In this appendix Eurocode 2 and reference [31] have been used.

**Material**

Concrete C30/37:

\[ f_{ck} := 30 \text{MPa} \]

Characteristic compressive strength.

\[ \gamma_c := 1.5 \]

Partial safety factor for concrete.

\[ f_{cd} := \frac{f_{ck}}{\gamma_c} \]

Design compressive strength.

\[ E_{cm} := 32 \text{GPa} \]

Young's modulus.

\[ \rho_c := 25 \frac{kN}{m^3} \]

Unity self-weight of prestressed concrete.

Prestressing steel: 7-wire strands

\[ f_{pk} := 1770 \text{MPa} \]

Characteristic value of the ultimate strength.

\[ f_{p01k} := 1526.7 \text{MPa} \]

Characteristic value of the 0.1% proof stress.

\[ \gamma_s := 1.1 \]

Partial safety factor for steel.

\[ f_{pd} := \frac{f_{p01k}}{\gamma_s} = 1387.909 \text{MPa} \]

Design value of steel strength.

\[ E_p := 1.9 \cdot 10^5 \text{MPa} \]

Young's modulus.

\[ \varepsilon_{1000} := 2.5\% \]

Maximum relaxation at 20º C. after 1000 h.

\[ \phi_{nominal} := 15.7 \text{mm} \]

Nominal diameter of the strand.

\[ A_{nominal} := 150 \text{mm}^2 \]

Nominal area of the strand.

\[ n_s := 11 \]

Number of strands forming a tendon.

\[ A_p := n_s A_{nominal} = 1650 \text{mm}^2 \]

Cross sectional area of a tendon.

\[ n_p := 56 \]

Number of tendons every cross section.

\[ \phi_{duct} := 50 \text{mm} \]

Diameter of the ducts.
Dimensions and properties of the cross section

Height of the tower: 
\[ h_{\text{tower}} := 100 \text{m} \]

Outer diameter of the cylinder: 
\[ \phi_{\text{outer}} := \begin{cases} 4 \\ 4.75 \\ 5.25 \\ 6 \\ 6.5 \end{cases} \text{m} \]

Tickness of the cylinder: 
\[ t := \begin{cases} 290 \\ 360 \\ 420 \\ 460 \\ 500 \end{cases} \text{mm} \]

Inner diameter of the cylinder: 
\[ \phi_{\text{inner}} := \phi_{\text{outer}} - 2 \cdot t \]

Outer radius of the cylinder: 
\[ r_{\text{outer}} := \frac{\phi_{\text{outer}}}{2} \]

Inner radius of the cylinder: 
\[ r_{\text{inner}} := \frac{\phi_{\text{inner}}}{2} \]

Radius of the cylinder medium section: 
\[ r_{\text{tower}} := r_{\text{outer}} - \frac{t}{2} \]

Diameter of the cylinder medium section: 
\[ \phi_{\text{tower}} := r_{\text{tower}}^2 \]

Total area of the cross section: 
\[ A_g := \pi \left( r_{\text{outer}}^2 - r_{\text{inner}}^2 \right) \]

Steel area of the cross section: 
\[ A_s := A_p \cdot n_p = 92400 \cdot \text{mm}^2 \]

Concrete area of the cross section: 
\[ A_c := A_g - A_s \]

Loads
\[ F_f := 0.1 \cdot 1000 \text{kN} = 100000 \cdot \text{N} \]

Horizontal fatigue load coming from the wind: 
\[ M_z := F_f \cdot h = \begin{cases} 2 \times 10^6 \\ 4 \times 10^6 \\ 6 \times 10^6 \\ 8 \times 10^6 \\ 10 \times 10^6 \end{cases} \cdot \text{N} \cdot \text{m} \]

Bending moment produced by the fatigue load.
Control for fatigue in concrete

\[ f_{cd,\text{fat}} := f_{cd} \left(1 - \frac{f_{ck}}{250\text{MPa}}\right) = 17.6\text{MPa} \]

Design fatigue strength of concrete EN 1992-1-1 (6.76)

\[ \sigma_c := \frac{M_z}{0.5 \times b \times z} \]

Compressive stress in the concrete section exposed to cyclic loading. [31]

\[ x := d \cdot \alpha \cdot \rho \left(\sqrt{1 + \frac{2}{\alpha \cdot \rho}} - 1\right) \]

Distance to the neutral layer. [31]

\[ d \] is the distance between bottom and top reinforcement. Since the tower has a circular section, \( d \) has not a constant value. For this reason an average distance has been considered:

\[ x_g := 2 \frac{\phi_{\text{outer}}}{3 \cdot \pi} \]

The average value adopted for parameter \( d \) corresponds to the distance between the tendons which are situated in the centroid of the semicircle.

\[ d := 2 \cdot \sin \left(\frac{\pi}{3} \cdot \frac{4}{\pi}\right) \]

\[ r_{\text{tower}} = \begin{pmatrix} 3359.289 \\ 3975.007 \\ 4373.414 \\ 5016.296 \\ 5432.812 \end{pmatrix} \text{mm} \]

\[ \alpha := \frac{E_p}{E_{cm}} = 5.938 \]

Ratio between stiffness of the reinforcement and the concrete.

\[ \rho := \frac{A_s}{A_c} \]

Reinforcement ratio.

\[ x := d \cdot \alpha \cdot \rho \left(\sqrt{1 + \frac{2}{\alpha \cdot \rho}} - 1\right) = \begin{pmatrix} 5356.16 \\ 6854.17 \\ 7999.545 \\ 9182.659 \\ 10117.565 \end{pmatrix} \text{mm} \]

Distance to the neutral layer. [31]
D - Fatigue Limit State design for the prestressed concrete tower

\[ z := \left( d - \frac{x}{3} \right) \]

Inner lever.

\[ b := 2 \cdot t \]

Considered width of the cross section.

\[ \sigma_{c,\text{max}} := \frac{M_z}{0.5 \cdot b \cdot z} \quad \text{MPa} \]

Maximum compressive stress at a fibre. 

EN 1992-1-1 6.8.7 (2)

\[ \sigma_{c,\text{min}} := \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad \text{MPa} \]

Minimum compressive stress at the same fibre where \( \sigma_{c,\text{max}} \) occurs. If \( \sigma_{c,\text{min}} < 0 \), then \( \sigma_{c,\text{min}} = 0 \). 

EN 1992-1-1 6.8.7 (2)

Verification 1:

\[ \frac{\sigma_{c,\text{max}}}{f_{c,d,\text{fat}}} \leq 0.5 + 0.45 \frac{\sigma_{c,\text{min}}}{f_{c,d,\text{fat}}} = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} \]

EN 1992-1-1 6.8.7 (6.77)

Verification 2:

\[ 0.5 + 0.45 \frac{\sigma_{c,\text{min}}}{f_{c,d,\text{fat}}} \leq 0.9 = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} \]

EN 1992-1-1 6.8.7 (6.77)
Control for fatigue in reinforcement

Parameters for S-N curves of prestressing steel: EN 1992-1-1 (table 6.5N)

\[ N_{cycles} := 10^6 \]
\[ k_1 := 5 \]
\[ k_2 := 10 \]
\[ \Delta \sigma_{Rsk} := 150 \text{MPa} \]

EN 1992-1-1 6.8.4 Figure 6.30

\[ n_{cycles} := 800 \cdot 10^6 \]

Number of cycles of wind tower service life.

\[ \Delta \sigma_s \text{ at } n_{cycles} \text{ is found by interpolation of the graph showed in EN-1-1 6.8.4 Figure 6.30} \]

\[ m := \tan \left( \frac{1}{k_2} \right) = 0.1 \]
\[ n := \log \left( \frac{n_{cycles}}{N_{cycles}} \right) = 8.903 \]
\[ p := n \cdot \tan(m) = 0.89 \]

\[ \Delta \sigma_s := \Delta \sigma_{Rsk} - 10^p \text{MPa} = 142.233 \text{ MPa} \]

Stress range at N cycles from the appropriate S-N curves given in Figure 6.30.

\[ \sigma_s := \frac{M_z}{A_S z} = \begin{pmatrix} 13.752 \\ 25.611 \\ 38.043 \\ 44.277 \\ 52.529 \end{pmatrix} \text{ MPa} \]

Half of the steel stress considering one direction of the cyclic load.

\[ \Delta \sigma_{s,r} := 2 \cdot \sigma_s = \begin{pmatrix} 27.505 \\ 51.222 \\ 76.085 \\ 88.554 \\ 105.058 \end{pmatrix} \text{ MPa} \]

Maximum steel stress under cyclic load.

Verification \[ 3 := \Delta \sigma_s \geq \Delta \sigma_{s,r} = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} \]

EN 1992-1-1 6.8.5 (6.7.1)