Localized resource for UK

NCCI: Verification of columns in simple construction – a simplified interaction criterion

This NCCI proposes a new expression for the verification of columns that will avoid the calculation of "k" factors in Annexes A and B of EN 1993-1-1.

Contents

1. Simplified interaction criterion

For the design of columns in the following situations:

- The column is a hot rolled I or H section, or rectangular hollow section,
- The cross section is class 1, 2 or 3 under compression,
- The bending moment diagrams about each axis are linear,
- The column is restrained laterally in both the y and z directions at each floor but is unrestrained between floors;

The following expression may be used to verify the member:

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

This expression may be used within the limitations on ψ value given in section 2.2.5. This expression is a simplified version of expression (6.62) in section 6.3.3 of EN1993-1-1. In deriving this expression k_{zy} has been taken as 1.0 and k_{zz} has been taken as 1.5. The parameters in this expression are as follows:

N_{Ed}, $M_{\mathrm{y,Ed}}$, $M_{\mathrm{z,Ed}}$ are as defined in EN1993-1-1 section 6.3.3.

$N_{\mathrm{min,b,Rd}}$ is the lesser of $\dfrac{\chi_{\mathrm{y}} f_{\mathrm{y}} A}{\gamma_{\mathrm{M1}}}$ and $\dfrac{\chi_{\mathrm{z}} f_{\mathrm{y}} A}{\gamma_{\mathrm{M1}}}$.

$M_{\mathrm{y,b,Rd}}$ is equal to $\chi_{\mathrm{LT}} \dfrac{f_{\mathrm{y}} W_{\mathrm{pl}}}{\gamma_{\mathrm{M1}}}$.

$M_{\mathrm{z,cb,Rd}}$ is given by $M_{\mathrm{z,cb,Rd}} = \dfrac{f_{\mathrm{y}} W_{\mathrm{pl}}}{\gamma_{\mathrm{M1}}}$, which is the same as the design value of the bending resistance of the cross section $M_{\mathrm{c,Rd}}$ $\left(= \dfrac{f_{\mathrm{y}} W_{\mathrm{pl}}}{\gamma_{\mathrm{M0}}}\right)$ when $\gamma_{\mathrm{M1}} = \gamma_{\mathrm{M0}}$.

2. Background: derivation of simplified expression from EN 1993-1-1, Annex B

2.1 Design expressions in EN 1993-1-1

Designing columns to EN 1993-1-1 requires verification according to expressions 6.61 and 6.62, given in clause 6.3.3(4) as shown below:

$$\frac{N_{\mathrm{Ed}}}{\dfrac{\chi_{\mathrm{y}} N_{\mathrm{Rk}}}{\gamma_{\mathrm{M1}}}} + k_{\mathrm{yy}} \frac{M_{\mathrm{y,Ed}} + \Delta M_{\mathrm{y,Ed}}}{\chi_{\mathrm{LT}} \dfrac{M_{\mathrm{y,Rk}}}{\gamma_{\mathrm{M1}}}} + k_{\mathrm{yz}} \frac{M_{\mathrm{z,Ed}} + \Delta M_{\mathrm{z,Ed}}}{\dfrac{M_{\mathrm{z,Rk}}}{\gamma_{\mathrm{M1}}}} \leq 1 \qquad (6.61)$$

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + k_{zy} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + k_{zz} \frac{M_{z,Ed} + \Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1 \qquad (6.62)$$

For Class 1, Class 2 and Class 3 cross sections, $\Delta M_{y,Ed} = \Delta M_{z,Ed} = 0$.

Writing $\chi_y \frac{N_{y,Rk}}{\gamma_{M1}}$ as $N_{y,b,Rd}$, $\chi_z \frac{N_{z,Rk}}{\gamma_{M1}}$ as $N_{z,b,Rd}$, $\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}$ as $M_{y,b,Rd}$ and $\frac{M_{z,Rk}}{\gamma_{M1}}$ as $M_{z,cb,Rd}$, equations 6.61 and 6.62 become:

$$\frac{N_{Ed}}{N_{y,b,Rd}} + k_{yy} \frac{M_{y,Ed}}{M_{y,b,Rd}} + k_{yz} \frac{M_{z,Ed}}{M_{z,cb,Rd}} \leq 1 \qquad \text{(ex 6.61)}$$

$$\frac{N_{Ed}}{N_{z,b,Rd}} + k_{zy} \frac{M_{y,Ed}}{M_{y,b,Rd}} + k_{zz} \frac{M_{z,Ed}}{M_{z,cb,Rd}} \leq 1 \qquad \text{(ex 6.62)}$$

2.2 Simplification

The determination of interaction factors "*k*" is made using Annex A and Annex B of EN1993-1-1. The values of these factors are often difficult to determine, especially when using Annex A. In order to avoid the time-consuming calculation of these factors, a simplified expression derived from (ex 6.61) and (ex 6.62) is needed.

The simplified expression should use specific values for the interaction parameters that will be conservative over the practical range of bending of columns. For reasons discussed below, the chosen values are:

$k_{yy} = k_{zy} = 1.0$ and

$k_{yz} = k_{zz} = 1.5$.

The range of bending moment diagram for which these values are valid is examined below.

Because the same values are chosen for k_{yy} and k_{zy}, and for k_{yz} and k_{zz}, the use of a single expression is justified because with restraints at the same level in both directions, $N_{z,b,Rd}$ will always be less than $N_{y,b,Rd}$. The expression in Section 1 therefore uses only $N_{z,b,Rd}$, which it refers to simply as $N_{b,Rd}$.

2.2.1 Use of k_{yy} = 1.0

For Class 1 and 2 sections:

The value of k_{yy} is given by Table B.2 and Table B.1.

$$k_{yy} = C_{my} \left(1 + \left(\bar{\lambda}_y - 0.2 \right) \frac{N_{Ed}}{N_{y,b,Rd}} \right)$$

but for plastic properties, $k_{yy} \le C_{my}\left(1+0.8\dfrac{N_{Ed}}{N_{y,b,Rd}}\right)$

For valid design situations, $\dfrac{N_{Ed}}{N_{y,b,Rd}} \le 1$, hence $k_{yy} \le C_{my}\left(1+0.8\times 1\right)=1.8C_{my}$

Therefore, $k_{yy} \le 1.0$ when $C_{my} \le \dfrac{1.0}{1.8}=0.556$

From Table B.3 for straight-line bending moment diagrams, $C_{my} = 0.6+0.4\psi_y$ (but ≥ 0.4)

Therefore $0.6+0.4\psi_y \le 0.556 \quad\Rightarrow\quad \psi_y \le \dfrac{0.556-0.6}{0.4}=\dfrac{-0.044}{0.4}=-0.11$

Therefore, using k_{yy} = 1.0 is safe for $\psi_y \le -0.11$

For the case where the member is pin-ended (ψ_y = 0 and thus C_{my} = 0.6), the use of k_{yy} = 1 will still be safe if a lower limit to the value of $N_{Ed}/N_{y,b,Rd}$ applies:

$$0.6\left(1+0.8\frac{N_{Ed}}{N_{y,b,Rd}}\right)\le 1.0 \text{ and thus } \frac{N_{Ed}}{N_{y,b,Rd}}\le\frac{1.0-0.6}{0.48}=0.83$$

For Class 3 sections:

Table B.2 says that k_{yy} should be found from Table B.1

Table B.1 gives:

$$k_{yy}=C_{my}\left(1+0.6\bar{\lambda}_y\frac{N_{Ed}}{N_{y,b,Rd}}\right)$$

but for elastic properties, $k_{yy} \le C_{my}\left(1+0.6\dfrac{N_{Ed}}{N_{y,b,Rd}}\right)$

Because $\dfrac{N_{Ed}}{N_{y,b,Rd}} \le 1$, $k_{yy} \le C_{my}\left(1+0.6\times 1\right)=1.6C_{my}$

Therefore, for $k_{yy} \le 1.0$, $C_{my} = \dfrac{k_{yy}}{1.6} \le \dfrac{1.0}{1.6}=0.625$

From Table B.3 for straight-line bending moment diagrams, $C_{my} = 0.6+0.4\psi_y \ge 0.4$

Therefore $0.625 \ge 0.6+0.4\psi_y \Rightarrow \psi_y \le \dfrac{0.625-0.6}{0.4}=\dfrac{0.025}{0.4}=0.0625$

Therefore, $k_{yy} = 1.0$ is valid for $\psi_{y} \leq 0.0625$

2.2.2 Use of $k_{yz} = 1.5$

I and H sections

For Class 1 and 2 sections:

Table B.2 says that k_{yz} should be found from Table B.1

Table B.1 gives $k_{yz} = 0.6k_{zz}$,

Therefore:

$$k_{yz} = 0.6 C_{mz} \left(1 + \left(2\bar{\lambda}_{z} - 0.6 \right) \frac{N_{Ed}}{N_{z,b,Rd}} \right)$$

but for plastic properties of I and H sections, $k_{yz} \leq 0.6 C_{mz} \left(1 + 1.4 \frac{N_{Ed}}{N_{z,b,Rd}} \right)$

For $\frac{N_{Ed}}{N_{z,b,Rd}} \leq 1$, $k_{yz} \leq 0.6 C_{mz} \left(1 + 1.4 \times 1 \right) = 1.44 C_{mz}$

For $k_{yz} \leq 1.5$, $C_{mz} = \frac{k_{yz}}{1.44} \leq \frac{1.5}{1.44} = 1.04$

From Table B.3 for straight-line bending moment diagrams, $C_{mz} = 0.6 + 0.4\psi_{z} \geq 0.4$

And $-1 \leq \psi \leq 1$

Therefore $k_{yz} = 1.5$ is valid for all cases

RHS sections

Table B.2 says that k_{yz} should be found from Table B.1

Table B.1 gives $k_{yz} = 0.6k_{zz}$,

Therefore:

$$k_{yz} = 0.6 C_{mz} \left(1 + \left(\bar{\lambda}_{z} - 0.2 \right) \frac{N_{Ed}}{N_{z,b,Rd}} \right)$$

but for plastic properties of RHS sections, $k_{yz} \leq 0.6 C_{mz} \left(1 + 0.8 \frac{N_{Ed}}{N_{z,b,Rd}} \right)$

For $\frac{N_{\text{Ed}}}{N_{\text{z,b,Rd}}} \leq 1,\ k_{\text{yz}} \leq 0.6 C_{\text{mz}} \left(1 + 0.8 \times 1\right) = 1.08 C_{\text{mz}}$

For $k_{\text{yz}} \leq 1.5,\ C_{\text{mz}} = \frac{k_{\text{yz}}}{1.08} \leq \frac{1.5}{1.08} = 1.389$

From Table B.3 for straight-line bending moment diagrams, $C_{\text{mz}} = 0.6 + 0.4\psi_{\text{z}} \geq 0.4$

And $-1 \leq \psi \leq 1$

Therefore k_{yz} = 1.5 is valid for all cases

For Class 3 sections:

Table B.1 gives $k_{yz} = k_{zz}$,

Therefore for elastic properties of RHS sections, :

$$k_{\text{yz}} = C_{\text{mz}} \left(1 + 0.6 \bar{\lambda}_{z} \frac{N_{\text{Ed}}}{N_{\text{z,b,Rd}}}\right)$$

$$k_{\text{yz}} \leq C_{\text{mz}} \left(1 + 0.6 \frac{N_{\text{Ed}}}{N_{\text{z,b,Rd}}}\right)$$

$$\frac{N_{\text{Ed}}}{N_{\text{z,b,Rd}}} \leq 1,\ k_{\text{yz}} \leq C_{\text{mz}} \left(1 + 0.6 \times 1\right) = 1.6 C_{\text{mz}}$$

For $k_{\text{yz}} \leq 1.5,\ C_{\text{mz}} = \frac{k_{\text{yz}}}{1.6} \leq \frac{1.5}{1.6} = 0.938$

From Table B.3 for straight-line bending moment diagrams, $C_{\text{mLT}} = 0.6 + 0.4\psi \geq 0.4$

Therefore $0.938 \geq 0.6 + 0.4\psi \Rightarrow \psi_{\text{z}} \leq \frac{0.938 - 0.6}{0.4} = \frac{0.338}{0.4} = 0.845$

Therefore k_{yz} = 1.5 for $\psi_{\text{z}} \leq 0.845$

2.2.3 Use of k_{zy} = 1.0

For Class 1 and 2 sections:

From Table B.2, for plastic sections:

$k_{\text{zy}} = \left[1 - \frac{0.1 \bar{\lambda}_{\text{z}}}{\left(C_{\text{m,LT}} - 0.25\right)} \frac{N_{\text{Ed}}}{N_{\text{z,b,Rd}}}\right]$ but $\geq \left[1 - \frac{0.1}{\left(C_{\text{m,LT}} - 0.25\right)} \frac{N_{\text{Ed}}}{N_{\text{z,b,Rd}}}\right]$, so that k_{zy} is less than 1.0

Therefore k_{yz} = 1.0 is valid for all cases.

For Class 3 sections:

From Table B.2, for elastic sections:

$$\left[1-\frac{0.05\bar{\lambda}_{z}}{\left(C_{m,LT}-0.25\right)}\frac{N_{Ed}}{N_{z,b,Rd}}\right] \text{but} \geq \left[1-\frac{0.05}{\left(C_{m,LT}-0.25\right)}\frac{N_{Ed}}{N_{z,b,Rd}}\right]$$, so that k_{zy} is less than 1.0

Therefore k_{zy} = 1.0 is valid for all cases.

2.2.4 Use of k_{zz} = 1.5

I and H sections

For Class 1 and 2 sections:

Table B.2 says that k_{zz} should be found from Table B.1

Table B.1 gives k_{zz} for plastic I and H sections:

$$C_{mz}\left(1+\left(2\bar{\lambda}_{z}-0.6\right)\frac{N_{Ed}}{N_{z,b,Rd}}\right)$$

$$\leq C_{mz}\left(1+1.4\frac{N_{Ed}}{N_{z,b,Rd}}\right)$$

For $\frac{N_{Ed}}{N_{z,b,Rd}} \leq 1,\ k_{zz} \leq C_{mz}\left(1+1.4\times 1\right) = 2.4C_{mz}$

For $k_{zz} \leq 1.5,\ C_{mz} = \frac{k_{zz}}{2.4} \leq \frac{1.5}{2.4} = 0.625$

From Table B.3 for straight-line bending moment diagrams, $C_{mz} = 0.6 + 0.4\psi \geq 0.4$

Therefore $0.625 \geq 0.6 + 0.4\psi \Rightarrow \psi_{z} \leq \frac{0.625-0.6}{0.4} = \frac{0.025}{0.4} = 0.0625$

Therefore k_{zz} = 1.5 for $\psi_{z} \leq 0.0625$

RHS sections

Table B.1 gives k_{zz} for plastic RHS sections:

$$k_{zz} = C_{mz}\left(1+\left(\bar{\lambda}_{z}-0.2\right)\frac{N_{Ed}}{N_{z,b,Rd}}\right)$$

but $k_{zz} \leq C_{mz}\left(1+0.8\frac{N_{Ed}}{N_{z,b,Rd}}\right)$

For $\frac{N_{Ed}}{N_{z,b,Rd}} \leq 1$, $k_{zz} \leq C_{mz}(1+0.8\times 1) = 1.8C_{mz}$

For $k_{yz} \leq 1.5$, $C_{mz} = \frac{k_{yz}}{1.8} \leq \frac{1.5}{1.8} = 0.833$

From Table B.3 for straight-line bending moment diagrams, $C_{mz} = 0.6 + 0.4\psi_z \geq 0.4$

Therefore $0.833 \geq 0.6 + 0.4\psi_y \Rightarrow \psi_y \leq \frac{0.833-0.6}{0.4} = \frac{0.233}{0.4} = 0.583$

Therefore, $k_{yz} = 1.5$ is valid for $\psi_z \leq 0.583$

For Class 3 sections:

Table B.1 gives for elastic sections k_{zz}:

$$k_{zz} = C_{mz}\left(1+0.6\bar{\lambda}_z\frac{N_{Ed}}{N_{z,b,Rd}}\right)$$

$$k_{zz} \leq C_{mz}\left(1+0.6\frac{N_{Ed}}{N_{z,b,Rd}}\right)$$

$\frac{N_{Ed}}{N_{z,b,Rd}} \leq 1$, $k_{zz} \leq C_{mz}(1+0.6\times 1) = 1.6C_{mz}$

For $k_{zz} \leq 1.5$, $C_{mz} = \frac{k_{zz}}{1.6} \leq \frac{1.5}{1.6} = 0.938$

From Table B.3 for straight-line bending moment diagrams, $C_{mLT} = 0.6 + 0.4\psi \geq 0.4$

Therefore $0.938 \geq 0.6 + 0.4\psi \Rightarrow \psi_z \leq \frac{0.938-0.6}{0.4} = \frac{0.338}{0.4} = 0.845$

Therefore $k_{zz} = 1.5$ for $\psi_z \leq 0.845$

2.2.5 Summary of limitations for proposed factors

The following tables summarise the maximum Ψ_i values for the validation of the simplified interaction formulae using specific values for the interaction parameters (i.e. $k_{yy} = k_{zy} = 1.0$ and $k_{yz} = k_{zz} = 1.5$).

Table 2.1 ***ψ_i limits for validity of $k_{yy} = k_{zy} = 1.0$ and $k_{yz} = k_{zz} = 1.5$ for class 1 and 2 sections***

	I and H sections	RHS
$k_{yy} = 1.0$	-0.11 (see note)	-0.11(see note)
$k_{yz} = 1.5$	Valid for all cases	Valid for all cases
$k_{zy} = 1.0$	Valid for all cases	Valid for all cases
$k_{zz} = 1.5$	0.0625	0.583

Note: If the column is pin-ended ($\psi = 0$), the simplified expression is still valid with $k_{yy} = 1,0$ if $N_{Ed}/N_{y,b,Rd} \leq 0,83$. This limit will usually be easily achieved.

Table 2.2 ***ψ_i limits for validity of $k_{yy} = k_{yz} = 1.0$ and $k_{yz} = k_{zz} = 1.5$ for class 3 sections***

	I and H sections	RHS
$k_{yy} = 1.0$	0.0625	0.0625
$k_{yz} = 1.5$	0.845	0.845
$k_{zy} = 1.0$	Valid for all cases	Valid for all cases
$k_{zz} = 1.5$	0.845	0.845

2.2.6 Summary of parametric study

A parametric study has been conducted of columns using the following sections:

- HD 400 × 237
- HD 400 × 677
- HD 260 × 93
- HD 260 × 172
- UC 356 × 368 × 202
- UC 254 × 254 × 107
- UC 102 × 102 × 30
- HE 200B
- HE 340A
- IPE 330
- IPE 500

All the sections were analysed in lengths of 4 and 8 m, and using both S275 and S355 steel grades.

The applied forces were increased for each section until all of them were in the critical load, this is, until the sum of the three terms of the governing equation (whichever it was for each particular case) was 1. This lead to the following range of loads:

- $0.725 \leq \dfrac{N_{\mathrm{Ed}}}{N_{\mathrm{b,Rd,z}}} \leq 0.998$
- $0 \leq k_{\mathrm{zy}} \dfrac{M_{\mathrm{y,Ed}}}{M_{\mathrm{y,b,Rd}}} \leq 0.138$
- $0 \leq k_{\mathrm{zz}} \dfrac{M_{\mathrm{z,Ed}}}{M_{\mathrm{z,cb,Rd}}} \leq 0.2737$

This showed that for H-section columns with their height, *h*, approximately equal to their breadth, *b*, the proposed equation is safe for (ψ_y, ψ_z) of (0,0); (0,-0.5); (-0.5,0); (-0.5,-0.5).