Stress Limitations and Prestress Losses

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Stresssing Force in Tendon During Tensioning

- EN1992-1 Sec. 5.10.2.1 – Maximum stressing force
  \[ P_{\text{max}} = A_p \sigma_{p,\text{max}} \]

  \( A_p \) = cross-sectional area of tendon
  \( \sigma_{p,\text{max}} \) = max stress in tendon

  \[ \sigma_{p,\text{max}} = \min \{0.8 f_{p,k}; 0.9 f_{p,0.1k}\} \]
Initial Prestress Force $P_{m0}(x)$

- EN1992-1 Sec. 5.10.3: Immediately after tensioning or after transfer of prestressing $P_{m0}(x)$ is obtained by subtracting from $P_{\text{max}}$ the immediate losses $\Delta P_i(x)$ and should not exceed:
  \[ P_{m0}(x) = A_p \sigma_{pm0}(x) \]
  \[ \sigma_{pm0}(x) = \text{stress in tendon after tensioning or transfer} \]
  \[ \sigma_{pm0}(x) = \min \{0.75 f_{pk}, 0.85 f_{p0,1k}\} \]

Mean Value of Stress in Tendons

- EN1992-1 Sec. 7.2 (5): The mean value of stress in the prestressing tendons should not exceed $0.75 f_{pk}$
Limitation of Concrete Stress

- EN1992-1 Sec. 5.10.2.2: Concrete compressive stresses at time of tensioning or release:
  \[ \sigma_c \leq 0.6 \ f_{ck}(t) \]

  \[ f_{ck}(t) = \text{design compressive strength at time under consideration} \]

Control of Cracks at Serviceability

- EN1992-1 Sec. 7.1 (2): Section is considered uncracked if its flexural tensile stress does not exceed \( f_{ct,\text{eff}} \)

  \[ f_{ct,\text{eff}} = f_{ctm} \text{ or } f_{ctm,fl} \]

  \[ f_{ctm} = \text{Mean value of axial tensile strength} \]

  \[ f_{ctm,fl} = \text{Mean flexural tensile strength} \]
Prestress Losses

- Two categories of losses:
  - Immediate losses $\Delta P_i(x)$
    - Losses due to elastic deformation of concrete $\Delta P_{el}$
    - Losses due to short term relaxation $\Delta P_r$
    - Losses due to friction $\Delta P_{f(x)}$
    - Losses due to anchorage slip $\Delta P_{sl}$
  - Time dependent losses $\Delta P_{c+s+r}(x)$
    - C for creep
    - S for shrinkage
    - R for long term relaxation

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Losses Due to Elastic Deformation of Concrete

This loss, $\Delta P_{el}$, may be assumed as a mean loss in each tendon as follows:

$$\Delta P_{el} = A_p \cdot E_p \cdot \sum \left[ j \cdot \frac{\Delta \sigma_c(t)}{E_{cm}(t)} \right]$$

$\Delta \sigma(t)$ is the variation of stress at the centre of gravity of the tendons applied at time $t$ for the variations due to permanent actions applied after prestressing.

$j$ is a coefficient equal to $(n-1)/2n$ where $n$ is the number of identical tendons successively prestressed. As an approximation $j$ may be taken as $1/2$.  

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Losses Due to Friction

The losses due to friction $\Delta P_\mu(x)$ in post-tensioned tendons may be estimated from

$$\Delta P_\mu(x) = P_{\text{max}} (1 - e^{-\mu(\theta + kx)})$$

- $\theta$ is the sum of the angular displacements over a distance $x$ (irrespective of direction or sign)
- $\mu$ is the coefficient of friction between the tendon and its duct
- $k$ is an unintentional angular displacement for internal tendons (per unit length)
- $x$ is the distance along the tendon from the point where the prestressing force is equal to $P_{\text{max}}$ (the force at the active end during tensioning)

Losses at Anchorage

- Account should be taken of the losses due to wedge draw-in of the anchorage devices, during the operation of anchoring after tensioning, and due to the deformation of the anchorage itself.
- Values of the wedge draw-in are given in the European Technical Approval
Time Dependent Losses

A simplified method to evaluate time dependent losses at location x under the permanent loads

\[
\Delta P_{c+s r} = A_p \Delta \sigma_{p,c+s r} = A_p \left( \varepsilon_{cs} E_p + 0.8 \Delta \sigma_{pc} + \frac{E_p}{E_{cm}} \varphi(t, t_0) \sigma_{t, QP} \right) + \frac{E_p}{E_{cm}} A_p A_p \left( 1 + \frac{A_p}{A_c} z_{cp}^2 \right) [1 + 0.8 \varphi(t, t_0)]
\]

\( \Delta \sigma_{p,c+s+r} \) is the absolute value of the variation of stress in the tendons due to creep, shrinkage and relaxation at location x, at time t

\( \varepsilon_{cs} \) is the estimated shrinkage strain according to 3.1.4(6) in absolute value

\( E_p \) is the modulus of elasticity for the prestressing steel, see 3.3.3 (9)

\( E_{cm} \) is the modulus of elasticity for the concrete (Table 3.1)

\( \Delta \sigma_{pr} \) is the absolute value of the variation of stress in the tendons at location x, at time t, due to the relaxation of the prestressing steel. It is determined for a stress of \( \sigma_p = \sigma_p(G+Pm0+ \psi 2Q) \) where \( \sigma_p = \sigma_p(G+Pm0+ \psi 2Q) \) is the initial stress in the tendons due to initial prestress and quasi-permanent actions.

\( \varphi(t, t_0) \) is the creep coefficient at a time t and load application at time t0
Time Dependent Losses

\( \sigma_{c,QP} \) is the stress in the concrete adjacent to the tendons, due to self-weight and initial prestress and other quasi-permanent actions where relevant. The value of \( \sigma_{c,QP} \) may be the effect of part of self-weight and initial prestress or the effect of a full quasi-permanent combination of action \( (sc(G+P_m+y^2Q)) \), depending on the stage of construction considered.

- \( A_p \) is the area of all the prestressing tendons at the location \( x \)
- \( A_c \) is the area of the concrete section.
- \( I_c \) is the second moment of area of the concrete section.
- \( z_{cp} \) is the distance between the centre of gravity of the concrete section and the tendons.