STRUCTURAL CALCULATIONS

FOR

CONCRETE SLEEPER AND PANEL

Prepared by:
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60 Wyatt Street, Adelaide SA 5000
Ph: (08) 8223 7433

PROJECT NO. 150933

DOCUMENT NO: WGA150933-CA-ST-0003[D]

REV: D

DATE: 5th May 2020

<table>
<thead>
<tr>
<th>Rev</th>
<th>Date</th>
<th>Issue</th>
<th>Engineer</th>
<th>Checked</th>
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<td>A</td>
<td>09/05/2019</td>
<td>Client Issue</td>
<td>RS</td>
<td>CL</td>
</tr>
<tr>
<td>B</td>
<td>24/05/2019</td>
<td>Client Reissue</td>
<td>RS</td>
<td>CL</td>
</tr>
<tr>
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<td>03/04/2020</td>
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<td>NM</td>
<td>CL</td>
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<tr>
<td>D</td>
<td>05/05/2020</td>
<td>Client Reissue</td>
<td>NM</td>
<td>CL</td>
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</tbody>
</table>

The following Australian Standards have been used in the preparation of this design:

- AS 1170.0 Structural Design Actions Part 0: General Principles
- AS 1170.1 Structural Design Actions Part 1: Permanent, Imposed & Other Actions
- AS 3600 Concrete Structures
2m LONG SLEEPERS
Sleeper Length = 2000 mm  
Sleeper Depth = 200 mm  
Height of Wall = 2000 mm  
Thickness of Sleeper = 75 mm

| Project Number: 150933 |  
| Designer: NM |  
| Date: 03/07/2019 |  

**Parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Compressive strength of concrete</td>
<td>f’c = 60 MPa</td>
</tr>
<tr>
<td>Yield Strength of Steel Reinforcement (N Grade)</td>
<td>fsy = 500 MPa</td>
</tr>
<tr>
<td>Elastic Modulus Steel</td>
<td>Ec = 37400 MPa</td>
</tr>
<tr>
<td>f</td>
<td>b = 200 mm</td>
</tr>
<tr>
<td>d</td>
<td>d = 40 mm</td>
</tr>
<tr>
<td>Friction Angle of Soil</td>
<td>φ = 26.1°</td>
</tr>
<tr>
<td>Bulk Unit Weight of Backfill Soil</td>
<td>γs = 18 kN/m³</td>
</tr>
<tr>
<td>Surcharge</td>
<td>Q = 5 kPa</td>
</tr>
<tr>
<td>k</td>
<td>η₀ = 1.94 kPa</td>
</tr>
<tr>
<td>k</td>
<td>η₁ = 13.30 kPa</td>
</tr>
<tr>
<td>k</td>
<td>w₀ = 0.39 kN/m</td>
</tr>
<tr>
<td>k</td>
<td>w₁ = 2.66 kN/m</td>
</tr>
<tr>
<td>k</td>
<td>γ₀ = 0.60</td>
</tr>
</tbody>
</table>

**Design Actions:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>w’</td>
<td>1.25G’ + 1.5Q’</td>
</tr>
<tr>
<td>M’</td>
<td>w’L²/8</td>
</tr>
<tr>
<td>V’</td>
<td>w’L/2</td>
</tr>
</tbody>
</table>

**Flexural Strength of Sleeper**

Capacity Reduction Factor (bending) - AS3600 Table 2.2.2

\[ A_{st,req} = \frac{f'c b}{\sqrt{2fsy}} \left( d - \sqrt{d^2 - 2.4M'/\phi f'c b} \right) \]

| No. of bars | n = 2 |
| Diameter of bar | d_b = 10 mm |
| A_st | A_{st} = 157.08 mm² |
| \(\phi M_u\) | \(\phi M_u = 2.27 \text{kNm}\) |

Ductility Check

\[ k_u = 0.32 \text{ Okay} \]

**Shear Strength of Sleeper**

Capacity Reduction Factor (shear) - AS3600 Table 2.2.2

\[ \phi = 0.7 \]

AS3600 - Clause 8.2.4.1:

\[ V_{uc} = 6.20 \text{kN} \]

\[ fV_{uc} = 4.34 \text{kN} \]

\[ V^* > fV_{uc} \]

\[ \phi V_{uc} > V^* \text{ Therefore, no shear reinforcement required} \]
Sleeper Length = 2000 mm
Sleeper Depth = 200 mm
Height of Wall = 3000 mm
Thickness of Sleeper = 100 mm

Parameters:
- Compressive strength of concrete: \( f'_c = 60 \text{ MPa} \)
- Elastic Modulus of Steel: \( E_s = 200000 \text{ MPa} \)
- Yield Strength of Steel Reinforcement: \( f_{sy} = 500 \text{ MPa} \)
- Mass of Concrete: \( \gamma_s = 18 \text{ kN/m}^3 \)
- Surcharge: \( Q = 5 \text{ kPa} \)
- Friction Angle of Soil: \( \phi = 26.1^\circ \)

Design Actions:
- Weight of Sleeper: \( w = 5.66 \text{ kN/m} \)
- Moment of Sleeper: \( M* = 2.83 \text{kNm} \)
- Shear of Sleeper: \( V* = 5.66 \text{kN} \)

Flexural Strength of Sleeper
- Capacity Reduction Factor (bending) - AS3600 Table 2.2.2: \( \phi = 0.8 \)
- Capacity of Sleeper: \( A_{st,req} = 113.81 \text{ mm}^2 \)
- No. of bars: \( n = 2 \)
- Diameter of bar: \( d_b = 10 \text{ mm} \)
- Shear of Sleeper: \( \phi M_u = 3.84 \text{kNm} \)
- Ductility Check: \( ku = 0.20 \text{ Okay} \)

Shear Strength of Sleeper
- Capacity Reduction Factor (shear) - AS3600 Table 2.2.2: \( \phi = 0.7 \)
- Capacity of Sleeper: \( V_{uc} = 10.07 \text{kN} \)
- Shear of Sleeper: \( fV_{uc} = 7.05 \text{kN} \)

\( \phi V_{uc} > fV_{uc} \) Therefore, no shear reinforcement required
<table>
<thead>
<tr>
<th>Parameters:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength of concrete</td>
<td>$f_c = 60$ MPa</td>
</tr>
<tr>
<td>Elastic Modulus of Steel</td>
<td>$E_c = 37400$ MPa</td>
</tr>
<tr>
<td>Yield Strength of Steel Reinforcement (N Grade)</td>
<td>$f_{sy} = 500$ MPa</td>
</tr>
<tr>
<td>Friction Angle of Soil</td>
<td>$\phi = 26.1^\circ$</td>
</tr>
<tr>
<td>Design Actions:</td>
<td></td>
</tr>
<tr>
<td>$w^* = 1.25G^* + 1.5Q^*$</td>
<td>$w^* = 7.41$ kN/m</td>
</tr>
<tr>
<td>$M^* = w^*L^2/8$</td>
<td>$M^* = 3.70$ kN-m</td>
</tr>
<tr>
<td>$V^* = w^*L/2$</td>
<td>$V^* = 7.41$ kN</td>
</tr>
</tbody>
</table>

**Flexural Strength of Sleeper**

Capacity Reduction Factor (bending) - AS3600 Table 2.2.2

$$A_{st,req} = \frac{f'_{c,b}}{\phi (d - \sqrt{d^2 - 2.4M^*/\phi f'_{c,b}})}$$

Capacity Reduction Factor (shear) - AS3600 Table 2.2.2

$$V_{uc} = k_v b d_v \sqrt{f_c}$$

$$\text{No. of bars} = n = 2$$

$$\text{Diameter of bar} = d_b = 10 \text{ mm}$$

$$\phi M_u = 4.47 \text{ kNm}$$

$$\phi V_{uc} > f V_{uc}$$

$\phi M_u > M^*$ Therefore, okay in bending

$\phi V_{uc} > V^*$ Therefore, no shear reinforcement required
Plain Concrete End Bearing Zones - Length of 2m

Design Shear:

$V^* = \text{Reduced Shear (refer Appendix A for calculation)}$

<table>
<thead>
<tr>
<th>$t$</th>
<th>$H$ (mm)</th>
<th>$V^*$ (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>2000</td>
<td>3.52</td>
</tr>
<tr>
<td>100</td>
<td>3000</td>
<td>5.09</td>
</tr>
<tr>
<td>110</td>
<td>4000</td>
<td>6.67</td>
</tr>
</tbody>
</table>

End Region Shear Strength:

$\phi V_u = \phi_r 0.15tb f'_c^{1/3}$

<table>
<thead>
<tr>
<th>$t$</th>
<th>$b$ (mm)</th>
<th>$f'_c$ (MPa)</th>
<th>$\phi V_u$ (kN)</th>
<th>$\phi V_u &gt; V^*$, Okay</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>200</td>
<td>60</td>
<td>5.29</td>
<td>True</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>60</td>
<td>7.05</td>
<td>True</td>
</tr>
<tr>
<td>110</td>
<td>200</td>
<td>60</td>
<td>7.75</td>
<td>True</td>
</tr>
</tbody>
</table>
End Region Flexural Strength - Length of 2m

Design Bending Moment:
Refer Appendix A for calculation of $M^*$

<table>
<thead>
<tr>
<th>for $t = $</th>
<th>75 mm</th>
<th>H = 2000 mm</th>
<th>Ld = 130 mm</th>
<th>$M^* =$</th>
<th>0.46 kNm</th>
</tr>
</thead>
<tbody>
<tr>
<td>for $t = $</td>
<td>100 mm</td>
<td>H = 3000 mm</td>
<td>Ld = 130 mm</td>
<td>$M^* =$</td>
<td>0.67 kNm</td>
</tr>
<tr>
<td>for $t = $</td>
<td>110 mm</td>
<td>H = 4000 mm</td>
<td>Ld = 130 mm</td>
<td>$M^* =$</td>
<td>0.88 kNm</td>
</tr>
</tbody>
</table>

End Region Flexural Strength:

$b = 200$ mm

<table>
<thead>
<tr>
<th>for $t = $</th>
<th>75 mm</th>
<th>$\phi Mu =$</th>
<th>0.52 kNm</th>
<th>$\phi Mu&gt;M^*$, Okay</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f'c =$</td>
<td>60 MPa</td>
<td>$f'cf =$</td>
<td>4.65 MPa</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>for $t = $</th>
<th>100 mm</th>
<th>$\phi Mu =$</th>
<th>0.93 kNm</th>
<th>$\phi Mu&gt;M^*$, Okay</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f'c =$</td>
<td>60 MPa</td>
<td>$f'cf =$</td>
<td>4.65 MPa</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>for $t = $</th>
<th>110 mm</th>
<th>$\phi Mu =$</th>
<th>1.12 kNm</th>
<th>$\phi Mu&gt;M^*$, Okay</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f'c =$</td>
<td>60 MPa</td>
<td>$f'cf =$</td>
<td>4.65 MPa</td>
<td></td>
</tr>
</tbody>
</table>
2.4m LONG SLEEPERS
Sleeper Length = 2400 mm
Sleeper Depth = 200 mm
Height of Wall = 1600 mm
Thickness of Sleeper = 80 mm

Parameters:

Compressive strength of concrete
$f'c = 60$ MPa

Ec = 37400 MPa

Yield Strength of Steel Reinforcement (N Grade)

$fsy = 500$ MPa

Elastic Modulus Steel

Es = 200000 MPa

Friction Angle of Soil

$\phi = 26.1^\circ$

$K_a = \tan(45 - \phi/2)^2$

$K_a = 0.39$

Bulk Unit Weight of Backfill Soil

$\gamma_s = 18$ kN/m$^3$

Surcharge

Q = 5 kPa

$\eta_0 = 1.94$ kPa

$\eta_1 = 10.50$ kPa

$w_0 = 0.39$ kN/m

$w_1 = 2.10$ kN/m

$\gamma = 0.60$

Design Actions:

$w^* = 1.25G^* + 1.5Q^*$

M$^* = w^*L^2/8$

$V^* = w^*L/2$

$\phi = 0.8$

$A_{st,req} = 139.10$ mm$^2$

No. of bars

n = 2

Diameter of bar

$d_b = 10$ mm

$A_{st} = 157.08$ mm$^2$

$\phi M_u = 2.58$ kNm

Ductility Check

$\phi M_u > M^*$ Therefore, okay in bending

Shear Strength of Sleeper

Capacity Reduction Factor (shear) - AS3600 Table 2.2.2

$\phi = 0.7$

$K_s = 0.100$

$V_{uc} = 6.97$ kN

$fv_{uc} = 4.88$ kN

$V^* > fV_{uc}$ Therefore, no shear reinforcement required
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleeper Length</td>
<td>2400 mm</td>
</tr>
<tr>
<td>Sleeper Depth</td>
<td>200 mm</td>
</tr>
<tr>
<td>Height of Wall</td>
<td>2400 mm</td>
</tr>
<tr>
<td>Thickness of Sleeper</td>
<td>100 mm</td>
</tr>
</tbody>
</table>

### Parameters:

- **Compressive strength of concrete**
  \[ f'_c = 60 \text{ MPa} \]
- **Elastic Modulus of Concrete**
  \[ E_c = 37400 \text{ MPa} \]
- **Yield Strength of Steel Reinforcement (N Grade)**
  \[ f_{sy} = 500 \text{ MPa} \]
- **Elastic Modulus of Steel**
  \[ E_s = 200000 \text{ MPa} \]
- **Friction Angle of Soil**
  \[ \phi = 26.1^\circ \]
- **Bulk Unit Weight of Backfill Soil**
  \[ \gamma_s = 18 \text{ kN/m}^3 \]
- **Surcharge**
  \[ Q = 5 \text{ kPa} \]
- **Ductility Check**
  \[ k_u = 0.20 \]

#### Design Actions:

- **Flexural Strength of Sleeper**
  \[ M^* = w^* L^2 / 8 \]
  \[ V^* = w^* L / 2 \]

#### Shear Strength of Sleeper

- **Capacity Reduction Factor (shear)**
  \[ \phi = 0.7 \]

### Capacity Reduction Factor (shear) - AS3600 Table 2.2.2

\[ V_{uc} = 10.07 \text{ kN} \]
\[ fV_{uc} = 7.05 \text{ kN} \]

\[ V^* > fV_{uc} \]

\[ \phi_Mu > M^* \] Therefore, okay in bending

\[ \phi_Vuc > V^* \] Therefore, no shear reinforcement required
Sleeper Length = 2400 mm
Sleeper Depth = 200 mm
Height of Wall = 4000 mm
Thickness of Sleeper = 130 mm

<table>
<thead>
<tr>
<th>n =</th>
<th>dp =</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

**Parameters:**

- Compressive strength of concrete: $f'_c = 60$ MPa
- Elastic Modulus of Concrete: $E_c = 37400$ MPa
- Yield Strength of Steel Reinforcement (N Grade): $f_{sy} = 500$ MPa
- Elastic Modulus Steel: $E_s = 200000$ MPa

- $b =$
- $d =$
- Friction Angle of Soil: $\phi = 26.1^\circ$
- Bulk Unit Weight of Backfill Soil: $\gamma_s = 18$ kN/m³
- Surcharge: $Q =$
- $w_0 =$
- $w_1 =$
- $\gamma =$

**Design Actions:**

- $w^* = 7.41$ kN/m
- $M^* = 5.33$ kNm
- $V^* = 8.89$ kN

**Flexural Strength of Sleeper**

Capacity Reduction Factor (bending) - AS3600 Table 2.2.2

- $A_{st,req} = \frac{f'_c b}{2 f_{sy}} (d - \sqrt{d^2 - 2.4 M^*/\phi b f'_c b})$

No. of bars: $n =$

Diameter of bar: $d_b =$

- $\phi M_u = \phi f_{sy} A_{st} d (1 - 0.6 A_{st} f_{sy} / b d f'_c) = 5.72$ kNm

Ductility Check: $k_u =$

- $\phi M_u > M^*$ Therefore, okay in bending

**Shear Strength of Sleeper**

Capacity Reduction Factor (shear) - AS3600 Clause 8.2.4.1

- $V_{uc} =$
- $f_{V_{uc}} =$

- $V^* > f_{V_{uc}}$

- $\phi V_{uc} > V^*$ Therefore, no shear reinforcement required
Plain Concrete End Bearing Zones - Length of 2.4m

Design Shear:
\[ V^* = \text{Reduced Shear (refer Appendix A for calculation)} \]
for \( t = 80 \text{ mm} \quad H = 1600 \text{ mm} \quad V^* = 3.53 \text{ kN} \)

End Region Shear Strength:

\[ \phi V_u = \phi_r 0.15tb f'_c \]^{1/3} \\
\[ b = 200 \text{ mm} \]
\[ \phi_r = 0.6 \quad \text{Bearing Capacity Reduction Factor} \]

for \( t = 80 \text{ mm} \quad \phi V_u = 5.64 \text{ kN} \quad \phi V_u > V^*, \text{Okay} \)

\[ f'_c = 60 \text{ MPa} \]
End Region Flexural Strength - Length of 2.4m

Design Bending Moment:
Refer Appendix A for calculation of $M^*$
for $t = 80$ mm $H = 1600$ mm $L_d = 130$ mm $M^* = 0.56$ kNm

End Region Flexural Strength:

$b = 200$ mm

for $t = 80$ mm $\phi Mu = 0.59$ kNm $\phi Mu > M^*$, Okay

$f'_c = 60$ MPa

$f'cf = 4.65$ MPa
Plain Concrete End Bearing Zones - Length of 2.4m

Design Shear:
\( V^* = \text{Reduced Shear (refer Appendix A for calculation)} \)

- for \( t = 100 \text{ mm} \), \( H = 2400 \text{ mm} \), \( V^* = 5.07 \text{ kN} \)
- for \( t = 130 \text{ mm} \), \( H = 4000 \text{ mm} \), \( V^* = 8.15 \text{ kN} \)

End Region Shear Strength:

\[
\phi V_u = \phi_r 0.15tb f'_c^{1/3}
\]

- \( b = 200 \text{ mm} \)
- \( \phi_r = 0.6 \)

<table>
<thead>
<tr>
<th>( t )</th>
<th>( f'_c )</th>
<th>( V_u )</th>
<th>Bearing Capacity Reduction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mm</td>
<td>60 MPa</td>
<td>7.05 kN</td>
<td>( \phi V_u &gt; V^* ), Okay</td>
</tr>
<tr>
<td>130 mm</td>
<td>60 MPa</td>
<td>9.16 kN</td>
<td>( \phi V_u &gt; V^* ), Okay</td>
</tr>
</tbody>
</table>
End Region Flexural Strength - Length of 2.4m

Design Bending Moment:
Refer Appendix A for calculation of $M^*$

<table>
<thead>
<tr>
<th>$t$ (mm)</th>
<th>$H$ (mm)</th>
<th>$L_d$ (mm)</th>
<th>$M^*$ (kNm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>2400</td>
<td>130</td>
<td>0.80</td>
</tr>
<tr>
<td>130</td>
<td>4000</td>
<td>130</td>
<td>1.28</td>
</tr>
</tbody>
</table>

End Region Flexural Strength:

$b = 200$ mm

<table>
<thead>
<tr>
<th>$t$ (mm)</th>
<th>$f'_c$ (MPa)</th>
<th>$f'_{cf}$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>60</td>
<td>4.65</td>
</tr>
<tr>
<td>130</td>
<td>60</td>
<td>4.65</td>
</tr>
</tbody>
</table>

$\phi Mu = 0.93$ kNm, $\phi Mu > M^*$, Okay

$\phi Mu = 1.57$ kNm, $\phi Mu > M^*$, Okay
EARTHQUAKE DESIGN
EARTHQUAKE LOADING OF RETAINING WALL

THE FOLLOWING CALCULATIONS ARE TO DETERMINE THE E/D REQUIREMENTS AS PER AS 4679, APPENDIX I.

STRUCTURAL CLASSIFICATION - CLASS B  
TABLE II A. APPENDIX A

ACCELERATION COEFFICIENT (N) - 0.10  
FOR ADELAIDE, MELBOURNE VALUE IS LOWER
TABLE I

SOIL PROFILE & SITE FACTOR (E) - 1.25  
TABLE I2

E/D DESIGN CATEGORY - CEF  
TABLE I3 (AS .0.5)

DESIGN REQUIREMENTS - DESIGN FOR STATIC LOADS, DEAD LOAD FACTOR OF 1.5 (IN LCE OF 1.25), NO FURTHER WORK READ
TABLE I4

FOR THE E/D LOAD CASE, THE LIVE LOAD SURCHARGE CAN BE REDUCED AS PER AS170.4

0.4Q = 0.4 x SWH = 2.0kPa

IN THE FOLLOWING CALCULATIONS, THERE ARE A COUPLE OF INSTANCES WHERE THE END REGION FLEXURAL STRENGTH FAILS.

THIS IS DUE TO L13.1.2.4, WHICH STATES THAT PARTIAL DEVELOPMENT OF A BAR CANNOT BE TAKEN UNTIL 12D. REALISTICALLY THE BAR WILL DEVELOP STRESS PRIOR TO THIS POINT AND WILL NOT RESULT IN BRITTLE FAILURE. NON-LINE DAMAGE TO THE LEEPER PANELS MAY OCCUR IN THESE REGIONS, HOWEVER COLLAPSE IS NOT ENVISAGED DUE TO THE REINFORCEMENT BARS (AS PER FOREWORD IN AS170.4 COMMENTARY).

ACCEPT OVERSTRENGTH END FLEXURAL REGIONS (ASSUMED UNREINFORCED IN CALLS) FOR EARTHQUAKE LOADING.

REFER TO SHEET 26(2) FOR ASSOCIATED CALCULATION.
2m LONG SLEEPERS - EARTHQUAKE DESIGN
Sleeper Length = 2000 mm
Sleeper Depth = 200 mm
Height of Wall = 2000 mm
Thickness of Sleeper = 75 mm

Parameters:

- Compressive strength of concrete: $f'c = 60$ MPa
- Elastic Modulus of Concrete: $Ec = 37400$ MPa
- Yield Strength of Steel Reinforcement (N Grade): $f_{sy} = 500$ MPa
- Elastic Modulus of Steel: $Es = 200000$ MPa
- Friction Angle of Soil: $\phi = 26.1^\circ$
- Bulk Unit Weight of Backfill Soil: $\gamma_s = 18$ kN/m$^3$
- Surcharge: $Q = 2$ kPa
- No. of bars: $n = 2$
- Diameter of bar: $d_b = 10$ mm
- Compressive strength of concrete: $f'c = 60$ MPa
- Yield Strength of Steel Reinforcement: $f_{sy} = 500$ MPa
- Elastic Modulus of Steel: $Es = 200000$ MPa
- Friction Angle of Soil: $\phi = 26.1^\circ$
- Bulk Unit Weight of Backfill Soil: $\gamma_s = 18$ kN/m$^3$
- Surcharge: $Q = 2$ kPa
- No. of bars: $n = 2$
- Diameter of bar: $d_b = 10$ mm

Design Actions:

- $w* = 4.22$ kN/m
- $M* = 2.11$ kNm
- $V* = 4.22$ kN

Flexural Strength of Sleeper

Capacities

- $A_{st,req} = 145.17$ mm$^2$
- $\phi M_u = 2.27$ kNm

Shear Strength of Sleeper

- $V_{uc} = 6.20$ kN
- $fV_{uc} = 4.34$ kN

- $\phi V_{uc} > fV_{uc}$ Therefore, no shear reinforcement required
Sleeper Length = 2000 mm
Sleeper Depth = 200 mm
Height of Wall = 3000 mm
Thickness of Sleeper = 100 mm

<table>
<thead>
<tr>
<th>Parameters:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength of concrete</td>
</tr>
<tr>
<td>Yield Strength of Steel Reinforcement (N Grade)</td>
</tr>
<tr>
<td>Elastic Modulus Steel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Actions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w^* = 6.32$ kN/m</td>
</tr>
<tr>
<td>$M^* = 3.16$ kNm</td>
</tr>
<tr>
<td>$V^* = 6.32$ kN</td>
</tr>
</tbody>
</table>

**Flexural Strength of Sleeper**

Capacity Reduction Factor (bending) - AS3600 Table 2.2.2

$$A_{st,req} = 127.91 \text{ mm}^2$$

No. of bars: $n = 2$

Diameter of bar: $d_b = 10$ mm

$$A_{st} = 157.08 \text{ mm}^2$$

$$\phi M_u = 3.84 \text{ kNm}$$

Ductility Check

$$k_u = 0.20 \quad \text{Okay}$$

**Shear Strength of Sleeper**

Capacity Reduction Factor (shear) - AS3600 Table 2.2.2

$$\phi = 0.7$$

$$k_v = 0.100$$

$$V_{uc} = 10.07 \text{ kN}$$

$$f_{Vuc} = 7.05 \text{ kN}$$

$$V^* > f_{Vuc}$$

$\phi V_{uc} > V^*$ Therefore, no shear reinforcement required

$\phi M_u > M^*$ Therefore, okay in bending
Sleeper Length = 2000 mm
Sleeper Depth = 200 mm
Height of Wall = 4000 mm
Thickness of Sleeper = 110 mm

Parameters:

Sleeper Length = 2000 mm
Sleeper Depth = 200 mm
Height of Wall = 4000 mm
Thickness of Sleeper = 110 mm

Compressive strength of concrete
f’c = 60 MPa
Ec = 37400 MPa

Yield Strength of Steel Reinforcement (N Grade)
fsy = 500 MPa
Es = 200000 MPa
b = 200 mm
d = 75 mm

Friction Angle of Soil
φ = 26.1°

Bulk Unit Weight of Backfill Soil
γs = 18 kN/m3

Surcharge
Q = 2 kPa

Design Actions:

w* = 1.5G* + 1.5Q*
M* = w*L^2/8
V* = w*L/2

Flexural Strength of Sleeper

Capacity Reduction Factor (bending) - AS3600 Table 2.2.2

\[ A_{st,req} = \frac{f'c}{2fsy} \left( d - \sqrt{d^2 - 2.4M*/\phi f'c b} \right) \]

No. of bars
n = 2

Diameter of bar
\[ A_{st} = \pi d_b^2 \]
\[ fM_u = \phi f_{sy} A_{st} d (1 - 0.6 \frac{A_{st} f_{sy}}{b d f'c}) \]

φM_u > M* Therefore, okay in bending

Shear Strength of Sleeper

Capacity Reduction Factor (shear) - AS3600 Table 2.2.2

φ = 0.7

\[ V_{uc} = k_s \sqrt{f_c} \]
\[ fV_{uc} = 8.13 kN \]
\[ V^* < fV_{uc} \]

Within 10% - ACCEPT
Plain Concrete End Bearing Zones - Length of 2m

Design Shear:
$V^* = \text{Reduced Shear (refer Appendix A for calculation)}$

<table>
<thead>
<tr>
<th>$t$ (mm)</th>
<th>$H$ (mm)</th>
<th>$V^*$ (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>2000</td>
<td>3.80</td>
</tr>
<tr>
<td>100</td>
<td>3000</td>
<td>5.69</td>
</tr>
<tr>
<td>110</td>
<td>4000</td>
<td>7.58</td>
</tr>
</tbody>
</table>

End Region Shear Strength:

$\phi V_u = \phi_r 0.15tb f'_c^{1/3}$

- $b = 200$ mm
- $\phi_r = 0.6$
- $f'_c = 60$ MPa

<table>
<thead>
<tr>
<th>$t$ (mm)</th>
<th>$f'_c$ (MPa)</th>
<th>$\phi V_u$ (kN)</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>60</td>
<td>5.29</td>
<td>$\phi V_u &gt; V^*$, Okay</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
<td>7.05</td>
<td>$\phi V_u &gt; V^*$, Okay</td>
</tr>
<tr>
<td>110</td>
<td>60</td>
<td>7.75</td>
<td>$\phi V_u &gt; V^*$, Okay</td>
</tr>
</tbody>
</table>
End Region Flexural Strength - Length of 2m

Design Bending Moment:
Refer Appendix A for calculation of M*

<table>
<thead>
<tr>
<th>t</th>
<th>H</th>
<th>Ld</th>
<th>M*</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>2000</td>
<td>130</td>
<td>0.50</td>
</tr>
<tr>
<td>100</td>
<td>3000</td>
<td>130</td>
<td>0.75</td>
</tr>
<tr>
<td>110</td>
<td>4000</td>
<td>130</td>
<td>1.00</td>
</tr>
</tbody>
</table>

End Region Flexural Strength:

\[ b = 200 \text{ mm} \]

<table>
<thead>
<tr>
<th>t</th>
<th>H</th>
<th>Ld</th>
<th>φ_Mu</th>
<th>φ_Mu &gt; M*, Okay</th>
</tr>
</thead>
</table>
| 75  | 2000| 130 | 0.52 | Y |}
| 100 | 3000| 130 | 0.93 | Y |}
| 110 | 4000| 130 | 1.12 | Y |}

f'c = 60 MPa
f'cf = 4.65 MPa
2.4m LONG SLEEPERS - EARTHQUAKE DESIGN
Sleeper Length = 2400 mm
Sleeper Depth = 200 mm
Height of Wall = 1600 mm
Thickness of Sleeper = 80 mm

**Parameters:**

- Compressive strength of concrete: $f_c = 60$ MPa
- Yield Strength of Steel Reinforcement (N Grade): $f_{sy} = 500$ MPa
- Elastic Modulus Steel: $E_s = 200000$ MPa
- $b = 200$ mm
- $d = 45$ mm
- Friction Angle of Soil: $\phi = 26.1^\circ$
- Bulk Unit Weight of Backfill Soil: $\gamma_s = 18$ kN/m$^3$
- Surcharge $Q = 2$ kPa
- $w_0 = 0.16$ kN/m
- $w_1 = 2.10$ kN/m
- $\gamma = 0.60$
- $\eta_0 = K_a Q$
- $\eta_1 = K_a \gamma_s H - K_a \gamma_s H(b/2)$
- $w = \eta_t d$

**Design Actions:**

- $w^* = 1.5G^* + 1.5Q^* = 3.38$ kN/m
- $M^* = w^* L^2 / 8 = 2.44$ kNm
- $V^* = w^* L / 2 = 4.06$ kN

**Flexural Strength of Sleeper**

- Capacity Reduction Factor (bending) - AS3600 Table 2.2.2
- $\phi = 0.8$
- $A_{st,req} = 147.43$ mm$^2$
- No. of bars: $n = 2$
- Diameter of bar: $d_b = 10$ mm
- $A_{st} = 157.08$ mm$^2$
- $\phi M_u = 2.58$ kNm
- Ductility Check: $\phi M_u > \phi M^*$

**Shear Strength of Sleeper**

- Capacity Reduction Factor (shear) - AS3600 Table 2.2.2
- $\phi = 0.7$
- $k_s = 0.100$
- $V_{uc} = 6.97$ kN
- $fV_{uc} = 4.88$ kN
- $V^* < fV_{uc}$

**Results:**

- $\phi M_u > \phi M^*$ Therefore, okay in bending
- $\phi V_{uc} > V^*$ Therefore, no shear reinforcement required
Sleeper Length = 2400 mm
Sleeper Depth = 200 mm
Height of Wall = 2400 mm
Thickness of Sleeper = 100 mm

**Parameters:**

- Compressive strength of concrete: \( f'_c = 60 \text{ MPa} \)
- Elastic Modulus Steel: \( E_s = 200000 \text{ MPa} \)
- Yield Strength of Steel Reinforcement (N Grade): \( f_{sy} = 500 \text{ MPa} \)
- Bulk Unit Weight of Backfill Soil: \( \gamma_s = 18 \text{ kN/m}^3 \)
- Friction Angle of Soil: \( \phi = 26.1^\circ \)
- Design Actions:
  - \( w^* = 5.06 \text{ kN/m} \)
  - \( M^* = 3.65 \text{ kNm} \)
  - \( V^* = 6.08 \text{ kN} \)

**Flexural Strength of Sleeper**

Capacity Reduction Factor (bending) - AS3600 Table 2.2.2

\[
A_{st,req} = \frac{f'_c b}{\phi f_{sy} d} \left( d - \sqrt{d^2 - 2.4 M^* / \phi b f'_c} \right)
\]

\[
A_{st,req} = 148.75 \text{ mm}^2
\]

- No. of bars: \( n = 2 \)
- Diameter of bar: \( d_b = 10 \text{ mm} \)
- \( \phi M_u = 3.84 \text{ kNm} \)
- Ductility Check: \( \eta_1 = 0.20 \) Okay

**Shear Strength of Sleeper**

Capacity Reduction Factor (shear) - AS3600 Table 2.2.2

\[
\phi = 0.7
\]

\[
V_{uc} = 10.07 \text{ kN}
\]

\[
fV_{uc} = 7.05 \text{ kN}
\]

**Design Actions**

- \( w^* = 5.06 \text{ kN/m} \)
- \( M^* = 3.65 \text{ kNm} \)
- \( V^* = 6.08 \text{ kN} \)

\[
\phi M_u > M^* \text{ Therefore, okay in bending}
\]

\[
\phi V_{uc} > V^* \text{ Therefore, no shear reinforcement required}
\]
Sleeper Length = 2375 mm
Sleeper Depth = 200 mm
Height of Wall = 4000 mm
Thickness of Sleeper = 130 mm

**Parameters:**

- Compressive strength of concrete: \( f'_c = 60 \text{ MPa} \)
- Elastic Modulus of Steel: \( E_s = 200000 \text{ MPa} \)
- Yield Strength of Steel Reinforcement (N Grade): \( f_{sy} = 500 \text{ MPa} \)
- Friction Angle of Soil: \( \phi = 26.1^\circ \)
- Bulk Unit Weight of Backfill Soil: \( \gamma_s = 18 \text{ kN/m}^3 \)

**Design Actions:**

- Bending: \( w^* = 8.42 \text{ kN/m} \)
- Shear: \( V^* = 10.00 \text{ kN} \)

**Flexural Strength of Sleeper**

- Capacity Reduction Factor (bending) - AS3600 Table 2.2.2

\[ A_{st,req} = \frac{f'_c}{2f_{sy}} (d - \sqrt{d^2 - 2.4M^*/\phi f'_c b}) \]

- No. of bars: \( n = 2 \)
- Diameter of bar: \( d_b = 10 \text{ mm} \)
- \( A_{st} = 157.08 \text{ mm}^2 \)
- \( \phi M_u = 5.72 \text{ kNm} \)

**Shear Strength of Sleeper**

- Capacity Reduction Factor (shear) - AS3600 Table 2.2.2

\[ V_{uc} = k_v b d_* \sqrt{f'_c} \]

- \( \phi V_{uc} > V^* \) Therefore, no shear reinforcement required
Plain Concrete End Bearing Zones - Length of 2.4m

Design Shear :
\( V^* = \text{Reduced Shear (refer Appendix A for calculation)} \)
for \( t = 80 \text{ mm} \) \( H = 1600 \text{ mm} \) \( V^* = 3.72 \text{ kN} \)

End Region Shear Strength:
\[ \phi V_u = \phi_r 0.15tb f'_c^{1/3} \]
\( b = 200 \text{ mm} \)
\( \phi_r = 0.6 \)
\( f'_c = 60 \text{ MPa} \)
\( \phi V_u = 5.64 \text{ kN} \) \( \phi V_u > V^* \), Okay
End Region Flexural Strength - Length of 2.4m

Design Bending Moment:
Refer Appendix A for calculation of M*
for t = 80 mm  H = 1600 mm  Ld = 130 mm  M* = 0.59 kNm

End Region Flexural Strength:

b = 200 mm

for t = 80 mm  φMu = 0.59 kNm  φMu>M*, Okay
f'c = 60 MPa
f'cf = 4.65 MPa
Plain Concrete End Bearing Zones - Length of 2.4m

Design Shear:

\[ V^* = \text{Reduced Shear (refer Appendix A for calculation)} \]

<table>
<thead>
<tr>
<th>t (mm)</th>
<th>( H ) (mm)</th>
<th>( V^* ) (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>2400</td>
<td>5.57</td>
</tr>
<tr>
<td>130</td>
<td>4000</td>
<td>9.16</td>
</tr>
</tbody>
</table>

End Region Shear Strength:

\[ \phi V_u = \phi_r 0.15tb f'_c^{1/3} \]

<table>
<thead>
<tr>
<th>( t ) (mm)</th>
<th>( f'_c ) (MPa)</th>
<th>( \phi V_u ) (kN)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>60</td>
<td>7.05</td>
<td>( \phi V_u &gt; V^* ), Okay</td>
</tr>
<tr>
<td>130</td>
<td>60</td>
<td>9.16</td>
<td>WITHIN 10%</td>
</tr>
</tbody>
</table>
End Region Flexural Strength - Length of 2.4m

Design Bending Moment:
Refer Appendix A for calculation of $M^*$

- for $t = 100$ mm, $H = 2400$ mm, $L_d = 130$ mm, $M^* = 0.88$ kNm
- for $t = 130$ mm, $H = 4000$ mm, $L_d = 130$ mm, $M^* = 1.43$ kNm

End Region Flexural Strength:

- $b = 200$ mm
- for $t = 100$ mm, $f'c = 60$ MPa, $f'cf = 4.65$ MPa, $\phi Mu = 0.93$ kNm, $\phi Mu > M^*$, Okay
- for $t = 130$ mm, $f'c = 60$ MPa, $f'cf = 4.65$ MPa, $\phi Mu = 1.57$ kNm, $\phi Mu > M^*$, Okay