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RESISTANCE OF COMPOSITE COLUMN TO COMPRESSION AND BENDING

SUMMARY

Design of the composite steel-concrete columns subjected to compression and bending, according to Eurocode 4, is shown in the paper. The effects of imperfections in the axial compression are taken into account indirectly by using the relevant European buckling curves. When a composite column is subjected to combined axial compression and bending, the analysis includes an increase in bending moment due to second order effects. The verification of the column resistance to compression and bending is based on the use of interaction curve. For the cross sections of fully encased columns with the I steel sections, very practical sets of continuous interaction curves are given. The curves are constructed for different composite column dimensions, steel sections and concrete classes.

Key words: composite steel-concrete columns, interaction curves, resistance

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1. INTRODUCTION

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In this paper, only the composite steel-concrete columns with double symmetrical cross-section are considered. The analysis of composite columns is based on concept of limit states. Ultimate limit state is verified when section forces for the most unfavorable combination of actions in all column cross-sections are not greater than the corresponding column resistance. The second-order effects and imperfections have to be considered, while shrinkage and creep effects of concrete should be taken into account only when there is a possibility that they will significantly reduce the stability of the column. Verification of the serviceability limit states for columns is unnecessary. The simplified design method according to Eurocode 4 (ENV 1994) is used.

2. RESISTANCE OF A COLUMN CROSS-SECTION

The resistance of the fully plastified cross-section $N_{pl,Rd}$ is equal to the sum of the resistances of a steel section (a), reinforcement (s) and concrete (c):

$$N_{pl,Rd} = A_a \cdot f_{yd} + A_c \cdot \alpha \cdot f_{cd} + A_s \cdot f_{sd} \, , \tag{1}$$

where A_a, A_c, A_s represent areas of the steel section, concrete and reinforcement; f_{yd}, f_{sd}, f_{cd} represent the corresponding design strengths for each of these materials. For concrete-filled circular hollow steel sections the increased concrete resistance due to confining effect can be taken into account (Deretić-Stojanović et al. 2011).

When a composite section is subjected to combined compression and bending, the previously described resistance to compression $N_{pl,Rd}$, decreases. The relationship between resistance to compression $N_{pl,Rd}$ and resistance to bending $M_{pl,Rd}$ is given by the interaction curve (Fig 1.a). This curve shows the reduction of the section resistance to compression with increase of the bending moment.

A cross-section subjected to the design axial force N_{Ed} and the design bending moment M_{Ed} has sufficient resistance if the point (N_{Ed} , M_{Ed}) is within the area limited with the interaction curve.

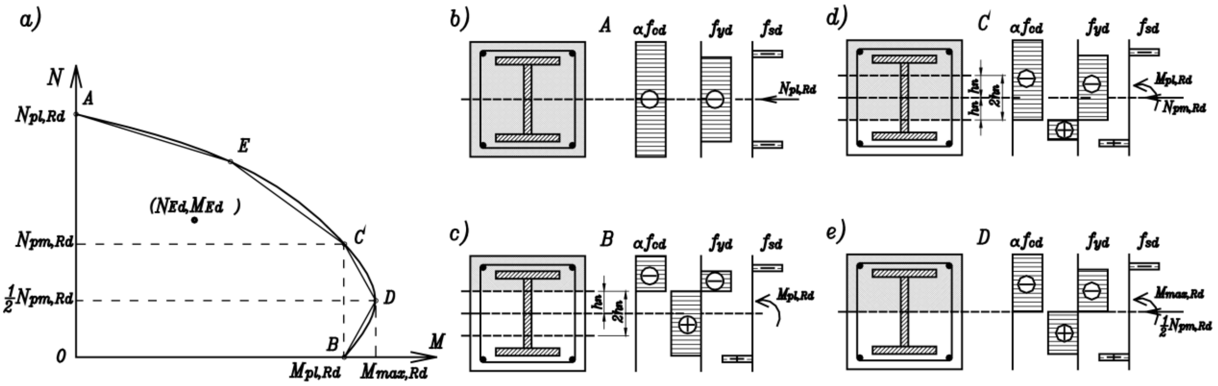


Fig. 1. a) Interaction curve N-M for compression and uniaxial bending;
b)-e) Stress diagrams for different points on the interaction curve

Interaction curve can be constructed point by point, considering different positions of the plastic neutral axis. Assuming the rectangular stress block diagram, for each position of the neutral axis, values of axial force and corresponding bending moment can be calculated. If the neutral axis moves in small steps, the continuous interaction curve can be obtained.

The simplified design method of Eurocode 4 (ENV 1994) allows simple calculation of only four or five points of the interaction curve (A,B,C,D and E). The real interaction curve can be approximated with the polygonal curve passing through these points (Fig. 2.a).

3. RESISTANCE OF COMPOSITE COLUMN

3.1. Resistance of composite column to axial compression

The column is considered as an individual member loaded at its ends with the axial compression force determined from the global analysis. If the global analysis is not based on the second order theory, which is common, for the largest number of individual columns the local analysis is performed according to the second order theory, taking into account the column imperfections (Johnson 2004).

According to the simplified design method of EC4, the effect of imperfections in the axial compression is taken into account indirectly, during the calculation of column resistance using the relevant European buckling curves

(ENV 1994; Johnson 2004; Deretić-Stojanović et al. 2011). Therefore, it is not necessary to determine the bending moment caused by the initial imperfection, since its influence on the column resistance is included through the buckling curves.

In composite columns in reality loaded with axial compression force, due to the presence of the geometrical imperfections, the secondary bending moments (imperfection moments) appear, and the resistance to axial compression determined from the expressions (1) reduces by a reduction coefficient χ.

The verification of the column resistance to axial compression, therefore, includes the satisfaction of the following condition:

$$N_{Ed} \leq \chi \cdot N_{pl,Rd} \qquad (2)$$

where: N_{Ed} is the design value of axial force that acts on the column; $N_{pl,Rd}$ is the resistance of the composite cross section to compression obtained from the expression (1); χ is the reduction coefficient for the relevant buckling model of Eurocode 3 (ENV 1993).

3.2. Resistance to compression and uniaxial bending

If a column imperfection in the global analysis is neglected it should be included in the column analysis (Deretić-Stojanović et al. 2011; Johnson 2004; Johnson and Anderson 2004). Besides initial imperfection (e_o) which is always present in reality and which produces the additional imperfection moment $N_{Ed}e_o$ (Fig. 2.a) at the mid-span, the analysis also includes an increase in bending moment due to additional deformations (second order effects). Second order effects can be neglected in some cases, but the additional bending moment due to imperfections has to be taken into account (Fig. 2.a,b).

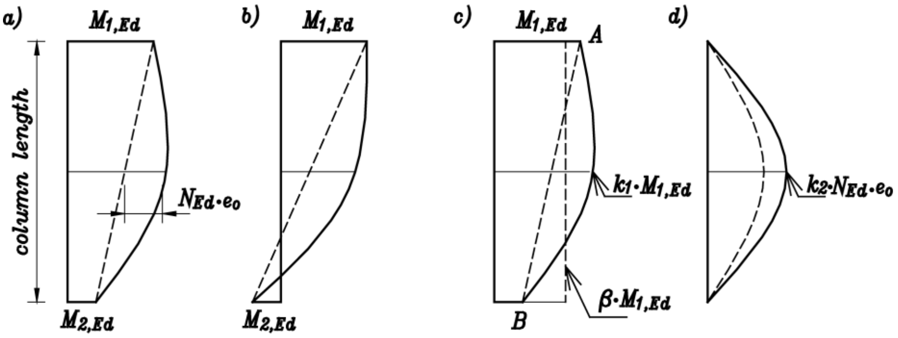


Fig. 2: First order and second order bending moment diagrams:
a) and b) First order bending moments and imperfection moment;
c) Increase of end moments due to second order effects;
d) Increase of imperfection moment due to second order effects

Eurocode 4 (ENV 1994) gives the criteria when the second order effects need to be included in the determination of the greatest column bending moment. As an additional simplification in the simplified design method of Eurocode 4, the second order effects can be taken into account by multiplying the greatest design bending moment M_{Ed} by a factor k given by:

$$k = \frac{\beta}{1 - N_{Ed} / N_{cr,eff}}, \geq 1{,}0 \qquad (3)$$

where β is an equivalent moment factor, $N_{cr,eff}$ is the critical elastic normal force.

The procedure for determining the column resistance to compression and uniaxial bending is based on the interaction diagram shown in Fig. 3.a (for bending about y axes), which is the cross-section ultimate capacity interaction curve (Fig. 2.a).

Firstly, the column resistance to compression is verified as it is explained in the section 3.1. If the condition (2) is satisfied, i.e. $N_{Ed} \leq \chi \cdot N_{pl,Rd}$, the bending moment that corresponds to the design axial force N_{Ed} on the interaction curve (Fig. 3.a), is $M_{pl,N,Rd} = \mu_d M_{pl,Rd}$. The column has sufficient resistance if the following condition is satisfied:

$$\frac{M_{Ed}}{M_{pl,N,Rd}} = \frac{M_{Ed}}{\mu_d M_{pl,Rd}} \leq \alpha_M \tag{4}$$

where: M_{Ed}=$M_{Ed,max}$ is the greatest design column bending moment (at the end sections or somewhere between); $M_{pl,N,Rd}$ is the design plastic moment resistance, including axial force N_{Ed}, determined as $\mu_d M_{pl,Rd}$, according to Fig. 3.a (for bending about y axes) $M_{pl,Rd}$ is the plastic resistance moment.

The coefficient α_M includes approximations introduced during the construction of interaction curves (Fig. 1.a), such as the assumption of rectangular stress diagram in the compressed concrete up to the neutral axis. Also, the effective flexural stiffness $(EI)_{eff}$ that neglects cracking of concrete is used. Therefore, it is necessary to correct the calculated bending resistance. For steel grades between S235 and S355, the coefficient α_M is equal to 0.9, while for grades S420 and S460 it is 0.8.

3.3 Resistance to compression and biaxial bending

The composite column subjected to axial compression and biaxial bending should be verified for each plane of bending separately, as explained in section 3.2. According to the Fig. 3, values μ_{dy} and μ_{dz} can be determined. Imperfections should be considered only in the plane in which the failure is expected to occur.

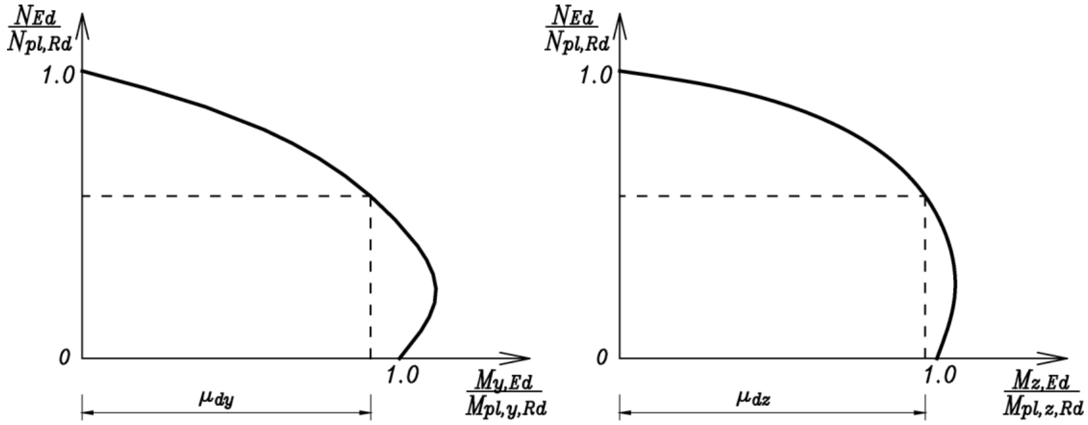


Fig. 3: Column resistance to compression and biaxial bending

The column should satisfy the following conditions:

$$\frac{M_{y,Ed}}{\mu_{dy} M_{pl,y,Rd}} \leq \alpha_{M,y} \quad , \quad \frac{M_{z,Ed}}{\mu_{dz} M_{pl,z,Rd}} \leq \alpha_{M,z} \tag{5}$$

$$\frac{M_{y,Ed}}{\mu_{dy} M_{pl,y,Rd}} + \frac{M_{z,Ed}}{\mu_{dz} M_{pl,z,Rd}} \leq 1{,}0 \tag{6}$$

$M_{pl,y,Rd}$ and $M_{pl,z,Rd}$ are the plastic bending resistances of the relevant plane of bending,

$M_{y,Ed}$ and $M_{z,Ed}$ are the design bending moments including the second order effects and imperfections.

4. INTERACTION CURVES

In design of composite columns subjected to combined axial compression and bending, the construction of N-M interaction curves represents the large part of computation (Kostić et al. 2011). For this reason, the practical interaction curves for common dimensions of square cross sections with encased steel section and for common concrete classes are constructed.

The following steel sections are considered: HEA 220, HEA 240, HEA 260, HEA 280, HEA 300 and HEA 320. Dimensions of side of concrete section vary between 30 and 60 cm. For each of the studied steel sections, dimensions of concrete are determined to satisfy the Eurocode 4 requirements about dimensions of concrete cover, and to have steel contribution ratio between 0.2 and 0.9. Also, for each of the studied composite cross section, the interaction curves are plotted for two different concrete classes C35/45 and C45/55. Reinforcement is neglected, and therefore, the presented interaction curves are on the safe side. Interaction curves for bending about strong (y) axes are given in Figs. 4-9. Extended set of interaction curves that includes also the N-M_z curves, where z is the weak bending axis, can be found in Kostic et al. (2011).

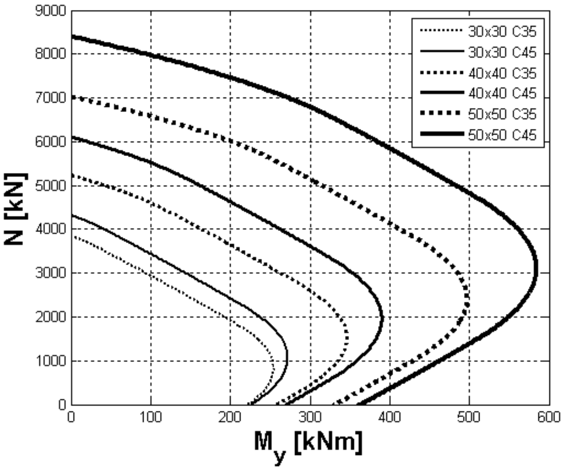


Fig. 4. HEA 220: interaction curves for columns 30x30, 40x40 and 50x50cm

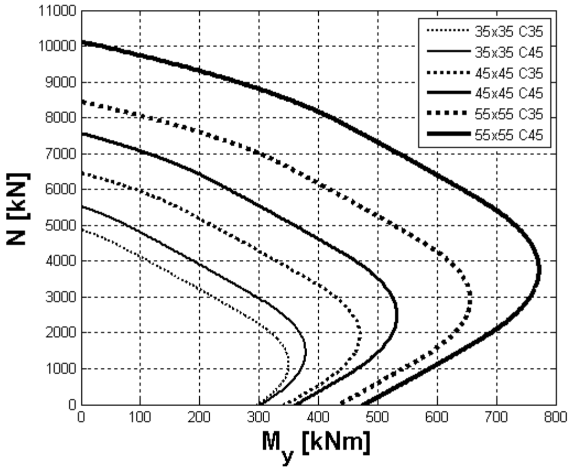


Fig. 5. HEA 240: interaction curves for columns 35x35, 45x45 and 55x55cm

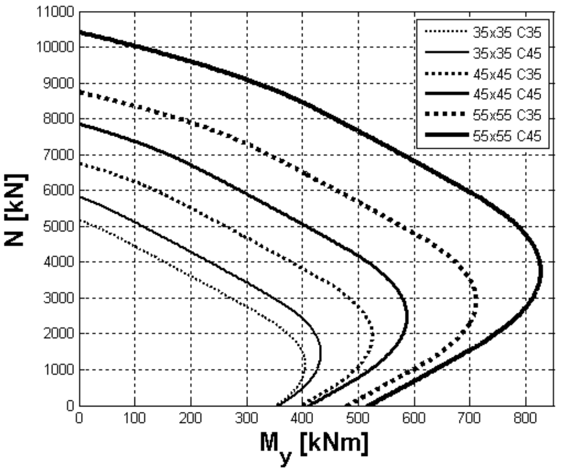


Fig. 6. HEA 260: interaction curves for columns 35x35, 45x45 and 55x55cm

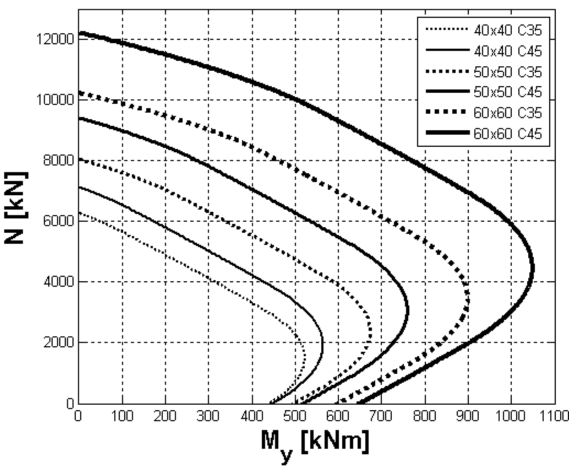
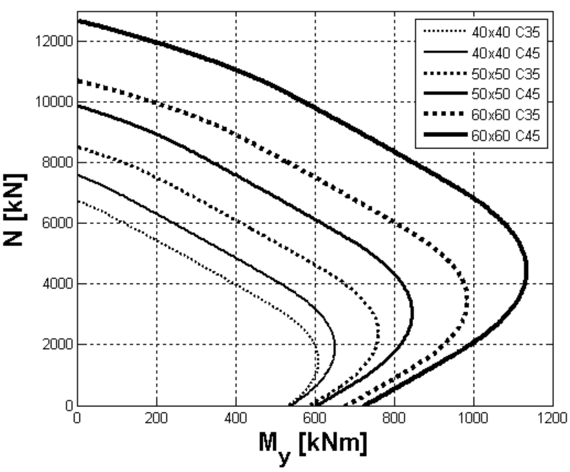


Fig. 7. HEA 280: interaction curves for columns 40x40, 50x50 and 60x60cm



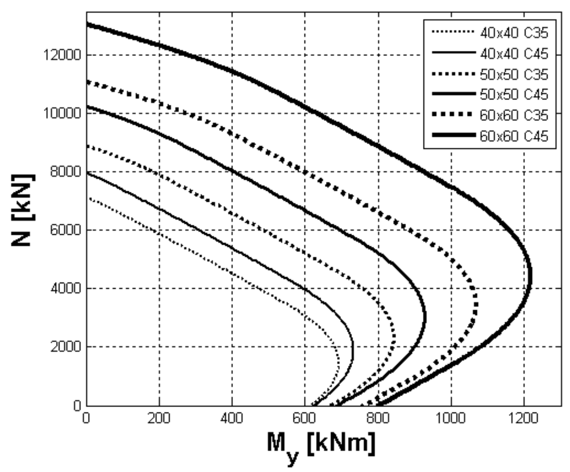


Fig. 8. HEA 300: interaction curves for columns 40x40, 50x50 and 60x60cm

Fig. 9. HEA 320: interaction curves for columns 40x40, 50x50 and 60x60cm

Given interaction curves simplify the design of the composite columns with encased I steel section by simplifying the choice of dimensions of concrete section, steel section and concrete class, for known design actions. Consequently, number of iterations during design reduces.

5. CONCLUSIONS

In the paper, design of composite steel-concrete columns based on the simplified design method of Eurocode 4 is presented. The application of this method is limited to composite columns with double symmetric and uniform cross section. As this type of composite columns is used very often in engineering practice, the presented type of analysis is very useful since allows simple and efficient, but enough accurate analysis of composite columns.

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