Structural Steel and Timber Design SAB3233

Columns subjected to combined bending and axial load

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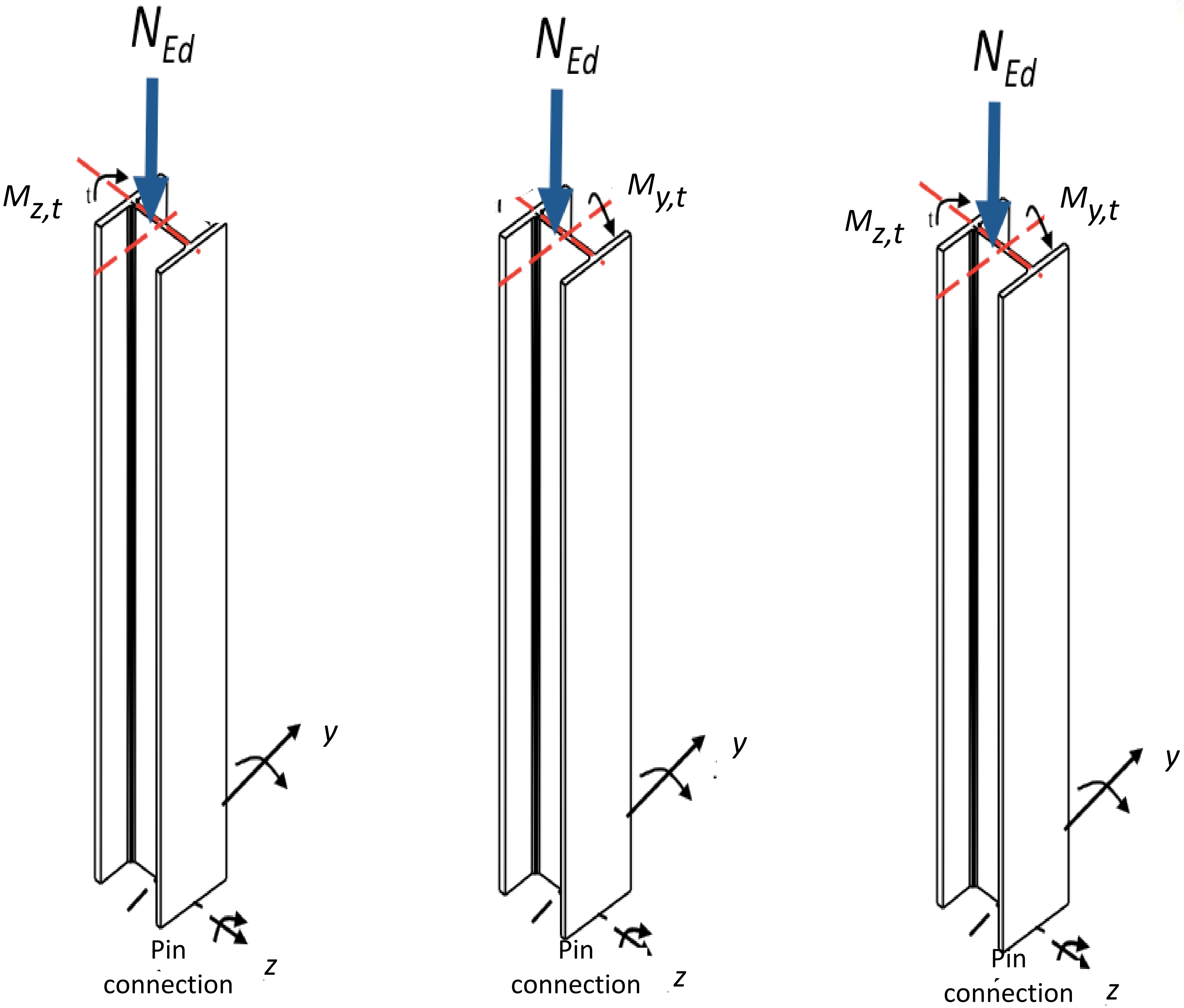
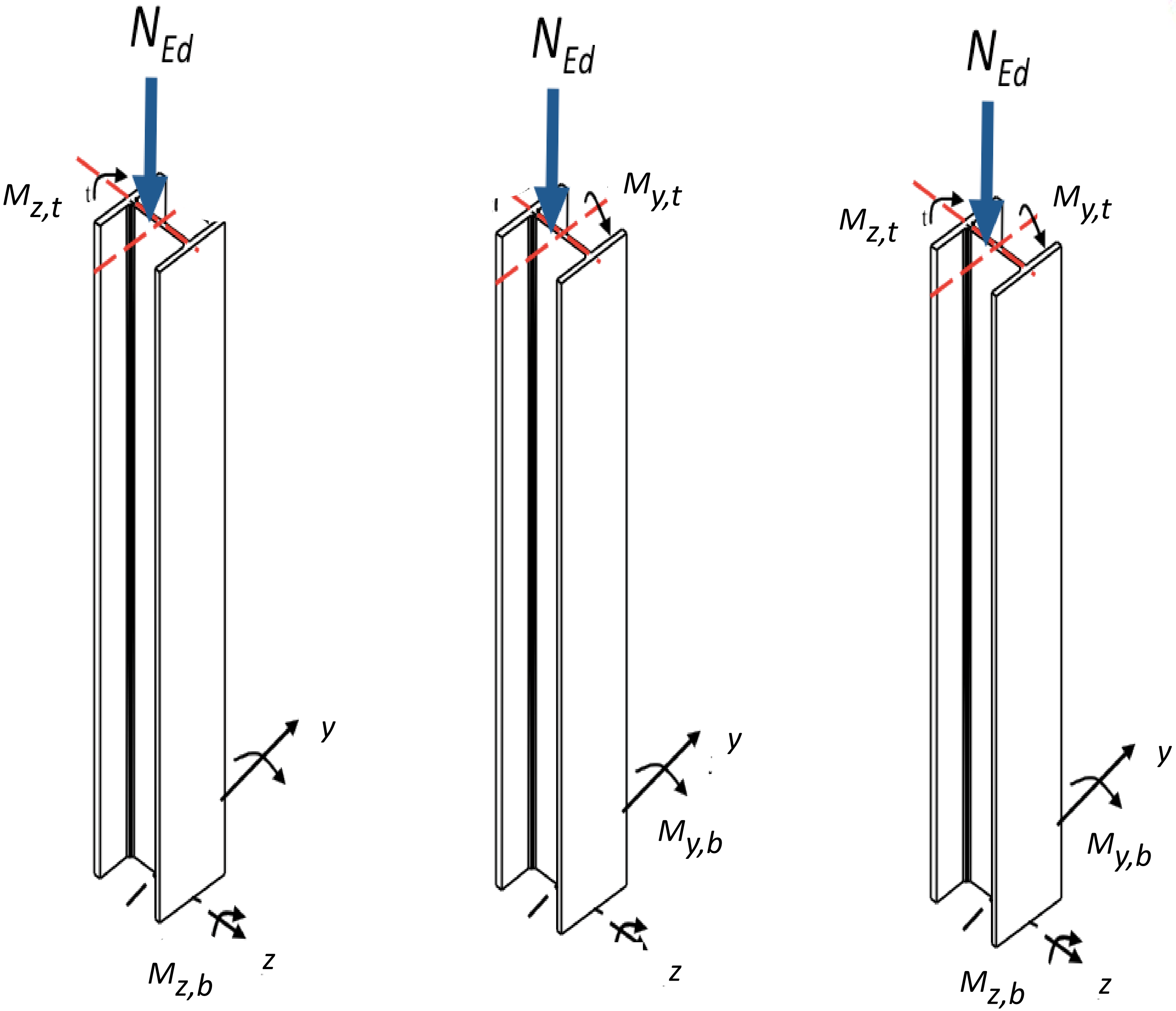
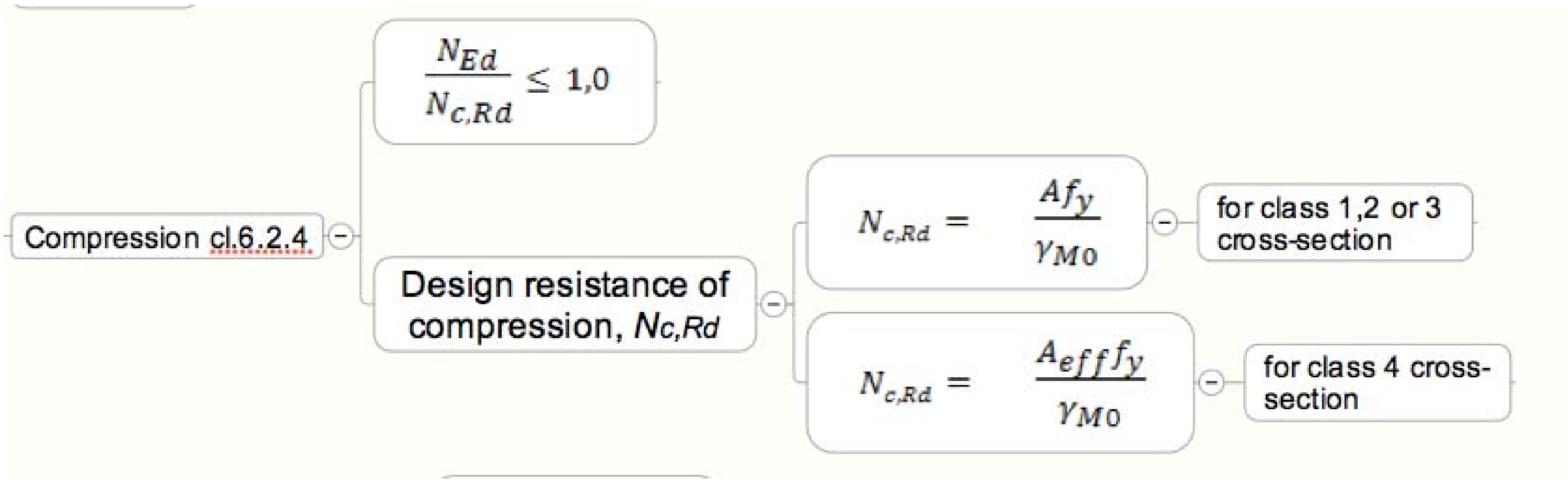


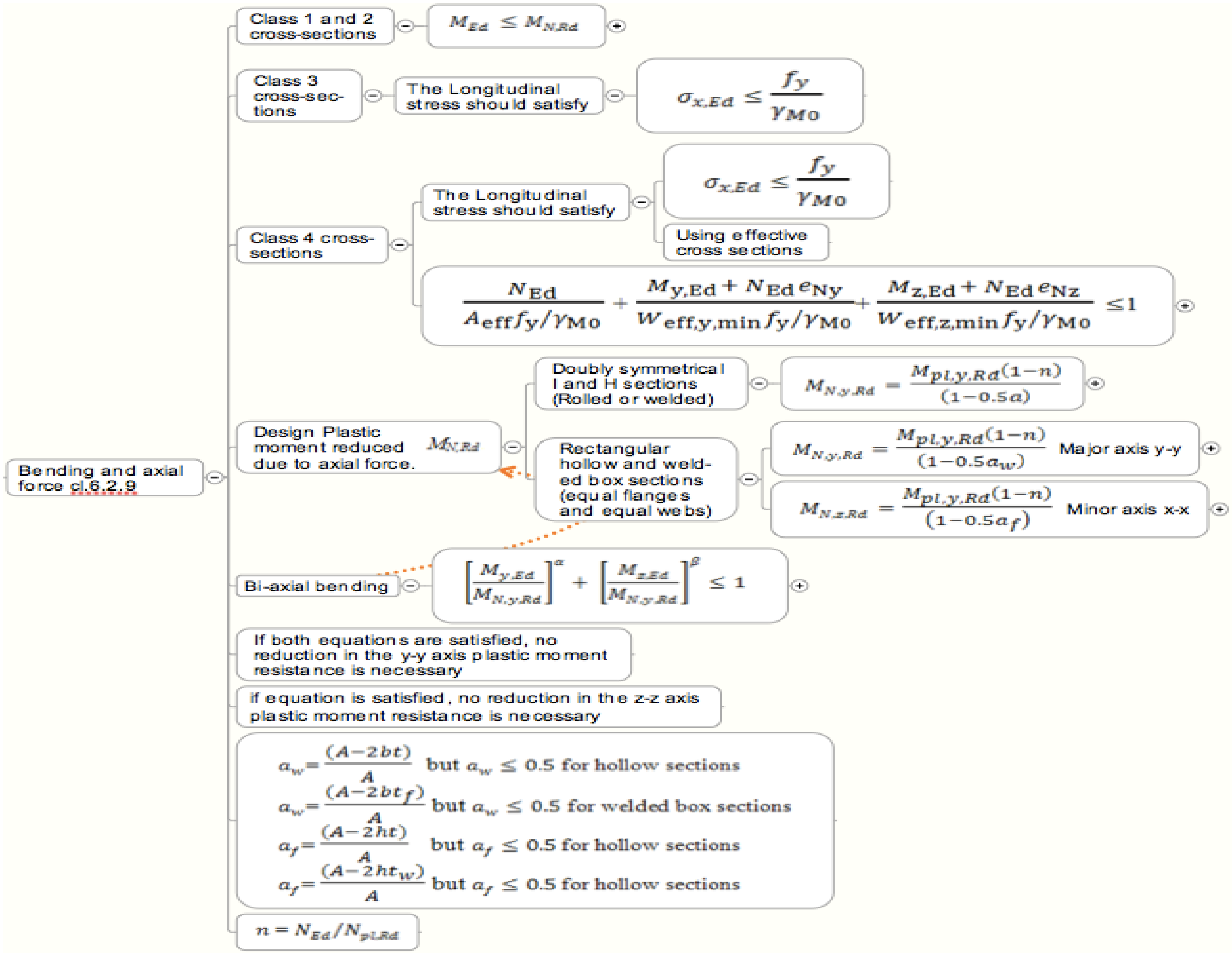
N_{Ed}
$M_{z,t}$
y
Pin connection
z
N_{Ed}
$M_{y,t}$
y
Pin connection
z
N_{Ed}
$M_{z,t}$
$M_{y,t}$
y
Pin connection
z



NEd
Mz,t
Mz,b
y
z
NEd
My,t
My,b
y
z
NEd
Mz,t
My,t
My,b
Mz,b
y
z


Compression cl.6.2.4
$\frac{N_{Ed}}{N_{c,Rd}} \leq 1,0$
Design resistance of compression, $N_{c,Rd}$
$N_{c,Rd} = \frac{A f_y}{\gamma_{M0}}$
for class 1,2 or 3 cross-section
$N_{c,Rd} = \frac{A_{eff} f_y}{\gamma_{M0}}$
for class 4 cross-section

- Bending moment cl.6.2.5
  - $\frac{M_{Ed}}{M_{c,Rd}} \leq 1,0$
  - Design resistance of bending, *Mc,Rd*
    - $M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} f_y}{\gamma_{M0}}$
    - $M_{c,Rd} = M_{el,Rd} = \frac{W_{el,min} f_y}{\gamma_{M0}}$
      - For class 3 cross-sections
      - *Wel,min* elastic section modulus
    - $M_{c,Rd} = \frac{W_{eff,min} f_y}{\gamma_{M0}}$
      - For class 4 cross-sections
      - *Weff,min* effective section modulus



Bending and axial force cl.6.2.9
Class 1 and 2 cross-sections
$M_{Ed} \leq M_{N,Rd}$
Class 3 cross-sections
The Longitudinal stress should satisfy
$\sigma_{x,Ed} \leq \frac{f_y}{\gamma_{M0}}$
Class 4 cross-sections
The Longitudinal stress should satisfy
$\sigma_{x,Ed} \leq \frac{f_y}{\gamma_{M0}}$
Using effective cross sections
$\frac{N_{Ed}}{A_{eff} f_y/\gamma_{M0}} + \frac{M_{y,Ed} + N_{Ed} e_{Ny}}{W_{eff,y,min} f_y/\gamma_{M0}} + \frac{M_{z,Ed} + N_{Ed} e_{Nz}}{W_{eff,z,min} f_y/\gamma_{M0}} \leq 1$
Design Plastic moment reduced due to axial force. $M_{N,Rd}$
Doubly symmetrical I and H sections (Rolled or welded)
$M_{N,y,Rd} = \frac{M_{pl,y,Rd}(1-n)}{(1-0.5a)}$
Rectangular hollow and welded box sections (equal flanges and equal webs)
$M_{N,y,Rd} = \frac{M_{pl,y,Rd}(1-n)}{(1-0.5a_w)}$ Major axis y-y
$M_{N,z,Rd} = \frac{M_{pl,y,Rd}(1-n)}{(1-0.5a_f)}$ Minor axis x-x
Bi-axial bending
$\left[\frac{M_{y,Ed}}{M_{N,y,Rd}}\right]^{\alpha} + \left[\frac{M_{z,Ed}}{M_{N,y,Rd}}\right]^{\beta} \leq 1$
If both equations are satisfied, no reduction in the y-y axis plastic moment resistance is necessary
if equation is satisfied, no reduction in the z-z axis plastic moment resistance is necessary
$a_w = \frac{(A-2bt)}{A}$ but $a_w \leq 0.5$ for hollow sections
$a_w = \frac{(A-2bt_f)}{A}$ but $a_w \leq 0.5$ for welded box sections
$a_f = \frac{(A-2ht)}{A}$ but $a_f \leq 0.5$ for hollow sections
$a_f = \frac{(A-2ht_w)}{A}$ but $a_f \leq 0.5$ for hollow sections
$n = N_{Ed}/N_{pl,Rd}$

- Uniform members in compression cl.6.3.1
  - Neglect buckling resistance if
    - $\bar{\lambda} \leq 0.2$
    - $\frac{N_{Ed}}{N_{cr}} \leq 0.04$
  - $\frac{N_{Ed}}{N_{b,Rd}} \leq 1,0$
    - $N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}}$
      - For class 1,2 and 3 cross sections
    - $N_{b,Rd} = \frac{\chi A_{eff} f_y}{\gamma_{M1}}$
      - For class 4 cross sections
    - Reduction Factor, χ
      - $\chi = \frac{1}{\phi + \sqrt{\phi^2 + \bar{\lambda}^2}}$ but $\chi \leq 1.0$
  - Slenderness
    - Flexural buckling
      - $\bar{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}} = \frac{L_{cr}}{i} \frac{1}{\lambda_1}$
      - $\bar{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}} = \frac{L_{cr}}{i} \frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1}$
    - Torsional and torsional-flexural buckling
      - $\bar{\lambda}_T = \sqrt{\frac{A f_y}{N_{cr}}} = \frac{L_{cr}}{i} \frac{1}{\lambda_1}$
      - $\bar{\lambda}_T = \sqrt{\frac{A_{eff} f_y}{N_{cr}}} = \frac{L_{cr}}{i} \frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1}$

- Uniform members in bending cl.6.3.2
  - $\frac{M_{Ed}}{M_{b,Rd}} \leq 1,0$
    - M_{Ed} Design Moment
    - $M_{b,Rd}$ Design buckling resistance moment
  - $M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{MI}}$
    - $w_y = w_{pl,y}$
      - For class 1 and 2 cross-sections
    - $w_y = w_{el,y}$
      - For class 3 cross-sections
    - $w_y = w_{eff,y}$
      - For Class 4 cross-sections
  - χ_{LT} Reduction Factor
    - General
    - For rolled section or equivalent welded sections
      - $\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 + \beta\lambda_{LT}^2}}$ but $\begin{cases} \chi_{LT} \leq 1.0 \\ \chi_{LT} \leq \frac{1}{\lambda_{LT}^2} \end{cases}$
      - $\chi_{LT,mod} = \frac{\chi_{Lt}}{f}$ but $\chi_{LT,mod} \leq 1$ With moment distribution between lateral restraint of members
    - Simplified assessment method for beams with restraints

Column subjected to axial load and bending -Uniform members in bending and axial compression cl.6.3.3

$$\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + k_{yy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + k_{yz}\frac{M_{z,Ed}+\Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + k_{zy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + k_{zz}\frac{M_{z,Ed}+\Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1$$

where

- N_{Ed}, $M_{y,Ed}$ and $M_{z,Ed}$: Design values of compression and maximum moments about y-y and z-z axis along members.
- $\Delta M_{y,Ed}$, $\Delta M_{z,Ed}$: Moments due the shift of centroidal axis for class 4.
- χ_y and χ_z: Reduction factor due to flexural buckling
- χ_{LT}: Reduction factor due to Lateral torsional buckling
  - χ_{LT} = 1.0 if not susceptible to torsional deformation
- k_{yy}, k_{yz}, k_{zy}, k_{zz}: Interaction factors
  - Annex A (alternatives method 1)
  - Annex B (alternatives method 2)

Table 6.7 Values for $N_{Rk} = f_y A_i$, $M_{i,Rk} = f_y W_i$ and $\Delta M_{i,Ed}$

Class	1	2	3	4
A_i	A	A	A	A_{eff}
W_y	$W_{pl,y}$	$W_{pl,y}$	$W_{el,y}$	$W_{eff,y}$
W_z	$W_{pl,z}$	$W_{pl,z}$	$W_{el,z}$	$W_{eff,z}$
$\Delta M_{y,Ed}$	0	0	0	$e_{N,y}N_{Ed}$
$\Delta M_{z,Ed}$	0	0	0	$e_{N,z}N_{Ed}$

simple construction

‘Simple construction’ is commonly used for the design of multi-storey buildings

- Beams are designed as simply supported
- Columns are designed for nominal moments arising from the eccentricity at the beam-to-column connection.

The moment components are small for simple construction, the interaction factors can be conservatively simplified to :

$$\frac{N_{Ed}}{N_{b,z,Rd}} + \frac{M_{y,Ed}}{M_{b,Rd}} + 1.5\frac{M_{z,Ed}}{M_{c,z,Rd}} \leq 1$$

Example 1 : Design of column with combined bending and axial load

Thank You