Columns in simple design according to the Eurocodes

Dorota Koschmidder of SCI explains the simplified method of designing continuous columns in simple construction according to the Eurocodes.

Introduction

Structures of simple design are composed of members connected by nominally pinned joints and resistance to horizontal forces is provided by bracing. This assumption makes the design of beams much easier, as each of them can be treated as simply supported. Beams are connected to the column face usually inducing a small bending moment in the column because of the eccentric application of transferred force. The columns are usually continuous over the height of the building.

Design rules regarding continuous columns in simple structures were given starting from the early versions of BS 449. BS 5950-1:2010 gave simplified rules specifically for this type of construction in Clause 4.7.7. However in BS EN 1993-1-1 the only option for members in combined axial compression and bending is the general guidance in Clause 6.3.3 (4), which is very complex compared to the elegance of Clause 4.7.7 in BS 5950. The subject of columns in simple design structures is addressed in the UK-specific NCCI: Verification of columns in simple design - a simplified interaction criterion, SN048b-EN-GB. This document can be found at *http://www. steelbiz.org/*.

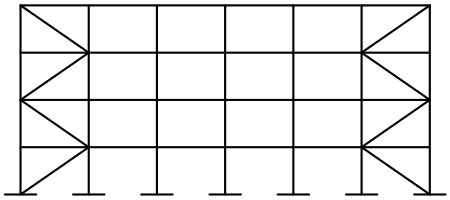


Figure 1: Example of simple construction

BS 5950 rules

BS 5950-1 offers comprehensive guidance for columns in simple design. There is no need to consider pattern loading – all the beams supported by the column should be assumed to be fully loaded. To determine the nominal bending moments in the column, beam reactions are taken as acting 100 mm from the face of the column, with the exception of members supported on cap plates.

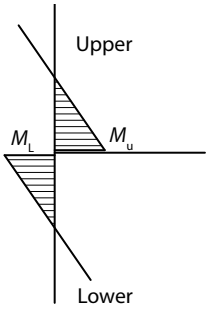


Figure 2: Distribution of nominal moments from floor beams

The moment applied by these eccentric reactions should be divided between column lengths above and below the level considered in proportion to their stiffness (as shown diagrammatically in Figure 2), unless the stiffness ratio is below 1.5, in which case the moment may be divided equally.

The buckling resistance moment for simple construction M_{bs} is determined using an equivalent slenderness value of $\lambda_{LT} = 0.5L/r_y$, where L is the distance between levels, at which the column is laterally restrained in both directions.

General approach for members under combined bending and axial compression in BS EN 1993-1-1

Clause 6.3.3(4) of BS EN 1993-1-1 gives two expressions that should be satisfied for members under combined bending and compression.

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}\left(M_{y,Rk}/\gamma_{M1}\right)} + k_{yz}\frac{M_{z,Ed}+\Delta M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \le 1.0$$

And:

$$\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}\left(M_{y,Rk}/\gamma_{M1}\right)} + k_{zz}\frac{M_{z,Ed}+\Delta M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \le 1.0$$

where:

χ_y, χ_z are the reduction factors for flexural buckling about the major and minor axes

χ_{LT} is the reduction factor for lateral-torsional buckling

k_{yy}, k_{yz}, k_{zz} and k_{zy} are interaction factors determined from either Annex A or B of BS EN 1993-1-1. The calculation of the "*k*" factors to either Annex is tedious and requires careful evaluation of effects coexisting in various situations.

Simplified guidance in SN048

This NCCI document was developed in order to offer a simplified expression for the verification of columns that will avoid the calculation of "*k*" factors required in Expressions 6.61 and 6.62 of BS EN 1993-1-1. The objective is to closely follow guidance similar to that given in BS 5950, so the initial assumptions are very familiar.

The NCCI gives rules for the design of columns of Class 1, 2 or 3 cross section under compression provided the following criteria are satisfied:

- The column is a hot rolled I, H or RHS section
- The bending moment diagrams about each axis are linear
- The column is restrained laterally in both the y and z directions at each floor level but is unrestrained between floors

- The bending moment ratios (ψ_i) as defined in Table B.3 in BS EN 1993-1-1 are below the values given in Tables 2.1 or 2.2 in the NCCI document SN048.
  Or
  If the column base is nominally pinned ($\psi_y = \psi_z = 0$) the axial force ratio is such that $\frac{N_{Ed}}{N_{y,b,Rd}} \leq 0.83$, where $N_{y,b,Rd}$ is the resistance to buckling about the major axis.

When the above mentioned conditions are fulfilled member verification may be carried out using the simplified expression:

$$\frac{N_{Ed}}{N_{min,b,Rd}} + \frac{M_{y,Ed}}{M_{y,b,Rd}} + 1.5\frac{M_{z,Ed}}{M_{z,cb,Rd}} \leq 1.0$$

where:

N_{Ed} , $M_{y,Ed}$ and $M_{z,Ed}$ are the design values of axial force and nominal bending moments about y-y and z-z axis respectively

$N_{min,b,Rd}$ is the lesser of $\frac{\chi_y f_y A}{\gamma_{M1}}$ and $\frac{\chi_z f_y A}{\gamma_{M1}}$, where χ_y , χ_z are the reduction factors for flexural buckling about the major and minor axes

$M_{y,b,Rd}$ is equal to $\chi_{LT} \frac{f_y W_{pl,y}}{\gamma_{M1}}$, where χ_{LT} is the reduction factor for lateral torsional buckling

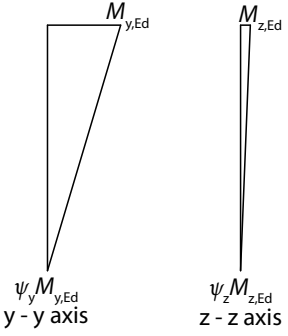
$M_{z,cb,Rd}$ is given by the expression $\frac{f_y W_{pl,z}}{\gamma_{M1}}$ for Class 1 and 2 sections and $\frac{f_y W_{el,z}}{\gamma_{M1}}$ for Class 3 sections, which is the same as the design value of the bending resistance of the cross section, when $\gamma_{M1} = \gamma_{M0}$.

In this Eurocode-compliant guidance there is no equivalent of $\lambda_{LT} = 0.5L/r_y$ slenderness reduction and the designers need to follow the general method of determining $\bar{\lambda}_{LT}$. Values of $M_{y,b,Rd}$ and $N_{min,b,Rd}$ can be taken from the SCI "Blue Book" (P363) for convenience.

Worked example

Consider a 203 × 203 × 46 UKC column in simple design in S275 steel subject to the following values of forces and moments:

Design compression force	N_{Ed}	= 589 kN
Design bending moment about the y-y axis	$M_{y,Ed}$	= 11.11 kNm
Design bending moment about the z-z axis	$M_{z,Ed}$	= 0.35 kNm



Axial force ratio and cross section classification

The design resistance obtained from SCI publication P363
$N_{pl,Rd}$ = 1610 kN

$$n = \frac{N_{Ed}}{N_{pl,Ed}}$$

Limiting value of n for Class 2 sections is 1.0

$$n = \frac{589}{1610} = 0.37 < 1.0$$

Therefore, under bending and N_{Ed} = 589 kN the section is at least Class 2.

Interaction criterion

As the sections meets the criteria in the NCCI document SN048, the simplified interaction equation may be used

$$\frac{N_{Ed}}{N_{min,b,Rd}} + \frac{M_{y,Ed}}{M_{y,b,Rd}} + 1.5\,\frac{M_{z,Ed}}{M_{z,cb,Rd}} \le 1.0$$

For buckling length L = 5 m and $n \le 1.0$ member buckling table from P363 gives the following values

$N_{b,y,Rd}$ = 1310 kN
$N_{b,z,Rd}$ = 762 kN
Therefore,
$N_{min,b,Rd}$ = 762 kN

Conservatively, the value for $M_{b,Rd}$ may be taken from the axial and bending table in SCI P363 ($M_{b,Rd}$ = 109 kNm) where the values are based on C_1 = 1.0. However, a more exact value may be determined from the bending resistance table.

For a column nominally pinned at the base, C_1 = 1.77
For C_1 = 1.77 and L = 5 m it was calculated that $M_{b,Rd}$ = 135 kNm

For bending about the minor axis, $M_{z,cb,Rd} = \dfrac{W_{pl,z} f_y}{\gamma_{M1}}$

As the section is Class 2 and the UK National Annex to BS EN 1993-1-1 gives the same value for γ_{M0} and γ_{M1},

$$M_{z,cb,Rd} = M_{c,z,Rd} = \frac{W_{pl,z} f_y}{\gamma_{M0}}$$

The value of $M_{z,cb,Rd}$ = 63.5 kNm is obtained from SCI publication P363.

Therefore

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

$$= \left(\frac{589}{762}\right) + \left(\frac{11.11}{135}\right) + 1.5 \times \left(\frac{0.35}{63.5}\right) = 0.86 < 1.0$$

Therefore the resistance of the member is adequate.

Conclusion

Design of continuous columns in simple construction is not explicitly covered in the Eurocodes, but there is NCCI available. Limitations on the application of the NCCI are usually not critical and the designers are given a simple interaction equation as an alternative to the general equations (6.61) and (6.62) given in BS EN 1993-1-1.