90 - R)}{CYS} \]

\[ T = 0.166 \times 9.26 \times (90 - 48) \]

\[ T = 37.08 \text{ cm} \]
Problem: Calculate equivalent 'c' value of a three layer pavement section having undrained 'c' value as.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>C-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bituminous Pavement</td>
<td>12.5 cm</td>
<td>62</td>
</tr>
<tr>
<td>2. Cement treated Base</td>
<td>25.0 cm</td>
<td>180</td>
</tr>
<tr>
<td>3. Well graded gravel</td>
<td>20 cm</td>
<td>25</td>
</tr>
</tbody>
</table>

Solution:
Convert all thickness in terms of well graded gravel

1. Bituminous Pavement
\[ B = 12.5 \text{ cm}, \quad W = 62, \quad C_B = 25 \]
\[ \sqrt{B} \left( \frac{C_W}{C_B} \right)^{1/5} = W \]
\[ \sqrt{12.5} \left( \frac{25}{62} \right)^{1/5} = 9 \]

2. Cement treated Base
\[ C = 180, \quad C_W = 25 \]
\[ \sqrt{C} \left( \frac{C_W}{C_B} \right)^{1/5} = W \]
\[ \sqrt{180} \left( \frac{25}{62} \right)^{1/5} = 25 \left( \frac{180}{25} \right)^{1/5} = 25 \times 1.25 \]
\[ \sqrt{25} \times 1.25 = 37.5 \text{ cm} \]

3. Well graded gravel
\[ \sqrt{20} = 20 \text{ cm} \]
Total thickness of pavement in terms of well graded gravel:

\[ T_{\text{wo}} = T_{\text{w2}} + T_{\text{w3}} \]

\[ T_{\text{w2}} = 14.98 + 37.10 + 20 \text{ cm} \]

\[ T_{\text{w3}} = 72.08 \text{ cm} \]

\[ C_{\text{w}} = 25 \]

\[ T_{\text{p}} = 57.5 \text{ cm} \]

\[ C_{\text{p}} = 9 \]

\[ \Rightarrow \frac{T_{\text{wo}}}{T_{\text{p}}} = \left( \frac{C_{\text{p}}}{C_{\text{w}}} \right)^{5} \]

\[ \Rightarrow C_{\text{p}} = C_{\text{w}} \left( \frac{T_{\text{w}}}{T_{\text{p}}} \right)^{5} = 25 \left( \frac{72.08}{57.5} \right)^{5} \]

\[ \Rightarrow C_{\text{p}} = 77.38 \]

**Problem:** Design a flexible pavement using WBM Base Course 7.5 cm thick, bituminous pavement by using California R-value method.

- C-value of WBM = 15
- C-value of Bituminous pavement = 62
- Traffic index = 9.5

**Data for Soil Subgrade B**

<table>
<thead>
<tr>
<th>Moisture Content</th>
<th>R-value</th>
<th>Expansion Pressure</th>
<th>Exudation Pressure</th>
<th>( T_R )</th>
<th>( P_e )</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.7%</td>
<td>56</td>
<td>0.185</td>
<td>36.5</td>
<td>38.70</td>
<td>64.3</td>
</tr>
<tr>
<td>19.5%</td>
<td>44</td>
<td>0.099</td>
<td>26.5</td>
<td>42.20</td>
<td>47.1</td>
</tr>
<tr>
<td>21.1%</td>
<td>25</td>
<td>0.055</td>
<td>18.0</td>
<td>59.60</td>
<td>26.2</td>
</tr>
<tr>
<td>24.1%</td>
<td>14</td>
<td>0.034</td>
<td>-18.0</td>
<td>67.7</td>
<td>16.2</td>
</tr>
</tbody>
</table>
Solution:

Design procedure

In California R-value method pavement thickness should be as per
(1) R-value
(2) Expansion pressure
(3) Exudation pressure

→ Exudation pressure is value of pressure required to force out water from a soil.

Steps:

1. Calculate thickness based on R-value

\[ T_R = \frac{k \cdot T_L \cdot (90 - R)}{GYS} \]

2. Thickness is calculated as per expansion pressure

\[ T_e = \frac{\text{Expansion pressure (kg/cm}^2\text{)}}{\text{Soil density (0.0021 kg/cm}^3\text{)}} \]

2100 kg/m\(^3\)

3. Plot \( T_R/T_e \) on a graph sheet. Draw a line-fitting point from the value where

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

4. Find out thickness corresponding to 28 kg/cm\(^2\) exudation pressure. Say \( T_2 \text{ cm} \)

5. Thickness of pavement

\[ T = \text{higher of } T_1 \text{ and } T_2 \]
1. Thickness as per R-value (using warm layers)

\[ TR = \frac{0.166 \times 9.5 \times (90 - R)}{15} \]

\[ TR = 0.9145 (90 - R) \]

\[ TR_1 = 31.20 \text{ cm} \]

\[ TR_2 = 0.9145 \times (90 - 44) \]

\[ TR_2 = 42.20 \]

\[ TR_3 = 59.6 \]

2. Thickness as per expansion pressure

\[ T_e = \frac{\text{Exp pressure}}{0.0021} \]
Thickness of pavement $T_1 = T_R = T_e = 4.4 \text{ cm}$

8. $T_R$ for $28 \text{ pg/cm}^2$

Excavation pressure

$T_2 = 31.20 + \left( \frac{36.5 - 31.20}{36.5 - 31.20} \right) (56.5 - 28)$

$T_2 = 40.55 \text{ cm}$

θ Thickness of pavement required (in terms of WBM layer)

$= \max \text{ of } T_1 \text{ and } T_2$

$= 4.4 \text{ cm}$

7.5 cm thickness of bituminous

$P_B = 7.5 \text{ cm}$

$P_W = 9$

$C_B = 62$

$C_W = 15$

$\Rightarrow P_{co} = P_B \left( \frac{C_B}{C_W} \right)^{1/5}$

$P_{co} = 7.5 \left( \frac{62}{15} \right)^{1/5} = 9.96 \text{ cm}$

Net thickness of WBM layer

$44 - 9.96 = 34.04 \text{ cm}$
(4) Trial Method:

(i) Thickness of pavement required

For single layer: \( t = \sqrt{\left( \frac{3pxY}{2\pi E_0A} \right)^2 - a^2} \)

\( p = \) total load in kg
\( x = \) Traffic coefficient
\( Y = \) Rainfall coefficient
\( E_0 = \) Young’s modulus of soil subgrade (kg/cm²)
\( a = \) radius of contact area in cm
\( A = \) A design deflection in cm

For two-layer system: \( t_p = \sqrt{\left( \frac{3pxY}{2\pi E_0} \right)^2 - a^2} \times \left( \frac{E_s}{E_p} \right)^{1/3} \)

\( E_s = \) Young’s modulus of soil subgrade,
\( E_p = \) pavement
\( t_p = \) Thickness of pavement in cm.

Two Layer System

\[ \text{Pavement} \quad E_p \quad \text{1st layer} \]
\[ \backslash \text{Soil Subgrade} \quad E_s \quad \text{2nd layer} \]

Compare two pavements

\[ \frac{t_1}{t_2} = \left( \frac{E_2}{E_1} \right)^{1/3} \]
Problem: Design a pavement section by triaxial method using
wheel load = 14000 kg
Radius of contact area = 15 cm
Traffic coeff = 1.6
Rainfall coeff = 0.7
Design deflection = 0.25 cm
Pavement consists of
Bitumen layer 6 cm thick \( E_{bit} = 1900 \text{ kg/cm}^2 \)
Base course = \( E_b = 360 \text{ kg/cm}^2 \)
Soil Subgrade = \( E_s = 120 \text{ kg/cm}^2 \)

Solution:
Let us design thickness of base course material over soil subgrade

\[
T_1 = \left( \sqrt{\frac{3P \cdot Y}{2 \pi E_s A}} \right)^2 - a^2 \left( \frac{E_b}{E_s} \right)^{1/3}
\]

\[
T_1 = \left( \sqrt{\frac{3 \times 14000 \times 0.7}{2 \pi \times 120 \times 0.03}} \right)^2 - 15^2 \left( \frac{360}{120} \right)^{1/3}
\]

\[
T_1 = 48.3 \text{ cm} \rightarrow \text{(total thickness of pavement) note}
\]

Top layer of bitumen 6 cm

\[
T_{bit} = 6 \text{ cm} \quad E_{bit} = 1900
\]

\[
T_{base} = 9 \quad E_{base} = 360
\]
\[
\frac{P_{\text{Base}}}{P_{\text{Rut}}} = \left( \frac{E_{\text{Rut}}}{E_{\text{Base}}} \right)^{\frac{1}{3}} = 189
\]

\[
P_{\text{Base}} = P_{\text{Rut}} \left( \frac{E_{\text{Rut}}}{E_{\text{Base}}} \right)^{\frac{1}{3}} = 6 \times \left( \frac{12000}{260} \right)^{\frac{1}{3}}
\]

\[
P_{\text{Base}} = 8.96 \text{ cm}
\]

Net thickness of base course = 48.80 - 8.96 = 39.84 cm

6m of fill \[\text{base course}\]
39.34 cm \[\text{Ep}\]
1 Base course

5. **Bryan's Method:** This method is also based on Young's modulus of elasticity of different layers of pavement:

As per layer system

\[E_{\text{Surface}} > E_{\text{Base}} > E_{\text{Sub base}} > E_{\text{Subgraded}} \quad \text{Sub base course} \quad \text{Sub base course}
\]

Assumptions:

- All materials in each layer are isotropic, homogenous, and elastic.
- Pavement forms a stiffer layer than soil subgraded \((E_p > E_s)\).
- Surface layer is infinite in horizontal direction but finite in vertical direction.
- Layers are in continuous contact.
→ Compression:

- When stress are acting over a soil subgrade/over a pavement:
  1. Due to pavement layer, stresses are reduced largely within pavement layer.
  2. If \( \frac{E_s}{E_p} = \frac{1}{10} \) then \( \frac{E_p}{E_s} = 10 \)

\[ h = a \] for this particular example, stresses reduced for 70% to 80% at particular location.

→ Design method:

Based on \( \frac{E_s}{E_p} \) value, Barrowman introduced a factor called \( F_2 \)

---

![Graph showing stress distribution with curves labeled \( F_2 \), \( \gamma_9 \), \( \gamma_{10} \), \( \gamma_{100} \), and \( \gamma_{500} \).](image-url)
(2) For a single layer system: (No pavement)
then \( h = 0 \)
\( \frac{h}{a} = 0 \) \( \text{(19)} \)
\( F_2 = 1.0 \)

(3) Displacement relationship by Gaswinder:
(a) For flexible plate:
\[ \Delta = 1.80 \frac{P_a}{E_s} \times F_2 \]
(b) For rigid plate:
\[ \Delta = 1.18 \frac{P_a}{E_s} \times F_2 \]

\( P = \) Pressure over surface \((\text{kg/cm}^2)\)
\( a = \) Radius of contact area \((\text{cm})\)
\( E_s = \) Modulus of elasticity of soil subgrade \((\text{kg/cm}^2)\)
\( \Delta = \) Design deflection \((\text{cm})\)

(4) Flexible plate:
when wheel load is acting over road surface. It is considered a flexible case.

\[ p = \frac{P}{A} \]

(5) Rigid plate:
when plate load test is conducted over soil subgrade.
Over pavement:
\( a = \) Radius of steel plate
\[ p = \frac{P}{\pi a^2} \]
Problem: Plate bearing test conducted with 80 cm diameter plate on a soil subgrade yielded pressure of 1 kg/cm² at 3 mm deflection.

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

Design the pavement section for a wheel load of 4100 kg with a tyre pressure of 6.7 kg/cm² & allocate deflection of 5 mm. Use Caminster method.

Solution:

1. Plate load test over soil subgrade
   - Dia. of plate = 80 cm
   - \[ a = 15 \text{ cm} \]
   - For single layer system
     \[ F_2 = 1.0 \]
   - Pressure \( p = 1 \text{ kg/cm}^2 \)
   - Deflection \( \Delta = 0.5 \text{ cm} \)

   This is rigid case
   For a rigid plate
   \[
   \Delta = 1.19 \times \frac{p \cdot a}{E_s} \times F_2
   \]
   \[
   0.5 = 1.19 \times \frac{1 \times 15}{E_s} \times 1
   \]
   \[
   E_s = \frac{1.19 \times 15}{0.5} = 35.4 \text{ kg/cm}^2
   \]

2. Plate load test over base course:
   - Thickness of pavement \( h = 12 \text{ cm} \)
   - \( P = 5 \text{ kg/cm}^2 \)
   - \( \Delta = 5 \text{ mm} = 0.5 \text{ cm} \)
   - \( E_s = 35.4 \text{ kg/cm}^2 \)

   (For two layer system)
For rigid plate

\[ \Delta = 1.19 \times \frac{P_a}{E_s} \times F_2 \]

\[ 0.5 = 1.19 \times \frac{5 \times 15}{35.4} \times F_2 \]

\[ F_2 = 0.2 \]

Use the chart:

\[ \frac{h}{a} = 1.2 \quad \text{and} \quad F_2 = 0.2 \]

Get:

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

\[ E_p = 100 \times E_s = 100 \times 35.4 \]

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

\[ \text{Design of pavement for wheel load} \]

**Flexible case**

\[ \Delta = 1.5 \times \frac{P_a}{E_s} \times F_2 \]

For pavement

\[ 0.5 = 1.5 \times \frac{6 \times 14.75}{35.4} \times F_2 \]

\[ F_2 = 0.133 \]

Use the chart:

\[ \text{for } F_2 = 0.133 \]

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

\[ \frac{h}{a} = 1.9 \]

\[ a = 5 \text{ mm} = 0.5 \text{ cm} \]

\[ E_s = 35.4 \text{ kg/cm}^2 \]

\[ h = 2.8 \times 0.25 \text{ cm} \]
1) Modulus of Subgrade reaction (K)
   (of Soil Subgrade)
   \[ K = \frac{P}{\Delta} \text{ (kg/cm}^2\text{)} \]

2) Radius of Relative Stiffness (r)
   \[ r = \left[ \frac{Eh^3}{12(1-\nu^2)} \right]^{1/4} \]

3) Equivalent radius of resisting section. (Area efficating in resisting the load)
   \[ b = \sqrt{1.6a^2 + h^2} - 0.675h \]
   \[ b = a \]

4) Stresses due to load:
   Wester guard's stress equation
   \[ \sigma_1 = \frac{0.316}{h^2} \cdot p \left[ 4.18 \cdot \frac{b}{h} + 1.069 \right] \]
(1) Edge Stress
\[ S_e = \frac{0.573}{h^2} \cdot P \left[ 1 - \log_{10} \left( \frac{4b}{a} \right) + 0.359 \right] \]

(2) Corner Stress
\[ S_c = \frac{3P}{h^2} \left[ 1 - \left( \frac{a \sqrt{2}}{d} \right)^{0.67} \right] \]

(2) Problem 20076
Define: L = b, calculated wheel load stresses due to

1. Design wheel load = 42000 kg
2. Cement concrete = 2.36 \times 10^5 kg/cm^2
3. \( h = 20 \text{ cm} \)
4. \( E = 0.15 \)
5. \( k = 7 \text{ kN/cm}^3 \)
6. Radius of contact area = 1.4 cm

Solution:
1. Radius of relative thickness:
\[ L = \left( \frac{E h^2}{13 \pi (1-\mu^2)} \right)^{\frac{1}{2}} = \left( \frac{2.36 \times 10^5 \times 0.15}{13 \times 7 \times (1-0.15^2)} \right)^{\frac{1}{2}} \]
\[ L = 22.27 \text{ cm} \]

2. Equivalent radius of resisting section
\( a = 14 \text{ cm}, \ h = 20 \text{ cm} \)
\( a < 1.724 h \)
\[ b = \sqrt{1.6a^2 + h^2} = \sqrt{1.6 \times 14^2 + 20^2} - 0.673 h \]
\[ b = 13.21 \text{ cm} \]
(a) Interior Stress:

\[ S_1 = \frac{0.316}{h^2} \left[ 4.1 \log_{10} \left( \frac{1}{b} \right) + 1.06q \right] \]

\[
S_1 = \frac{0.316}{20^2} \left[ 4 \log_{10} \left( \frac{73.29}{13.21} \right) + 1.06q \right]
\]

\[ S_1 = 13.34 \text{ kg/cm}^2 \]

(b) Edge Stress:

\[ S_e = \frac{0.573}{h^2} \left[ 4.1 \log_{10} \left( \frac{1}{b} \right) + 0.359 \right] \]

\[ S_e = \frac{0.573}{20^2} \left[ 4 \log_{10} \left( \frac{73.29}{13.21} \right) + 0.359 \right] \]

\[ S_e = 19.89 \text{ kg/cm}^2 \]

(c) Corner Stress:

\[ S_c = \frac{3 \rho}{h^2} \left[ 1 - \left( \frac{a + \sqrt{2}}{h} \right)^{0.6} \right] \]

\[ S_c = \frac{3 \times 11200}{20^2} \left[ 1 - \left( \frac{11 \times \sqrt{2}}{72.27} \right)^{0.6} \right] \]

\[ S_c = 17.01 \text{ kg/cm}^2 \]
1. Behaviour of load stresses:
   a. Interior Stress:
      
   b. Edge Stresses:
      
   c. Corner Stresses:
      
2. Temperature Stress:
   a. Weeping Stress:
      i. During Day:
      
      Weeping Stress: $C \text{ (neg)} \quad T \text{ (pos)}$
      
   ii. During Night:
      
      $C = C \text{ (neg)}$
      $T = T \text{ (pos)}$
Values (hoop stress)

1. Interior region: 
   \[ \sigma_h = \frac{E \sigma_T}{2} \left[ \frac{C_x + \mu C_y}{1 - \mu^2} \right] \]

   \[ L = \frac{L_x}{2} \text{ or } \frac{L_y}{2} \]

   \[ C_x = \text{Coefficient in } L_x \text{ direction} \]

   \[ C_y = \text{Coefficient in } L_y \text{ direction} \]

   \[ \mu = \text{Poisson ratio} \]

   \[ \sigma_T = \text{Temp. variation} \]
(2) **Edge Stress (Tensile)**

\[ \sigma_{te} = \frac{C_x \cdot dET}{2} \text{ or } \frac{C_y \cdot dET}{2} \]

(whichever is more)

(3) **Corner Stress:**

\[ \sigma_{tc} = \frac{E \cdot t}{3(1-\nu)} \left( \sqrt{a^2+b^2} \right) \]

(6) **Torsional Stress:**

Due to seasonal variation of temperature

(1) **During Summer:**

\[ c = (T) \nu e \]

\[ \eta = (T) \nu e \]

(2) **During Winter**

Entire pavement will be in tension
Value of frictional stresses:

\[ F = Pr = F \left( \frac{1}{2} B \times h \times W \right) \]  \[ \text{(1)} \]

\[ F_r = SF \times B \times h \]  \[ \text{(2)} \]

Equating eq. (1) & (2)

\[ SF \times B \times h = F \times \frac{1}{2} \times L \times K \times K \times W \]

\[ SF = \frac{W \times F \times L}{2} \] [\text{kg/m}^2]

\[ SF = \frac{W \times F \times L}{2 	imes 10^4} \] [\text{N/m}^{2}]

\[ \text{Frictional stress developed} \]
<table>
<thead>
<tr>
<th>Location</th>
<th>Load Stress</th>
<th>Day</th>
<th>Night</th>
<th>Functional</th>
<th>Permanent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior</td>
<td>Top</td>
<td>C(-)</td>
<td>C(+)</td>
<td>T</td>
<td>c</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>T(+)</td>
<td></td>
<td>T(+)</td>
<td>c</td>
</tr>
<tr>
<td>Edge</td>
<td>Top</td>
<td>C(-)</td>
<td>C(-)</td>
<td>T(+)</td>
<td>c</td>
</tr>
<tr>
<td></td>
<td>Bottom</td>
<td>T(+)</td>
<td></td>
<td>T(+)</td>
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<td>Corner</td>
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<td>T(+)</td>
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<tr>
<td></td>
<td>Bottom</td>
<td>C(-)</td>
<td>T(+)</td>
<td>c</td>
<td>T</td>
</tr>
</tbody>
</table>

(1) At Interior: 
- Worst combination is: 
  1) During day  
  2) At bottom 
  3) At dummy window

\[
\text{Stress} = (\text{Load Stress}) + (\text{Warping Stress}) + (\text{Functional Stress})
\]

\[
(\text{SL}) + (\text{Stu}) + (\text{SF})
\]

(2) At edge (Same as above)

(3) At corner: 
- Worst combination is: 
  1) At top  
  2) All night  
  3) At dummy corner

\[
\text{Stress} = (\text{Load Stress}) + (\text{Warping Stress}) + (\text{Functional Stress})
\]

\[
(\text{Sc}) + (\text{Sde}) + (\text{SF})
\]
Problem: A pavement slab 22 cm thick (cement concrete pavement) is constructed over a subbase having modulus of subgrade reaction, $K=190$ kN/m². Spacing between joints are

- Transverse joint = 5.50 m
- Longitudinal joint = 4.20 m

$\rho = 4500$ kg/m³
$T = 20^\circ C$ (Seasonal / day-night)

$\alpha = 15$ cm
$E_c = 8 \times 10^5$ kN/cm²
$\mu = 0.15$
$\alpha = 12 \times 10^6$ / °C
$F = 15$

Find out stresses due to load / temp. & worst combination.

Solution:

1. Radius of Relative Stiffness,

$$l = \left(\frac{Eh^3}{12K(U-\mu^2)}\right)^{\frac{1}{4}} = \left(\frac{3 \times 10^5 \times 22^3}{12 \times 18 (1-0.15^2)}\right)^{\frac{1}{4}}$$

$$l = 62.39 \text{ cm}$$

2. Equivalent radius of resisting section

$a = 15$ cm, $h = 22$ m

$$a < 1.74 h$$

$$b = \sqrt{1.6a^2 + h^2} - 0.675 h = \sqrt{1.6 \times 15^2 + 22^2} - 0.675 \times 22$$

$$b = 14.20 \text{ cm}$$

3. Load stresses (Weatherhead's equation)

4. Interior

$$\sigma = \frac{1000P}{h^2} \left[14.109 \left(\frac{1}{10^6}\right) + 1.069\right]$$
\[ 2a3 \]

\[ g_l = \frac{0.316 \times 4500}{22^2} \left[ 4 \log_{10} \left( \frac{62.37}{14.80} \right) + 1.069 \right] \]

\[ g_l = 10.69 \text{ kg/cm}^2 \]

\( \text{ii) Edge Stress} \)

\[ S_e = \frac{0.572 \times 4500}{22^2} \left[ 4 \log_{10} \left( \frac{62.37}{14.80} \right) + 0.359 \right] \]

\[ S_e = 15.88 \text{ kg/cm}^2 \]

\( \text{iii) Corner Stress} \)

\[ S_c = \frac{3e}{h^2} \left[ 1 - \left( \frac{15\sqrt{2}}{62.37} \right) ^{0.6} \right] \]

\[ S_c = 13.28 \text{ kg/cm}^2 \]

\( \text{iv) Warping Stresses} \)

\[ L_x = 5.80 \text{ m} = 580 \text{ cm} \]

\[ L_y = 4.20 \text{ m} = 420 \text{ cm} \]

\[ \frac{L_x}{L} = \frac{580}{62.37} = 9.32 \]

\[ L_y = 420 \text{ cm} \rightarrow \frac{L_y}{L} = 6.73 \]

\[ L_x' = 1.05 \text{ (From Mohr's Circle)} \]

\[ S_{el} = \frac{E \times \pi L_x}{L} \left[ \frac{L_x + L_y}{L} \right] \]

\[ S_{el} = \frac{3 \times 10^5 \times 412 \times 10^{-6} \times 20}{2} \left[ \frac{104 + (0.15 \times 0.94)}{1 - 0.15^2} \right] = 48.50 \text{ kg/cm}^2 \]
6. Edge Stress:
\[ \sigma_{ec} = \frac{G_y \cdot E_{ct}}{2} = \frac{1.05 \times 3 \times 10^5 \times 10^{-8} \times 30}{2} \]
\[ \sigma_{ec} = 37.44 \text{ kg/cm}^2 \]

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7. Corner Stress:
\[ \sigma_{oc} = \frac{E \cdot T}{3(1-\nu)} \left( \sqrt{0.14} \right) \]
\[ \sigma_{oc} = \frac{3 \times 10^5 \times 13 \times 10^{-6} \times 80}{3 \times (1-0.15)} \times \sqrt{15/62.57} \]
\[ \sigma_{oc} = 13.65 \text{ kg/cm}^2 \]

8. Fractional Stress:
\[ \sigma_F = \frac{WLF}{2 \times 10^4} = \frac{2400 \times 5.5 \times 1.50}{2 \times 10^4} \]
\[ \sigma_F = 0.79 \text{ kg/cm}^2 \]

(Perf Combinations):

1. Interior: At bottom + during day + during winter
\[ \sigma_{total} = \sigma_{ec} + \sigma_{ct} + \sigma_F \]
\[ = 10.69 + 43.80 + 0.79 \]
\[ = 55.3 \text{ kg/cm}^2 \]

2. Edge: At bottom + during day + during winter
\[ \sigma_{total} = \sigma_{st} + \sigma_{ct} + \sigma_F \]
\[ = 2.28 + 31.44 + 0.79 \]
\[ = 34.51 \text{ kg/cm}^2 \]

3. Corner: At top + during night + during winter
\[ \sigma_{total} = \sigma_{ct} + \sigma_{st} + \sigma_F = 13.48 + 18.84 + 0.79 = 33.11 \text{ kg/cm}^2 \]
Design of joints:

1. Expansion joints: provided for allowing expansion due to $T_c$ uncrass

Max Spacing = 1.40 m

IF $\Delta$ = Gap provided at expansion joint
(The gap is such that (No) gap is always there even after expansion)

Total expansion allowed $= \frac{\Delta}{2}$

for one length of slab

\[ L \cdot \alpha \left( T_2 - T_1 \right) = \Delta / 2 \]
Problem: Design spacing of expansion joints for a cement concrete pavement. If width of expansion joint gap is 2.0 cm, if laying temperature is 20°C & max. 97°C in summer, season is 48°C.

Solution: Max. expansion allowed

\[ \Delta = \frac{S}{2} = \frac{2.0}{2} = 1.0 \text{ cm} \]

\[ \Delta = 1.0 \text{ (T2 - T1)} \]

Spacing of expansion joint

\[ L = \frac{1.0}{12 \times 10^{-6} (T2 - T1)} \]

\[ L = 2976.2 \text{ cm} \]

\[ L = 30 \text{ m} \]
Case(a) when no reinforcement is provided:

In case of contraction of slab stress developed

\[ S_f = \frac{WLF}{2 \times 10^4} \text{ kg/cm}^2 \]

Spacing of contraction joint

\[ L = \frac{2 \times 10^4 S_f}{W \cdot F} \text{ m} \]

If \( S_f \) = Tensile strength of concrete (kg/cm^2)

\( W \) = unit weight (kg/cm^2)
When reinforcement is provided to bear tensile stresses:

In this case tensile stresses are taken by steel alone.

Face of force (F): \[ F = Fr = F \left( \frac{L}{2} \times 8 \times h \times w \right) \]

Face of resistance (by steel): \[ = F_{st} \times 6_{st} \]

\[ F_{st} \times 6_{st} = F \left( \frac{L}{2} \times 8 \times h \times w \right) \]

Spacing of contact to steel:

\[ L = \frac{2 \times A_{st} \times 6_{st}}{W \times F \times h} \] (in meter)

Where:
- \( A_{st} \) = Area of steel (cm²)
- \( 6_{st} \) = Permissible stress of steel (kg/cm²)
- \( W \) = Unit weight (kg/cm³)
- \( B \) = Width in meter
- \( h \) = Depth in meter
Problem: A pavement slab 4.5 m wide and 0.5 cm thick. Design contraction joint, if:

1. Pce is used.
2. Reo is used.

F = 1.5, permissible stress for concrete in tension
= 0.21 kg/cm²

For Pce, 12 mm @ bars @ 300 mm dc has been used

\[ \sigma_{st} = 1400 \text{ kg/cm}² \]

Solution:

\[ \text{If Pce is used,} \]

\[ \Rightarrow \beta \times F = F = FR = F \cdot \frac{L}{2} \times B \times h \times w \]

\[ \Rightarrow \text{spacing of concrete joint} \]

\[ \Rightarrow L = \frac{2 \times 10^4 \times 10^4}{WF} = \frac{2 \times 10^4 \times dF}{WF} \]

\[ L = \frac{2 \times 10^4 \times 0.8}{2400 \times 1.5} \]

\[ L = 2.4 \text{ m} \]
(1) When Oeo is used:

$$\Rightarrow \text{Act. Est.} = F \times \frac{L}{2} \times B \times h \times w$$

Spacing of concrete contraction joint:

$$L = \frac{2 \text{Act. Est.}}{W \times F \times B \times h}$$

$$L = 2 \times \left( \frac{4800}{300} \right) \times \frac{210}{11.2} \times 1400$$

$$= 2500 \times 1.5 \times 4.5 \times 0.25$$

$$L = 11.26 \text{ m}$$

(2) Design of the beam:

At longitudinal joints:

![Diagram of beam design]

The bars are provided at longitudinal joint.
\[ R = B \times 1 \times h \times w \]

Force of Friction \( F = F_R \)

\[ F = F_R \times B \times h \times w \]

\[ A_{st} \times \sigma_{st} = F \times B \times h \times w \]

Choose a diameter \( A_{st} \):

\[ A_{st} = \frac{F \times B \times h \times w}{\sigma_{st}} \]

Spacing of the bars:

\[ \text{Spacing of the bars} = \frac{1000}{A_{st}} \times \frac{\pi}{4} (\phi)^2 \]

Length of the bars:

\[ L = \frac{\phi \sigma_{st}}{4 \times \tau_{int}} \]

Length of the bars \( = 2L \).
Problem: A cement concrete pavement has a thickness of 24 cm & has two lanes of total width 4.2 m, with a longitudinal joint. Design the dimension & spacing of bars using following data:

- Allowable working stress in steel: 
  - Tension = 14.00 kg/m²
  - W = 24.00 kg/m³
  - F = 1.5
- Allowable bond stress = 24.6 kg/m²

Solution:

\[ B = \sqrt[3]{4.2} = 3.60 \text{ m} \]

Total width = 2 x 3.60 = 7.20 m

Consider 1 m length of slab

\[ F = FR \]

\[ A_{st} = \frac{F 	imes b 	imes h 	imes w}{60} \]
Ast = \frac{1.5 \times 3.6 \times 0.034 \times 1 \times 5000}{1400} = 22.2 \text{ cm}^2

Ast = 222 \text{ mm}^2

Using 8 mm \phi bars

Spacing = \frac{1000 \times \pi \times (8)^2}{222 \times 84} = 22.6 \text{ cm}

provided 8 mm \phi @ 220 mm c/c

@ length of the bars = \frac{2 \times d \times 654}{4 \times 6d}

= \frac{2 \times 0.8 \times 100}{4 \times 24.6}

= 22.76 \text{ cm} \approx 23 \text{ cm}
Dowel bars:

- In this case, no dowel bars provided.

Purpose of dowel bars:
1. To transfer the load of wheel from one slab to another.
2. To reduce differential deflection between two slabs.

Design of dowel bars:

Dowel bars are designed only using Bowditch analysis.

1. Value of $l_d$ (length of embedment):

$$l_d = 5d \left[ \frac{F_E}{F_{Rb}} \times \frac{l_d + 15d}{l_d + 0.8d} \right]^{1/2}$$

2. By trial and error, $l_d$ is calculated.
3. Total length of Dowel Bars: \( L_d + d \)

4. Load carrying capacity of a single dowel bar:
   a. For Shear
      \[ P' = \frac{\pi (d)^2}{4} f_y \]
   b. For Bending
      \[ P' = \frac{3d^3f_y}{L_d + 8.8d} \]
   c. For Jacking
      \[ P' = \frac{f_0 \times \frac{L_d^2}{d} \times \frac{R}{d}}{1.5(L_d + 1.5d)} \]

   The value of \( P' \) is considered min. of above three.

5. Load carrying capacity of dowel group system
   \[ = 0.40 \times \text{wheel load} \]
   \[ = 0.40P \]

6. Required load carrying factor of dowel group system
   \[ = \frac{\text{Load Carrying Capacity}}{\text{Load Carrying Capacity}} \]
   \[ = 0.40P \]
   \[ = P' \]

7. Capacity factor of dowel group system = 1.0
   - 1.0 for Dowel bars just below wheel load.
   - 0.0 for dowel bars at (1.8L) distance from wheel load.

   \( r = \) Radius of relative stiffness
Total capacity factor of axial group system

\[ = 1.0 + \frac{(1.801-5)}{1.801} + \frac{(1.801-26)}{1.801} \]

The End