HAND WRITTEN NOTES:
OF
CIVIL ENGINEERING

SUBJECT:
TRANSPORTATION
Introduction:

1. Cross Section of a Railway Track

(3)

Earl Subgrade

2. Gauges In India:

1. BG (Broad Gauge) → 1.676 m
2. MG (Meter Gauge) → 1.0 m
3. NG (Narrow Gauge) → 0.762 m
4. LG (Light Gauge) → 0.61 m

Gauge is distance between inner face of rails. (Running face)

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 of rail seat in central position such that also centered.
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.

Purposes:
1. To keep train just in central position during movement.
2. To reduce wear & tear of flange and rails.
3. Over every 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 & distance travelled on two rails on adjusted automatically.
(1) 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 allowed to expand due to which the stresses are developed in rail section. This stress is arrested by fixtures & sleepers.

If \( L \) = length of welded rail

Due to \( T \) = temperature increase

Increase in length = \( L \times T \)

Then

Strain developed in rail = \( \frac{\Delta L}{L} = L \times T \)

Stress developed (IF above strain is not allowed)

\[ \sigma = \frac{E \times \Delta L}{A} \]

Stress developed in rail section

\[ \sigma = \frac{P}{A} \]

\[ \sigma = A \times E \times T \]

If one sleeper is provided, \( R \) resistance.
Min. No. of Sleeper required to resist P force.

\[ n = \frac{P}{R} \quad (6) \]

Min. length of long welded rail required

\[ \text{mm} \times (n-1) \times S \]

Min. length of Rail required so that central portion of rails does not move = 2.1 min.

Problem:

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

Use following data:

1. Rail: D 52kg rail section
2. C/S A = 66.15 mm²
3. E = 2.1 \times 10^6 N/mm²
4. \( a = 11.5 \times 10^{-6} \)

Solution:

\[ S = 60 \text{ cm} \]
\[ R = 800 \text{ kg/m} \]

Due to 30°C temperature increase:

Increase in length = 1.5 ft
Stress: \( \sigma \)

Force developed in rail section if no moment is allowed:

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

\[
P = 66.15 \times 2.1 \times 10^6 \times 70 \times 115 \times 10^{-6} \times 30
\]

\[
P = 47,925.67 \text{ kg}
\]

Min no. of sleeper are required: \( \frac{P}{p} = \frac{47,925.67}{300} \)

\[
= 159.75 \quad \text{(60 nos)}
\]

Min. length of rail on one side required: \( (n-1) \times l_s \)

\[
l_{min} = (160-1) \times 70.60
\]

\[
l_{min} = 95.4 \; \text{m}
\]

Total length are required (for no movement of centre portion):

\[
r = \frac{l_{total}}{2} = \frac{190.8}{2} = 95.4 \; \text{m}
\]

Diagram:

```
+----------------+----------------+
|                |                |
+----------------+----------------+
|                |                |
+----------------+----------------+
|                |                |
+----------------+----------------+
|                |                |
```

\( l_{min} \)
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

Min Value of C.S.I

(a) Prack, sleeper = 783
(b) Crossing " = 1852
(c) Bridge " = 1455

7.2 Sleeper Density:

No. of sleeper are required for one rest 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

Example: B.G. track, \( n = 12.8 \text{ m} \), \( n = 13 \text{ m} \)

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

18 nos of sleepers

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

= 15+5

= 18 nos
Minimum Depth of Ballast: $\geq 9$

![Diagram of ballast depth calculation]

If $S =$ Spacing of Sleepers
$W =$ Width of Sleepers

Minimum Depth of Ballast cushion required:

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

Geometrical Design:

1. Speed of Train:
   - Design speed is decided as per下列
     - Max. Speed decided by Indian Railways.
     - Safe Speed from Martin's Formula on Curve.
     - Max. Speed as per Cont. provided.
     - As per Length of Transition Curve.

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

2. On Transition Curve:

For Safe Speed:

- For 0.75 $\leq M_G$

$$V_{\text{max}} = 4.35 \sqrt{R} - 67$$
2. For N.G Track

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

5. For high speed train:

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

6. On non-transitioned curved

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

\[ V_{\text{max}} = 0.8 \times 4.58 \sqrt{R} - 67 \]

7. On N.G Track

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

8. For high speed & train

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

4. Radius of Curve / Degree of Curve:

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

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

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

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

<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

\[ \frac{20}{D'} = \frac{2\pi R}{360} \]

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

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

<table>
<thead>
<tr>
<th>$D'$</th>
<th>1</th>
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<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$</td>
<td>1146</td>
<td>573</td>
<td>382</td>
<td>281</td>
<td>XXX</td>
</tr>
</tbody>
</table>
Verseine of Curve =>

\[ O \]

\[ A \]

\[ B \]

\[ C \]

\[ D \]

\[ E \]

\[ V \]

\[ \frac{1}{2} \times \frac{1}{2} = V(2R-V) \]

Hence \((2R-V) \approx 2R\)

\[ \frac{1.3}{2} = V \cdot 2R \]

\[ V = \frac{1.3}{2R} \]
Superelevation and Cant:

To counteract the effect of centrifugal force, outer rails are raised compared to inner rails, this race is called superelevation and cant.

\[ \text{Weight} = mg \]
\[ \text{Centrifugal Force} = \frac{mv^2}{R} \]

For equilibrium condition:
Ecluding forces along the surface of two rails:

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

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

Superelevation or Cant:

\[ e = G \cdot \tan \delta = \frac{Gv^2}{R} \]
\[ e = \frac{G \cdot (0.878v)^2}{9.81 R} \]
\[ e = \frac{Giv^2}{127R} \]

Ex. for BR Track:
\[ e = \frac{1.676v^2}{127R} \]
Equilibrium Speed

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

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

3. Weighted average speed.
   \( n_1 \) No. of train \( \Rightarrow V_1 \) Speed
   \( n_2 \) " " " \( \Rightarrow V_2 \) " "
   Weighted average speed = \( \frac{n_1 V_1 + n_2 V_2 + \ldots}{n_1 + n_2 + \ldots} \)
   \( V_{\text{average}} = \frac{\sum n V}{\sum n} \)
\[ \text{Cant provided} = \text{actual Cant} = \frac{G \cdot V^2}{127R} \]

2. **Cant Deficiency**

- Max speed on track (80) = 100 km/h
- Equilibrium Speed = 75 km/h
- \( R = 5.73 \) m
- Actual Cant provided

\[ \frac{G \cdot V^2}{127R} = \frac{1.676 \times 75^2}{127 \times 5.73} \]

\[ = 0.1295 \text{ m} \]

\[ = 12.95 \text{ cm} \]

Cant required for max speed at 100 km/h

\[ \frac{G \cdot V^2}{127R} = \frac{1.676 \times 100^2}{127 \times 5.73} \]

\[ = 23.03 \text{ cm} \]

\[ \text{Cant deficiency} \]

- For a high-speed train, total cant required is less than that actually provided for equilibrium speed. The deficit of cant for a high-speed train is called cant deficiency. A train is allowed to move with a certain max. value of cant deficiency.
Limit of Actual Cant Provided and Cant Deficiency.

<table>
<thead>
<tr>
<th>Types of Track</th>
<th>Actual Cant Provided</th>
<th>Cant Deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>Speed &lt; 120 kmph = 165 cm</td>
<td>Speed &lt; 100 kmph = 7.60 cm</td>
</tr>
<tr>
<td></td>
<td>Speed &gt; 120 kmph = 185 cm</td>
<td>Speed &gt; 100 kmph = 16.00 cm</td>
</tr>
<tr>
<td>C3</td>
<td>Speed &lt; 100 kmph = 100 cm</td>
<td>Speed &gt; 100 kmph = 8.10 cm</td>
</tr>
<tr>
<td>C5</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 U curve (B.G. Track).

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

Solution: \( V_{au} = 80 \text{ kmph} \)

U curve

Radius of curve \( R = \frac{1720}{41} \)

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

(i) actual cant required

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

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

\( \sqrt{3} \approx 19.64 \text{ m} \)

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

Actual Cant provided = 16.50 cm
(ii) After allowing max. cant deficiency = 7.60 cm

Theoretical cant

\[ \varepsilon_{th} = \varepsilon_{act} + 7.60 \]

\[ = 24.9 \text{ cm} \]

Max. Speed = \[ \frac{C_1 \cdot v_{max}^2}{127 \cdot R} \]

\[ V_{max} = \sqrt{\frac{127 \cdot R \cdot \varepsilon_{th}}{C_1}} \]

\[ V_{max} = \sqrt{\frac{127 \times 480 \times 0.24}{1.676}} \]

\[ V_{max} = 88.6 \text{ kmph} \]

5) 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 (4) ve SE, provided for main track shall become a (-) ve SE for branch track.

If max. speed allowed on main track

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

\[ \begin{align*}
\text{Max. Speed} & \rightarrow e_{\text{th}} \\
\text{Average Speed} & \rightarrow e_{\text{act}} \\
\end{align*} \]

\[ e_{\text{th}} = e_{\text{act}} + \Delta \\
\]

\[ e_{\text{act}} = e_{\text{th}} - \Delta \]

Theoretical cant on main track

\[ C_{\text{th (man)}} \]

Actual cant that can be provided on main track

\[ C_{\text{act (man)}} = e_{\text{th (man)}} - \Delta \]
\[ e_t = -E_{act}(m) \] - (19)

Theoretical cant for branch = \( e_{th}(b) = e_m + \theta \) = \( -e_m + \theta \)

Max speed allowed on branch track

\[ V_{max}(b) = \sqrt{\frac{127 \cdot E_{th}(m) \cdot R}{G_N}} \]

Problem: A branch track of 6° curve is diverting from a 8° main curve in opposite direction. (E.G. Track)

If max. speed allowed on main track is 65 km h⁻¹, calculated actual cant provided for main/branch track.

Max. speed allowed from the branch track.

Solution:

Radius of main track (8° curve)

\[ R_m = \frac{1920}{3} \approx 640 \text{ cm} \]

Radius of branch track (6° curve)

\[ R_b = \frac{1920}{6} = 320 \text{ m} \]
Max speed allowed on main track

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

Theoretical cant for main track

\[ e_{\text{th}}(m) = \frac{6 \times 3^2}{127 + p_m} = \frac{1.676 \times 65^2}{127 \times 57.3} \]

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

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

Actual cant provided

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

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

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

(We use S.E. for main track)

Actual cant available for branch track

\[ e_{\text{act}}(b) = -e_{\text{act}}(m) = -2.13 \text{ cm} \]
Transition Curve: →

→ Purpose: A parabolic curve is introduced to the straight & curve track to serve the following purpose:
   (i) To provide super elevation (cant) in a gradual manner (from toe to summit)
   (ii) To reduce the radius of curve gradually (from R=∞ at straight junction to R= R at curve junction)
   (iii) To reduce the effect of sudden jerk 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=∞
       at curved junction R=R
   (ii) Rate of change of curvature should remain equal to 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 curves are almost same up to a deflection angle of 3'10.5".

Path followed by these 3 curves are almost same up to 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 \( x = 0 \)

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

\[ \text{then} \quad c = 0 \]

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

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

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

\[ \text{then} \quad b = 0 \]

At end point

\[ x = L \]

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

\[ \Rightarrow \quad \frac{d}{\frac{1}{P}} = 6ax \]

\[ \Rightarrow \quad a = \frac{1}{6bL} \]
For cubic parabola,

1. Deflection: \( y = \frac{c x^3}{6 a} \)

2. Slope: \( \frac{dy}{dx} = 3a x^2 = \frac{3c x^2}{6 a} = \frac{c x^2}{2 a} \)

3. Curvature: \( \frac{d^2 y}{dx^2} = 6a x = \frac{6c x}{6 a} = \frac{c x}{a} \)

4. Slope at end
   
   at \( x = L \)
   
   \( \frac{dy}{dx} = \frac{x^2}{2 a} = \frac{L^2}{2 a} = \frac{L}{2} \)

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

   \( \phi = \tan \phi \)

   \( \tan \phi = \frac{dy}{dx} = \frac{c x^2}{2 a L} \)

   \( \phi_{\text{max}} \) at \( x = L \)

   \( \frac{L^3}{2 a L} = \frac{L}{2} \)

6. Deflection angle (\( \alpha \)): \( \alpha = \frac{c}{a} \int \sqrt{\frac{1}{x}} \)

   \( \frac{4}{x^2} = \frac{c^3}{6 a L^2} = \frac{x^3}{6 a L} \)

   \( \alpha = \frac{x^3}{6 a L} = \frac{x^3}{3 a^2 R L} = \phi / 3 \)
Transition curve is provided as shown in Fig.

If \( R \) = Radius of curve.

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

\( T_1 \) = First tangent point.

\( T_2 \) = Last "

\( \angle O \alpha A = \frac{L/2}{R} = \frac{L}{2R} \)

= \( \phi \) Splay angle.

So \( \angle AOB = (\Delta - 2\phi) \)

If change of point \( y \) is given.

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

Radius = \( (R + S) \)

Tangent length

\( PV = (R + S) \tan \Delta/2 \)
Total tangnet length,
\[ T_{tu} = \frac{4}{2} + PV = (R + s) \tan \frac{A}{2} + \frac{4}{2} \]

Chainage to \( T_i \)
Chainage \( \nu - \nu_{T_i} \)

Chainage of \( A \)
Chainage of \( T_i + L \)

Length of \( AB \)
Length of simple curve
\[ L = \frac{2\pi r}{360} \times (A - 2\theta) \]

Chainage of \( B \)
Chainage of \( A + L \)
Chainage \( T_{\nu} = \) change of \( B + L \)

Shift \( PR = PB - RS \)
\[ = y - (OR - OS) \]
\[ = y - (R - R\cos\theta) \]
\[ = xy - R(1 - \cos\theta) \]
\[ = y - R \times \sin\theta/2 \]
\[ S = \frac{L^2}{6R} - 2R \left( \frac{L}{4R} \right)^3 \]
\[ S = \frac{L^2}{6R} - 2R \left( \frac{L}{4R} \right)^2 \]
\[ S = \frac{L^2}{6R} - \frac{L^3}{8R} \]
\[ S = \frac{L^3}{24R} - \frac{3L^2}{24R} \]

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

---

**Length of Transition Curve:**

There are two approaches:

1. **First approach**
   (As per Indian Railway)
   
   (i) \( L = 7.20e \)  \( v \cdot e \) = Cent in cm
   
   (ii) \( L = 0.093 \cdot V_{max} \)

   \( v \) = speed in kmph
   
   \( e \) = cent deficiency in cm
(iii) $L = 0.073 \cdot V_{\text{max}}$

3. Length of transition curve:

(i) $L = 4.4 \cdot \sqrt{R}$
   \[ R = \text{Radius in meter} \]
   \[ L = \text{Length in meter} \]

(ii) $L = 3.6 \cdot e$
   \[ e = 6 \text{ cm} \]
   \[ L = \text{m} \]

3. Based on rate of change of radial acceleration:

\[ L = \frac{3.29 \cdot v^3}{R} \]
   \[ v = \text{Speed in m/sec} \]
   \[ R = \text{m} \]
   \[ L = \text{m} \]

\[
\begin{align*}
R & = \infty \\
\tan \left( \frac{v^2}{R} \right) & = 0 \\
\Rightarrow v^2/R & = 0 \text{ Radial acceleration} \\
\end{align*}
\]

- Radial acceleration = $v^2/R$
- at straight section $R = \infty$
  \[
  \frac{v^2}{R} \rightarrow \frac{v^2}{\infty} = 0
  \]
- at curved section $v^2/R$

Radial acceleration changes from 0 to $v^2/R$.

If train takes time $T$ to see the change $v^2/R$,

\[
T = 4 \cdot \frac{L}{v}
\]

Rate of change of radial acceleration = $a_c$

\[ a_c = \frac{v^2}{R} \]
Equating
\[ \frac{L}{V^2} = \frac{V^2}{CR} \]
\[ L = \frac{V}{CR} \]
\[ L = \frac{V}{0.3048R} \]
\[ L = 3.290V^3 \]

**Problem:** Equilibrium curve is provided on a BG track of 4° curve for an equilibrium speed of 80 kmph.
- Total deflection angle \( \delta = 45' \)
- (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 an important point on the curve with transition curve.
- (v) Set out the transition curve of every 10 m distance.

**Solution:**
- Radius of curve \( R = 1720/45 = 480 \) m
- Equilibrium speed \( V_{eq} = 80 \) kmph
- (i) Equilibrium cant (actual cant) provided
  \[ e = \frac{Cv^3}{27R} = \frac{1.676 \times 80^3}{127 \times 480} \]
  \[ e = 0.196 = 19.6 \) cm
\[ C_{\text{max}} = 16.50 \, \text{cm} \]

Provided \( e = 16.50 \, \text{cm} \)

(ii) Max Speed

\( \theta \) Cont + Cont efficiency

Cont \( e = 16.50 \)

Allow max. and deficiency = 7.60

Total (Theoretical cont = 24.1 cm

\[ \begin{align*}
V_{\text{max}} &= \sqrt{\frac{127.95 \theta}{61}} \\
V_{\text{max}} &= \sqrt{\frac{127 \times 480 \times 0.241}{1.676}} \\
V_{\text{max}} &= 88.6 \, \text{Kmph}
\end{align*} \]

(6) Max. Safe speed on curve by marston annual

\[ \begin{align*}
V_{\text{max}} &= 4.35 \sqrt{R - 67} \\
V_{\text{max}} &= 4.35 \sqrt{480 - 67} \\
V_{\text{max}} &= 82.90 \approx 83 \, \text{Kmph}
\end{align*} \]

Max. Speed allowed = 83 Kmph

(iii) Length of transition curve

\( \theta \)

\( L = 4.41 \sqrt{R} = 4.41 \sqrt{480} = 91.24 \, \text{m} \)

\( \theta \)

\( L = 3.6e = 3.6 \times 16.50 = 59.4 \, \text{m} \)

\( \theta \)

\[ \begin{align*}
L &= 3.28 \frac{V_{\text{max}}^2}{R} \\
L &= 3.28 \frac{(0.278 \times V_{\text{max}})^3}{R} \\
L &= 3.28 \times 10^{-2} \frac{83^3}{480} \\
L &= 93.79 \, \text{m} \approx 94 \, \text{m}
\end{align*} \]
(iv) Chainage of important points:

Chainage of \( V \) = 805.2 m

\[ R = 430 \text{ m} \]

Shift \( s = \frac{L^2}{24R} = \frac{943^2}{24 \times 430} \]

\[ = 0.86 \text{ m} \]

Total tangent length

\[ VT_1 = T_1 + PV \]

\[ VT_1 = \frac{L}{2} + (R + S) \tan \frac{B}{2} \]

\[ VT_1 = \frac{943}{2} + (430 + 0.86) \tan \frac{85}{2} \]

\[ VT_1 = 4411.81 \]

Chainage \( AB \) = \( T_1 \) = chainage of \( V \) - \( VT_1 \)

\[ = 805.2 - 4411.81 \]

\[ = 7610.19 \text{ m} \]
Length \( AB = L = \frac{\pi R}{360} \times (\theta - 2\phi) \)

\[
= \frac{\pi \times 430}{360} (185 - 2 \times 6'15'45")
\]

\[
= 548.92 \text{ m}
\]

Point \( T_1 = 7610.19 \text{ m} \)

\( L = 94 \)

Change \( A = 7904.19 \text{ m} \)

\( +AB = 548.92 \text{ m} \)

\( +L = 94 \)

Change = 8342.11 m

of \( T_2 \)

(v) Setting out of transition curve

\[
\frac{x^3}{6RL} = \frac{x^3}{6 \times 430 \times 94}
\]

\[
\frac{y}{2520} = \frac{x^8}{4620}
\]
Problem: Determine the length of transition curve & offsets at every 15m distance for a 200m curved track having curvature & cant of 12cm. Max permissible speed on the curved is 85 kmph.

Solution:

(i) Max. Speed

(ii) Cant formula

Theoretical cant = Actual cant + Cant deficiency

\[ V = \sqrt{\frac{127 R \text{eth}}{G7}} \]

\[ R = 1720/9 \]

\[ R = 1930 \text{ M} \]

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

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

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

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

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

(C) Max. Speed permissible = 85 kmph

Max. allowable speed = 79.90 kmph
(a) Length of Transition Curve

(i) \[ L = \frac{7.20 \times C}{2} = 7.20 \times 12 = 86.4 \text{ m} \]

(ii) \[ L = 0.73 \cdot \text{e} \cdot V_{\text{max}} = 0.73 \times 12 \times 80 = 70.08 \text{ m} \]

(iii) \[ L = 0.073 \cdot \text{d} \cdot V_{\text{max}} = 0.73 \times 0.76 \times 80 = 44.38 \text{ m} \]

\[ h = 86.4 \text{ m} \approx 86.7 \text{ m} \]

(b) Setting out the Transition Curve

\[ y = \frac{x^3}{6RL} = \frac{x^3}{6 \times 80 \times 87} \]

\[ y = \frac{x^3}{22040} \]

<table>
<thead>
<tr>
<th>( x ) (m)</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>87</th>
</tr>
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<tr>
<td>( y ) (m)</td>
<td>0</td>
<td>0.015</td>
<td>0.12</td>
<td>0.406</td>
<td>0.962</td>
<td>1.879</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 & off sets at every 15 m.

Solution: 5' curve

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

Max. Speed

@ Cant. Formula

Theoretical cant = \( E_{th} = E + \frac{d}{3} \)

= 14 + 7.60

= 21.60 cm

= 0.276 m

\[
V_{max} = \sqrt{\frac{127.36}{67}}
\]

\[
V_{max} = \sqrt{\frac{127 &times 344 &times 276}{1.676}}
\]

\[
V_{max} = 75.03 \text{ kmph}
\]

@ Safe speed on curve by marthing formula:

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

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

\[
V_{max} = 72.89 \text{ kmph}
\]

Max. permissible speed = 90 kmph

Allowable speed \( V_{max} = 72.89 \text{ kmph} \)
Length of transition curve

1. \( L = 4.4 \sqrt{R} = 4.4 \sqrt{344} \approx 81.6 \text{ m} \)

2. \( L = 3.6^2 e = 3.6 \times 14 = 50.4 \text{ m} \)

3. \( L = \frac{3.28 \times (0.278 \times 72)^3}{R} \)

   \( L = \frac{3.28 \times (0.278 \times 72)^3}{8044} \)

   \( L = 76.4 \text{ m} \)

\[ h = 81.6 \pm 8.2 \text{ m} \]

Problem: On a transitional curve on a Track speed roundabout, speed formula \( v = 4.35 \sqrt{R-67} + 18 \) times speed obtained by cant formula allowing cant deficieny of 7.6 cm. 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:

\( v = 4.35 \sqrt{R-67} \) — (i)

If Radius = \( R \)

Actual cant \( e = \frac{64v^2}{127R} = \frac{1.696 \times 80^2}{127 \times R} \)

\( e = \frac{844}{R} \)

Theoretical cant \( e_{th} = e + 0.1 \)

\( e_{th} = \frac{844}{R} + \frac{7.6}{100} \)

\( e_{th} = \frac{844}{R} + 0.076 \)
Speed by cant formula

\[ V_{max} = V_2 = \sqrt{\frac{127 + R \times e}{67}} \]

\[ V_2 = \sqrt{\frac{127 \times \frac{R}{1.676} \times (84.4 + 0.076)}{1.676}} \]

\[ V_1 = 1.85 V_2 \]

\[ 4.85 \sqrt{R - 67} = 1.85 \sqrt{\frac{127 \times \frac{R}{1.676} \times (84.4 + 0.076)}{1.676}} \]

Square on both sides

\[ 10.38 (R - 67) = \frac{R}{1.676} (84.4 + 0.076 R) \]

\[ 10.38 R - 695.64 = 630.56 + 5.76 R \]

\[ R = 1534.84 m \]

\[ \approx 1535 m \]

(6) Max. Speed

for cant formula

\[ V_{max} = V_2 = \sqrt{\frac{127 \times 1535 (84.4 + 0.076)}{1.676}} \]

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

(7) Actual cant

\[ e = 84.4 \left(\frac{R}{1535} \right) \]

\[ e = 0.055 m \]

\[ e = 5.5 cm \]
Problem: Calculate max. speed allowed on a curve for a BG1 track for given particulars.

A) Curve

B = max. speed allowed by railway = 140 kmph

C = length of transition curve = 120 m

Solution: curve \( R = \frac{1720}{2} = 860 m \)

Max speed shall be min at following

1. Safe speed from Martin's formula

\[ v = 4.35 \sqrt{R - 0.67} \]

\[ v = 4.35 \sqrt{860 - 0.67} \]

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

Use formula for high speed trains

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

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

\[ v = 184.8 \text{ kmph} \]

2. Cant formula

Theoretical formula \( v = \frac{G \sqrt{2}}{127R} \)

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

\[ v = 27.95 \text{ kmph} \]

Use max. actual cant = 18.50 cm

\( \text{Cant deficiency, } \delta = 10 \text{ cm} \)

Total cant = 28.50 cm

\[ v_{\text{max}} = \sqrt{\frac{127 \times 860 \times 28.5}{1.676}} \]

\[ v_{\text{max}} = 136.28 \text{ kmph} \]
3. As per length of transition curve

\[ \text{Max. Speed for speed up to } 100 \text{ kmph} \]

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

\[ V_{\text{max}} = \frac{184L}{e} \]

\[ V_{\text{max}} = \frac{198L}{12} \]

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

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

2. Max. Speed allowed = 145

So max. speed = 128 kmph

(i) Max. Speed

\[ \text{Max. allowed} \]

\[ \text{Transition curve} \]

(ii) Length of transition curve

\[ \text{Use } V_{\text{max}} \]

\[ \text{consider max. length } L \]

(iii) \( e_{\text{hy}} = e + D \)

\[ \text{Max. avg. Speed} \]

\[ \text{Speed} \]
Extra widening on curve

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

\[ V \] B = Rigid wheel base (in m)
\[ = 6.0 \text{ m} \text{ (for B:60 Track)} \]
\[ = 4.88 \text{ m} \text{ (for M:07 Track)} \]

R = Radius of curve (in m)

L = Lap of flange (in m)

\[ L = 0.02 \sqrt{h^2 + 0.1d} \text{ m} \]

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

D = Diameter of wheel (in cm)
Problem: For a 150 ft. 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 3.15 cm. Radius of curve is 480 m.

Solution: Lap of flange \( L = 0.02 \sqrt{h^2 + d^2} \)

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

\[ L = 0.44 \text{ cm} \]

\[ d = \frac{13(3 + L)^2}{R} \]

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

\[ d = 1.25 \text{ cm} \]
Vertical Curve

1. Gradient

1.1 Rolling Gradient: The max. gradient that can be provided in most general conditions is called rolling gradient.

For plains: 1 in 150 to 1 in 200
For hilly: 1 in 100 to 1 in 150

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

1.2 Momentum Gradient: When an up gradient is meet 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.

2. Higher Gradient: In very extraordinary situations new gradient can be provided more steeper 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 much slope is required just for drawing purpose. High gradient should be avoided to avoid automatic movement of trains.

- 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.

- Track
  - B. O. Track: 0.048° per degree of curve
  - M. O. Track: 0.031°
  - N. O. Track: 0.024°

If rolling gradient = 1 in 150

Ex: If a curve of 4° is there, on a B.O. Track, what will be grade compensation and compensated gradient.

- Grade compensation = \( \frac{0.048}{100} \times 4 = 0.00192 \)
- Compensated Gradient = \( \frac{1}{150 - 0.00192} \)
  
  = \( \frac{1}{149.99808} \)
  
  = 0.0067°
Vertical Curve

1. Summit Curve
2. Valley Curve
A general case

Summit curve:

\[ BD = DE \]

TWO gradients are \( q_1 \) at \( \text{up gradient} \) - 1st grad. \( q_1 \)

\( -q_2 \) at \( \text{down gradient} \) - 5th grad. \( q_2 \)

\( q_1 \) \( \rightarrow \) rate of change of gradient per chain length

Total length of Summit (valley) curve

\[ L = q_1 - q_2 = 2n \text{ chains} \]

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

IF length of chain = \( l \)

1. Chainage of \( B \) = known
2. Chainage of \( A \) = chainage of \( B - nx \cdot l \)
3. Chainage of \( C \) = chainage of \( B + nx \cdot l \)
Reduced level

1. RL of E = Given
2. RL of A = RL of B - \( \frac{g_1 \times dL}{100} \)
3. RL of C = RL of B - \( \frac{g_2 \times dL}{100} \)
4. RL of D = \( \frac{RL(A) + RL(C)}{2} \)
5. RL of D = \( \frac{RL(B) + RL(E)}{2} \)

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

\[ y = ax^2 + bx + c \quad (1) \]

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

Slope Eq.

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

Slope \( x = 0 \)
\[ \frac{dy}{dx} = c \]
\[ c = b \]

Equation

\[ y = ax^2 + bx + c \quad (2) \]

P(x, y) is point on the curve to get RL of LP
RL of O = RL of A + g_1 \times dL of x
RL of P = PL of OA - PO

Value of PO (th)

PO (th) = PO - PR = \((C + g_1x) - y\) = \((C + g_1x) - (ax^2 + g_1x + C)\) = \(-ax^2\) = \(kx^3\)

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

\(F_c = F_{0_1} + g_c\)

\(F_c = g_1 \frac{r_1}{100} + g_2 \frac{r_2}{100}\)

e_1 = \text{rise/fall per chain length} \quad e_2 = \frac{g_1 \frac{r_1}{100}}{100}

e_2 = \frac{g_2 \frac{r_2}{100}}{100}

h = e_1 n + e_2 n

General eq.

\(h^2 = n(e_1 - e_2)\)

\(kx^2 = n(e_1 - e_2)\)

\(K(2n)^2 = n(e_1 - e_2)\)

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

Note: Value of \(x\) for point = 2nd chain
Eq. for \( h = \frac{1}{4}\pi e^2 \) = \( \frac{(e_1 - e_2)}{4n} \) \( e^2 \) \[49\]

Here value of \( x \) = no. of chains
\( = 1, 2, 3, 4 \ldots \)

RL of point P = RL of O - PO
\( = RL\) of \( O - h \).

Problem: A summit curve has two gradient +0.85% \& -0.85% rate of change of gradient per chain length \( b \) 0.15%. If RL & chainage of point of intersection is 350. 50 m & 2500 m respectively, calculate RL & chainage of different point of the summit curve using 30 m chain.

Solution:

![Diagram of summit curve with calculations and chainage marks]
\[ g_1 = 0.65 \pi \]
\[ g_2 = -0.85 \pi \]
\[ r = 0.15 \text{ per chain length} \]

**Length of curve**

\[ L = \frac{g_1 - g_2}{r} = \frac{0.65 - (-0.85)}{2} \]
\[ L = 10 \text{ m} \]
\[ L = 20 \]

**Change of point A = change of B - nl**

\[ = 2500 - 5 \times 10 \]
\[ = 2350 \text{ m} \]

**Change of point C = change of B + nl**

\[ = 2500 + 150 \]
\[ = 2650 \text{ m} \]

**RL of A = RL of B - \frac{g_1 \text{ m}}{100}**

\[ = 350.50 - 0.65 \times 5 \times 30 \]
\[ = 349.525 \text{ m} \]

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

\[ = 344.225 \text{ m} \]

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

\[ = \frac{349.525 + 349.225}{2} \]
\[ = 349.375 \text{ m} \]
\[ RL \text{ OF D} = RL \text{ OF B} + RL \text{ OF E} \]

\[ \frac{57}{2} = \frac{850.50 + 349.375}{2} \]

\[ = 349.9375 \text{ m} \]

\[ \text{Value of } n = k x^2 \]

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

\[ V \geq e_1 = \frac{211}{100} = \frac{0.65 + 30}{100} \]

\[ e_1 = 0.195 \]

\[ e_2 = -\frac{0.211}{100} = -\frac{0.85 \times 30}{100} \]

\[ e_2 = 0.255 \]

\[ k = \frac{e_1 - e_2}{4n} = \frac{0.195 - 0.255}{4n} \]

\[ A = 0.0225 \]

\[ h = 0.225 x^2 \]
<table>
<thead>
<tr>
<th>Point A</th>
<th>Change</th>
<th>RL of 1st Tangent</th>
<th>$h = kx^2$</th>
<th>RL of Point on Curve</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>2.350</td>
<td>349.525</td>
<td>0</td>
<td>349.525</td>
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<tr>
<td>10</td>
<td>2.650</td>
<td>351.475</td>
<td>2.25</td>
<td>349.225</td>
</tr>
</tbody>
</table>

**Valley Curve**

RL of P = RL of OTH
(On first tangent)
Problem:

Point and Crossing:

Railway switch:

A railway switch is a combination of point and crossing. It is used to direct the train from one track to another, so that flexibility of routes can be obtained in different tracks.

There are the weakest location of railway tracks; so proper design, Strong material and proper maintenance is need.
@ Scratch / point:

Important terms:

(1) Heel divergence (heel clearance): It is the distance by which the running of stock rail and tongue rail measured at the heel of the switch.

In India:

- G 07 Track: 13.7 cm to 13.3 cm
- M 07 Track: 14.1 cm to 14.7 cm
- N 07 Track: 9.8 cm to 10

(ii) Flange way clearance: It is the distance between 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:
- 1 in 9 crossing = 6.0 + 0.6 cm = 6.6 cm

(iii) Flange way Depth: Depth from top of rail to top of heel block is called flange way depth.

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

- B 07: 9.5 cm
- M 07: 8.9 cm

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

\[ \sin \beta = \frac{h}{s_2} \quad \text{--- (1)} \]

\[ \sin \beta = \frac{h - t}{s_1} \quad \text{--- (2)} \]

\[ \beta = \sin^{-1} \left( \frac{h - t}{s_2} \right) = \sin^{-1} \left( \frac{h - t}{s_1} \right) \]

Diagram showing heel, divergence, heel, and divergence with the equations and calculations involved.
(a) Crossing should be rigid enough to sustain heavy impact loading from wheel.
(b) Special type of steel (high magnesium steel) is used for pointed crossing.
(c) Crossing should be as long as possible.

Important terms:

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

3. Number of crossing (Angle of crossing):

\[ \text{Number of Crossing} = \frac{\text{Speed of train of crossing}}{\text{Length of rail from TNC}} \]

4. Cole'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 \[ \cot y = N \]  

Angle of crossing \[ y = \cot^{-1} N \]  

57

Different number of crossing used

1 in 6 → used in Symmetrical split \( (y = 9.27'44'') \)

(2) 1 in 8\( \frac{1}{2} \) → used in Station yards where space is restricted or on Sharp turnout \( (y = 6'48'35'') \)

(3) 1 in 12 → used in Station yards of mainline \( (y = 4'45'79'') \)

(4) 1 in 16 → used in High Speed turnout on BG/MG. Pack \( (y = 3'34'35'') \)

Example: No. of crossing 1 in 12

\[ N = 12 \]
\[ N = \cot y \]
\[ \tan y = \frac{12}{\tan^{-1} y} \]
\[ y = \tan^{-1} (y_{12}) \]

\[ y = 4'45'49'11'' \]
6. Center Line Method :

This method is used for

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

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

\[ q_2 = \cot^{-1} 2N \]

Number of crossing = \[ N = \frac{1}{2} \cot \frac{\theta}{2} \]

\[ q = 2 \cot^2 2N \]

Consider Penrose Method :

(used for trusses)

\[ \tan \frac{\theta'}{2} = \frac{Y_2}{N} = \frac{1}{2N} \]

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

\[ q_2 = \csc^{-1} (2N) \]

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

\[ N = \frac{1}{2} \csc \frac{\theta}{2} \]
A Design calculation of a Turn Out:

 Important Terms:

1. **Curved Lead (C.L)**: Distance from the toe of Switch to Tip along the Straight track.

2. **Switch Lead (S.L)**: Distance from the toe of Switch to heel of Switch along the Straight track.

3. **Crossing Lead (C.L)**: Distance from the heel of Switch and toe along the Straight track.

\[ C.L = S.L + L \]  \[ R = R_o - \frac{S.L}{2} \]

4. **Outer Radius Curve (R_o)**: Outer Radius Curve

5. **Angle of Switch (θ)**

6. **Angle of crossing (α)** / Number of Crossing

7. **Track Order (O)**

8. **Crossing (C)**
Design calculations:

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

Given values:
- $\theta$ = gauge
- $n$ = No of crossing

1. Curve end (CL):

\[ CL = BL \]
\[ CL = BE + ET \]
\[ CL = G \cot \alpha + EC \]
\[ CL = G \cot \alpha + G \cos \alpha \]
\[ CL = GN + G \sqrt{1 + \cot^2 \alpha} \]
\[ CL = GN + G \sqrt{1 + N^2} \]
\[ CL = G(N + \sqrt{1 + N^2}) = GN + G(N + \sqrt{1 + N^2}) \]
\[ CL = 2GN \]

\[ \sqrt{1 + N^2} \]
\[ \tan \frac{\theta}{2} = \frac{c_1}{c_2} \]

\[ c_1 = c_1 \cot \frac{\theta}{2} \]

(1)

3. Using property of circle:

\[ c_1 R_0 = 2 c_1 \times c_1 (2 R_0 - c_1) \]

\[ c_1 R_0 = 2 c_1 R_0 - c_1^2 \]

\[ R_0 = \sqrt{2 c_1 R_0} \]

3. Radius (R_0):

\[ R_0 = 0.27 + 2 \overline{G} \]

\[ R_0 = c_1 \cot \frac{\theta}{2} + \overline{G} \]

\[ R_0 = 2 \overline{G} \sqrt{2} + c_1 \]

\[ R_0 = c_1 + 2 \overline{G} \sqrt{2} \]

As per Indian Army's data

\[ R_0 = 1.5 c_1 + 2 \overline{G} \sqrt{2} \]

\[ R = R_0 - \frac{c_1}{2} \] -> control radius.

3. Search load (S_C):

Using property of circle

\[ S_C \times S_C = \frac{h}{2} \left( 2 R_0 - h \right) \]

\[ S_C^2 = 2 h R_0 \]

\[ S_C = \sqrt{2 h R_0} \] [this very very little as compared to R_0]
(a) Lead or Crossing lead:
\[ L = c_L - s_L \]

(b) Heel divergence:
\[ h = \frac{s_L^2}{2R_0} \]

**Problem:** Calculate angle of splay and heel divergence of the
1. Total length of tongue rail = 5.10 m
2. Thickness of toe of tongue rail = 0.65 cm
3. Actual length of tongue tongue rail = 4.80 m

**Solution:**

\[ s_1 = 4.80 \text{ m} \]
\[ s_2 = 5.10 \text{ m} \]
\[ t = 0.65 \text{ cm} \]

In triangle ABE
\[ \sin B = \frac{h}{s_2} \quad \text{(i)} \]

In triangle ABE
\[ \sin \theta = \frac{h - t}{s_1} \quad \text{(ii)} \]

\[ \sin \theta = \frac{h}{s_2} = \frac{h - t}{s_1} \]
\[ \Rightarrow h = \frac{s_1 \cdot 0.65}{4.80} \]
\[ \Rightarrow h_{\text{BE}} = 5.10 - 0.65 \times 5.10 \]
\[ h = \frac{331.5}{(510 - 490)} \]
\[ h = 11.05 \text{ cm} \]

on eq. (10)

\[ \sin B = \frac{h}{L} = \frac{11.05}{510} \]
\[ B = \sin^{-1}\left(\frac{11.05}{510}\right) \]
\[ B = 1° 14' 29.42'' \]

**Problem:** Calculate necessary elements to set out a tangent taking from a straight \( B \) in track.

**No. of crossing = 11/12**

**Heel divergence = 12.0 cm**

The curve is starting from toe of starting and passes through the

**Solution:**

1. **Current (Load)**
   - \( C_l = 25 \text{ GN} \)
   - \( C_l = 271.167 \text{ GN} \)
   - \( C_l = 470.72 \text{ GN} \)

2. **Radius \( R_0 \)**
   - \( R_0 = 1.50 + 20 \text{ m} \)
   - \( R_0 = 1.5 + 1.676 \times 12.2 \)
   - \( R_0 = 185.30 \text{ m} \)
   - \( R = R_0 - C_l = 185.30 - \frac{11.05}{2} = 184.364 \text{ m} \)
(3) Switch lead (SL):

\[ SL = \sqrt{2 \times 4.85 \times 10 \times 0.12} \]

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

(4) Crossing lead:

\[ L = CL - SL \]

\[ L = 40.234 - 10.79 \]

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

Method III: In this case, we have to calculate only the crossing lead (LL).

Radius:

Angle of crossing = \( \alpha \)

Angle of Switchch = \( \beta \)
0 Crossing head:

\[
L = (C_1 + h - x \sin \alpha) \cot \left( \frac{\gamma + \beta}{2} \right) + x \cos \alpha
\]

0 Padou:

\[
\alpha = \frac{(G_1 - h - x \sin \alpha)}{(\cos \beta - \cos \alpha)}
\]

ES 1994 Problem:

Calculate the necessary elements to set out a 1in 8 1/2 turnout taking from a straight 80l Track with 93 cm radius starting from heel of the Switch and ending at a distance 860 mm from TNC. Given that:

- Heel divergence: 136 mm
- Switch angle \( \alpha = 1.3^\circ \) 27"

Make a Free hand Sketch showing value of calculated elements.

Solution:

No. of crossing

\[
N = 8 \frac{1}{2} = 8.5
\]

\[
N = \cot \alpha = 8.5
\]

\[
\alpha = \tan^{-1}(N) = 8.5
\]

\[
\beta = 6^\circ 42' 35.4''
\]

Switch angle \( \beta = 1.3^\circ \) 27"

- 136 mm
- 0.136 m

Straight length (x) before TNC

\[
x = 860 mm
\]

\[C_1 = 1.676 m\]

- Crossing head

\[
L = (C_1 - h - x \sin \alpha) \cot \left( \frac{\gamma + \beta}{2} \right) + x \cos \alpha
\]
\[ L = (1.696 - 0.136 - 0.864 \times \sin 6.42^\circ 35.4^\prime) \cos \left( \frac{6^\circ \times 35.4^\prime + 1^\circ 36.2^\prime}{2} \right) \]

\[ + 0.864 \times \cos 6.42^\circ 35.4^\prime \]

\[ L = 30.78 \text{ m} \]

2. Radial \( R = \frac{(G1 - h - x \sin \theta)}{\cos \beta - \cos \gamma} \)

\[ R = \frac{(1.696 - 0.136 - 0.864 \sin 6.42^\circ 35.4^\prime)}{\cos 1^\circ 36.2^\prime - \cos 6.42^\circ 35.4^\prime} \]

\[ R = 232.3 \text{ m} \]
\[ \angle CFB = (\alpha - \beta) \]
\[ \angle FBX = \angle FKT = \frac{\alpha - \beta}{2} \]
\[ \angle KBS = \alpha - \left( \frac{\alpha - \beta}{2} \right) = \frac{2\alpha - \alpha + \beta}{2} = \frac{\alpha + \beta}{2} \]
\[ \angle KBS = \left( \frac{\alpha + \beta}{2} \right) \]

(i) \text{Crossing Load} \( L \):

\[ \tan \left( \frac{\alpha + \beta}{2} \right) = \frac{KJ}{BS} \]
\[ \tan \left( \frac{\alpha + \beta}{2} \right) = \left( \frac{\alpha - h}{2} \right) \]
\[ L = (\alpha - h) \cot \left( \frac{\alpha + \beta}{2} \right) \]

(ii) \text{Radius} \( R_0 \):

\[ \sin \left( \frac{\alpha - \beta}{2} \right) = \frac{BT}{OB} \]
\[ OB = R_0 = \frac{BT}{8m(\alpha - \beta)} \]

In triangle \( BKJ \)
\[ \sin \left( \frac{\alpha + \beta}{2} \right) = \frac{KJ}{BK} \]
\[ BK = \frac{(\alpha - h)}{8m(\alpha + \beta)} \]
\[ BK = 2 \times BI \]
\[ R_x = \frac{(G_1 - h)}{2\sin\left(\frac{\pi}{2} + \theta\right)} \]  

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

\[ R_0 = \frac{(G_1 - h)}{2\sin\left(\frac{\pi}{2} + \theta\right)\sin\left(\frac{\pi}{2} - \theta\right)} \]  

\[ R_0 = \frac{(G_1 - h)}{\cos\theta - \cos\phi} \]

**Method - III**: 

In this case, a straight length is provided just before the curve. The curve is starting from the heel of the curve and end at the starting point of the straight length before the curve.

We need:

1. Crossing lead \( L \)
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 D: With an intermediate straight portion like two running.

\[ K = \text{Overall length of cross over cases} \]

Length of turnout = Curved lead
\[ CL = 2Gm \]

Length of straight length of cross over by two turnout
\[ LH = S \]

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

In triangle \( BCE \)
\[ Ec = G \sec \psi \]
\[ EL = (D-G) - G \sec \psi \]

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

\[ LH = EL \cot \theta \]

\[ LH = \left[ (D-G_i) - G_i \sec \theta \right] \cot \theta \]

\[ LH = (D-G_i)N - G_i \sqrt{1+Yi^2} \]

\[ LH = S \]

\[ S = (D-G_i)N - G_i \sqrt{1+Yi^2} \]

\[ S = (D-G_i)N - G_i \sqrt{1+Yn^2} \]

Overall length of cross over:

\[ = 4G_iN + S \]

\[ = 4G_iN + (D-G_i)N - G_i \sqrt{1+Yi^2} \]

**Case (c):**

Without any straight portion, the two turnout intermediated portion is also curved. (No straight Portion)
Given value: 

1. G  
2. No. of crossing
   - 1 in N_1 and 1 in N_2

\[ R_{10} = 1.5G + 2G \cdot N_1^2 \]
\[ R_1 = R_{10} - G/2 \]
\[ R_{20} = 1.5G + 2G \cdot N_2^2 \]
\[ R_2 = R_{20} - G/2 \]

Length \( O_1 \) and \( O_2 \)

\[ O_1O_2 = R_1 + R_2 \]

The distance between two tracks

\[ QA = R_1 + (R_2 - D) \]
\[ \Rightarrow QA = (R_1 + R_2 - D) \]

Over all length of cross over along track

\[ O_2A = \sqrt{9 \cdot O_2^2 - QA^2} \]
\[ \Rightarrow O_2A = \sqrt{(R_1 + R_2)^2 - (R_1 + R_2 - D)^2} \]
\[ \Rightarrow O_2A = \sqrt{(2R_1 + 2R_2 - D)} \]

\[ \frac{N_1}{N_1} \]
\[ R_1 = R_2 \]

Overall length = \( \sqrt{(4R - D)} \)
\[ \text{Diamond Crossing:} \]

\[ \text{\# 72} \]

\[ \text{IF } 1 \text{ in } N \text{ is number of crossing} \]

\[ N = \cot \alpha \]

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

Components

\( \Box \) Length \[ AB = BC = CD = DA = G_1 \cos \phi \]

\( \Box \) Length \[ BE = DF = G_1 \cot \phi \]

\[ \text{In triangle } \triangle DEF \]

\[ \tan \phi = \frac{G_1}{DF} \]

\[ DF = G_1 \cot \phi \]

3. Diagonal \( AC \)

In triangle \( \triangle ACF \)

\[ \sin \theta_1 = \frac{G_1}{AC} = \frac{A}{} \]

\[ AC = G_1 \cos \theta_1 \]

4. Diagonal \( BD = RH \)

In triangle \( \triangle ADH \)

\[ \tan \theta_2 = \frac{DH}{AH} \]
\[ D_H = AH \tan \frac{q}{2} \]
\[ D_H = \frac{1}{2} AC \tan \frac{q}{2} \]
\[ D_H = \frac{1}{2} G \cosec \varphi \cdot \tan \frac{q}{2} \]
\[ D_H = \frac{1}{2} G \cosec \varphi \cdot \frac{\sin q}{\cos q} \]
\[ \Rightarrow D_H = \frac{1}{2} G \cosec \varphi \]

Then
\[ B_H = 2D_H \]
\[ \Rightarrow B_H = 2 \times \frac{1}{2} G \cosec \varphi \]
\[ \Rightarrow B_H = G \cosec \varphi \]

ES - 1995

Problem: A crossover occurs at a point parallel CG. Draw the track of same crossing No. 1 in 8 m with a straight intermediate portion 4 m in reverse curve. C/L distance blue track is 5m. Find the overall length of crossover.

Solution:

\[ \text{Crossing Number} \]
\[ N = 8.5 \]
\[ CL = 26N \]
\[ CL = 27.1 \times 6.76 \times 8.5 \]
\[ CL = 28.492 \text{ m} \]

\[ CFL = 3.67 \]
\[ CFL = 5 - 1.676 \]
\[ CFL = 3.324 \]

\[ CF = \frac{G}{S_{0.02}} \]
\[ CF = 1.676 \sqrt{1 + \frac{1}{N^2}} \]
\[ CF = 1.676 \sqrt{1 + \frac{1}{8.5^2}} \]
\[ CF = 1.687 \]

\[ FL = 3.394 - 1.687 \]
\[ FL = 1.636 \]

\[ LI = FL \cot \theta \]
\[ LI = 1.636 \times 8.5 \]
\[ LI = 13.91 \]

**Overall length of C/L**
\[ = 40N + 5 \]
\[ = 27.28 \times 19.2 + 13.91 \]
\[ = 70.89 \text{ m} \]
To understand this topic, three important points are:

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

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

   \[ H_c = F = mR = m \times W_d \]

   \[ H_c = m \times n \times W_d \]

   If \( n \) = no. of pair of driving wheels,

   \( W_d \) = wt. 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.

   \[ \text{Total Resistance} \leq Te \]
Steam Engine Cylinder

Let us consider a Steam engine for which

- $A =$ area of piston/cylinder
- $p =$ pressure difference
- $L =$ length of stroke
- $n =$ no of cylinder
- $D =$ dia of wheel
- $d =$ dia of sq piston

⇒ Power generated = work done on wheel

⇒ $n \cdot p \cdot A \cdot L = \pi \cdot D \cdot T_e$

⇒ $n \cdot p \cdot \frac{\pi d^2}{4} \cdot L = \pi \cdot D \cdot T_e$

⇒ $T_e = \frac{n \cdot \pi \cdot d^2}{2 \cdot D}$ - Tractive effort.

Speed = Diameter of wheel ($D$),

but $T_e \propto \frac{1}{D}$, so there should be a balance, so that sufficient speed is obtained without reducing the tractive effort.
Hauling Capacity:

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

\[ \text{He} = \mu \cdot n \cdot \text{Wd} \]

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

\[ \mu = \text{Coefficient of friction} \]

\[ = 0.10 \text{ to } 0.30 \quad \text{Note} \rightarrow 0.10 \rightarrow \text{at high speed} \]

\[ = 0.20 \rightarrow \text{at average speed} \]

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

\[ \mu = \frac{1}{6} = 0.166 \]

as per old book

Driving wheel:

(from text)

Diagram:

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

1. \( 4 \cdot 4 \cdot 2 = 4 \frac{1}{2} = 3 \)
2. \( 4 \cdot 6 \cdot 2 = 6 \frac{1}{2} = 3 \)

\[ \Rightarrow \text{the value of } \mu \text{ at low speed } \]

\[ \text{at high speed } \mu \text{ is less.} \]

Hauling Capacity = Total Resistance
5. Total Resistance:

a. Train Resistance:
   i. Resistance independent of speed (Rolling Resistance) \( R_{T1} \):
   \[ R_{T1} = 0.0016 \omega \]  
   Note: Haulage in tonnes of train
   \[ \omega = \text{Weight of train in tonnes} \]
   \[ N_0 = \text{Total wt of train} \]
   \[ V = \text{Speed in kmph} \]

b. Resistance due to track profile.

6. Resistance due to starting and accelerating

7. Wind Resistance.

8. Train Resistance \( R_T \):

   (i) Resistance independent of speed (Rolling Resistance) \( R_{T1} \):
   \[ R_{T1} = 0.0016 \omega \]  
   Note: Haulage in tonnes of train
   \[ \omega = \text{Weight of train in tonnes} \]
   \[ N_0 = \text{Total wt of train} \]
   \[ V = \text{Speed in kmph} \]

   (ii) Resistance dependent on speed \( R_{T2} \):
   \[ R_{T2} = 0.000006 \omega \cdot V \]

   (iii) Atmospheric Resistance \( R_{T3} \):
   \[ R_{T3} = 0.0000006 \omega \cdot V^2 \]

Total train resistance
\[ R_T = R_{T1} + R_{T2} + R_{T3} \]
\[ R_T = 0.0016 \theta + 0.0008 \theta V + 0.000006 \theta V^2 \]

\[ R_F = 0.0016 \theta \theta \]

(6) **Resistance due to Trunk Profile:**

(1) **Due to Gradient:**

\[ \text{Resistance, } R_g = \frac{W \tan \theta}{\cos \theta} \]

\[ R_g = W \sin \theta \]

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

(2) **Due to Curve (Curve Resistance):**

\[ R_c = 0.04 \theta \text{ of } \theta \]

\[ R_c = 0.0004 \theta \text{ for } BG \]

\[ R_c = 0.0003 \theta \text{ for } MG \]

\[ R_c = 0.0002 \theta \text{ for } N \theta \]
Resistance

1. Due to starting and acceleration:

\[ R_{sa} = 0.15w_1 + 0.05w_2 \]

\[ v = \frac{w_1}{\text{Locomotive}} \]

\[ w_2 = \text{wt. of wagon} \]

2. Due to acceleration:

If \( a = \text{acceleration} \)

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

\[ R_{ac} = 0.028w_1 \]

\[ R_{ac} = 0.028w_1 \left( \frac{v_2 - v_1}{t} \right) \text{ kmph/see.} \]

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

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

\( w = \text{tonnes} \)

3. Wind Resistance:

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

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

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

4. For movement:

\[ H \cdot C > \text{total resistance} \]

\[ T_e > \text{total resistance} \]
For solving question:

\[ T_e = H_c = \text{Total Resistance} \]

In normal case, total resistance: \( R_{T1} + R_{T2} + R_{T3} \) (81)

**Problem:**
Determine the max permissible train load that can be pulled by a locomotive having 4 pairs of driving wheels, carrying an axial load of \( n \) at each. The train has to run at a speed of 80 mph on a straight level on track. Also determine the reduction in speed of the train when it has to climb a gradient of 110 parts.

**Solution:**

Locomotive = no. of pairs of driving wheel

\( n = 4 \)

Weight on each pair (axle)

\( W = 20t \)

Hauling capacity

\[ H_c = W - \eta \cdot f \cdot d \]

\[ H_c = 6.20 \times 4 \times 24 \]

\[ H_c = 19.2t \]

**Case 1:**
Train loading = \( W_0 \)

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

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

\[ 19.2 = 0.0016w + 0.0008 \cdot 80 + 0.000006 \cdot 80^2 \]

\[ 19.2 = 0.0016w + 0.0008 \cdot 80 + 0.000006 \cdot 80^2 \]

\[ 19.2 = 6.40 \]

\[ w = 1.021.62t \]
Case (a)
At a gradient 1 in 200 is there

\[ H_w = R_{T1} + R_{T2} + R_{T3} + \omega \cdot \tan \theta \]

\[ \Rightarrow 19.2 = 10 \left( 0.0018 + 0.00008v + 0.0000006v^2 \right) + \omega \cdot \tan \theta \]

\[ \Rightarrow V = 23.295 \]

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

Ex-1995
Problem:

A train having 20 wagon weighing 19.4 t each, is to run at a speed of 50 kmph. The tractive effort of a 2-8-2 locomotive with 235.1 t load on each driving axle is 15 t. The G.W. of locomotive is 120 t. The rolling resistance of wagon and locomotive are 2.5 ft/l and 8.5 ft/l respectively. The resistance which depends upon speed is 3.65 t. Hence, find out the steepest gradient for conditions.

Solution:

![Diagram of train configuration]

Weight of wagons = 20 \times 19.4 = 388 t

Weight of locomotive = 120 t

Weight of train \( w = 480 t \) total
Locomotive \( \Rightarrow 2-8-2 \)

- Number of pairs of driving wheel \( n = 9 \)
- Weight of each pair of driving wheel \( W_d = 22.5 \text{ t} \)

- Hauling capacity \( C_h = 0.20 \times 4 \times 22.5 \)
  \[ C_h = 19 \text{ t} \]

The traction force \( T_e = 15 \text{ t} \)

So the train can move with the \( T_e \) of 15 \text{ t} only.

- Train load \( t_o = 480 \text{ t} \)
- Speed \( v = 50 \text{ kmph} \)

- Maximum gradient \( \tan \theta = \frac{2}{9} \)

- \( H.C. (or \ T_e) = \text{Total Resistance} \)
  \[ = RT_1 + RT_2 + RT_3 + \text{wagons} \]
  \[ = \frac{2.5 \text{ t} \times 380}{\text{wagons}} + \frac{2.5 \text{ t} \times 180}{\text{Locomotive}} \]

  \[ \Rightarrow RT_1 = 1820 \text{ kg} \]
  \[ \Rightarrow RT_1 = 1.820 \text{ t} \]

- \( RT_2 = \text{Resistance, depends on speed} \),
  \[ RT_2 = 8.65 \text{ t} \]

- \( RT_3 = 0.40 \text{ NN} \)

  \[ \Rightarrow RT_3 = 0.40 \times 980 \times 50^3 \]

  \[ \Rightarrow RT_3 = 0.72 \text{ t} \]
Problem: Determine the tractive effort developed by a two cylinder engine from the following data:
1. Wheel 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 or not.

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

Tractive effort developed by engine
\[ T_e = \frac{npLd'^2}{2.71} \]
\[ T_e = \frac{2 \times 0.75 \times 42 \times 32^2}{1 \times 2 \times 153} \]
\[ T_e = 743 \, \text{kg} \]
\[ T_e = 0.743 \, \text{Tonnes} \]
Problem: A locomotive with 3 pairs of driving wheels is to haul a train on a 60 km track at 75 kmph. The load on each axle of driving wheel is 22 tonnes; the coefficient of friction is 0.02. What is the max load the engine can pull on a straight & level track?

When the same track goes on a slope

When the track goes on a 2° curve on a level ground speed = 8

Gradient or curve \( \Rightarrow \) Speed

Solution:
1. Hauling capacity:
   - Pairs of driving wheels \( \eta = 3 \)
   - Weight on each pair \( w = 22t \)
   \[ H_c = \frac{11.1 \times 10^3}{0.22 \times 0.02} = 13.2t \]

2. On a straight & level track
   - \( H_c = \text{Train Resistance} \)
   \[ H_c = 0.00016w + 0.00008 \frac{v^2}{2} + 0.00000001w^2 \]
   \[ 13.2 = 0.0016w + 0.00008 \frac{75^2}{2} + 0.00000001w^2 \]
   \[ w = 13.03 \text{t} \]
when track goes on a gradient 1/180

\[
H \cdot C = 0.0018 \omega + 0.00008 \omega \nu + 0.000006 \nu^2 + \text{corrections}
\]

\[
\Rightarrow 13.2 = 0.0016 \times 1202.73 + 0.00008 \times 1202.73 \nu
\]
\[
+ 0.000006 \times 1202.73 \nu^2 + 1202.73 \nu \text{\ } 1/180
\]

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

\[
\Rightarrow 4597 = 0.097 \nu + 0.00096 \nu^2
\]

\[
\Rightarrow \nu = 37.3 \text{ km/h}
\]

Reduction in speed = 75 - 37.3

= 37.7 km/h

c) when it is a curve of 2'

\[
He = \frac{1}{190} + 0.00004 \nu^2 + 0.0001 \times 1202.73 \nu
\]

\[
He = 10.962
\]

\[
\nu =
\]

c) when gradient + curve

\[
He = \frac{1902.73}{190} + 0.962
\]

\[
\nu =
\]
1) Highway Egg:
   Introduction:
   Important events:

   1. Jaykar committee recommendation
      For in 1927
      Submitted report -> 1928 (Fed)

   2. Central Road Fund -> 1929
   3. Indian Road Congress -> 1934
   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 -> 1981
      (Jodhpur)

10) Jaykar Committee recommendation:

   1. Road development is public should be considered as of
      national interest.
   2. As duty on petrol should be released for road development
      duties.
      Result -> Central Road Fund (1929)
   3. A semi-official Government body should be formed for road
      development planning.
      Result -> Indian Road Congress -> 1934
In re: Search Institute should be housed for research & development work.

Result: CRRR → 1950.

<table>
<thead>
<tr>
<th>Road Development Plane</th>
<th>First</th>
<th>Second</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Venue</td>
<td>Mangpar</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>
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<tr>
<td></td>
<td>160 sq km</td>
<td>100 sq km</td>
<td>100 sq km</td>
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<tr>
<td>3 Classification</td>
<td>Express</td>
<td>Express</td>
<td>Primary</td>
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<td>Express way</td>
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<td>Express way</td>
</tr>
</tbody>
</table>
Membrane Roads: 

- Heavy foundation stone

Esquieu Construction:

Macedum:

Macedum was first who used smalled stressed stones for bottom layers.

- Stress at bottom layers are less than stress at top layers
- Slope at top & bottom layers
- Side drains
Geometrical Design:

1. Cross-section elements:
   - Friction:
     - Longitudinal coefficient of friction
       $\mu = 0.35$ to $0.45$
       \( \mu = 0.35 \) (generally) considered.
     - Lateral coefficient of friction
       $\mu = 0.5$

2. Skid: when brakes are applied
   - Longitudinal movement $> \text{Circumferential moment}$

3. Slip: when vehicle is being accelerated
   - Circumferential moment $> \text{Longitudinal movement}$

4. Camber: to drain off water from road surface
   - Straight
   - Paraboloid
   - Straight Paraboloid
<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</td>
<td>1.7 ft</td>
<td>20 ft (1 in 50)</td>
</tr>
<tr>
<td>② Simple bituminous or wax</td>
<td>2.0 ft</td>
<td>2.5 ft (1 in 40)</td>
</tr>
<tr>
<td>③ Gravel road</td>
<td>2.5 ft</td>
<td>3.0 ft (1 in 33.3)</td>
</tr>
<tr>
<td>④ Earth road</td>
<td>3.0 ft</td>
<td>4.0 ft (1 in 25)</td>
</tr>
</tbody>
</table>

- **Side Distance:**

- **Stopping Sight Distance:** As per IRC
Stopping sight distance:

= lag distance + braking distance

- Lag distance: Distance travelled by the vehicle during reaction time of driver

PIEV theory:

P→ Perception → Time taken to send signal from eye of brain

I→ Information → Time taken to understand a station, rearranging different thoughts

E→ Emotion → Extra time taken due to emotions

V→ Valuation → Time for final action

Total time taken = Reaction time

Vary from 0.5 to 0.8 sec

Generally \( t_R = 0.5 \) to \( 0.8 \) sec

\[
\text{lag distance} = \text{speed} \times \text{reaction time}
\]

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

\[
= 0.278 V \times t_R
\]

\( \text{Braking distance} \)
After application of brake, vehicle moves a distance.

1. Full brake efficiency (1.007) is to be considered as after brakes, wheels are fully jammed.

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

   \[
   \Rightarrow \frac{mu^2}{2} = (F_R + s)S
   \]

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

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

   **Stopping Sight Distance**

   \[
   \Rightarrow S = \frac{\sqrt{u^2}}{2g (S \sin \theta + Fr \cos \alpha)}
   \]

   \[
   \Rightarrow S = \frac{\sqrt{u^2}}{2g (\tan \alpha + f)}
   \]

   \[
   \Rightarrow S = \frac{\sqrt{u^2}}{2g (F + S \alpha)}
   \]

   **Total Stopping Sight Distance**

   = log distance + stopping distance

   \[
   = \left(0.278 \cdot V \cdot t \cdot p \right) + \frac{(0.278 \cdot u)^2}{2g \left( F + S \alpha \right)}
   \]

   \(\pm\) \(\nu\) for upward slope

   \(\mp\) \(\nu\) for downward slope
(1) One way traffic / one lane road  \[ \rightarrow \text{SSD} \]
(2) Two lane road / two way traffic  \[ \rightarrow \text{SSD} \]
(3) One lane road / two way traffic  \[ \rightarrow \text{SSD} \]
(4) Headlight - sight distance  \[ \rightarrow \text{SSD} \]

Intermediate sight distance  \[ = 2 \cdot \text{SSD} \]
Overtaking right 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 in reaction time}

\[ d_1 = 0.4298 \times V_B \times t \]  \hspace{1cm} (1)

(A = B forced to move with same speed, that of B
Speed of 0 just before B = $V_B$

(2) Distance $d_2$:

If $t_{sec}$ is total time required from A to move for

$2 + 0.5$

\[ d_2 = V_B t + \frac{1}{2} a t^2 \]

\[ d_2 = 0.278 V_B t + \frac{1}{2} a t^2 \]  \hspace{1cm} (2)

According to vehicle (B)
\[ d_2 = b + 2s \]

\[ d_2 = 0.298V_Bt + 2s \] \( \square \) (96)

\[ q = \frac{aT^2}{q} \]

\[ q = \sqrt{\frac{2s}{a}} \]

\( a = \text{acceleration of vehicle} \)
\( S = \text{min. distance to be maintained btw two vehicle} \)

\[ S = 0.7xV_B + l \]
\[ S = 0.7x0.298V_B + 6 \]

\[ S = 0.2V_B + 6 \]

\( t = \text{reaction time} \)
\( l = \text{length of vehicle} \)

Distance \( d_3 \):

\[ d_3 = 0.298V_c \cdot T \]

Total overtaking side distance = \( d_1 + d_2 + d_3 \)
Problem: The driver of a vehicle travelling to reach, up a gradient requires 9 m less to stop after applying the brakes than a driver travelling at the same speed down the same gradient.

What is the gradient?

Solution:

$F = 0.9$

Moment up the gradient:

$s_1 = \frac{V^2}{2g (F + s_f)}$

$s_1 = \frac{(0.278 \times 60)^2}{2 \times 9.81 (0.40 + s_f)}$

$s_1 = 14.18 / (0.40 + s_f)$

Down the gradient:

$s_2 = \frac{(0.278 \times 60)^2}{2 \times 9.81 (F - s_f)} = \frac{14.18}{(0.40 - s_f)}$

$s_2 \times s_1 = 9$
\[ \frac{14.18}{0.40+5} - \frac{14.18}{0.40-5} = 9 \]

\[ \frac{(0.45s + s - 0.40 - s)}{(0.40^2 - s^2)} = 9 \]

\[ \frac{2s}{0.16 - s^2} = \frac{9}{14.18} \]

\[ 0.16 - s^2 = 1.57565 \]

\[ s^2 + 1.57565 - 0.16 = 0 \]

\[ s = 0.05 = \sqrt{20} \text{ ANS} \]

**Problem:** On a two way road, the speed of overtaking & overtaken vehicles are 65 & 40 kmph respectively. \( a = 0.92 \text{ m/sec}^2 \)

Determine:
1. Safe overtaking safe distance.
2. Min. length of overtaking zone & show the details of overtaking zone by a neat sketch.

**Solution:**

\[ v_A = 65 \text{ kmph} \]

\[ v_B = 40 \text{ kmph} \]
Distance $d_1$

$$d_1 = 0.278 \times v_0 \times 9.8$$

$$[d_1 = 27.8 \text{ m}]$$

Distance $d_2$

$$d_2 = 0.278 \times v_0^2 \times t + \frac{1}{2} a t^2$$

$$S_{d_2} = 0.2 \times v_0 + 6$$

$$\Rightarrow S = 0.2 \times 40 + 6$$

$$S = 14 \text{ m}$$

$$t = \sqrt{\frac{2S/a}{a}} = \sqrt{\frac{4 \times 14}{0.92}}$$

$$t = 7.8 \text{ sec}$$

$$d_2 = 0.278 \times 40 \times 0.78 + \frac{1}{2} \times 0.92 \times (7.8)^2$$

$$[d_2 = 114.72 \text{ m}]$$

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 SSD = $d_1 + d_2 + d_3$

$$= 27.8 + 114.72 + 140.95$$

$$= 283.47 \text{ m}$$
Overtaking Zone: 

\[ sp_2 \]

\[ \text{Minimum length} = 3 \times \text{OSD} \]

\[ v = 3 \times 283.47 = 850.41 \text{ m} \]

4. Desirable length of overtaking: 

\[ sp_1 \rightarrow \text{Overtaking zone ahead} \]

\[ sp_2 \rightarrow \text{End of Overtaking zone.} \]

Value of acceleration
Value of acceleration & OSD:

<table>
<thead>
<tr>
<th>Speed</th>
<th>$a m/\text{sec}^2$</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.

\[
\begin{align*}
F &= \frac{mv^2 \cos \theta}{R} \\
W &= mg \\
mg \cos \theta + \frac{mv^2 \sin \theta}{R} &= R \\
\theta &= \tan^{-1} \left( \frac{mv^2}{mgR} \right)
\end{align*}
\]

- Reaction \( R = mg \cos \theta + \frac{mv^2 \sin \theta}{R} \)
- Force of friction \( F = FR = F \left( mg \cos \theta + \frac{mv^2 \sin \theta}{R} \right) \)
- Equating all force along surface of road.
\[ mg \sin \theta + F = \frac{m u^2 \cos \theta}{R} \]
\[ mg \sin \theta + F (mg \cos \theta + \frac{m u^2}{R} \sin \theta) = \frac{m u^2}{R} \cos \theta \]

\[ g \tan \theta + F g = \frac{F u^2}{R} \tan \theta = \frac{v^2}{R} \]

Super elevation
\[
\tan \theta = e
\]

\[ g e + F g = \frac{v^2}{R} (1 - e F) \]
\[ g (e F + F) = \frac{v^2}{(1 - e F)} \]

\[ \frac{(e + F)}{(1 - e F)} = \frac{v^2}{g R} \]

\[ 1 - e F \ll 1.00 \]

Then
\[ e + F = (0.276v)^2 \]
\[ g \times 0.276 R \]

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

Totaling force
\[ e = \frac{v^2}{127 R} - F \]
Max Value of Super-elevation:

1. On plain & rolling = 7/1 = 0.07
2. On fully road = 10/1 = 0.10
3. On urban road (with = 4/1 = 0.04
   frequent intersection)

Design Steps:

1. If design speed = V kmph
   Super-elevation is calculated for 75+ for design speed
   (value of F 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
   \[ e < E_{max} \]

3. If \[ e > E_{max} \]
   then check value of F considering full design speed using \[ E_{max} \]
   value.
   Provide \[ E_{max} \]
   \[ e + F = \frac{V^2}{127R} \]
   \[ F = \frac{V^2}{127R} - E_{max} < 0.05 \]
If \( f < 0.15 \) OK

\[ \text{Provide } E_{\text{max}}. \]

(4) If \( f > 0.15 \)

Design Speed should be restricted.

Max. Speed allowed

\[ (E_{\text{max}} + F_{\text{max}}) = \frac{v^2}{127R} \]

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

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 \( R = 420 \text{m} \). What should be the value of S.E. provided check max. allowed speed.

Solution: \[ v = 110 \text{ kmph} \]

1) Super-elevation

\[ e = \frac{(0.75 \times v)^2}{127R} = \frac{(0.75 \times 110)^2}{127 \times 420} \]

\[ e = 0.1297 \]

\[ E_{\text{max}} = 0.07 \]

\[ e \geq E_{\text{max}} \]

2) \( E_{\text{max}} = 0.07 \)

Check

\[ E_{\text{max}} + F = \frac{v^2}{127R} \]

\[ 0.07 + F = \frac{110^2}{127 \times 420} \]
\( F = 0.1568 > 0.15 \)

1. Max. Speed allowed
   \[ E_{\text{max}} + F_{\text{max}} = \frac{V_{\text{max}}^2}{127\pi} \]
   \[ V_{\text{max}} = \sqrt{127\pi (E_{\text{max}} + F_{\text{max}})} \]
   \[ V_{\text{max}} = 108.2 \text{ kmph} \]
   Ans

2. Min. radius of curve
   \[ E_{\text{max}} + F_{\text{max}} = \frac{V^2}{127\pi} \]
   \[ R_{\text{min}} = \frac{V^2}{127( E_{\text{max}} + F_{\text{max}} )} \]
   \[ R_{\text{min}} = \]
Extra width required

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

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

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

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

Extra width

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

(\(2R + E_w > 2R\))

If \(n\) = Total no. of lanes

\[ E_w = \frac{nd^2}{2R} \]
1. Mechanical widening:

\[ L = \frac{W \cdot V}{2R} \]

2. Psychological widening:

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

Total Extra widening required = \[ \frac{W \cdot V}{2R} + \frac{V}{9.5 \sqrt{R}} \]

3. Transition Curve:

- Length of Transition Curve:

4. As per rate of change of radial acceleration (C):

\[ \text{Length of Transition Curve} = \frac{V^3}{CR} = \left(0.278V\right)^3 \]

\[ C = \left(\frac{8V}{V + 75}\right) \]

- Rate of change of super elevation:

\[ C = [0.50 < C < 0.80] \]

- Calculate super elevation:

\[ E = \frac{V^3}{225R} \]

- 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
\[ x = \frac{(W + E_w)}{2} x \]

Length of transition curve as per super elevation
\[ \begin{align*}
&= 150x \rightarrow \text{for plan region} \\
&= 100x \rightarrow \text{for build up area} \\
&= 60x \rightarrow \text{for holly area}
\end{align*} \]

3. As per empirical formula,

For plain 2 rolling
\[ L = \frac{2.370v^2}{\rho} \]
\[ v = \text{kmph} \]
\[ R = \text{M} \]

(2) for mountainous & steep terrain

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

- **Terrain classification:**
  1. **Steep terrain** → \( \geq 30 \text{ degree} \) cross slope > 60%.
  2. **Mountainous region** → 25 to 60%.
  3. **Rolling terrain** → 10 to 25%.
  4. **Plain terrain** → < 10%.

- **Set back Distance:**

  **Case 1:** One lane road (\( L > SSD \))

  Set back distance is min clearance required from any 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 = SD = S

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

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

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

Set back distance CD = m

\[ m = OC - OD \]

\[ m = R - R\cos\theta/2 \]

\[ m = R\left(1 - \cos\theta/2\right) \]

Case 3: One lane road (L < SD)
Length \( AC = \frac{S - L_c}{2} \)

\[ = \frac{(S - L_c)}{2} \]

Sight distance = ACEDB = S

Length of curve = CED = L_c

\[ L_c < S \]

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

\[ \Rightarrow x = \frac{180 L_c}{\pi R} \]

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

Set back distance

\[ m = EG = EF + FG \]

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

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

\[ ADB = 5 \]

- Radius is measured from centre of road (total width)
  \[ OA = (R - d) \]

- \( d \) = half of inner lane
- Set-back distance is measured from centre line of total width of road.
  \[ m = CE \text{ distance} \]

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

\[ \Rightarrow \alpha = \frac{180 \times S}{\pi (R - d)} \]
Set back distance

\[ m = CE = OC - OE \]

\[ m = R - (R - d) \cos \theta/2 \]

Case 4: Two lane road if length of curve:

\[ \Rightarrow \Phi C = \frac{S - Lc}{2} \]

\[ \Rightarrow \frac{Lc}{\pi (R - d)} = \frac{\theta}{360} \]

\[ \Rightarrow \theta = \frac{180 Lc}{\pi (R - d)} \]

\[ \Rightarrow \theta/2 = \frac{1800 Lc}{2\pi (R - d)} \]
Set back distance:

\[ m = EH \]
\[ m = EG + GH \]
\[ m = (OE - OG7) + CI \]
\[ m = R - (R-d) \cos \theta/2 + \left( \frac{S-Lc}{2} \right) \sin \theta/2 \]

4. Design of vertical alignment:

(a) Gradient:

(i) Rolling Gradient: max gradient that can be provided in general conditions

As per IRC:

- Plain & Rolling: 1 in 30
- Mountainous: 1 in 20
- Steep region: 1 in 16.7

(b) Limiting Gradient: due to cost factor & topographic condition gradient can be increased up to limiting gradient

- Plain & Rolling: 1 in 20
- Mountainous: 1 in 16.7
- Steep region: 1 in 14.3

(c) Extra ordinary condition: exceptional gradient can be provided

- Plain & Rolling: 1 in 15
- Mountainous: 1 in 14.3
- Steep region: 1 in 12.5
(7) Length of summit curve:

Case (1) \( L > (SSD \text{ or OSD}) \)

\[
L = \frac{NS^2}{(\sqrt{bh} + \frac{1}{2}h)^2}
\]

**F**: \( h = \text{height of driver eye} = 1.20 \text{ m} \)

\( h = \text{height of obstruction} = 0.15 \text{ m} \)

\( N = \text{total change in gradient} \)

\( N = |N_1 - N_2| \)

**S**: \( \text{Stopping Sight distance} \)

\[
L = \frac{NS^2}{(\sqrt{2x1.2 + 20h})^2}
\]

\[\boxed{\frac{NS^2}{4h}}\]

(2) For overtaking sight distance: \( h = H = 1.20 \text{ m} \)

\[
L = \frac{NS^2}{(\sqrt{bh} + \frac{1}{2}h)^2}
\]

\[
L = \frac{NS^2}{(\sqrt{2x1.2 + 2x1.2})^2}
\]
\[ L = \frac{N s^3}{9.6} \]

**Case 5:** If \( L < SSD \) or \( OSD \)

\[ L = 25 - \frac{(V_{2H} + V_{1H})^2}{N} \]

*for SSD*

\[ L = 25 - \frac{4.4}{N} \]

*for OSD*

\[ L = 25 - \frac{9.6}{N} \]

---

**Valley Curve:**

Length is calculated.

1. Comfort Condition: Based on rate of change of radial acceleration \((c)\).

![Diagram of valley curve](image)

**Total length of valley curve**: \( L_c \)

\[ L = 2L_c \]

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

In this case, R = \frac{L_c}{N}

\Rightarrow L_c = \frac{V^3}{C}\frac{1}{2}

\Rightarrow \frac{L_c^2}{C} = \frac{NV^3}{2}

\Rightarrow L_c = \sqrt{\frac{NV^3}{2}}

Total, Length of valley curve

\[ L = 2 \cdot L_c \]

\[ L = 2 \cdot \sqrt{\frac{NV^3}{2}} \]

(2) As per head light sight distance :\[
\]

For a simple parabola curve

\[ y = ax^2 \]
\[ \Rightarrow h_1 + s \tan B = (N/2L) s^2 \]

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

Length of curve

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

\[ L = 2s - 2 \left(\frac{h_1 + s \tan B}{\pi}\right) \quad \text{if } (L < s) \]

Generally

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

\[ = 1.20 \, \text{m} \]

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

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

Solution: Design speed

For national highway in fully road:

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

\[ R_{\text{min}} = \frac{v^2}{127 + (E + F)} \]

\[ E_{\text{max}} = 0.10 \]

\[ F_{\text{max}} = 0.15 \]

\[ R_{\text{min}} = \frac{50^2}{127 + (0.10 + 0.15)} \]

\[ R_{\text{min}} = 78.74 \text{ m} \]

Super elevation

For design speed of 50 kmph, design speed

\[ e = \frac{0.75v^2}{127 + R} = \frac{(0.75 \times 50)^2}{127 \times 79} \]

\[ e = 0.14 > 0.10 \]

Provide \( e = 0.10 \)
Look for \( F \) for all design speed

\[
e + f = \frac{V^2}{124R}
\]

\[
F = \frac{80^2}{(277 + 79)} = 0.10
\]

\[
F = 0.149 < 0.15 \text{ So we}
\]

\[
\text{provide } 8.0 \text{.}
\]

3) Extra widening

For a two lane road

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

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

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

\[
E_w = 1.05 \text{ m}
\]

Total width of road = \( \omega + E_w \)

\[
= 7 + 1.05
\]

\[
= 8.05 \text{ m}
\]

4) Transition curve

i) As per rate of change of radial radial acceleration

\[
L_s = \frac{V^2}{CR}
\]

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

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

\[
L_s = \frac{(0.248 \times 50)^3}{0.64 \times 79} = 53.1 \text{ m}
\]
ii) As per code of change of SE.
Assume pavement is rotated outer edge

\[
x = (\omega + \varepsilon_0) e
\]
\[
x = 8.03 \times 0.10 = 0.803 m
\]

Length of curve = \(60 \times x\)
\[
= 60 \times 0.803
\]
\[
= 48.2 m
\]

(iii) As per empirical formula
\[
L_s = \frac{v^2}{g} = \frac{50^2}{79} = 31.64 m
\]

Length of transition curve = 53.10 m

5) Set back distance
Assume length of curve > SSD
\[
L > SSD
\]

Stopping Sight distance
\[
SSD = 0.298 \times V \times t_r + \frac{(0.298 \times V)^2}{2g(F + S)}
\]
\[
SSD = 0.298 \times 58 \times 2.5 + \frac{(0.298 \times 58)^2}{2 \times 9.81 \times (0.35 + 0)}
\]
\[
- SSD = 62.44 m.
\]
\[ d = \frac{\omega + \epsilon \omega}{4} = \frac{8.05}{4} = 2.01 \text{ m} \]

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

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

\[ q = 23.405 \]

Set back distance

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

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

\[ m = 8.24 \text{ m} \]
Problem: As ascending gradient 1:60 meet a descending gradient 1:50. Find the length of summit curve for SSD = 180 m.

Solution: \[ N = |N_1 - N_2| = \frac{1}{50} - \left(-\frac{1}{60}\right) = \frac{1}{50} + \frac{1}{60} = \frac{1}{37.5} \]

Length of summit curve

Assuming \( L > SSD \)

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

\[ L = \frac{1}{37.29} \times 180^2 \]

\[ L = \frac{37.29}{(\sqrt{2} \times 1.2 + \sqrt{3.05})^2} \]

\[ L = 3.70 \text{ m} > (180 \text{ m}) \]

\( L > SSD \) (Assumption is correct)

\[ L = 370 \text{ m} \text{ asy} \]
Problem: A valley curve of a s.t. 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 \[ t_r = 2.5 \text{ sec} \]
\[ t_f = 0.35 \text{ m} \]

\[ \text{Solution:}\]

(i) Comfort condition

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

\[ L = 2l_s = 2\sqrt{\frac{c^2}{g}} \]

\[ L = 2\sqrt{\frac{(10.298 \times 10^{-3})}{981}} \]

\[ L = 28.17 \text{ m} \]

(ii) Head light sight distance condition

H.S.D. = S.S.D. = 0.279 + \( \frac{(0.279 \times 80)^2}{28 (1.85 \times 10^{-3})} \)

\[ N = \frac{V}{30} \]
\[ N = \frac{80}{30} \]
\[ N = \frac{80}{30} \]
Assuming $(L > S)$

$$L = \frac{N S^2}{2 \left( h + 3 \tan \beta \right)}$$

$$\Rightarrow L = \frac{\frac{3}{2} \times 127.6^2}{3 \left( 0.75 \times 127.6 \tan \beta \right)}$$

$$\Rightarrow L = 227.8 \text{ m} > s = (127.6)$$

$(L > S)$ Assumption is correct

$L = 227.8 \text{ m}$

$\Rightarrow$ length of valley curve provided

$\Rightarrow \max \text{ of above} \approx 227.8 \text{ m}.$
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 at a change of 460 m & RL of 260 m. Find the length of curve.

Solution:

Assume length of curve = 2L

\[ RL \text{ of } B = 251.48 \text{ m} \]

\[ RL \text{ of } C = RL \text{ of } E - \frac{251.48 \times 4}{100} \]

\[ = 251.48 - \frac{251.48 \times 4}{100} \]

\[ = 250.48 \text{ m} \]

\[ h \text{ value for point } P \]

\[ h = h_{OC} = RL \text{ of } P - RL \text{ of } C \]

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

\[ kx^2 = 9.52\text{m} \]

Value of \( x \) for point \( P = (1 + 25) \)

\[ k(1 + 25) = 9.52\text{m} \]  \((i)\)

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

\( x_2 = 21 \)

\[ h = 3.0FL + 4.1\text{OF}\]

\[ h = 0.03L + 0.04L \]

\[ h = 0.07L \]

\[ h = kx^2 = k(21)^2 \]

\[ k \times 0.4L^2 = 0.07L \]

\[ k = \frac{0.07L}{4.1^2} = 0.0175/L \]  \((ii)\)

Put in eq. (ii)

\[ 0.0175(1 + 25)^2 = 9.52 \]

\[ l^2 + 50l + 625 = 544l \]

\[ l^2 - 494l + 625 = 0 \]

\[ l = 49.87\text{m} \]

Total length of curve \( 15 \times 2l = 2\times 49.878 \]

\[ = 985.46\text{m} \]
Traffic Engineering

1. Traffic Engineering can be divided into:
   
   (a) Traffic characteristics:
       - Road user behaviour.
       - Vehicle characteristics.
       - Braking characteristics.

   (b) Traffic Studies:
       - Traffic volume
       - Speed Study
       - OBD Study
       - Delay Study
       - Capacity
       - Parking Study
       - Pedestrian Study.

2. Traffic Operation:
   
   (a) Traffic regulation:
       - Traffic control device
       - Warning
       - Inspector of road separators
       - Regulatory.

   (b) Traffic signal.
   
   (c) Road marking.
   (d) Traffic Island: pedestrian
   (e) Parking & Lighting.
Breaking characteristics:

\[ R = mg \]

Assumption:

1. 100% brake efficiency if there is no application of brake. Brake are fully applied when the vehicle is not sliding over the road surface.

\[ m = \text{mass of vehicle} \]
\[ f \cdot E \text{ lost} = \text{work done} \]
\[ \frac{1}{2} m u^2 = F x s \]
\[ = F \cdot A s. = F mg s \]

\[ v^2 = 2gs + s \]

Distance travelled

\[ S = \frac{v^2}{2g} \]

If deceleration = \( a \)
4. Capacity: Based on traffic condition max volume that can be accommodated on a road is called capacity of road.

1. Basic capacity: In most ideal condition max volume that can be found on a road is called basic capacity.

2. Possible capacity: In general condition of traffic, traffic volume vary in different condition

   - In worst 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:

   ![Diagram of vehicles in traffic flow]

   Theoretical capacity = \( \frac{100V}{S} \) (vehicles/hr)

   If \( S \) = The min clearance required for two vehicles
   \( S = (0.7 \times V + 1) \)
\[ S = (0.2V + 1) \]

Theoretical capacity := if time headway = 0.2 sec.
Vehicle = 4.5 sec.

Theoretical capacity = \( \frac{60 \times 60}{t_h} \)

**Problem:** 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 = \( 100V / S \)

\[ S = 0.2V + 1 \]
\[ S = 0.2 \times 55 + 5.2 = 16.2 \text{ m} \]

Capacity \( C = \frac{100 \times 55}{16.2} \)

\( C = 3395 \text{ veh./hr.} \)

**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 vehicle moving towards an crossing from right angle collide at an intersection.

 affliction 

3. A moving vehicle collide 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:

\[ (v_A, v_B) \]

Before collision | After collision
---|---
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 \( A \) and \( B \) = \( V_{A'} \) and \( V_{B'} \)

for seperation \( V_{B'} > V_{A'} \)

Velocity of seperation = \((V_B' - V_A')\)

Newton's law of collision: \( \Rightarrow \) As per Newton's law, velocity of seperation has a constant ratio with velocity of approach. The constant is called co-efficient of restituation denoted by \( 'e' \).

\[ e = \frac{\text{Velocity of seperation}}{\text{Velocity of approach}} = \frac{V_{B'} - V_{A'}}{V_A - V_B} \]

Value of \( e \) is 0 to 1

(0) For perfectly elastic collision: \( \Rightarrow \)

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

Both bodies will move together.

Analysis:

Analysis of a vehicle applied brakes.

\[ F = Fm g \]

\[ v_1 \]

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

\[ \frac{1}{2}mv_1^2 - \frac{1}{2}mv_2^2 = F_s_1 = Fm g \cdot s_1 \]

\[ v_1 - v_2 = 2gF_s_1 \]

\[ \Rightarrow v_2^2 - 0 = 2gF_s_2 \]

\[ v_2^2 = 2gF_s_2 \]

Case 0: Accident of a moving vehicle with a parked vehicle.

\[ \text{Analysis diagram} \]

\[ \text{Diagram showing the collision scenario} \]
(1) Before collision:

For Vehicle (A)

\[ v_1^2 - v_2^2 = 2gFS_1 \]  \( \text{(1)} \)

(5) Momentum equation:

Total momentum just after collision = Total momentum just before collision

\[ m_A v_2 + m_B v_0 = (m_A + m_B) v_3 \]

\[ v_2 = (\frac{m_A + m_B}{m_A}) v_3 \]  \( \text{(2)} \)

(3) After collision:

\[ v_3^2 - 0 = 2gFS_2 \]

(for combined vehicle A & B)

\[ v_3^2 = 2gFS_2 \]

\[ v_3 = \sqrt{2gFS_2} \]  \( \text{(3)} \)

Step(1) Find \( v_3 \)

(2) Calculate \( v_2 \) from momentum eq.

(3) Calculate \( v_1 \) from before collision eq.
Problem: A vehicle applied brakes and skid through a distance 40 m before collining another parked vehicle. The weight of which is 60% of former. From fundamental principle of motion calculate the initial speed of moving vehicle which both vehicles skid after collision is 12 m.

\[ F = 0.60 \]

Solution:

1. **After collision**
   For vehicle A + B
   \[ v_3^2 = \sqrt{2gh_{52}} = \sqrt{2 \times 9.8 \times 0.60 \times 12} \]
   \[ v_3^2 = 11.89 \text{ m/s} \]

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
   \[ m_B = 0.60 m_A \]
   \[ m_B = 0.60 m_A \]
   \[ v_2 = \left( \frac{m_A + 0.60 m_A}{m_A} \right) v_3 \]
   \[ v_2 = 1.60 \times v_3 = 1.60 \times 11.89 \]
   \[ v_2 = 19.02 \text{ m/s} \]
3. Before collision:

For Vehicle A:

\[ v_1^2 - v_2^2 = 2gF_{S_1} \]

\[ v_1 = \sqrt{v_2^2 + 2gF_{S_1}} \]

\[ v_1 = \sqrt{(19.02)^2 + 2 \times 9.81 \times 0.60 \times 40} \]

\[ v_1 = 28.85 \text{ m/s} \]

\[ v_1 = 103.79 \text{ mph} \]

\[ \text{AND} \]

Case B: Two vehicle approaching from right angle collision at an intersection:

N.B.: Given:

- \( S_{A_1}, S_{B_1}, S_{A_2}, S_{B_2} \)
- \( \alpha_{A_1}, \alpha_{B} \)
- \( F_{A_1}, F_{B_1} \)

Find:

- \( v_{A_1}, v_{A_2}, v_{A_3}, v_{B_1}, v_{B_2}, v_{B_3} \)

For A:

\[ v_{A_1}^2 - v_{A_2}^2 = 2gF_{S_{A_1}} \]

\[ v_{A_1} = \sqrt{v_{A_2}^2 + 2gF_{S_{A_1}}} \]

For B:

\[ v_{B_1}^2 - v_{B_2}^2 = 2gF_{S_{B_1}} \]

\[ v_{B_1} = \sqrt{v_{B_2}^2 + 2gF_{S_{B_1}}} \]
Momentum equation:

In the direction of VA:

\[ M_A \cdot V_{A_2} + M_B \cdot V_{o} = M_A \cdot V_{A_3} \cos \alpha + M_B \cdot V_{B_3} \sin \beta \]

\[ V_{A_2} = \frac{1}{M_A} \left( M_A \cdot V_{A_3} \cos \alpha + M_B \cdot V_{B_3} \sin \beta \right) \tag{3} \]

In the direction of VB:

\[ M_A \cdot V_{o} + M_B \cdot V_{B_2} = M_A \cdot V_{A_3} \sin \alpha + M_B \cdot V_{B_3} \cos \beta \]

\[ V_{B_2} = \frac{1}{M_B} \left( M_A \cdot V_{A_3} \sin \alpha + M_B \cdot V_{B_3} \cos \beta \right) \tag{4} \]

3. After collision:

For A:

\[ v_{A_3}^2 = 2gF_{SA_2} \]

\[ v_{A_3} = \sqrt{2gF_{SA_2}} \tag{5} \]

For B:

\[ v_{B_3}^2 = 2gF_{SB_2} \tag{6} \]

1996 Problem:
Two vehicles A & B approaching at right angle. A from west, B from south.

Vehicle A:
- Before collision: 50 m, N of W
- After collision: 75 m, 0 F of B

Vehicle B:
- Before collision: 30 m, E of N
- After collision: 36 m, 6 F

F = 0.55
Solution:

1. After collision:
   
   For (A) \( V_{A3} = \sqrt{2gF_A V_{A2}^2} \)
   \[ V_{A3} = \sqrt{2 \times 9.81 \times 0.55 \times 15} \]
   \[ V_{A3} = 12.72 \text{ m/sec} \]

   For (B) \( V_{B3} = \sqrt{2gF_B V_{B2}^2} \)
   \[ V_{B3} = \sqrt{2 \times 9.81 \times 0.55 \times 8.6} \]
   \[ V_{B3} = 19.71 \text{ m/sec} \]

2. Momentum equation:
   
   \( \theta_A = 100 - 50 = 150^\circ \)
   \( \theta_B = 60^\circ \)

   \[ V_{A2} = \frac{1}{M_B} (M_A V_{A3} \cos \theta_A + M_B V_{B3} \cos \theta_B) \]

   \[ V_{A2} = 12.72 \times \cos 150^\circ + \frac{1}{0.75} 19.71 \sin 60^\circ \]
(2) \[ V_{A2} = 14.58 \text{ m/s} \]

Indirection of \( B \)

\[ V_{B2} = M_B V_{A3} \sin \theta A + M_B V_{B3} \cos \theta B \]

\[ V_{B2} = \frac{M_A}{M_B} V_{A3} \sin \theta A + V_{B3} \cos \theta B \]

\[ V_{B2} = 0.75 \times 12.72 \sin 130^\circ + 19.71 \cos 60^\circ \]

\[ V_{B2} = 19.16 \text{ m/s} \]

(3) Before collision

\[ V_{A1} = \sqrt{V_{A2}^2 + 2gFS_A1} \]

\[ V_{A1} = \sqrt{14.58^2 + 2 \times 9.8 \times 0.55 \times 35} \]

\[ V_{A1} = 24.295 \text{ m/s} \]

\[ V_{A1} = 87.34 \text{ km/h} \]

\[ V_{B2} = \sqrt{V_{B2}^2 + 2gFS_B2} \]

\[ V_{B2} = \sqrt{19.16^2 - 2 \times 9.8 \times 0.55 \times 20} \]

\[ V_{B2} = 22.55 \text{ m/s} \]

\[ V_{B2} = 81.6 \text{ km/h} \]
Signal design:
for a Two phase Signal System:

1) Total Red time on one road = Green-time + Amber time on another road

\[ \begin{array}{c|c|c}
\text{AA} & \text{AB} \\
\hline
\text{Red} & \text{Green} & \text{Red} \\
\hline
\text{RB} & \text{GRB} & \text{AB} \\
\end{array} \]

\[ \text{GrB} = \sqrt{\frac{1}{r}} \]

\[ \text{PA} = \text{GrB} + \text{AB} \quad (1) \]

\[ \text{PB} = \text{GrA} + \text{AB} \quad (2) \]

2) Green time: when vehicles are allowed to go, the green time is calculated based on traffic volume at two roads.

3) Amber time: Amber time or yellow time is provided to serve following purpose.

   (i) All the vehicles that has entered into danger zone (within 300 distance from intersection) should be allowed to cross the intersection.
Total distance required to travelled for crossing vehicle = \((SSD+w+1)\)

\[ t_1 = \frac{Distance}{Velocity} \]  \[ 145 \]  

\( t_1 \) = min amber time for crossing vehicle

(ii) To allow sufficient time to stop the vehicle approaching the intersection.

For vehicle beyond SSD line.

Min time required

\[ t_2 = Reaction\ time + Breaking\ time \]

\[ t_2 = t_r + \left( \frac{v}{a} \right) \] 

\( t_r \) = retardation

(iii) Red amber time is also provided sometime at the end of 'red time', but it is part of red time only.

\[ G2A \quad P2A \quad R2A \quad A2F \]
4. Design of Signal Timings:
   1. Trial Cycle method.
   3. Webster's method.
   4. IRC Method.

1. Trial Cycle Method: (Two phase signal system:)

   If 15 minute traffic count is ha & hb on two roads

   Step:
   1. Assume a cycle time = T
   2. Number of vehicle accumulatd on two roads in one cycle time

\[ x_A = \frac{h_A}{15 \times 60} \times T \]
\[ x_B = \frac{h_B}{900} \times T \]

2. Min. Green time required
   (WA time headway = 3 + 8 second)

\[ G_A = x_A \times T \]
\[ G_B = x_B \times T \]
(1) Total cycle time: \( T = (G_A + A_A) + (G_B + A_B) \)

Note: \( T \) should be equal.

Problem: If 15 minute traffic count on two roads are 180 and 180 vehicle per lane. If time headway is 3 sec during green phase & amber time on two roads are 4.0 sec, design signal timings by trail cycle method.

Solution:

\[ n_A \text{ in 15 min} = 180 \text{ veh/lane} \]
\[ n_B \text{ in 15 min} = 180 \text{ veh/lane} \]

Let us assume cycle time = 60 sec.

In one cycle time

No. of vehicles accumulated

\[ x_A = \frac{n_A \times T}{15 \times 60} \]
\[ x_A = \frac{180 \times 60}{15 \times 60} = 12 \]

\[ x_B = \frac{n_B \times 60}{15 \times 60} = 10 \]

Green time required

\[ G_A = 12 \times 3 = 36 \text{ sec} \]
\[ G_B = 10 \times 3 = 30 \text{ sec} \]

Total cycle time = \((G_A + A_A) + (G_B + A_B)\)

\[ = (36 + 4) + (30 + 4) \]
\[ = 74 \text{ sec} \]
3. Approximate Method: This method is based on pedestrian time to cross the road & traffic volume

1. Time required for pedestrian to cross the road:
   \[ \text{Time} = \frac{WA}{\text{Speed}} = \frac{WA}{1.3 \text{ m/sec}} = \text{clearance interval} \]

2. Minimum green time for pedestrian signal:
   For Road A:
   \[ G_{PA} = 7 \text{ sec} + \frac{WA}{1.24} \]
   \[ G_{PA} = \text{Initial walk period} + \text{clearance interval} \]

3. Red time required for traffic signal:
   \[ R_A = G_{PA} \]
   \[ R_B = G_{PB} \]
4. Minimum green time for traffic signal:

\[ G_{IA} = P_B - AA \]
\[ G_{IB} = PA - AB \]

5. Considered any one green time as another is calculated based on traffic volume

\[ \frac{G_{IA}}{G_{IB}} = \frac{n_A}{n_B} \]

If \( G_{IA} \) is considered

\[ G_{IB} = \frac{n_B}{n_A} \times G_{IA} \]

6. Total cycle time:

\[ T = (G_{IA} + AA) + (G_{IB} + AB) \]

7. Red time:

\[ PA = G_{IB} + G_{AB} \]
\[ P_B = G_{IA} + AA \]

8. Don't walk period:

\[ DwA = G_{IA} + GA \]
\[ DwB = G_{IB} + GB \]
c) Clearance Interval:  
\[ C_{IA} = \frac{W_A}{1.2} \]  
\[ C_{IB} = \frac{W_B}{1.2} \]

(55)

(6) Walk Period:  
\[ W_A = P_A - C_{IA} \]  
\[ W_B = P_B - C_{IB} \]

(9) Webster's Method: This method is based on normal flow (traffic volume) & saturation flow on two road.

Normal: Saturation:

A → na SA  
B → nb SB

1. \( \gamma_A = \frac{na}{SA} \), \( \gamma_B = \frac{nb}{SB} \)

2. \( \gamma = \gamma_A + \gamma_B = \gamma \)

3. Optimum Cycle Time

\[ C_0 = \frac{1.5L + 5}{(1 - \gamma)} \]

4. \( T = \) Total lost time per cycle.

\[ T = (2 \cdot n + R) \]

5. \( n = \) No. of phase.  
6. \( R = \) All Red time (Generally 16 sec)
4. Green Time required:

\[ G_A = \frac{N_A \times (C_0 - L)}{Y} \]
\[ G_B = \frac{N_B \times (C_0 - L)}{Y} \]

5. IRC Method: It is a combination of Approximate method, Webster method & another check suggested.

Design Speed Step:

1. Use approximate method:

\[ T = (G_A + A_A) + (G_B + A_B) \]

2. IRC Check

Calculate NO. OF Vehicles accumulated on two road in one cycle time:

\[ \text{Road } A = \frac{N_A \times T}{60 \times 60} \]

Min Green Time required to clear all traffic

\[ = 6 \text{ Sec.} + (C_0 - 1) \times 2 \text{ Sec.} \]

For first vehicle

For remaining

\[ A_A = \frac{N_A \times T}{60 \times 60} \]

\[ C_0 \times A_B = 6 + (C_0 - 1) \times 2 \text{ Sec.} \]

\[ G_A \& G_B \text{ calculated by approximate method should not be less than above values.} \]
(a) Check by Webster method:

<table>
<thead>
<tr>
<th>Approach road width</th>
<th>Saturation flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 m</td>
<td>1850</td>
</tr>
<tr>
<td>3.5 m</td>
<td>1890</td>
</tr>
<tr>
<td>4.0 m</td>
<td>1952</td>
</tr>
<tr>
<td>4.5 m</td>
<td>2250</td>
</tr>
<tr>
<td>5.0 m</td>
<td>2550</td>
</tr>
<tr>
<td>5.5 m</td>
<td>2990</td>
</tr>
<tr>
<td>&gt; 5.5 m</td>
<td>525 Veh/hour per meter width of road</td>
</tr>
</tbody>
</table>

Problem: A right-angle intersection for two roads A & B

<table>
<thead>
<tr>
<th>Road A</th>
<th>Road B</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. oflan</td>
<td>6</td>
</tr>
<tr>
<td>Width</td>
<td>19.0m</td>
</tr>
<tr>
<td>Value of traffic in one direction</td>
<td>1360 Veh/hr</td>
</tr>
<tr>
<td>In other direction</td>
<td>1250 Veh/hr</td>
</tr>
<tr>
<td>Amber time</td>
<td>4.5 sec</td>
</tr>
</tbody>
</table>

Solution:

Design volume per lane for Road A = \( \frac{1360}{3} \) = 453

\[ \text{3 lane road} \]
For road $B = 810 = NB$

(1) Approximate method:

(a) Min Green time for pedestrian:

$G_{PA} = 7 \text{ sec} + \frac{W_A}{1.2}$

$G_{PA} = 7 + \frac{19}{1.2} = 22.83 \text{ sec} \approx 23 \text{ sec}$

$G_{PB} = 7 + \frac{45/1.2} = 13.85 \text{ sec} \approx 14 \text{ sec}$

(b) Min delay time on traffic signal

$PA = G_{PA} = 23 \text{ sec}$

$PB = G_{PB} = 14 \text{ sec}$

(c) Min green time on traffic signal

$G_{IA} = P_B - P_A$

$= 14 - 23 = 10 \text{ sec}$

$G_{IB} = P_A - P_B = 23 - 4 = 19 \text{ sec}$
(i) if \( g_A = 10 \) sec, it is considered

\[
\frac{g_A}{g_B} = \frac{n_A}{n_B}
\]

\[
g_B = \frac{n_B}{n_A} \cdot g_A
\]

\[
g_B = \frac{2}{3} \times 10 = 6.67 \text{ sec.} < g_B \Rightarrow
\]

if \( g_B = 19 \) sec, it is considered.

\[
g_A = \frac{n_A}{n_B} \cdot g_B
\]

\[
g_A = \frac{454}{310} \times 19 = 27.87 \text{ sec.}
\]

Total cycle time

\[
T = (g_A + \Delta t) + (g_B + \Delta B)
\]

\[
T = (18 + 4) + (19 + 4)
\]

\[
T = 55 \text{ sec}
\]

(ii) Check for IRE method.

Check for green time required to clear traffic

\[
\text{Total no. of vehicles accumulated in one cycle time}
\]

\[
\text{on road A} = \frac{n_A}{60 \times 60} \times T
\]

\[
\text{on road A} = \frac{151}{60 \times 60} \times 55 = 6.91 \text{ cars}
\]

\[
g_A = 6.91 \text{ sec.} < 27.87 \text{ sec. calculated}
\]

\[
\text{on road B} = \frac{n_B}{60 \times 60} \times 55
\]

\[
x_B = 4.76 \text{ cars}
\]
G_n = 6 + (5-1) \times 2.86 \\
G_n = 14.86 < 19.86 \text{ provided o.k.}

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 = \( \frac{19}{2} = 9.5 \text{ m} \)
\[ S_A = 9.5 \times 825 = 4987.5 \text{ veh/hr/lane} \]
\[ S_A = \frac{4987.5}{3} \text{ veh/hr/lane} \]
\[ S_A = 1663 \text{ veh/hr/lane} \]

Road B) for width = \( \frac{3.5}{2} = 3.75 \text{ m} \)
\[ S_B = \frac{1890 + 1950}{2} = 1920 \text{ veh/hr/lane} \]

\[ t_A = \frac{n_A}{S_A} = \frac{450}{1663} = 0.27 \]

\[ t_B = \frac{n_B}{S_B} = \frac{310}{1920} = 0.16 \]

\[ t = t_A + t_B = 0.27 + 0.16 = 0.43 \]

Total lost time \( L = 2n_t f^2 = 2 \times 2 + 16 = 20 \text{ sec.} \)

Optimum cycle time
\[ C_0 = \frac{1.5L + \delta}{1 - t} \]
\[ C_0 = \frac{1.5 \times 20 + 5}{1 - 0.48} = 61.4 \text{ sec} \]

\[ G_p = \frac{G_p (C_0 - L)}{C_0} = \frac{0.27}{0.48} (61.4 - 70) \]

\[ G_p = 46.8 \text{ sec} < 28 \text{ sec} \quad (\text{provided OK}) \]

\[ G_\beta = \frac{G_\beta (C_0 - L)}{C_0} = \frac{0.16}{0.48} (61.4 - 20) \]

\[ G_\beta = 15.4 \text{ sec} < 19 \text{ sec} \quad (\text{provided 80 ok}) \]

\[ P_A \]

\[ P_B \]

\[ P \]

1. Red Time
   \[ P_A = G_\beta + A_B = 19 + 4 = 23 \text{ sec} \]
   \[ P_B = P_{AA} + G_\beta = 28 + 3 = 32 \text{ sec} \]

2. Donot walk periods
   \[ P_{WWA} = G_{WA} + A_A = P_B = 32 \text{ sec} \]
   \[ P_{WWB} = G_{WB} + A_B = P_A = 23 \text{ sec} \]

3. Clearance Interval
   \[ C_{IA} = \frac{P_{WA}}{1.2} = \frac{19}{1.2} = 15.83 \text{ sec} \]
   \[ C_{IB} = \frac{P_{WB}}{1.2} = \frac{23}{1.2} = 19.17 \text{ sec} \]
56. ES 1995

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 = 4.5 sec
- Reaction time = 1.5 sec
- Retardation = 3 m/s²
- Car length = 4.6 m
- Intersection = 15 m

Solution:

Amber time is required for two purpose.
1. To allow the vehicle just head of danger area to cross the intersection

\[ SSD = 0.278 \times v^2 \times r + \frac{(0.278v)^2}{2g(F+0.1\gamma)} \]

\[ SSD = 0.278 \times 50 \times 1.5 + \frac{(0.278 \times 50)^2}{2 \times 9.81 (0.35)} \]

\[ = 48.98 \text{ m} \]
\[ = 49 \text{ m} \]

Total distance to be traveled to cross = SSD + WD + L

\[ = 49 + 15 + 4.5 = 68.6 \text{ m} \]

Required time traveled = \[ \frac{68.6}{0.278 \times 50} = 4.98 \text{ sec} \] > 4.5 sec

Yes, danger zone exist for crossing vehicle.

2. For stopping vehicle

Total time required to stop = Reaction time + Braking time

Braking time = \[ t = \frac{0.278 \times 50}{a} \]

\[ = 4.63 \text{ sec} \]

Total time = 1.5 + 4.63 = 6.13 sec > 4.5 sec

So, yes driver claim is correct.
Problem: The speed-density relationship for a particular road was found to be \( u = 42.76 - 0.22k \).

If \( u \) is speed in km/hr.

\( k \) is density in Veh/km.

Find the capacity of road.

Give your comment on the result. Sketch relationship between density & flow & show an important traffic flow parameter.

Solution: Speed \( u = 42.76 - 0.22k \)

Capacity of the road = Traffic volume

\[
C = \text{Speed} \times \text{density} = \frac{\text{km/hr}}{\text{km/hr}} = \text{Veh/hr}
\]

\[ C = u \times k \]

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

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

If \( C = 0 \), \( k = 0 \)

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

\[ k = \frac{42.76}{0.22} = 194.36 \]

For max \( C \)

\[ \frac{dC}{dk} = 42.76 - 0.22 \implies k = 0 \]

\[ k = \frac{42.76}{0.44} = 97.18 \]

Max \( C \)

\[ C = 42.76 \times 97.18 - 0.22 \times 97.18^2 \]

\[ C = 2078 \]
Comment:
1. Relation $b/w$ $c$ & $k$ possible.
2. Value of $c_b$ zero to $k = 0$ & $k = 94.36$ Ve$h/\text{hr}$.
3. Value of capacity increases with increase in density up to 97-18 Ve$h/\text{hr}$ where $c_b$ max = 207.8 Ve$h/\text{hr}$ after which capacity reduces.

Design of Tetrapod Intersection:

1. Shapes:
   - Circular:
   - Elliptical:
   - Turbine:
   - Tangential:
2. Design Speed Values:
   - Rural area = 40 kmph
   - Urban area = 30 kmph

3. Radius of Circle:
   - No SE 18 provided: $e = 0$
   - $R_{min} = \frac{V^2}{12T(1+e)} = \frac{V^2}{12T}$
   - Value of $F = 0.43 \Rightarrow 40$ kmph
   - $0.47 \Rightarrow 30$ kmph
Radius of entry curve:

\[ R_{entry} = 20 \text{ to } 35 \text{ m} \rightarrow \text{For } 40 \text{ kmph} \]
\[ = 15 \text{ to } 25 \text{ m} \rightarrow \text{For } 30 \text{ kmph} \]

5. Min. radius of central island:

\[ = 1.23 \times R_{entry} \]

6. Width of entry = \( e_1 \)

Minimum = 5 m

Asphalt road width:

<table>
<thead>
<tr>
<th>Width (m)</th>
<th>Value (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 m</td>
<td>6.5 m</td>
</tr>
<tr>
<td>10.5 m</td>
<td>7.0 m</td>
</tr>
<tr>
<td>14.0 m</td>
<td>8.0 m</td>
</tr>
</tbody>
</table>

7. Width of non-weakening section = \( e_2 \)

If no value suggested, take \( e_2 = e_1 \)

8. Width of weakening section (\( w \)):

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

9. Length of weakening section (\( L \)):

\[ L = 4w \text{ min.} \]

Recommended Values:

For 40 kmph → 45 to 90 m
For 30 kmph → 30 to 60 m
(b) Capacity of flyover: 

\[ C = \frac{280W (1 + \frac{e}{W}) (1 - 1/3)}{(1 + W/L)} \]

Where: 
- \( W \) = Width of weaving section
- \( e = \frac{e_1 + e_2}{2} \)

\( p \) = Weaving ratio = \( \frac{b+c}{(a+b+c+d)} \)

\( L \) = Length of weaving section

Weaving ratio is ratio of weaving traffic to total traffic on both lanes. (value b/a 0.45 to 1.0)
Problem:
A road intersection has five legs designed 0.3, 1, 2, 3, 4. Leg 1 is in N-S direction & others are marked clockwise.

\[
\begin{align*}
V_{12} & \rightarrow 32 \quad V_{31} \rightarrow 46 \quad V_{41} \rightarrow 18 \quad V_{51} \rightarrow 45 \\
V_{13} & \rightarrow 303 \quad V_{32} \rightarrow 12 \quad V_{42} \rightarrow 34 \quad V_{52} \rightarrow 132 \\
V_{14} & \rightarrow 64 \quad V_{34} \rightarrow 47 \quad V_{43} \rightarrow 18 \quad V_{53} \rightarrow 62 \\
V_{15} & \rightarrow 52 \quad V_{35} \rightarrow 68 \quad V_{45} \rightarrow 116 \quad V_{54} \rightarrow 15 \\
\end{align*}
\]

Find the weaving ratio for long 122 what the use of this value? Draw a sketch showing the traffic volume b/w 122.

Solution:

For weaving ratio b/w 122

\[
\begin{align*}
a = V_{12} & = 32 \\
b = V_{13} & + V_{14} + V_{15} \\
c = 303 + 64 + 52 = 419 \\
d = V_{32} + V_{42} + V_{52} \\
e = 122 + 54 + 132 = 300 \\
\end{align*}
\]
\[ d = V_{w3} + V_{w3} + V_{w4} \]
\[ d = 90 + 62 + 15 \]
\[ d = 167 \]

Weaving ratio \( p = \frac{b+c}{a+b+c+d} = \frac{34 + 419 + 308}{37 + 419 + 308 + 95} \)

\[ p = 0.846 \]

1. Weaving ratio is ratio of weaving traffic to total traffic.
2. It is used to calculate capacity of rotary.

Problem: Traffic flow in an urban area at right angle with section of two major roads, in the design year are given below. Total width of carrying way is 15 m.

Traffic Flow

<table>
<thead>
<tr>
<th>Approach Road</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>300</td>
<td>550</td>
<td>200</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>800</td>
</tr>
</tbody>
</table>

Design a four way rotary intersection and check for practical capacity marking suitable assumptions as per...

Solution: Weaving ratio:

1. Between North to East (NE)
   \[ a = 45 \]
   \[ b = 650 + 300 = 950 \]
   \[ c = 300 + 225 = 525 \]
   \[ d = 300 \]
\[ P = \frac{b+c}{a+b+c+d} = \frac{9.50 + 7.25}{415 + 9.50 + 7.25 + 380} \]

\[ P = 0.70 \]

3. Between E-S
   - \( a = 300 \)
   - \( b = 550 + 250 = 800 \)
   - \( c = 650 + 300 = 9.50 \)
   - \( d = 300 \)
   - \[ P = \frac{800 + 9.50}{800 + 300 + 9.50 + 380} = 0.745 \]

4. Between S-E
   - \( a = 350 \)
   - \( b = 400 + 2.5 = 625 \)
   - \( c = 550 + 300 = 850 \)
   - \( d = 250 \)
   - \[ P = \frac{625 + 850}{350 + 625 + 850 + 250} = 0.71 \]
Between A-N

\( a = 400 \)
\( b = 800 + 300 = 800 \)
\( c = 400 + 250 = 650 \)
\( d = 2.25 \)

\[
P = \frac{800 + 650}{400 + 800 + 6.10 + 2.25} = 0.698 \approx 0.70
\]

we use
\( P = 0.745 \)

capacity
\( c = \frac{280 \times w \left( 1 + \frac{e}{w} \right) \left( 1 - \frac{P}{3} \right)}{(1 + \frac{w}{L})} \)

\( e_1 = 6.5 \text{ m (for 7.5 m)} \)
\( e_2 = e_1 \)
\( e = \frac{e_1 + e_2}{2} = 6.5 \text{ m} \)
\( W = \frac{e_1 + e_2 + 3.5}{2} = 6.5 + 3.5 \)
\( W = 10 \text{ m} \)
\( L = 4 \times W = 40 \text{ m} \)

\[
c = \frac{280 \times 10 \left( 1 + \frac{6.5}{10} \right) \left( 1 - \frac{0.745}{3} \right)}{(1 + \frac{10}{40})}
\]

\[
c = 2798 \text{ veh/hm}
\]
Pavement Design

Types:
1. Flexible Pavement:
   - Constructed by using stone aggregate with binder materials like earth, bitumen.
   - 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 transfer is 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.
   - Flexural strength is high.
   - Load transfer is by slab action.
   - It can bridge over minor undulations.
8. Semi-rigid pavement: Semi-rigid pavement constructed by using soil cement soil lime mixture, Pozzolana 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 (EwL) = 40.85 kN

2. Stress due to a wheel load below ground level:

\[
\sigma = \frac{P}{2\pi r (a^2 + z^2)^{3/2}} \\
\text{Boussinesque's Eq.}
\]

\( P = \) surface pressure

\( r, a, z = \) radius of contact area, depth below ground, due to load \( P \)
3. ESWL - For a dual wheel assembly:

IF $S =$ centre to centre distance b/w wheels,
$d =$ clear distance b/w wheels
$At = \frac{d^2}{2} \text{ depth} = \text{ESWL} = P$
$at 2S \text{ depth} = \text{ESWL} = 2P$
Problem: Calculate ESWL of a dual wheel assembly, assuming 2050 kg each wheel, for pavement thickness 15, 20, 25 cm. If c/l spacing H.W. types is 30, 30 cm distance H.W. types is 20 cm.

Solution:

\[ S = 30 \text{ cm} \]
\[ d = 12 \text{ cm} \]
\[ d/2 = 6 \text{ cm} \]
\[ P = 2050 \text{ kg} \]
\[ E_{SWL} = P = 2050 \text{ kg} \]

at 25 depth = 2 x 60 = 120, 601
\[ E_{SWL} = 2P = 4100 \text{ kg} \]

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Log(depth)</th>
<th>E_{SWL} (kg)</th>
<th>Log(E_{SWL})</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.778</td>
<td>2050</td>
<td>3.312</td>
</tr>
<tr>
<td>15</td>
<td>1.176</td>
<td>2903</td>
<td>3.432</td>
</tr>
<tr>
<td>20</td>
<td>1.301</td>
<td>2947</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1.398</td>
<td>3182</td>
<td>3.613</td>
</tr>
<tr>
<td>30</td>
<td>1.778</td>
<td>4100</td>
<td></td>
</tr>
</tbody>
</table>

\[
3.312 + \frac{(3.613 - 3.312)}{(1.778 - 0.778)} \times (1.778 - 0.778)
\]

\[
3.312 + (3.613 - 3.312) \times (1.398 - 0.778)
\]

\[
3.312 + (3.613 - 3.312) \times (1.398 - 0.778)
\]
1. Rigidty Factor:

- Tyre Pressure is effective for top layers (surface layer only).
- Contact pressure effect on bottom layers.

2. 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

\[ G.I. = 0.2a + 0.005ac + 0.01bd \]

\[ a = P - 25 \leq 40 \]
\[ b = P - 15 \leq 40 \]
\[ c = P \leq 40 \leq 80 \]
\[ d = 10 \leq 20 \]

\[ T = 9 \]

<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</td>
<td>&lt;7 kg/cm²</td>
<td>7 kg/cm²</td>
</tr>
<tr>
<td>Contact Pressure</td>
<td>7</td>
<td>Tyre Pressure</td>
<td>&lt;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>
\[ P = \text{percent fines passing from 0.07 mm sieve.} \]
\[ W_L = \text{liquid limit} \]
\[ I_p = \text{plasticity index} \]

- 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 value.
- Table & charts are used.

<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>

Limitations:

- 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:

\[ P = 60\% \]
\[ \omega_L = 45\% \]
\[ \omega_P = 20\% \]

Plasticity Index, \( I_P = \omega_L - \omega_P = 25\% \)

\[ a = P - 35 = 60 - 35 = 25 < 40 \text{ OK} \]
\[ b = P - 15 = 60 - 15 = 45 > 40 \text{ OK} \]
\[ c = \omega_L - 40 = 45 - 40 = 5 < 20 \text{ OK} \]
\[ d = I_P - 10 = 25 - 10 = 15 < 20 \text{ OK} \]
Group Index:

\[ G_{1.1} = 0.04 + 0.005ae + 0.01 bd \]
\[ = (0.2 \times 25) + (0.005 \times 25 \times 5) + (0.01 \times 40 \times 15) \]
\[ = 11.625 \]

Total thickness required
\[ = 62 + \left( \frac{28 - 62}{15 - 10} \right) \times (11.625 - 10) \]
\[ = 69.2 \text{ cm} \]

2) CBR Method: (California bearing ratio method):

CBR Value (CBR Test)

1) A soil sample is kept in a vessel and load is applied over soil. Load value and corresponding penetration both are measured.

2) Load values for 2.5 mm & 5.0 mm penetration are found (say P1 & P2)

3) These load are compared with standard load values of 25 mm & 50 mm penetration over standard aggregate

   Standard load values
   
   For 2.5 mm \( \rightarrow 1390 \text{ kg} \)
   For 5.0 mm \( \rightarrow 2055 \text{ kg} \)

4) CBR Value

   For 2.5 mm \( \rightarrow \frac{P1}{1390} \times 100 = CBR_{2.5} \)
   For 5.0 mm \( \rightarrow \frac{P2}{2055} \times 100 = CBR_{5.0} \)
6. Generally a 5 mm CBR value is found more. In this case the value is accepted as CBR value.

6. If 5.0 mm CBR value is higher
   → Test is repeated, if same result are not 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 loose soil sample. In this case origin is got shifted by drawing a tangent from steepest point of curve to x-axis.

8. Design of pavement:

   Thickness of pavement

   $$ T = \sqrt{\frac{1.95P}{CBR} - \frac{P}{P_{11}}} $$

   Here, P = wheel load (in kN)
   h = True pressure = P/A
A = Contact area = \( \pi a^2 \)

- \( a \) = radius of contact area

CBR = CBR value is 1.7

Limitation:
- Same as G.I.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>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>48</td>
<td>49.8</td>
<td>59</td>
<td>70</td>
<td>79</td>
</tr>
</tbody>
</table>

Following material are required to be used over this soil subgrade:

- (a) Compacted soil (CBR = 6%)
- (b) Poorly graded gravel (CBR = 12%)
- (c) Well graded gravel (CBR = 60%)
- (d) Bituminous surface of 10m thick

Design the pavement using C.B.R method.

If wheel load = 1100 kg

Type pressure = \( 7 \text{ kN/m}^2 \)

Solution:
- \( P_1 = 60 \text{ kg} \) → for 2.5 mm
- \( P_2 = 82 \text{ kg} \) → for 5.0 mm

Well graded gravel

Poorly graded gravel

Compacted soil (CBR)

Sor& Sub graded CBR
CBR (2.5) = \frac{P_1}{1370} \times 100 = \frac{60}{1370} \times 100 = 4.38\% \\

CBR (5.0) = \frac{P_2}{2055} \times 100 = \frac{82}{2055} \times 100 = 3.99\%

\( T_1 = \sqrt{\frac{1.75P}{CBR} - \frac{P}{P_{TR}}} = \sqrt{\frac{1.75 \times 1100}{4.38} - \frac{4100}{7 \times 11}} \)

\( T_1 = 38.10\text{ cm} \) - Say 39 cm

Total thickness required above compacted soil (CBR = 6.1)

\( T_2 = \sqrt{\frac{1.75 \times 1100}{6}} = \frac{4100}{7 \times 11} \approx 31.74\text{ cm} \) \( \approx 32\text{ cm} \)

Thickness of compacted soil req.

\( T_1 - T_2 = 39 - 32 = 7\text{ cm} \)
(4) Total thickness required above poorly graded gravel

\[ T_3 = \sqrt{\frac{1.75 \times 9100}{12} - \frac{4100}{7 \times 11}} = 20.28 \text{ cm} \]

Day 21 cm

Thickenss of poorly graded gravel

\[ T_2 - T_3 = 32 - 21 = 11 \text{ cm} \]

(5) Thickness of well graded gravel

\[ T_3 - y = 21 - 4 = 17 \text{ cm} \]

Method:

3. California R-value (Resistance value) method:

This method is based on:

1. Stabilometer - R' Value
2. cohesion meter - C' Value

Thickenss of pavement required

\[ T (\text{cm}) = \frac{k \times T_1 (90 - R)}{C \times Y} \]

If k = Constant

\[ T_1 = \text{Traffic Index based on (Ewl) Value} = 1.35 (Ewl)^{0.11} \]

Thickness of pavement required

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

\[ T = 0.22 (Ewl)^{0.11} (90 - R) \]
Annual average of Equivalent wheel load based on AADT value for different class of wheel. As per no. of axle 180.

<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>3750</td>
<td>470</td>
<td>320</td>
<td>120</td>
</tr>
</tbody>
</table>

Assume 60% increase in traffic in next 10 years. Then calculate thickness of pavement required. In this case, if

- R-value = 148
- C-value = 16

Use California R-value method.

Solution: EWL of present.
<table>
<thead>
<tr>
<th>No. of axle</th>
<th>Aadt volume</th>
<th>EWL constant</th>
<th>Total EWL value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3750</td>
<td>330</td>
<td>1237500</td>
</tr>
<tr>
<td>3</td>
<td>470</td>
<td>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>

\[ \text{Total present EWL} = 3082000 \]

\[ \text{EWL of next 10 year} = 1.6 \times 3082000 = 4931200 \]

\[ \text{Average value} = \frac{3082000 + 4931200}{2} = 4006600 \]

\[ \text{Total EWL for 10 year period} = 10 \times 4006600 = 40066000 \]

\[ \text{Traffic index} = 1.35 \times (\text{EWL})^{0.11} = 1.35 \times (40066000)^{0.11} \]

\[ TI = 9.26 \]

\[ T = \frac{K \times TI \times (90 - R)}{c} \times 5 \]

\[ T = 0.166 \times 9.26 \times (90 - 48) \times 5 \]

\[ T = 37.08 \text{ cm} \]

\[ \text{Ans.} \]
Problem: Calculate equivalent 'c' value of a three layer pavement section having individual 'c' value as:

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>C-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous Pavement</td>
<td>12.5 cm</td>
<td>62</td>
</tr>
<tr>
<td>Cement treated Base</td>
<td>25.0 cm</td>
<td>180</td>
</tr>
<tr>
<td>Well graded gravel</td>
<td>20 cm</td>
<td>25</td>
</tr>
</tbody>
</table>

Solution:
Convert all thickness in terms of well graded gravel

\[ T_{B} = 12.5 \text{ cm} \quad T_{W} = 9 \]
\[ C_{B} = 62 \quad C_{W} = 25 \]

\[ \Rightarrow \frac{T_{B}}{T_{W}} = \left( \frac{C_{W}}{C_{B}} \right) \Rightarrow \frac{T_{B}}{T_{W}} \left( \frac{C_{B}}{C_{W}} \right)^{Y_{5}} = T_{W} \]

\[ T_{W_1} = 12.5 \left( \frac{62}{25} \right)^{Y_{5}} = 14.96 \text{ cm} \]

2. Cement treated Base

\[ T_{C} = 25 \quad T_{W_2} = 9 \]
\[ C_{C} = 180 \quad C_{W} = 25 \]

\[ T_{W_2} = T_{C} \left( \frac{C_{C}}{C_{W}} \right)^{Y_{5}} = 25 \left( \frac{180}{25} \right)^{Y_{5}} \]

\[ T_{W_2} = 37.10 \text{ cm} \]

3. Well graded gravel

\[ T_{W_3} = 20 \text{ cm} \]
Total thickness of pavement in terms of well graded gravel

\[ T_{\text{total}} = T_{w1} + T_{w2} + T_{w3} \]

\[ T_{w1} = 14.98 \text{ cm} \]
\[ T_{w2} = 37.10 \text{ cm} \]
\[ T_{w3} = 20 \text{ cm} \]

\[ C_w = 25 \]
\[ T_p = 57.5 \text{ cm} \]
\[ C_p = 8 \]

\[ \frac{T_{w1}}{T_p} = \left( \frac{C_p}{C_w} \right)^{\frac{1}{5}} \]

\[ C_p = C_w \left( \frac{T_{w1}}{T_p} \right)^{\frac{1}{5}} = 25 \left( \frac{14.98}{57.5} \right)^{\frac{1}{5}} \]

\[ C_p = 77.38 \]

Problem: Design a flexible pavement using WBM Base Course. It is 7.5 cm thick, bituminous pavement. By using the 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>TR</th>
<th>Pe</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.5%</td>
<td>58</td>
<td>0.135</td>
<td>36.5</td>
<td>38.70 cm</td>
<td>64.3</td>
</tr>
<tr>
<td>18.7%</td>
<td>41</td>
<td>0.099</td>
<td>26.5</td>
<td>42.20</td>
<td>47.1</td>
</tr>
<tr>
<td>21.7%</td>
<td>25</td>
<td>0.055</td>
<td>18.0</td>
<td>59.60</td>
<td>76.2</td>
</tr>
<tr>
<td>24.1%</td>
<td>14</td>
<td>0.034</td>
<td>-15.0</td>
<td>67.7</td>
<td>16.3</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

\[ T_R = \frac{k \cdot T_i \cdot (90-R)}{c_y s} \]

2. Thickness is calculated as per expansion pressure

\[ T_e = \frac{\text{Expansion pressure (kg/cm}^2\text{)}}{\text{Soil density (0.0021 kg/cm}^3\text{)}} \text{ cm} \]

- 2100 kg/m\(^3\)
- 2100 kg/m\(^3\)

3. Plot \( T_R / T_e \) on a graph sheet. Draw a suitable line-fitting point show the value where

\[ T_R = T_e = T_i \text{ cm} \]

4. Find out thickness corresponding to 28 kg/cm\(^2\) exudation pressure. Say \( T_e \text{ cm} \)

5. Thickness of pavement

\[ T = \text{higher of } T_i \text{ or } T_e \]
(a) Thickness as per R-value (using warm layers)

\[ T_R = \frac{0.166 \times 9.5 \times (90 - R)}{(15) Y5} \]

\[ T_R = 0.9145(90 - R) \]

\[ T_R = 0.9145 \times (90 - 56) \]

\[ T_R = 31.20 \text{ cm} \]

\[ T_{R1} = 0.9145 \times (90 - 44) \]

\[ T_{R2} = 42.20 \]

\[ T_{R3} = 59.6 \]

(b) Thickness as per expansion pressure

\[ T_e = \frac{\text{Exp pressure}}{0.0021} \]
Thickness of pavement \( t_1 = T_R = T_e = 40 \text{ cm} \)

3. \( T_R \) for 28 kg/cm²

Excavation pressure

\[ T_2 = 31.20 + \left( \frac{42.20 - 31.20}{36.5 - 36.5} \right) (36.5 - 28) \]

\[ T_2 = 40.55 \text{ cm} \]

4. Thickness of pavement required (in terms of WBM layer)

\[ = \max \{ t_1, t_2 \} \]

\[ = 44 \text{ cm} \]

\[ 9.96 \text{ cm} \quad \text{Bituminous} \]

\[ 340 \text{ cm WBM} \]

7.5 cm thickness of Bituminous

\[ T_B = 7.5 \text{ cm} \quad C_B = 6.2 \]

\[ T_w = 9 \quad C_w = 15 \]

\[ T_{tw} = T_B \left( \frac{C_B}{C_w} \right) \]

\[ T_{tw} = 7.5 \left( \frac{6.2}{15} \right) = 9.13 \text{ cm} \]

Net thickness of WBM layer

\[ 44 - 9.96 \]

\[ 34.04 \text{ cm} \]
4) Terzaghi Method:

(1) Thickness of pavement required

For single layer: \( t = \sqrt{\left( \frac{3p\chi}{2\Pi E_s\alpha^2} \right)^2 - \alpha^2} \)

\( p = \) unbalanced load in kg
\( \chi = \) Traffic coefficient
\( Y = \) Rainfall coefficient
\( E_s = \) Young's modulus of soil subgrade (kg/m²)
\( a = \) radius of critical area in cm
\( \Delta = \) Design deflection in cm

For two-layer system:

\[ t_p = \sqrt{\left( \frac{3p\chi}{2\Pi E_p\alpha^2} \right)^2 - \alpha^2} \times \left( \frac{E_s}{E_p} \right)^{1/3} \]

\( E_s = \) Young's modulus of soil subgrade
\( E_p = \) pavement

\( t_p = \) Thickness of pavement in cm.

Two Layer System

\[ \text{Pavement} \]

\[ \text{Ep} \]

\[ \text{Es} \]

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 with
wheel load = 11000 kg
Radius of contact area = 15 cm
Traffic coeff = 1.6
Rainfall coeff = 0.7
Design deflection = 0.25 cm
Pavement consists of
Bituminous layer = 6 cm
Base course = EB = 360 kg/cm²
Soil Subgrade = ES = 120 kg/cm²

Solution: Let us design thickness of base course material over soil subgrade

Thickness of base course material
req.
Two layer system

\[ T_1 = \left( \sqrt{\frac{3P \gamma}{211E_sA}} \right)^2 - \alpha^2 \left( \frac{E_b}{E_s} \right)^{1/3} \]

\[ T_1 = \left( \sqrt{\frac{3 \times 460 \times 0.7}{211 \times 120}} \right)^2 - 15^2 \left( \frac{360}{120} \right)^{1/3} \]

\[ T_1 = 48.3 \text{ cm} \to \text{(Total thickness of pavement) note} \]

Top layer of bitumen = 6 cm
- \( T_{\text{bit}} = 6 \text{ cm} \)
- \( E_{\text{bit}} = 1900 \)
- \( T_{\text{base}} = 9 \text{ cm} \)
- \( E_{\text{base}} = 360 \)
\[
\frac{P_{\text{base}}}{P_{\text{fill}}} = \left( \frac{E_{\text{fill}}}{E_{\text{base}}} \right)^{\frac{1}{2}} = 18.9
\]

\[
P_{\text{base}} = P_{\text{fill}} \left( \frac{E_{\text{fill}}}{E_{\text{base}}} \right)^{\frac{1}{2}} = 6 \times \left( \frac{12,000}{360} \right)^{\frac{1}{2}}
\]

\[
P_{\text{base}} = 8.96 \text{ cm}
\]

Net thickness of base course = 48.38 - 8.96 = 39.42 cm

6 m of fill + Base course

39.42 cm + 6 m of fill

5. Gumaste’s Method:

This method is also based on Young's modulus of elasticity of different layers of pavement.

As per layer system

\[E_{\text{surface}} > E_{\text{base}} > E_{\text{sub base}} > E_{\text{sub graded}} = \text{Soil sub graded}\]

Assumptions:

1. Materials in each layer are isotropic, homogenous, & elastic.
2. Pavement forms a stiffer layer than soil sub graded (\(E_p > E_s\)).
3. Surface layer is infinite in horizontal direction but finite in vertical direction.
4. Layers are in continuous contact.
\[ \text{Consideration:-} \]

when stress are acting over a soil subgrade/over a pavement

1. Due to pavement layer, stresses are reduced largely within pavement layer.

\[ \text{If} \quad \frac{E_s}{E_p} = 10, \quad \frac{E_p}{E_s} = 10 \]

2. \( h = \alpha \) in this particular example, stresses reduced for 90% to 30% at particular location.

4. Design method:

Based on \( \frac{E_s}{E_p} \) and \( \frac{h}{\alpha} \) value, Barlow's introduced a factor called \( F_2 \)

\[ \begin{align*}
F_2 & \quad 0.5 \\
Y & \quad 1.5 \\
Y_0 & \quad 2.0 \\
Y_{10} & \quad 3.0 \\
Y_{50} & \quad 4.0 \\
Y_{100} & \quad 5.0 \\
Y_{500} & \quad 6.0 \\
\end{align*} \]
8. For a single layer system: (no pavement)
   \[ \text{then } h = 0 \]
   \[ \text{h} / \alpha = 0 \]
   \( F_2 = 1.0 \)

8. Displacement relationship by Duerinckx:
   a. For flexible plate:
      \[ \Delta = 1.5 \frac{P_0}{E_s} x F_2 \]
   b. For rigid plate:
      \[ \Delta = 1.18 \frac{P_0}{E_s} x F_2 \]

\( P = \) Pressure over surface (kg/cm²)
\( a = \) Radius of contact area (cm)
\( E_s = \) Modulus of Elasticity of soil subgrade (kg/cm²)
\( \Delta = \) Design deflection (cm)

9. a. Flexible plate:
   - When wheel load is acting over road surface, it is considere
     flexible case.
     \[ p = \frac{P}{A} \]

   b. 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 30 cm diameter plate on a soil subgrade yielded pressure of 1 kg/cm² at 5 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 kg/cm² & allocate deflection of 5 mm. Use Ceminski method.

Solution:

1. Plate load test over soil subgrade
   - Diameter of plate = 30 cm
   - Thickness = 15 cm
   - For single layer system, \( F_2 = 1 \)
   - Pressure = \( p = 1 \) kg/cm²
   - Deflection = \( \Delta = 0.5 \) cm

   This is rigid case.

   For a rigid plate, 
   \[
   \Delta = 1.19 \times \frac{p \cdot a}{E_s} \times F_2 
   \]
   
   \[
   0.5 = 1.19 \times \frac{1 \times 15}{E_s} \times 1 
   \]
   
   \[
   E_s = \frac{1.19 \times 15}{0.5} = 35.9 \text{ kg/cm}^2 
   \]

2. Plate load test over base course:
   - Thickness of pavement = 18 cm
   - Load = 5 kg/cm²
   - Deflection = 0.5 cm
   - 
   \[
   E_s = \frac{80 \times 2.1}{0.5} = 35.4 \text{ kg/cm}^2 
   \]

   (For two layer system)
For rigid plate

\[ \Delta = 1.190 \times \frac{P_a}{E_s} \times F_2 \]

0.5 = 1.190 \times \frac{5 \times 15}{35.4} \times F_2

Use the chart \( F_2 = 0.2 \)

\[ h = 100 \text{ cm} \]

\[ h/\alpha = 15/12 = 1.2 \]

Based on \( h/\alpha = 1.2 \) & \( F_2 = 0.2 \)

\[ \text{get: } \frac{E_s}{E_p} = \frac{1}{100} \]

\[ E_p = 100 \times E_s = 100 \times 35.4 \]

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

B 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 \times F_2}{35.4}

\[ F_2 = 0.133 \]

Use the chart

For \( F_2 = 0.133 \)

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

\[ h/\alpha = 1.9 \]

\[ h = 1.9 \times 14.75 \]

\[ h = 28.0 \text{ cm} \]
Rigid Pavement:

1. Modulus of Subgrade Reaction ($k$) 
   (of Soil Subgrade)
   \[ k = \frac{P}{\Delta} = \left( \frac{\text{kg}}{\text{cm}^2} \right) \]

2. Radius of Resisting Section
   \[ r = \frac{E h^3}{12 k (1 - \mu^2)} \]

3. Equivalent radius of resisting section (Area effective in resisting the load)
   \[ b = \sqrt{1.6 a^2 + h^2} - 0.675 h \]
   \[ b = a \]

4. Stresses due to load:
   Wester Guard's Stress equation
   \[ \sigma_1 = \frac{0.316}{h^2} P \left[ 4.1840 \left( \frac{1}{b} \right)^2 + 1.069 \right] \]
**Problem:**

1. Design wheel load = 4200 kg
2. Cement concrete $= 2.8 \times 10^5$ kg/cm$^2$
3. $h = 20$ cm
4. $e = 0.15$
5. $k = 7$ kN/cm$^3$
6. Radius of conflict area = 10 cm

**Solution:**

1. Radii of relative thickness

\[
L = \left( \frac{Eh^2}{13k(1-u^2)} \right)^{\frac{1}{2}} = \left( \frac{2.8 \times 10^5 \times 20^3}{13 \times 7 + 0.15^3} \right)^{\frac{1}{4}}
\]

$L = 23.29$ cm

2. Equivalent radius of resisting section

$a = 14$ cm, $h = 20$ cm

\[
a < 1.724 h
\]

\[
b = \sqrt{1.6a^2 + h^2} = \sqrt{1.6 \times 14^2 + 20^2} \approx 0.678 \times 20
\]

$b = 13.21$ cm
Load Stress (Using West-Guard equation)

(a) Interior Stress:
\[ S_1 = \frac{0.316}{h^2} \left[ 4.1 \log_{10}(\frac{1}{b}) + 1.069 \right] \]
\[ S_2 = \frac{0.316}{\pi} \left[ 4.1 \log_{10}(\frac{72.29}{18.21}) + 1.069 \right] \]
\[ S_3 = \frac{13.34 \text{ kg/cm}^2}{\text{cm}^2} \]

(b) Edge Stress:
\[ S_e = \frac{0.572}{h^2} \left[ 4.1 \log_{10}(\frac{1}{b}) + 0.359 \right] \]
\[ S_c = \frac{0.572}{\pi} \left[ 4.1 \log_{10}(\frac{72.29}{18.21}) + 0.359 \right] \]
\[ S_e = 19.89 \text{ kg/cm}^2 \]

(c) Corner Stress:
\[ S_c = \frac{3p}{h^2} \left[ 1 - \left( \frac{a \sqrt{2}}{h} \right)^{0.6} \right] \]
\[ S_c = \frac{3 \times 4200}{\pi} \left[ 1 - \left( \frac{10 \times \sqrt{2}}{72.27} \right)^{0.6} \right] \]
\[ S_e = 17.01 \text{ kg/cm}^2 \]
(1) Behaviour of load stresses:

1. Interior Stress:

(2) Edge Stresses:

\[ \frac{C}{(-)} \vee \frac{T}{(+)} \vee \]

(3) Corner Stresses:

(4) Temperature Stress:

(a) Warping Stress:

(i) During Stress:

\[ C (-) \vee T (+) \vee \]

(ii) During Night:

\[ C (-) \vee T (+) \vee \]

Expansion

Cable

Heated

Expansion

Comp.

Tension (+) \vee

Compression (-) \vee

Tension (-) \vee

Expansion
Values (bending Stresses)

1. Interior region: \( \sigma_{b1} = \frac{E \delta T}{2} \left[ \frac{C_x + \frac{1}{2} C_y}{1 - \frac{1}{2} \mu^2} \right] \)

\( E \) = Young's modulus of pavement
\( \delta \) = coefficient of thermal expansion
\( T \) = Temp. variation
\( C_x \) = Coefficient of \((-\frac{1}{2}x)\) in desired direction
\( C_y \) = (\(\frac{1}{2} C_y\))

\( l \) = radius of relative stiffness
\( \mu \) = Poisson ratio

<table>
<thead>
<tr>
<th>( \frac{L_x}{2} ) or ( \frac{L_y}{2} )</th>
<th>( C_x ) or ( C_y )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
</tr>
<tr>
<td>8</td>
<td>0.8</td>
</tr>
<tr>
<td>12</td>
<td>1.02</td>
</tr>
</tbody>
</table>

\( \frac{L_x}{2} \) or \( \frac{L_y}{2} \)

\( \frac{L_x}{2} \) or \( \frac{L_y}{2} \)
(2) Edge Stress (Warping)
\[ \sigma_{le} = \frac{C_x \cdot d \cdot E}{2} \text{ or } \frac{C_y \cdot d \cdot E}{2} \]
(whichever is more)

(3) Corner Stress:
\[ \sigma_{cc} = \frac{E \cdot t}{3(1-\mu)} \left( \sqrt{a^2 + b^2} \right) \]

(4) Torsional Stress:
Due to seasonal variation of temperature.

(a) During summer:
\[ c = (\tau) \cdot u \cdot e \]
\[ \tau = (\tau) \cdot u \cdot e \]

(b) During winter
Entire pavement will be tension

[Diagrams of expansion, compression, and stress diagram]
**Value of Functional Stresses:**

- **Functional Force**
  
  \[ F = Pr = F \left( \frac{1}{2} Bxh \times W \right) \]  

- **Resisting Force**
  
  \[ F_r = SFxBxh \]  

Equating eq. (1) \& (2)

\[ SFxh = F \cdot \frac{1}{2} L \times K \times K \times W \]

\[ SF = \frac{WFL}{2} \] [kg/m²]

\[ SF = \frac{WFL}{2 \times 10^4} \] [P]  

\[ SF \]  

\[ F \]  

\[ \text{Functional Stress developed} \]

\[ \text{Functional Stress developed} \]
<table>
<thead>
<tr>
<th>Interior</th>
<th>Load Stress</th>
<th>Day</th>
<th>Night</th>
<th>Functional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>C(-)</td>
<td>T(+)</td>
<td>C(-)</td>
<td>T</td>
</tr>
<tr>
<td>Bottom</td>
<td>T(+), T(+)</td>
<td>T(+)</td>
<td>C(-)</td>
<td>T[ ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Edge</th>
<th>Load Stress</th>
<th>Day</th>
<th>Night</th>
<th>Functional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>C(-)</td>
<td>T(+)</td>
<td>C(-)</td>
<td>T</td>
</tr>
<tr>
<td>Bottom</td>
<td>T(+)</td>
<td>T(+)</td>
<td>C(+)</td>
<td>T[ ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Corner</th>
<th>Load Stress</th>
<th>Day</th>
<th>Night</th>
<th>Functional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>T(+), C(-)</td>
<td>T(+)</td>
<td>C(-)</td>
<td>T</td>
</tr>
<tr>
<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 during night

   
   \[
   \text{Stress} = (\text{Load Stress}) + (\text{Warping Stress}) + (\text{Functional Stress})
   \]

   \[
   (Sc) + (Sde) + (Sf)
   \]

2. **At edge (Same as above)**

3. **At corner:**
   - **Worst Combination is:**
     1. At top
     2. At night
     3. At during winter

   
   \[
   \text{Stress} = (\text{Load Stress}) + (\text{Warping Stress}) + (\text{Functional Stress})
   \]

   \[
   (Sc) + (Sde) + (Sf)
   \]
Problem: A pavement slab 22 cm thick (cement concrete pavement) is constructed over a sub-base having \( K = 190 \text{ kg/m}^2 \). Spacing of joints are

- Transverse joint: 5.50 m
- Longitudinal joint: 4.20 m

\[ \rho = 4500 \text{ kg/m}^3 \]

\[ T = 30^\circ C \quad (\text{Seasonal}/\text{day} - \text{night}) \]

\[ a = 15 \text{ cm} \]

\[ E_c = 8 \times 10^5 \text{ kg/cm}^2 \]

\[ \mu = 0.15 \]

\[ q = 12 \times 10^6 \text{ /c'} \]

\[ F = 15 \]

Find out Stresses due to load / temp. & wind combination.

Solution:

1. Radius of Relative Stiffness,

\[ l = \left( \frac{E h^3}{12 K (1-\mu^2)} \right)^{1/4} = \left( \frac{3 \times 10^5 \times 22^3}{12 	imes 18 (1 - 0.15^2)} \right)^{1/4} \]

\[ l = 62.39 \text{ cm} \]

2. Equivalent radius of resisting section,

\[ a = 15 \text{ cm} \quad h = 22 \text{ m} \]

\[ a < 1.74h \]

\[ b = \sqrt{1.6a^2 + h^2} - 0.675h = \sqrt{1.6 \times 15^2 + 22^2} - 0.675 \times 22 \]

\[ b = 14.20 \text{ cm} \]

3. Load Stresses (webergaard's equation)

- Interior

\[ \sigma_{\text{int}} = \frac{q-a^2}{h^2} \left[ 4.01 \log_{10} \left( \frac{h}{a} \right) + 1.069 \right] \]
\[
2a3 \quad \mathcal{L} = \frac{4500}{22^2} \left( 4 \log_{10} \left( \frac{62.37}{34.80} \right) + 1.069 \right)
\]

\[
\sigma_L = 10.69 \text{ kg/cm}^2
\]

2) Edge Stress
\[
\sigma_e = \frac{0.572P}{h^2} \left[ 4 \log_{10} \left( \frac{49}{62.37} \right) + 0.359 \right]
\]

\[
\sigma_e = \frac{0.572 \times 4500}{22^2} \left[ 4 \log_{10} \left( \frac{62.37}{34.80} \right) + 0.359 \right]
\]

\[
\sigma_e = 15.58 \text{ kg/cm}^2
\]

3) Corner Stress
\[
\sigma_c = \frac{3P}{h^2} \left[ 1 - \left( \frac{15\sqrt{2}}{62.37} \right)^{0.6} \right]
\]

\[
\sigma_c = \frac{3 \times 4500}{22^2} \left[ 1 - \left( \frac{15\sqrt{2}}{62.37} \right)^{0.6} \right]
\]

\[
\sigma_c = 13.28 \text{ kg/cm}^2
\]

4) Warping Stresses:
\[
x = 5.80 \text{ m} = 580 \text{ cm}
\]
\[
y = 4.20 \text{ m} = 420 \text{ cm}
\]

\[
x = \frac{580}{22.82} = 8.82 \text{ (from Johnson's rule)}
\]

\[
y = \frac{420}{62.37} = 6.73 \text{ (from } 0.6 + \frac{1.1 - 0.60}{4} \times 3.73 = 2.09)
\]

5) Interior Stress
\[
\sigma_{ih} = \frac{E_t}{L^2} \left[ \frac{L_x + 11L_y}{11^2} \right]
\]

\[
\sigma_{ih} = \frac{3 \times 10^5 \times 412 \times 10^{-6} \times 220 \left[ \frac{1.04 + (0.15 \times 0.94)}{1 - 0.15^2} \right]}{2} = 48.20 \text{ kN/cm}^2
\]
6) Edge Stress: \[ S_{te} = \frac{C_{x} E_{xy}}{2} = \frac{1.05 \times 3 \times 10^{5} \times 10^{-6}}{2} \]
\[ S_{te} = 37.44 \text{ kg/cm}^2 \]

7) Corner Stress:
\[ S_{tc} = \frac{E X T}{3(1-\nu)} \left( \sqrt{0.14} \right) \]
\[ S_{tc} = \frac{3 \times 10^{5} \times 13 \times 10^{-6} \times 80}{3 \left(1-0.15\right)} \times \sqrt{15/73.37} \]
\[ S_{tc} = 13.85 \text{ kg/cm}^2 \]

8) Fractional Stress: \[ S_{f} = \frac{WLF}{2 \times 10^4} = \frac{2400 \times 5.5 \times 1.50}{2 \times 10^4} \]
\[ S_{f} = 0.99 \text{ kg/cm}^2 \]

9) First Combination:
1) Interior = At bottom during day + during winter
\[ S_{total} = S_{te} + S_{tc} + S_{f} \]
\[ = 10.69 + 43.50 + 0.99 \]
\[ = 55.18 \text{ kg/cm}^2 \to \text{most critical} \]

2) Edge = At bottom + during day + during winter
\[ S_{total} = S_{te} + S_{tc} + S_{f} \]
\[ = 13.89 + 18.84 + 0.99 \]
\[ = 52.71 \text{ kg/cm}^2 \]

3) Corner = At top + during night + during winter
\[ S_{total} = S_{te} + S_{tc} + S_{f} = 13.89 + 18.84 + 0.99 \]
Design of joints:

1. Expansion joints: Provided for allowing expansion due to \( T_c \) in excess.
   
   Max Spacing = 140 m

\[
\Delta = \text{Gap provided at expansion point}
\]

(This gap is such that (No) gap is always there even after expansion)

Total expansion allowed \( \Delta_1 \)

for one length of slab:

\[
L \cdot \Delta \left( T_2 - T_1 \right) = \Delta_1
\]
Spaing of Expansion joint

\[ L = \frac{A}{2 \times x \times (T_2 - T_1)} \]

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 T°C in summer season is 48°C, \( \alpha = 1.2 \times 10^{-6} / ^\circ C \)

Solution: Max. Expansion allowed

\[ \frac{S}{2} = \frac{2.0}{2} = 1.0 \text{ cm} \]

\[ L = (T_2 - T_1) \text{ cm} \]

Spacing of expansion joint

\[ L = \frac{1.0}{1.2 \times 10^{-6} \times (48 - 20)} \]

\[ L = 2976.2 \text{ cm} \]

\[ L = 30 m \]
Case (b) 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

\[ L = \frac{2 \times 10^4 S_f}{W.F.} \text{ m} \]

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.

\[ F = FR = (\frac{L}{2} \times b \times h \times W) \]

Face of resistance (by steel): →

\[ = A_{st} \times \sigma_{st} \]

\[ A_{st} \times \sigma_{st} = (\frac{L}{2} \times b \times h \times W) \]

Spacing of contraction joint:

\[ L = \frac{2 \times A_{st} \times \sigma_{st}}{W \times F \times h} \text{ (in meter)} \]

\( A_{st} = \text{Area of steel (cm}^2\)\
\( \sigma_{st} = \text{Permissible stress of steel (kg/cm}^2\)\
\( W = \text{unit weight (kg/cm}^3\)\
\( B = \text{width in meter} \)\
\( h = \text{depth in meter} \)
Problem: A pavement slab 4.5 m wide by 0.5 m thick. Design contraction joint, JF

1. PoE is used.
2. PoE is used.

\( F = 1.5 \), permissible stress for concrete in tension

\( = 0.9 \, \text{kg/cm}^2 \)

For ReE: 12 mm @ bars @ 300 mm dc has been used

\( f_{st} = 1400 \, \text{kN/m}^2 \)

Solution:

If 1, PoE is used

\( \Rightarrow \beta_{st} = \frac{F}{f_{st}} = \frac{F}{F = \frac{L}{2} \times \beta_{st} \times w} \)

Spacing of concrete joint

\( \Rightarrow L = \frac{2 \times f_{st} \times 10^4}{W F} = \frac{2 \times 10^4 \, \text{df}}{W F} \)

\( L = \frac{2 \times 10^4 \times 0.6}{2400 \times 1.5} \)

\( L = 2.14 \, \text{m} \)
when RCC is used:

\[ A_{\text{EST}} = F \times \frac{L}{2} \times B \times h \times w \]

Spacing of concrete contraction joint:

\[ L = \frac{2A_{\text{EST}}}{W \times F \times B \times h} \]

\[ L = 2 \times \frac{\left( \frac{4500}{300} \right) \times \frac{2}{4} (1.2)^2 \times 1400}{2500 \times 1.5 \times 4.5 \times 0.25} \]

\[ L = 11.26 \text{ m} \]

Design of the beam:

At longitudinal joints:

The bars are provided at longitudinal joint
\[ R = B \times 1 \times h \times w \]

Force of Friction \( F = F_R \)
\[ F = F \times B \times h \times w \]

\[ A_{st} \times c_{st} = F \times B \times h \times w \]

Choose a diameter:
\[ A_{st} = \frac{F \times B \times h \times w}{c_{st}} \]

Spacing of tie bars = \( \frac{10^{30}}{A_{st}} \times \frac{\pi (\phi)}{4} \)

Length of tie bars:
\[ \frac{A_{st} \cdot c_{st}}{\tau_{ld} \times \Sigma \circ \times L} \]

If \( \phi \times l \times c_{st} = \tau_{ld} \times l \times \phi \times L \times \gamma \)

\[ L = \frac{\phi \cdot c_{st}}{4 \cdot \tau_{ld}} \]

Length of tie bars = 2L
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 dimensions & spacing of bars using the following data:

Allowable working stress in steel:

\[ f_t = 1400 \text{ kg/m}^2 \]
\[ W = 2400 \text{ kg/m}^3 \]
\[ f = 1.5 \]

Allowable bond stress = 24.6 kg/m²

Solution:

\[
\begin{align*}
& B = 7.20/2 = 3.60 \text{ m} \\
& \text{Total width} = 2 \times B = 7.20 \text{ m} \\
& \text{Consider 1 m length of slab} \\
& F = FR
\end{align*}
\]

\[
A_{st} = \frac{F \cdot b \cdot h \cdot w}{60}
\]
$$A_{st} = \frac{1.5 \times 2.6 \times 0.24 \times 1 \times 2400}{1400}$$

$$A_{st} = 2.22 \text{ cm}^2$$

$$A_{st} = 222 \text{ mm}^2$$

Using 8 mm \(d\) bars

$$\text{Spacing} = \frac{1000}{222} \times \frac{\pi}{8} (8)^2$$

$$= 22.69$$

provided 8 mm \(d\) @ 220 mm c/c

8. length of the bars = \(24d\)

$$= \frac{24 \times 0.8 \times 1400}{4 \times 22.69}$$

$$= 23.76 \text{ cm} \cong 23 \text{ cm}$$
Dowel Bars

- In this case, no dowel bars provided.

Purpose of dowel bars:
1. To transfer the load of a wheel from one slab to another.
2. To reduce differential deflection between two slabs.

Design of dowel bars:

Dowel bars are designed only using Bresleby analysis.

- Value of $l_{d}$ (length of embedment):

$$l_{d} = 5d \left[ \frac{FE}{Fb} \times \frac{l_{d} + 15d}{l_{d} + 8.8d} \right]^{\frac{1}{2}}$$

by trial & error, $l_{d}$ is calculated.
(3) Total length of dowel bars: \( L_d + d \)

(3) Load carrying capacity of a single dowel bar.

(a) For Shear
   \[ p' = \frac{\pi d^3 f_s}{4} \]

(b) For Bending
   \[ p' = \frac{3.23 f_s E}{L_d + 0.5} \]

(c) For bearing
   \[ p' = \frac{f_0 \times \frac{L_d}{d} \times \frac{d}{d}}{0.5(L_d + 1.5d)} \]

The value of \( p' \) is considered min. of above three.

(4) Load carrying capacity of dowel group system

\[ = 0.40 \times 0.40 \times \text{wheel load} \]
\[ = 0.16 \times \text{wheel load} \]

(5) Required load carrying factor of dowel group system.

\[ = \frac{\text{load capacity of group}}{\text{load carrying capacity}} \]
\[ = \frac{0.40 \times \text{wheel load}}{p'} \]

(6) Capacity factor of dowel group system = 1.0

\[ = 1.0 \text{ for dowel bar just below wheel load.} \]
\[ = 0 \text{ for dowel bar at (1.8d) distance from wheel load.} \]

\[ R_A = \text{Radius ofrelative stiffness} \]
Total capacity factor of axial group system

\[ = 1.0 + \frac{(1.80 - s)}{1.80} + \left( \frac{1.80 - \frac{s}{2}}{1.80} \right) \]

\[ \text{The End} \]