6.7 Composite columns and composite compression members

6.7.1 General

(1)P Clause 6.7 applies for the design of composite columns and composite compression members with concrete encased sections, partially encased sections and concrete filled rectangular and circular tubes, see Figure 6.17.

(2)P This clause applies to columns and compression members with steel grades S235 to S460 and normal weight concrete of strength classes C20/25 to C50/60.

(3) This clause applies to isolated columns and columns and composite compression members in framed structures where the other structural members are either composite or steel members.

(4) The steel contribution ratio $\delta$ should fulfil the following condition:

$$0.2 \leq \delta \leq 0.9$$

where:

$\delta$ is defined in 6.7.3.3(1).

(5) Composite columns or compression members of any cross-section should be checked for:

- resistance of the member in accordance with 6.7.2 or 6.7.3,
- resistance to local buckling in accordance with (8) and (9) below,
– introduction of loads in accordance with 6.7.4.2 and
– resistance to shear between steel and concrete elements in accordance with 6.7.4.3.

(6) Two methods of design are given:
– a general method in 6.7.2 whose scope includes members with non-symmetrical or non-uniform cross-sections over the column length and
– a simplified method in 6.7.3 for members of doubly symmetrical and uniform cross section over the member length.

(7) For composite compression members subjected to bending moments and normal forces resulting from independent actions, the partial factor $\gamma_F$ for those internal forces that lead to an increase of resistance should be reduced by 20%.

(8) The influence of local buckling of the steel section on the resistance shall be considered in design.

(9) The effects of local buckling may be neglected for a steel section fully encased in accordance with 6.7.5.1(2), and for other types of cross-section provided the maximum values of Table 6.3 are not exceeded.

Table 6.3: Maximum values $(d/t)$, $(h/t)$ and $(b/t)$ with $f_y$ in N/mm$^2$

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>Max $(d/t)$, max $(h/t)$ and max $(b/t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular hollow steel sections</td>
<td>$\max (d/t) = 90 \frac{235}{f_y}$</td>
</tr>
<tr>
<td>Rectangular hollow steel sections</td>
<td>$\max (h/t) = 52 \sqrt{\frac{235}{f_y}}$</td>
</tr>
<tr>
<td>Partially encased I-sections</td>
<td>$\max (b/t) = 44 \sqrt{\frac{235}{f_y}}$</td>
</tr>
</tbody>
</table>

6.7.2 General method of design

(1) Design for structural stability shall take account of second-order effects including residual stresses, geometrical imperfections, local instability, cracking of concrete,
creep and shrinkage of concrete and yielding of structural steel and of reinforcement. The design shall ensure that instability does not occur for the most unfavourable combination of actions at the ultimate limit state and that the resistance of individual cross-sections subjected to bending, longitudinal force and shear is not exceeded.

(2)P Second-order effects shall be considered in any direction in which failure might occur, if they affect the structural stability significantly.

(3)P Internal forces shall be determined by elasto-plastic analysis.

(4) Plane sections may be assumed to remain plane. Full composite action up to failure may be assumed between the steel and concrete components of the member.

(5)P The tensile strength of concrete shall be neglected. The influence of tension stiffening of concrete between cracks on the flexural stiffness may be taken into account.

(6)P Shrinkage and creep effects shall be considered if they are likely to reduce the structural stability significantly.

(7) For simplification, creep and shrinkage effects may be ignored if the increase in the first-order bending moments due to creep deformations and longitudinal force resulting from permanent loads is not greater than 10%.

(8) The following stress-strain relationships should be used in the non-linear analysis:
   – for concrete in compression as given in EN 1992-1-1, 3.1.5;
   – for reinforcing steel as given in EN 1992-1-1, 3.2.7;
   – for structural steel as given in EN 1993-1-1, 5.4.3(4).

(9) For simplification, instead of the effect of residual stresses and geometrical imperfections, equivalent initial bow imperfections (member imperfections) may be used in accordance with Table 6.5.

6.7.3 Simplified method of design

6.7.3.1 General and scope

(1) The scope of this simplified method is limited to members of doubly symmetrical and uniform cross-section over the member length with rolled, cold-formed or welded steel sections. The simplified method is not applicable if the structural steel component consists of two or more unconnected sections. The relative slenderness \( \lambda \) defined in 6.7.3.3 should fulfill the following condition:
\[
\lambda \leq 2.0
\]  

(6.28)

(2) For a fully encased steel section, see Figure 6.17a, limits to the maximum thickness of concrete cover that may be used in calculation are:
\[
\max c_x = 0.3h \quad \max c_y = 0.4b
\]  

(6.29)
(3) The longitudinal reinforcement that may be used in calculation should not exceed 6% of the concrete area.

(4) The ratio of the cross-section’s depth \( h_c \) to width \( b_c \), see Figure 6.17a, should be within the limits \( 0.2 \leq h_c / b_c \leq 5.0 \).

### 6.7.3.2 Resistance of cross sections

(1) The plastic resistance to compression \( N_{pl,Rd} \) of a composite cross-section should be calculated by adding the plastic resistances of its components:

\[
N_{pl,Rd} = A_y f_{yd} + 0.85 A_c f_{cd} + A_s f_{sd} \tag{6.30}
\]

Expression (6.30) applies for concrete encased and partially concrete encased steel sections. For concrete filled sections the coefficient 0.85 may be replaced by 1.0.

(2) The resistance of a cross-section to combined compression and bending and the corresponding interaction curve may be calculated assuming rectangular stress blocks as shown in Figure 6.18, taking account of the design shear force \( V_{Ed} \) in accordance with (3). The tensile strength of the concrete should be neglected.

![Interaction curve for combined compression and uniaxial bending](image)

(3) The influence of transverse shear forces on the resistance to bending and normal force should be considered when determining the interaction curve, if the shear force \( V_{a,Ed} \) on the steel section exceeds 50% of the design shear resistance \( V_{pl,a,Rd} \) of the steel section, see 6.2.2.2.

Where \( V_{a,Ed} > 0.5V_{pl,a,Rd} \), the influence of the transverse shear on the resistance in combined bending and compression should be taken into account by a reduced design steel strength \((1-\rho) f_{yd}\) in the shear area \( A_v \) in accordance with 6.2.2.4(2) and Figure 6.18.

The shear force \( V_{a,Ed} \) should not exceed the resistance to shear of the steel section determined according to 6.2.2. The resistance to shear \( V_{c,Ed} \) of the reinforced concrete part should be verified in accordance with EN 1992-1-1, 6.2.

(4) Unless a more accurate analysis is used, \( V_{Ed} \) may be distributed into \( V_{a,Ed} \) acting on the structural steel and \( V_{c,Ed} \) acting on the reinforced concrete section by:
\begin{align*}
V_{a,Ed} &= V_{Ed} \frac{M_{pl,a,Rd}}{M_{pl,Rd}} \quad (6.31) \\
V_{c,Ed} &= V_{Ed} - V_{a,Ed} \quad (6.32)
\end{align*}

where:

- $M_{pl,a,Rd}$ is the plastic resistance moment of the steel section and
- $M_{pl,Rd}$ is the plastic resistance moment of the composite section.

For simplification $V_{Ed}$ may be assumed to act on the structural steel section alone.

(5) As a simplification, the interaction curve may be replaced by a polygonal diagram (the dashed line in Figure 6.19). Figure 6.19 shows as an example the plastic stress distribution of a fully encased cross section for the points A to D. $N_{pm,Rd}$ should be taken as $0.85 f_{cd} A_c$ for concrete encased and partially concrete encased sections, see Figures 6.17a – c, and as $f_{cd} A_c$ for concrete filled sections, see Figures 6.17d - f.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{interaction_curve.png}
\caption{Simplified interaction curve and corresponding stress distributions}
\end{figure}

(6) For concrete filled tubes of circular cross-section, account may be taken of increase in strength of concrete caused by confinement provided that the relative slenderness $\lambda$ defined in 6.7.3.3 does not exceed 0.5 and $e/d < 0.1$, where $e$ is the eccentricity of loading given by $M_{Ed} / N_{Ed}$ and $d$ is the external diameter of the column. The plastic resistance to compression may then be calculated from the following expression:

\begin{align*}
N_{pl,Rd} &= \eta_s A_c f_{yd} + A_e f_{cd} \left(1 + \eta_s \frac{t}{d} \frac{f_y}{f_{ck}} \right) + A_s f_{sd} \quad (6.33)
\end{align*}

where:

- $t$ is the wall thickness of the steel tube.
For members with $e = 0$ the values $\eta_a = \eta_{ao}$ and $\eta_c = \eta_{co}$ are given by the following expressions:

\[
\eta_{ao} = 0,25 (3 + 2 \bar{\kappa}) \quad \text{(but } \leq 1,0) \quad (6.34)
\]
\[
\eta_{co} = 4,9 - 18,5 \bar{\kappa} + 17 \bar{\kappa}^2 \quad \text{(but } \geq 0) \quad (6.35)
\]

For members in combined compression and bending with $0 < e/d \leq 0,1$, the values $\eta_a$ and $\eta_c$ should be determined from (6.36) and (6.37), where $\eta_{ao}$ and $\eta_{co}$ are given by (6.34) and (6.35):

\[
\eta_a = \eta_{ao} + (1 - \eta_{ao}) (10 e/d) \quad (6.36)
\]
\[
\eta_c = \eta_{co} (1 - 10 e/d) \quad (6.37)
\]

For $e/d > 0,1$, $\eta_a = 1,0$ and $\eta_c = 0$.

### 6.7.3.3 Effective flexural stiffness, steel contribution ratio and relative slenderness

(1) The steel contribution ratio $\delta$ is defined as:

\[
\delta = \frac{A_a f_{yd}}{N_{pl,Rd}} \quad (6.38)
\]

where:

- $N_{pl,Rd}$ is the plastic resistance to compression defined in 6.7.3.2(1).

(2) The relative slenderness $\bar{\lambda}$ for the plane of bending being considered is given by:

\[
\bar{\lambda} = \sqrt{\frac{N_{pl,Rk}}{N_{cr}}} \quad (6.39)
\]

where:

- $N_{pl,Rk}$ is the characteristic value of the plastic resistance to compression given by (6.30) if, instead of the design strengths, the characteristic values are used;
- $N_{cr}$ is the elastic critical normal force for the relevant buckling mode, calculated with the effective flexural stiffness $(EI)_{eff}$ determined in accordance with (3) and (4).

(3) For the determination of the relative slenderness $\bar{\lambda}$ and the elastic critical force $N_{cr}$, the characteristic value of the effective flexural stiffness $(EI)_{eff}$ of a cross section of a composite column should be calculated from:

\[
(EI)_{eff} = E_a I_a + E_s I_s + K_e E_{cmt} I_c \quad (6.40)
\]

where:

- $K_e$ is a correction factor that should be taken as 0,6.
- $I_a$, $I_c$, and $I_s$ are the second moments of area of the structural steel section, the uncracked concrete section and the reinforcement for the bending plane being considered.