Composite column design

Although not commonly used in the UK, composite columns can, from a structural, fire resistance and accidental loading perspective, be advantageous, as they combine the benefits of steel and concrete. They are widely used in tall buildings because of the high resistance-to-footprint ratio they enable. In this article Dr Graham Couchman outlines the process for ambient temperature design given in EN 1994-1-1[1], with a focus on simplified methods for cross-section and member resistance.

Introduction

In order to improve clarity, design complications, such as a need to consider long terms effects, transverse shear, and second order effects, are dealt with by references to relevant clauses. The upcoming Generation 2 EN 1994-1-1[2] presents the same approach, with minor changes to some notation and factors, and of course clause numbering.

Design to EN 1994-1-1

Ultimate limit state (ULS) design is covered in Section 6.7. Alongside a General Method, which I will not discuss, a Simplified Method with a scope limitation broad enough to not inhibit its use for most practical design is given (6.7.3). The scope is limited to cross-sections that are doubly symmetric and uniform over the length of the member. Limits related to concrete cover of embedded sections, aspect ratio of the cross-section, slenderness, amount of reinforcement and the nature of the steel element (you can have built-up sections, but you can't have multiple unconnected steel sections) are also defined in 6.7.3.

Cross-section resistance

The plastic resistance to compression is defined in 6.7.3.2. It is simply the sum of the resistances of the three components (structural steel, concrete and reinforcement). For an encased steel section:

$$N_{pl,Rd} = A_a f_{yd} + 0.85 A_c f_{cd} + A_s f_{yd}$$

For composite element notation, the subscripts a, c and s refer to structural steel, concrete and reinforcing steel respectively. For a concrete-filled hollow section the value of 0.85 is replaced by 1.0, presumably to reflect the benefits of concrete confinement, although 6.7.3.6 gives an enhanced axial resistance for concrete-filled hollow sections within a certain slenderness limit.

The impact of transverse shear, which we will assume is negligible, is considered in 6.7.3.2 (3) and (4).

A simplified method for considering the interaction of compression and bending on the cross-section resistance is given in 6.7.3.2(5) and illustrated in Figure 1 below. Different neutral axis positions are considered:

- Point A is pure compression
- Point B is pure bending
- Points C and D consider equilibrium of forces, with Point D showing that the presence of some axial compression can – like pre-stressing – enhance the moment resistance

Stiffness, slenderness and member analysis

Stiffness, slenderness and member analysis are covered in 6.7.3.3 and 6.7.3.4. For the determination of the relative slenderness and elastic critical force, the stiffness is taken as the sum of the stiffnesses of the three components:

$$(EI)_{eff} = E_a I_a + E_s I_s + K_e E_{cm} I_c$$

▸30

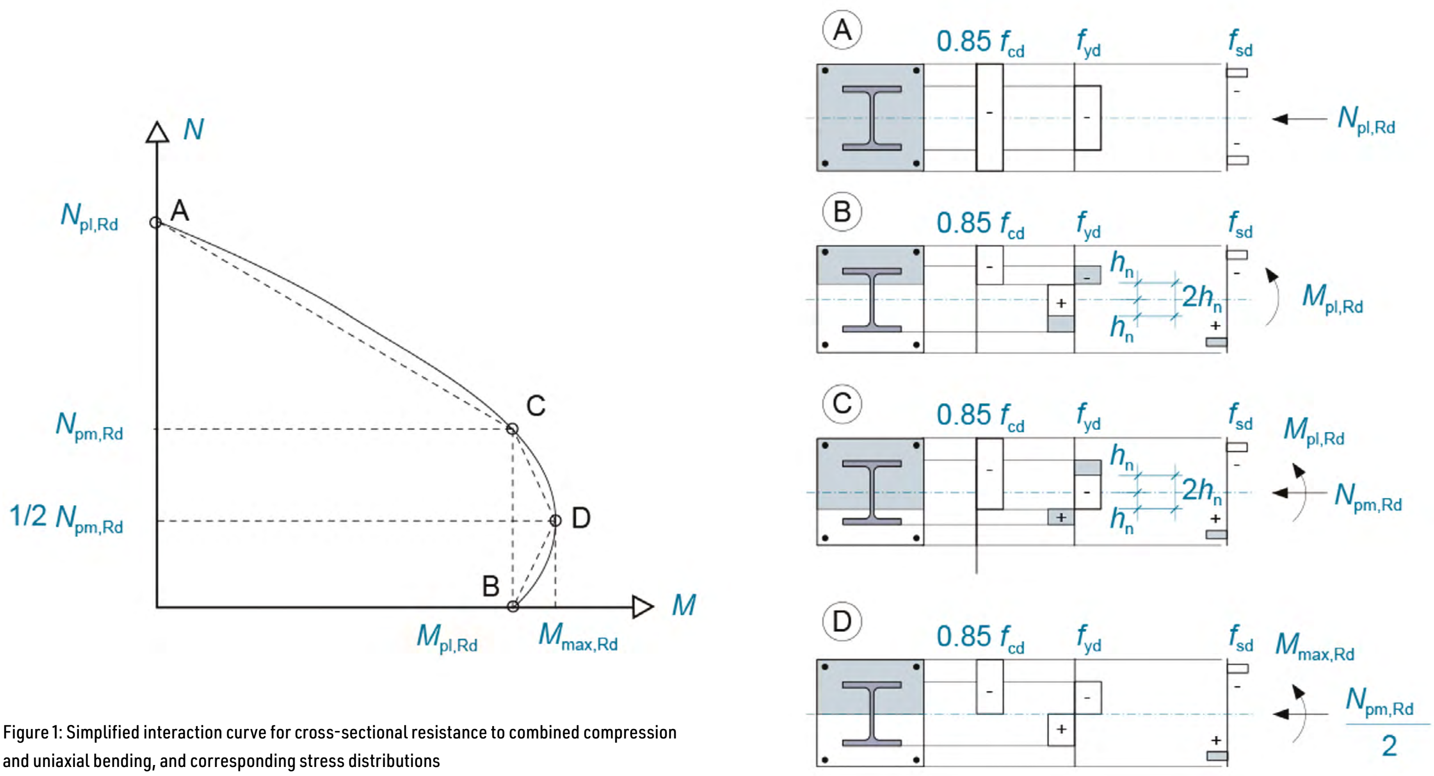

Figure 1: Simplified interaction curve for cross-sectional resistance to combined compression and uniaxial bending, and corresponding stress distributions

▸28 K_e is an approximate correction factor to allow for concrete cracking, that should be taken as 0.6. Second moments of area are for the plane of bending being considered, and the uncracked concrete value should be used.

The relative slenderness $\bar{\lambda}$ for the chosen plane of bending is given by:

$$\bar{\lambda} = \sqrt{\frac{N_{pl,Rk}}{N_{cr}}}$$

$N_{pl,Rk}$ is the characteristic value of the plastic resistance (characteristic values are used rather than design strengths of materials).

N_{cr} is the elastic critical normal force for the relevant buckling mode. For flexural bucking the elastic critical normal force is given by the Euler load:

$$N_{cr} = \frac{\pi^2 (EI)_{eff}}{{L_{cr}}^2}$$

L is the effective length, which may vary depending on the buckling mode being considered.

For the determination of internal forces, the stiffness is reduced using the factors defined below (note the values of 0.5 and 0.9 are defined in the code as variable calibration and correction factors respectively, with these values recommended):

$$(EI)_{eff,II} = 0.9(E_a I_a + E_s I_s + 0.5 E_{cm} I_c)$$

The concrete stiffness E_{cm} should be reduced to allow for any long-term effects, using 6.7.3.3(4).

Second order effects and imperfections are considered in 6.7.3.4(3) (4) and (5). For second order effects, (5) defines a simple magnification factor that multiplies the greatest first-order bending moment M_{Ed}:

$$k = \frac{\beta}{1 - N_{ed}/N_{cr,eff}} \geq 1.0$$

The critical normal force for use in this check, $N_{cr,eff}$, is determined using the effective stiffness, as defined above, but with an effective length taken as the column length. The equivalent moment factor β is taken from EN 1994-1-1 Table 6.4.

Member resistance

Members in pure axial compression are considered in 6.7.3.5(2). Member resistance is the cross-sectional resistance reduced by the factor χ according to EN 1993-1-1[3], 6.3.1.2, as a function of the relevant buckling curve and relative slenderness. The verification is therefore:

$$\frac{N_{ed}}{\chi N_{pl,Rd}} \leq 1.0$$

EN 1994-1-1 Table 6.5 identifies which buckling curve to use for different types of cross-section, and each axis of bending. It also defines member imperfections for each case.

Member resistance in combined axial compression and uniaxial bending is considered in 6.7.3.6. The maximum applied moment is compared with a moment resistance that is reduced to allow for the level of axial force present, using the following verification:

$$\frac{M_{ed}}{\mu_d M_{pl,Rd}} \leq \alpha_M$$

According to 6.7.3.6(2), the reduction factor μ_d is derived from the curve describing the cross-sectional resistance to combined compression and uniaxial bending (as shown in Figure 2). The factor α_M is taken as 0.9 for steel grades not more than S355, and 0.8 for S420 and S460.

The added complication of combined compression and biaxial bending is considered in 6.7.3.7, using the same principles as described above, (and therefore not repeated here).

Conclusions

Composite beams and composite slabs are widely used in the UK, as the benefits of combining the properties of steel and concrete are widely recognised. Composite columns are much less used, despite the performance benefits to be gained. This may be at least partly due to the frame erection process implications of combining the two materials in a column. Off-site manufactured elements could help to address this.

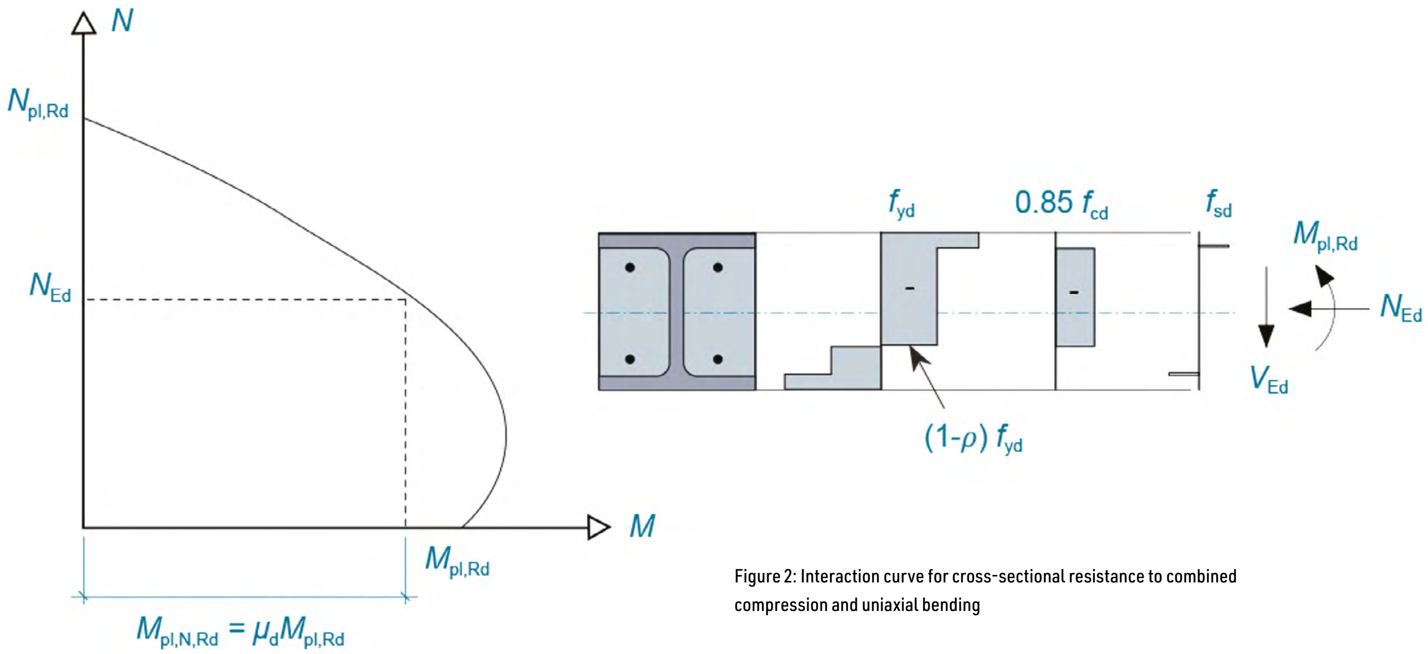

Figure 2: Interaction curve for cross-sectional resistance to combined compression and uniaxial bending

References

1. BS EN 1994-1-1:2004. *Eurocode 4: Design of composite steel and concrete structures.* Part 1-1: General rules and rules for buildings. Incorporating corrigendum April 2009. BSI, 2009.
2. Fpr EN 1994-1-1:2025. *Eurocode 4: Design of composite steel and concrete structures.* Part 1-1: General rules and rules for buildings. CEN, 2025.
3. BS EN 1993-1-1:2005. *Eurocode 3: Design of steel structures.* Part 1-1: General rules and rules for buildings. Incorporating corrigenda February 2006 and April 2009. BSI, 2010.

Recommended reading

- PN006 NCCI: Design of reinforced concrete filled, hot finished structural steel hollow sections in fire