ANNEX A: Elastic Displacement Response Spectrum [43]

A.1.1 For periods of long vibration period, the seismic action may be represented in the form of a displacement response spectrum, $S_{D_e}(T)$, as shown in Figure A.1.

![Elastic displacement response spectrum](image)

Figure A.1. Elastic displacement response spectrum.

A.1.2 Up to control period $T_E$, the spectral ordinates are obtained from Eqs.(3.2)-(3.5) converting $S_e(T)$ to $S_{D_e}(T)$ through Eq.(3.7). For vibration periods beyond $T_E$, the ordinates of the elastic displacement response spectrum are obtained from Eqs.(A.1) and (A.2).

\[
T_E \leq T \leq T_F
\]

\[
S_{D_e}(T) = a_g \cdot S \cdot T_C \cdot T_D \left[ 0.4\eta + \left( \frac{T - T_E}{T_F - T_E} \right) 0.025 - 0.4\eta \right]
\]

\[
T \geq T_F
\]

\[
S_{D_e}(T) = d_g
\]

where $S$, $T_C$, $T_D$ are given in Table 3.2, $\eta$ is given by Eq.(3.6) and $d_g$ is given by Eq.(3.12). The control periods $T_E$ and $T_F$ are presented in Table A.1.
Table A.1. Additional control parameters for Type 1 displacement spectrum.

<table>
<thead>
<tr>
<th>Sub-soil Class</th>
<th>$T_E$</th>
<th>$T_F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.5</td>
<td>10.0</td>
</tr>
<tr>
<td>B</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>C</td>
<td>6.0</td>
<td>10.0</td>
</tr>
<tr>
<td>D</td>
<td>6.0</td>
<td>10.0</td>
</tr>
<tr>
<td>E</td>
<td>6.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>
ANNEX B:

DETERMINATION OF TARGET DISPLACEMENT FOR NONLINEAR STATIC (PUSHOVER) ANALYSIS

The target displacement is determined from the elastic response spectrum (section 3.2.2.2). The pushover curve is used, which represents the relation between base shear force and control node displacement and is determined according to 4.4.3.5.

The following relation between normalized lateral forces $F_i$ and normalized displacements $\Phi_i$ is assumed

$$F_i = m_i \Phi_i$$

where $m_i$ is mass in $i$-th storey. Displacements are normalized in such a way that $\Phi_n = 1$, where $n$ is the control node (usually, $n$ denotes roof level). Consequently, $F_n = m_n$.

1. step: **Transformation to equivalent SDOF system**

The mass of equivalent SDOF system $m^*$ is determined as

$$m^* = \sum m_i \Phi_i = \sum F_i$$

and the transformation factor is given by

$$\Gamma = \frac{m^*}{\sum m_i \Phi_i^2} = \frac{\sum F_i^2}{\sum \left(\frac{F_i^2}{m_i}\right)}$$

The force $F^*$ and displacement $d^*$ of the equivalent SDOF system are computed as

$$F^* = \frac{F_b}{\Gamma}, \quad d^* = \frac{d_n}{\Gamma}$$

where $F_b$ and $d_n$ are base shear force and control node displacement of the MDOF system.

2. step: **Determination of the idealized elasto-perfectly plastic force – displacement relationship**

The yield force $F_{y^*}$, which represents also the ultimate strength of the idealized system, is equal to the force at the formation of plastic mechanism. The initial
stiffness of the idealized system is determined in such a way that areas under the actual and idealized force – deformation curves are equal (Figure B1). Based on this assumption, the yield displacement of the idealised SDOF system $d_y^*$ is given by

$$d_y^* = 2 \left( d_m^* - \frac{E_m^*}{F_y} \right)$$

(Figure A1).

3.step: Determination of the period of the idealized equivalent SDOF system

The period $T^*$ of the idealized equivalent SDOF system is determined by the formula

$$T^* = 2\pi \sqrt{\frac{m^* d_y^*}{F_y^*}}.$$

4.step: Determination of the target displacement for the equivalent SDOF system

The target displacement of the structure with period $T^*$ and unlimited elastic behaviour is given by

$$d_t^* = \left( \frac{T^*}{2\pi} \right)^2 S_x.$$

where $S_x \equiv S_x(T^*)$ is the value from the elastic response spectrum at the period $T^*$.

Different formulae are used for the determination of the target displacement $d_t^*$ for structures in short-period range and for structures in medium- and long-period range. The corner period between the short- and medium-period range is $T_C$ (see Figure 3.1 and Tables 3.2 and 3.3). In the medium- and long-period range the equal displacement rule applies.
a) $T^* < T_c$

$$d^*_i = \frac{d^*_{et}}{q_u} \left( 1 + q_u (1 - \frac{T_c}{T^*}) \right) \geq d^*_{cr}$$

$q_u$ is the ratio between the acceleration demands in the structure with unlimited elastic behaviour $S_e$ and in the structure with limited strength $F_y/m^*$

$$q_u = \frac{S_e m^*}{F_y}$$

If $F_y/m^* \geq S_e$, the response is elastic and $d^*_i = d^*_{cr}$.

b) $T^* \geq T_c$

$$d^*_i = d^*_{cr}$$

5.step: **Determination of target displacement for MDOF system**

The target displacement of the MDOF system is given by

$$d_t = \Gamma d^*_i$$

The target displacement corresponds to the control node.

The relation between different quantities can be visualized in Figures B2. The figures are plotted in acceleration - displacement format. Period $T^*$ is represented by the radial line from the origin of the coordinate system to the point at the elastic response spectrum defined by coordinates $d^* = \left( T^*/2\pi \right)^2 S_e$ and $S_e$. 

Figure B2.
ANNEX J: SEISMIC DESIGN OF THE SLAB REINFORCEMENTS OF COMPOSITE BEAMS WITH SLAB IN MOMENT FRAMES

AJ.1. General
The plastic hinges developed in the beam ends of a composite moment frame have to be ductile. Two conditions have to be fulfilled to ensure that a high ductility in bending is obtained:
- early buckling of the steel part must be avoided
- early crushing of the concrete of the slab must be avoided
Each of these two conditions brings a limit of the section $A_s$ of the reinforcement present in the slab of a composite T beam made of a steel section with slab.

AJ.2. Requirement on the section $A$ of re-bars in order to avoid premature buckling of the steel section
Rule 7.6.1 (4) applies.

AJ.3. Requirements on the section $A$ of re-bars in order to avoid premature cracking of the concrete.

AJ.3.1. Exterior column - bending of the column in direction perpendicular to façade
Applied beam bending moment is negative - $M<0$

AJ.3.1.1 No façade steel beam - no concrete edge beam  
See Figure AJ.1.(b)
When no façade steel beam and no concrete edge beam are present, the transferable moment is the steel beam plastic moment only.

AJ.3.1.2 No façade steel beam - concrete edge beam present
See Figure AJ.1.(c)
When there is a concrete edge beam and no façade steel beam, EC4 applies.
(a) M < 0

(b) no concrete edge beam
   no façade steel beam
   see section AJ.3.1.1.

(c) concrete edge beam
   no façade steel beam
   see section AJ.3.1.2.

(d) no concrete edge beam
    façade steel beam
    see section AJ.3.1.3.

(e) concrete edge beam
    façade steel beam
    see section AJ.3.1.4.
Figure AJ.1. Configurations of exterior composite beam-to-column nodes under negative bending moment in direction perpendicular to façade
AJ.3.1.3 Façade steel beam present – no concrete edge beam  See Figure AJ.1.(d)
(1) When a façade steel beam is present rather than a concrete edge beam, the only way to transfer the moment is to use the façade steel beam to anchor the slab forces.

(2) An effective anchorage of the re-bars on the shear connectors of the façade steel beam has to be realised.

(3) The façade beam has to be fixed to the column

(4) The reinforcing steel section $A_s$ in the effective width should check:

$$A_s \leq \frac{F_{rd3}}{(f_{sk}/s)}$$

where $F_{rd3} = n \times F_{stud}$ on the effective width

$n$ = number of connectors in the effective width

$F_{stud} = P_{rd}$ = design resistance of one connector

(5) The façade beam should be checked in bending, shear and torsion under the horizontal force applied at the connectors

AJ.3.1.4 Façade steel beam and concrete edge beam present  See Figure AJ.1.(e)
(1) When both a façade steel beam and a concrete edge beam are present, two mechanisms of transfer of forces are possible: the mechanism described in EC4 and the transfer through the façade steel beam.

(2) AJ.3.1.3 (3), (4) and (5) apply to the section of re-bars anchored to the transverse beam

(3) AJ.3.1.2 apply to the section of re-bars anchored in the concrete edge beam

AJ.3.2. Exterior column - bending of the column in direction perpendicular to façade

Applied beam bending moment is positive – $M>0$

AJ.3.2.1. No façade steel beam – no concrete edge beam See Figure AJ.2.(b-c)
(1) When the concrete slab is limited to the interior face of the column, the transfer of moment is made by direct compression of the concrete on the column flange.

(2) The maximal force transmitted to the slab is:

$$F_{rd1} = b_c \cdot d_{eff} \cdot f_{ck}/c$$
(3) Confining of the concrete close to the column flange is required. The section of these re-bars should comply with

\[ A_T \geq 0.21 \ d_{\text{eff}} \ b_c \ \frac{0.15 \ell - b_c}{0.15 \ell} \ \frac{f_{sk}}{\gamma_c} \]

over a length of beam equal to \( b_{\text{eff}} \) and should be uniformly distributed over that length. The distance of the first re-bar to the column flange should not exceed 30 mm.

(4) The section \( A_T \) of re-bars defined in (3) can be partly or totally realised by re-bars placed for other purposes, like for instance the bending resistance of the slab.
concrete edge beam or concrete into the column flanges no façade steel beam see section AJ.3.2.2.

(d)

concrete edge beam present or not façade steel beam see section AJ.3.2.3.

(f)

Mechanism 2

+ Mechanism 3

Figure AJ.2. Configurations of exterior composite beam-to-column nodes under positive bending moment in direction perpendicular to façade and possible transfer of slab forces.
AJ.3.2.2. No façade steel beam – concrete edge beam present or concrete into the column flanges

See Figure AJ.2.(c-d-e)

(1) When no façade steel beam is present, the transferable moment is linked with two mechanisms:

**Mechanism 1:** direct compression on the column

\[ F_{Rd1} = b_c d_{eff} \left( 0.85 f_{ck}/c \right) \]

**Mechanism 2:** compressed concrete struts inclined on the column sides. If incline is equal to 45°:

\[ F_{Rd2} = 0.7 h_c d_{eff} \left( 0.85 f_{ck}/c \right) \]

where for a solid slab \( d_{eff} \) is the overall depth of the slab
for a composite slab \( d_{eff} \) is the thickness of the slab above the ribs of the profiled sheeting

- \( b_c \) is the width of the column steel section
- \( h_c \) is the height of the column steel section

(2) The required tension tie steel section is (see Figure AJ.2.(e)):

\[ A_T \geq \frac{F_{Rd2}}{f_{sk,T}/f_t} = 0.3 h_c d_{eff} \frac{f_{ck}/f_t}{f_{sk,T}/f_t} \]

(3) Section \( A_T \) is distributed over a width equal to \( h_c \). It has to be fully anchored. The resulting length of re-bars is \( L = b_c + 4 h_c + 2 l_b \), where \( l_b \) is the anchorage length of the re-bars according to EC2.

(4) The maximum compression force transmitted is \( F_{Rd1} + F_{Rd2} = b_{eff} d_{eff} \left( 0.85 f_{ck}/c \right) \).

It corresponds to a maximal effective width of \( b_{eff,connec}^* = 0.7 h_c + b_c \).

\( M_{pl,Rd} \) should be computed considering \( b_{eff,connec}^* \).

AJ.3.2.3. Façade steel beam present – concrete edge beam present or not

See Figure AJ.2.(c-e-f-g)

(1) When a façade steel beam is present, a third force transfer \( F_{Rd3} \) implying the façade steel beam is activated in compression.

\[ F_{Rd3} = n \times F_{stud} \text{ in the effective width} \quad \text{with} \quad n = \text{number of connectors in the effective width} \]

\[ F_{stud} = P_{Rd} = \text{design resistance of one connector} \]

(2) AJ.3.2.2. applies

(3) The maximum compression force transmitted is \( b_{eff} d_{eff} \left( 0.85 f_{ck}/c \right) \). It is transmitted if:
F_{Rd1} + F_{Rd2} + F_{Rd3} > b_{eff} d_{eff} (0.85 f_{ck} / c)

The "full" composite plastic moment is achieved by choosing n in order to achieve the adequate F_{Rd3}. The maximum effective width is given in Table 7.5.

**AJ.3.3. Interior column - $A_T = A_S/2$**

![Diagram of an interior column, main beam, slab, and transverse beam](image)

Mechanism 1
Figure AJ.3. Possible transfer of slab forces in an interior composite beam-to-column node with and without transverse beam under positive bending moment at one side and negative bending at the other side.
AJ.3.3.1. No transverse beam present

(1) When no transverse beam is present, the transferable moment is linked with the two mechanisms:

   Mechanism 1: direct compression on the column
   \[ F_{Rd1} = b_c \, d_{\text{eff}} \left( 0.85 \frac{f_{ck}}{\gamma_c} \right) \]

   Mechanism 2: compressed concrete struts inclined at 45° on the column sides
   \[ F_{Rd2} = 0.7 \, h_c \, d_{\text{eff}} \left( 0.85 \frac{f_{ck}}{\gamma_c} \right) \]

(2) Required tension tie section:

   \[ A_T \geq \frac{F_{Rd2}}{f_{sk,T}/f_s} = 0.3 h_c \, d_{\text{eff}} \frac{f_{ck}/\gamma_c}{f_{sk,T}/f_s} \]

(3) The same section \( A_T \) has to be placed on each side of the column.

(4) The resistance is at the most:

   \[ F_{Rd1} + F_{Rd2} = (0.7 \, h_c + b_c) \, d_{\text{eff}} \left( 0.85 \frac{f_{ck}}{\gamma_c} \right) \]

   The action force is the sum of the tension coming from the re-bars at the negative moment side and the compression of the concrete at the positive moment side:

   \[ F_{St} + F_{Sc} = A_S \left( f_{ck} \right) + b^{*}_{\text{eff}} \, d_{\text{eff}} \left( 0.85 \frac{f_{ck}}{\gamma_c} \right) \quad \text{with} \quad A_S \text{ considered in effective width } b^{*}_{\text{eff}} \]

AJ.3.3.2. Presence of transverse beam

(1) When a transverse beam is present, a third force transfer \( F_{Rd3} \) implying the façade steel beam is activated.

   \[ F_{Rd3} = n \times F_{\text{stud}} \text{ in the effective width} \quad \text{with } n = \text{number of connectors in the effective width} \]

   \[ F_{\text{stud}} = P_{Rd} = \text{design resistance of one connector} \]

(2) AJ.3.3.1. applies for the condition on the tension tie for mechanism 2.

(3) The resistance is at the most:

   \[ F_{Rd1} + F_{Rd2} + F_{Rd3} = (0.7 \, h_c + b_c) \, d_{\text{eff}} \left( 0.85 \frac{f_{ck}}{\gamma_c} \right) + n \, F_{\text{stud}} \quad \text{in max } (b^{*}_{\text{eff}}, b^{*}_{\text{eff}}) \]

   The applied force is the sum of the tension coming from the re-bars at the negative moment side and the compression of the concrete at the positive moment side:

   \[ F_{St} + F_{Sc} = A_S \left( f_{ck} \right) + b^{*}_{\text{eff}} \, d_{\text{eff}} \left( 0.85 \frac{f_{ck}}{\gamma_c} \right) \quad \text{with} \quad A_S \text{ considered in effective width } b^{*}_{\text{eff}} \]
(4) In a design aiming at yielding located essentially in the bottom flange of the steel section and no crushing of concrete, the design condition is:

\[ 1.2 \left( F_{Sc} + F_{St} \right) \leq F_{Rd1} + F_{Rd2} + F_{Rd3} \]