STANDARDS
The calculations are carried out in accordance with:

For all NDPs (Nationally Determined Parameter) in the Eurocodes the recommended values are used.

NDP's are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\gamma_L$</th>
<th>$\gamma_s$</th>
<th>$\alpha_{cc}$</th>
<th>$\alpha_{ct}$</th>
<th>$c_{Rd,c}$</th>
<th>$v_{min}$</th>
<th>$k_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended value</td>
<td>1.5</td>
<td>1.15</td>
<td>1.0</td>
<td>1.0</td>
<td>0.12</td>
<td>0.035$k^{1/2}$ $f_{ck}^{1/2}$</td>
<td>0.15</td>
</tr>
</tbody>
</table>

*Table 1: NDP-s in EC-2.*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\gamma_{M0}$</th>
<th>$\gamma_{M1}$</th>
<th>$\gamma_{M2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended value</td>
<td>1.0</td>
<td>1.0</td>
<td>1.25</td>
</tr>
</tbody>
</table>

*Table 2: NDP-s in EC-3.*

QUALITIES
Concrete grade C35/45:

- $f_{ck} = 35.0$ MPa
- $f_{cd} = \alpha_{ct} f_{ck}/\gamma_s = 1.35/1.5 = 23.3$ MPa
- $f_{cd} = \alpha_{ct} f_{ck,0.05}/\gamma_s = 1.2 \cdot 20/1.5 = 1.46$ MPa
- $f_{bd} = 2.25 \eta_1 \eta_2 f_{ctd} = 2.25 \cdot 0.7 \cdot 1.0 \cdot 1.46 = 2.3$ MPa

- $f_{ck} := 35.0$ MPa $\Rightarrow$ Characteristic Cylinder Strength
- $f_{cd} := 1.0 \cdot \frac{f_{ck}}{1.5} = 3384.214$ psi $\Rightarrow$ Design Compressive Strength
- $f_{ctd0.05} := 2.2$ MPa $\Rightarrow$ Characteristic axial tensile strength of concrete
- $f_{ctd} := 1.0 \cdot \frac{f_{ctd0.05}}{1.5} = 212.722$ psi $\Rightarrow$ Design Tensile Strength

- $\eta_1$ is a coefficient related to the quality of the bond condition and the position of the bar during concreting
  = 1.0 for condition of good bond
  = 0.7 for all other cases and for bars in structural elements built with slipforms

- $\eta_2$ is related to bar diameter
  = 1.0 for $\Phi \leq 40$ mm (NDP)
  = $(140 - \Phi)/100$ for $\Phi > 40$ mm

- $\eta_1 := 0.7$ $\Rightarrow$ coefficient related to bond condition
- $\eta_2 := 1.0$ $\Rightarrow$ coefficient related to bar diameter
- $d_{bh} := 0.5$ in = 12.7 mm $\Rightarrow$ Use #4 Rebar
- $f_{bd} := 2.25 \eta_1 \eta_2 f_{ctd} = 335.037$ psi $\Rightarrow$ Design Bond Stress

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Reinforcement B500C:

\[ f_{yd} = f_y / \gamma_k = \frac{500}{1.15} = 435 \text{ MPa} \]

Design Yield Strength of Reinforcement

Structural steel S355:

Tension: \( f_{yd} = f_y / \gamma_M = \frac{355}{1.0} = 355 \text{ MPa} \)
Compression: \( f_{yd} = f_y / \gamma_M = \frac{355}{1.0} = 355 \text{ MPa} \)
Shear: \( f_{sd} = f_y / (\gamma_M \cdot \sqrt{3}) = 355 / (1.0 \cdot \sqrt{3}) = 205 \text{ MPa} \)

Design Tension Stress of Tube Steel
Design Compression Stress of Tube Steel
Design Shear Stress of Tube Steel

**DIMENSIONS**

Inner tube: HUP 100x50x6, Cold formed, S355
Outer tube: HUP 120x60x4, Cold formed, S355

**LOADS**

Vertical ultimate limit state load \( = F_V = 100 \text{kN} \).

\[ F_V := 100 \text{kN} = 22.481 \text{ kip} \]

*Figure 1: Forces acting on the unit.*
$F_V$ = External force on the inner tube

$R_{1i}, R_{2i} =$ Internal forces between the inner and outer tubes.

$R_1, R_2, R_3 =$ Support reaction forces the outer tube.

$g =$ distance to the middle plane of the anchoring stirrups in front of the unit.

\[ R_{1i} = \frac{F_V(L_1 - b - e)}{(L_1 - b - a - g - e)} = 185.185 \text{ kN} \]
\[ R_{1i} = 41.631 \text{ kip} \]
\[ R_{2i} = R_{1i} - F_V \]
\[ R_{2i} = 85.185 \text{ kN} \]
\[ R_{2i} = 19.15 \text{ kip} \]

**Figure 2: Forces acting on the inner tube.**

Equilibrium equations of the inner tube:

1): $\Sigma M = 0$: $F_V(L_1 - b - e) - R_{1i}(L_1 - b - a - g - e) = 0$

2): $\Sigma F_y = 0$: $F_V - R_{1i} + R_{2i} = 0$

Assuming Nominal Values:

$L_1 = 295 \text{ mm} \quad a = 75 \text{ mm} \quad b = 35 \text{ mm} \quad g = 40 \text{ mm} \quad e = 10 \text{ mm}$

$L_1 = 11.614 \text{ in} \quad a = 2.953 \text{ in} \quad b = 1.378 \text{ in} \quad g = 1.575 \text{ in} \quad e = 0.394 \text{ in}$

Results:

\[ R_{1i} = \frac{100kN \cdot (295 - 35 - 10)mm}{(295 - 35 - 75 - 40 - 10)mm} = 185.2kN \]
\[ R_{2i} = 185.2kN - 100kN = 85.2kN \]
Figure 3 Forces acting on the outer tube.

Exact distribution of forces depends highly on the behavior of the outer tube. Both longitudinal bending stiffness and local transverse bending stiffness in the contact points between the inner and the outer tubes affects the equilibrium. Two situations are considered:

1) Rigid outer tube.

Outer tube rotates as a stiff body. This assumption gives minimum reaction force at $R_{1i}$ and maximum reaction force at $R_2$. $R_3$ becomes zero. (The force $R_3$ will actually be negative, but since no reinforcement to take the negative forces is included at this position, it is assumed to be zero.)

Equilibrium equations of the outer tube:

1): $\sum M=0$: \[(R_{2i}-R_1)(L-3-g-d)-(R_{3i}-R_3)(L-3-g-c-d)=0 \]  
2): $\sum F_y=0$: \[R_2+R_3+R_{1i}-R_{2i}=0 \]

Assuming Nominal Values:

- $L := 348 \text{ mm}$
- $c := L_1 - b - a - g - e = 135 \text{ mm}$
- $g := 40 \text{ mm}$
- $e := 10 \text{ mm}$
- $d := 10 \text{ mm}$
- $L = 13.701 \text{ in}$
- $c = 5.315 \text{ in}$
- $g = 1.575 \text{ in}$
- $e = 0.394 \text{ in}$
- $d = 0.394 \text{ in}$

Assume $R_{3i} := 0 \text{ kip per discussion above}$

\[(185.2 - R_1) \cdot (348 - 3 - 40 - 10) - (85.2 - 0) \cdot (348 - 3 - 40 - 135 - 10) = 0 \]

$54634 - 295R_1 - 13632 = 0$

$R_1 = \frac{41002}{295} = 139 \text{ kN}$

Given

\[(R_{1i} - R_1)(L - 3 \text{ mm} - g - d) - (R_{2i} - R_3)(L - 3 \text{ mm} - g - c - d) \neq 0 \]

$R_{1i} \text{ := Find}(R_1) \quad R_{1i} = 138.983 \text{ kN} \quad R_{1i} = 31.245 \text{ kip}$

$R_2 = R_1 + R_{2i} - R_{1i} - R_3 = 139 + 85.2 - 185.2 = 39 \text{ kN}$

$R_{2i} = R_{1i} + R_{2i} - R_{1i} - R_{3i} \quad R_{2i} = 38.983 \text{ kN} \quad R_{2i} = 8.764 \text{ kip}$

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2) Outer tube without bending stiffness. No forces transferred to outer tube at the back of inner tube.

This assumption gives maximum reaction forces $R_1$ and $R_3$. $R_2$ becomes zero. The forces follow directly from the assumption: $R_1 = R_2$, $R_3 = R_{1i}$ and $R_2 = 0$

$$R_1 = 185.2kN$$  
$$R_2 = 0kN$$  
$$R_3 = 85.2kN$$

$$R_{1i} = R_{1i} \quad R_{1a} = 185.185 \text{kN} \quad R_{12} = 41.631 \text{kip}$$

$$R_{22} = 0 \text{kip}$$

$$R_{3i} = R_{2i} \quad R_{3a} = 85.185 \text{kN} \quad R_{32} = 19.15 \text{kip}$$

The magnitude of the forces will be somewhere in between the two limits, and the prescribed reinforcement ensures integrity for both situations. Reinforcement is to be located at the assumed attack point for support reactions.

**Use Maximum Reactions considering both assumptions**

$$R_1 := \max(R_1) \quad R_1 = 185.185 \text{kN} \quad R_1 = 41.631 \text{kip}$$

$$R_2 := \max(R_2) \quad R_2 = 38.983 \text{kN} \quad R_2 = 8.764 \text{kip}$$

$$R_3 := \max(R_3) \quad R_3 = 85.185 \text{kN} \quad R_3 = 19.15 \text{kip}$$

**Reinforcement Necessary to anchor the unit to concrete**

**Figure 4: Forces.**

**Eurocode Equations**

Reinforcement for $R_1 = 185.185 \text{kN}$

Reinforcement $R_1$: $A_{s1} = \frac{R_1}{f_{yd}} = 185.2 \text{kN}/435 \text{MPa} = 426 \text{mm}^2$

Select 2-Ø12 = 2×2×113 = 452 mm$^2$

Capacity selected reinforcement: $R = 452 \text{mm}^2 \cdot 435 \text{MPa} = 196.6 \text{kN}$

Bar Size

$$A_{s1} = 425.926 \text{mm}^2$$

Bars Required

$$N_{reqd} := \text{ceil} \left( \frac{A_{s1}}{A_{b,metric \cdot size \cdot metric}} \right)$$

$$N_{reqd} = 2$$

Capacity of Supplied Reinforcing

$$N_{reqd} \left( A_{b,metric \cdot size \cdot metric} \cdot 2 \cdot f_{yd} \right) = 196.522 \text{kN}$$
Reinforcement for $R_3 = 85.185 \text{kN}$

Reinforcement $R_3$: $A_s = R_3/f_{yd} = 85.2 \text{kN}/435 \text{MPa} = 196 \text{mm}^2$

Select $1-\varnothing 12 = 1\times2\times113 = 226 \text{mm}^2$

Capacity selected reinforcement: $R=226 \text{ mm}^2 \cdot 435 \text{ MPa} = 98.3 \text{kN}$

$$A_{s3} = \frac{R_3}{f_{yd}} = 195.926 \text{ mm}^2$$

Bar Size $s_{\text{metric}} := 12$

Bars Required $N_{\text{reqd}} := \text{ceil} \left( \frac{A_{s3}}{A_{\text{metric} s_{\text{metric}}}} \right)$

$N_{\text{reqd}} = 1$

Capacity of Supplied Reinforcing

$$N_{\text{reqd}} \left( A_{\text{metric} s_{\text{metric}}} \cdot f_{yd} \right) = 98.261 \text{kN}$$

Reinforcement for $R_2 = 38.983 \text{kN}$

Reinforcement $R_2$: $A_s = R_2/f_{yd} = 39 \text{kN}/435 \text{MPa} = 89 \text{ mm}^2$

Select $1-\varnothing 12 = 1\times2\times113 = 226 \text{mm}^2$

Capacity selected reinforcement: $R=226 \text{ mm}^2 \cdot 435 \text{ MPa} = 98.3 \text{kN}$

$$A_{s2} = \frac{R_2}{f_{yd}} = 89.661 \text{ mm}^2$$

Bar Size $s_{\text{metric}} := 12$

Bars Required $N_{\text{reqd}} := \text{ceil} \left( \frac{A_{s2}}{A_{\text{metric} s_{\text{metric}}}} \right)$

$N_{\text{reqd}} = 1$

Capacity of Supplied Reinforcing

$$N_{\text{reqd}} \left( A_{\text{metric} s_{\text{metric}}} \cdot f_{yd} \right) = 98.261 \text{kN}$$

**US equivalent Equations**

Reinforcement for $R_1 = 41.631 \text{ kip}$

Rebar Yield Strength $f_y = 60 \text{ ksi}$

Strength Reduction Factor for rebar in tension $\phi_t := 0.9$

$$A_{s1} = \frac{R_1}{\phi_t f_y} = 0.771 \text{ in}^2$$

Bar Size $s := 4$

Bars Required $N_{\text{reqd}} := \text{ceil} \left( \frac{A_{s1}}{A_{b s}} \right)$

Capacity of Supplied Reinforcing

$$N_{\text{reqd}} \left( A_{b s} \cdot \phi_t f_y \right) = 43.2 \text{ kip}$$

Reinforcement for $R_3 = 19.15 \text{ kip}$

Rebar Yield Strength $f_y = 60 \text{ ksi}$

Strength Reduction Factor for rebar in tension $\phi_t := 0.9$

$$A_{s3} = \frac{R_3}{\phi_t f_y} = 0.355 \text{ in}^2$$

Bar Size $s := 4$

Bars Required $N_{\text{reqd}} := \text{ceil} \left( \frac{A_{s3}}{A_{b s}} \right)$

Capacity of Supplied Reinforcing

$$N_{\text{reqd}} \left( A_{b s} \cdot \phi_t f_y \right) = 19.15 \text{ kip}$$

Reinforcement for $R_2 = 8.764 \text{ kip}$

Rebar Yield Strength $f_y = 60 \text{ ksi}$

Strength Reduction Factor for rebar in tension $\phi_t := 0.9$

$$A_{s2} = \frac{R_2}{\phi_t f_y} = 0.162 \text{ in}^2$$

Bar Size $s := 4$

Bars Required $N_{\text{reqd}} := \text{ceil} \left( \frac{A_{s2}}{A_{b s}} \right)$

Capacity of Supplied Reinforcing

$$N_{\text{reqd}} \left( A_{b s} \cdot \phi_t f_y \right) = 19.15 \text{ kip}$$
Width \( W_{\text{in Tube}} := 100 \text{ mm} \)

Thickness \( t_{\text{in}} := 6 \text{ mm} \)

Height \( H_{\text{in Tube}} := 50 \text{ mm} \)

Height \( d_{\text{in}} := H_{\text{in Tube}} \)

Tube Steel Yield Strength \( f_{\text{YS}} := 50 \text{ ksi} \)

**Eurocode Equations**

Shear Capacity of Tube Steel

Ultimate Shear

\[
\phi V_{\text{ts}} := f_{\text{yd ts}} \cdot 2 \cdot t_{\text{in}} \cdot (d_{\text{in}})
\]

\( \phi V_{\text{ts}} = 122.976 \text{ kN} \)

\( \phi V_{\text{ts}} = 27.646 \text{ kip} \)

Moment Capacity of Tube Steel

**Ultimate Moment @ Location of zero shear**

Zero shear \( = 4.654 \text{ in} \)  

\( M_{u, \text{zero}} := \left[ V_u, \left( 0 \right) \right] \)  

\( M_{u, \text{zero}} = 85.498 \text{ in kip} \)

Supplied Plastic Section Modulus

\( Z_{\text{supplied}} := 29200 \text{ mm}^3 \)

\( \phi M_p := f_{\text{yd ts}} \cdot Z_{\text{supplied}} \)

\( \phi M_p = 91.747 \text{ in kip} \)

\( Z_{\text{supplied}} = 1.782 \text{ in}^3 \)
**US equivalent Equations**

**Shear Capacity of Tube Steel**

**Ultimate Shear**
\[ F_v = 22.481 \text{ kip} \]
\[ \phi V_{ts} = 0.9 \cdot 0.6 \cdot F_{ys} \cdot 2 \cdot t_{in} \cdot (d_{in}) \]

**Moment Capacity of Tube Steel**

**Ultimate Moment @ Location of zero shear**
\[ M_{u, zero} = M_d(\text{ZeroShear}) \]
\[ M_{u, zero} = 85.498 \text{ in-kip} \]

**Supplied Plastic Section Modulus**
\[ Z_{supplied} = 1.782 \text{ in}^3 \]
\[ \phi M_p = 0.9 \cdot F_{ys} \cdot Z_{supplied} \]
\[ \phi M_p = 80.185 \text{ in-kip} \]

**Plastic Section Modulus not satisfied for US Code Equivalent, reduce Design Strength to**
\[ F_v = 21.3 \text{ kip} \]

**Moment Capacity of Tube Steel**

**Ultimate Moment @ Location of zero shear**
\[ M_{u, zero} = M_d(\text{ZeroShear}) \]
\[ M_{u, zero} = 80.056 \text{ in-kip} \]

**Supplied Plastic Section Modulus**
\[ Z_{supplied} = 1.782 \text{ in}^3 \]
\[ \phi M_p = 0.9 \cdot F_{ys} \cdot Z_{supplied} \]
\[ \phi M_p = 80.185 \text{ in-kip} \]