In this chapter, loads coming from the tower are calculated. All the forces applied to the wind turbine are transferred to the foundation base through the tendons as:

- Horizontal force $H$
- Vertical force $V$
- Overturining moment $M$

For this reason, two situations are considered:

- Applied loads at the bottom of the tower (1).
- Applied loads at the bottom of the slab (2).

Dimensions:

Slab:

- $b_{slab} := 15 m$
- $l_{slab} := 15 m$
- $A_{slab} := b_{slab} \cdot l_{slab} = 225 \cdot m^2$
- $t_{slab} := 2 m$

Tower:

- $h_{tower} := 100 m$
- $W_{tower} := 1811 \text{ tonne}$
- $\phi_{inner} := 5500 \text{ mm}$
- $\phi_{outer} := 6500 \text{ mm}$

Material properties:

- $\rho_{RC} := 2500 \frac{kg}{m^3}$
- $E_s := 210000 \text{ MPa}$
- $E_k := 33 \text{ MPa}$
- $\beta := 7.1 \text{ rad}$

Value depending on the length and width of the slab found in the following table.

<table>
<thead>
<tr>
<th>$B/L$</th>
<th>1.0</th>
<th>0.8</th>
<th>0.6</th>
<th>0.4</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta [\text{rad}]$</td>
<td>7.1</td>
<td>7.4</td>
<td>7.6</td>
<td>7.8</td>
<td>8.2</td>
</tr>
</tbody>
</table>
F1 - Loads transferred from the prestressed concrete tower to the slab

**Horizontal force H**

External loads:

\[ F_w := 1350 \text{kN} \]

- **\( H_1 := F_w = 1350 \text{kN} \)**: Horizontally load produced by the wind.
- **\( H_2 := F_w = 1350 \text{kN} \)**: Horizontally load applied to the tower.
- **\( H_3 := F_w = 1350 \text{kN} \)**: Horizontally load applied to the slab.

**Vertical force V**

Weight:

- **\( W_{\text{turbine}} := 80 \cdot 1.35 \text{tonne} \)**: Weight of the turbine.
- **\( W_{\text{tower}} = 1811 \text{tonne} \)**: Weight of the tower.
- **\( W_{\text{slab}} := A_{\text{slab}} \cdot t_{\text{slab}} \cdot \rho_c = 1125 \text{tonne} \)**: Weight of the slab.

Vertical load applied at the bottom of the tower:

\[ V_1 := \left( W_{\text{turbine}} + W_{\text{tower}} \right) \cdot g = 18818.961 \text{kN} \]

Vertical load applied at the bottom of the foundation:

\[ V_2 := \left( W_{\text{turbine}} + W_{\text{tower}} + W_{\text{slab}} \right) \cdot g = 29851.443 \text{kN} \]

**Overturning moment M**

Bending moment produced by the wind load:

- **\( M_{Fw.1} := F_w \cdot h_{\text{tower}} = 135000 \text{kN} \cdot \text{m} \)**: Moment applied to the tower.
- **\( M_{Fw.2} := F_w \left( h_{\text{tower}} + t_{\text{slab}} \right) = 137700 \text{kN} \cdot \text{m} \)**: Moment applied to the slab.

**a) First order analysis**:

- **\( \phi_0 := \frac{1}{200} \)**: Basic value.
- **\( \alpha_h := \begin{cases} \frac{2}{\sqrt{h_{\text{tower}}}} & \text{if } \frac{2}{3} \leq \frac{2}{\sqrt{h_{\text{tower}}}} \leq 1 \\ 1 & \text{otherwise} \end{cases} \)**: Reduction factor for height applicable to columns.
- **\( \alpha_h = 1 \)**
- **\( m_\alpha := 1 \)**
- **\( \alpha_m := \sqrt{0.5 \left( 1 + \frac{1}{m_\alpha} \right)} = 1 \)**: Number of columns of the structure.
- **\( \alpha_m = 1 \)**

Basic value.

Reduction factor for height applicable to columns.

Number of columns of the structure.

Reduction factor for the number of columns.
F1 - Loads transferred from the prestressed concrete tower to the slab

\[ \phi := \phi_0 \cdot \alpha_h \cdot \alpha_m = 0.005 \cdot \text{rad} \]

Global initial sway imperfections.

\[ \phi = 0.286 \cdot \text{deg} \]

The self-weight of the tower is a distributed pressure increasing towards the top. An approximation has been done considering an equivalent concentrated load applied in the centroid of the triangular distribution.

\[ \Delta_{\text{turbine}} := h_{\text{tower}} \cdot \tan(\phi) = 0.5 \cdot \text{m} \]

Displacement of the application point of \( W_{\text{turbine}} \).

\[ \Delta_{\text{tower}} := \frac{h_{\text{tower}}}{3} \cdot \tan(\phi) = 0.167 \cdot \text{m} \]

Displacement of the application point of \( W_{\text{tower}} \).

\[ \Delta M_{\text{turbine}} := W_{\text{turbine}} \cdot g \cdot \Delta_{\text{turbine}} = 529.564 \cdot \text{kN} \cdot \text{m} \]

Additional moment because of the displacement of the application point of \( W_{\text{turbine}} \).

\[ \Delta M_{\text{tower}} := W_{\text{tower}} \cdot g \cdot \Delta_{\text{tower}} = 2959.999 \cdot \text{kN} \cdot \text{m} \]

Additional moment because of the displacement of the application point of \( W_{\text{tower}} \).

b) Second order analysis: When the deformation of the structure critically affects its behaviour, moments have to be determined using a second-order analysis [19].

- Moments produced by the deformation of the soil \( \Delta \Omega \) and the displacement of the structure \( \Delta p \):

Displacement produced by the rotation of the soil: \( \Delta \Omega \)

Rotational stiffness of the soil:

\[ K_{\phi k} := \frac{E_k \cdot b_{\text{slab}}^2 \cdot l_{\text{slab}}}{\beta} = 1.569 \times 10^7 \cdot \frac{\text{kN} \cdot \text{m}}{\text{rad}} \]

Inverse of the rotational stiffness of the soil:

\[ F_j := \frac{1}{K_{\phi k}} = 6.375 \times 10^{-8} \cdot \frac{\text{rad}}{\text{kN} \cdot \text{m}} \]
Rotation of the soil.

\[ \Omega := F_w \cdot h_{tower} \cdot F_j = 8.606 \times 10^{-3} \cdot \text{rad} \]

\[ \Omega = 0.493 \cdot \text{deg} \]

\[ \Delta \Omega := \tan(\Omega) \cdot h_{tower} = 0.861 \cdot \text{m} \]

Displacement produced because of the rotation of the soil.

Displacement produced by the deformation of the structure because of the applied load: \( \Delta p \)

\[ I_z := \frac{\pi}{64} \left( \phi_{\text{outer}}^4 - \phi_{\text{inner}}^4 \right) = 42.706 \cdot \text{m}^4 \]

Inertia of the base cross-section of the tower.

\[ \Delta p := \frac{F_w \cdot h_{tower}^3}{3 \cdot E_s \cdot I_z} = 0.05 \cdot \text{m} \]

Displacement produced because of the applied loads.

Total displacement := \( \Delta p + \Delta \Omega = 0.911 \cdot \text{m} \)

Total displacement which produces second order moments.

\( \Delta M'_{\text{turbine}} := W_{\text{turbine}} \cdot g \cdot \text{Total displacement} = 964.649 \cdot \text{kN m} \)

Second order moment produced by \( W_{\text{turbine}} \).

\( \Delta M'_{\text{tower}} := W_{\text{tower}} \cdot g \cdot \text{Total displacement} = 5391.913 \cdot \text{kN m} \)

Second order moment produced by \( W_{\text{tower}} \).

- Amplification factor for the bending moments:

As the wind tower is a slender element, buckling phenomenon has to be taken into account. For this reason, bending moments are increased by using the appropriate amplification factor: EN 1992-1-1 (5.30).

\[ \mu := \sqrt{\frac{1 + 2.176 \cdot \frac{W_{\text{turbine}}}{W_{\text{turbine}} + W_{\text{tower}}}}{0.794}} = 1.189 \]

Ratio of the effective buckling length.

\[ P_{\text{crit}} := \frac{\pi^2 \cdot E_s \cdot I_z}{(\mu \cdot h_{\text{tower}})^2} = 6261182.413 \cdot \text{kN} \]

Euler’s critical load for the first buckling mode.

\[ N_d := (W_{\text{turbine}} + W_{\text{tower}}) \cdot g = 18818.961 \cdot \text{kN} \]

Loads producing buckling.

\[ C := \frac{1}{1 - \frac{N_d}{P_{\text{crit}}}} = 1.003 \]

Amplification factor for the moments.
F1 - Loads transferred from the prestressed concrete tower to the slab

Overturning moment applied at the bottom of the steel tower:

\[
M_1 := (M_{Fw.1} + \Delta M_{turbine} + \Delta M_{tower} + \Delta M'_{turbine} + \Delta M'_{tower}) \cdot C = 145282.795 \cdot \text{kN} \cdot \text{m}
\]

Overturning moment applied at the bottom of the foundation:

\[
M_2 := (M_{Fw.2} + \Delta M_{turbine} + \Delta M_{tower} + \Delta M'_{turbine} + \Delta M'_{tower}) \cdot C = 147990.935 \cdot \text{kN} \cdot \text{m}
\]