5 Columns

5.0 General

The calculations in this section illustrate:

5.1 Design of a non-slender edge column using hand calculation.

5.2 Design of a perimeter column using iteration of equations to determine reinforcement requirements.

5.3 Design of an internal column with high axial load.

5.4 Design of a slender column requiring a two-hour fire resistance.

In general, axial loads and first order moments are assumed to be available. The designs consider slenderness in order to determine design moments, M_{Ed}. The columns are designed and checked for biaxial bending. The effects of allowing for imperfections are illustrated.

A general method of designing columns is as follows. In practice, several of these steps may be combined.

■ Determine design life.	EC0 & NA Table NA 2.1
■ Assess actions on the column.	EC1 (10 parts) & UK NAs
■ Determine which combinations of actions apply.	EC0 & NA Tables NA A1.1 & NA A1.2(B)
■ Assess durability requirements and determine concrete strength.	BS 8500–1
■ Check cover requirements for appropriate fire resistance period.	Approved Document B, EC2–1–2
■ Determine cover for fire, durability and bond.	**Cl. 4.4.1**
■ Analyse structure for critical combination moments and axial forces.	**Section 5**
■ Check slenderness and determine design moments.	**Section 5.8**
■ Determine area of reinforcement required.	**Section 6.1**
■ Check spacing of bars and links.	**Sections 8 & 9**

5.1 Edge column

The intention of this calculation is to show a typical hand calculation that makes reference to design charts.

The Concrete Centre™ PART OF THE MINERAL PRODUCTS ASSOCIATION	Project details **Edge column**	Calculated by chg	Job no. CCIP – 041
		Checked by web	Sheet no. 1
		Client TCC	Date Oct 09

A 300 mm square column on the edge of a flat slab structure supports an axial load of 1620 kN and first order moments of 38.5 kNm top and –38.5 kNm bottom in one direction only‡. The concrete is grade C30/37, f_{ck} = 30 MPa and cover, c_{nom}, = 25 mm. The 250 mm thick flat slabs are at 4000 mm vertical centres.

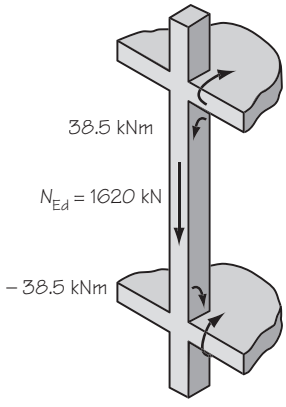

Figure 5.1 Forces in edge column

5.1.1 Check slenderness, λ

Effective length§, l_0 = factor × l — Cl. 5.8.3.2

where

factor = from Table C16, condition 2 each end — Table C16, PD 6687: 2.10

= 0.85

l = clear height = 3750 mm

$\therefore$ l_0 = 0.85 × 3750 = 3187 mm

Slenderness $\lambda = l_0/i$ — Exp. (5.14)

‡ For examples of load take-downs and 1st order moment analysis see Section 5.3.2

§ Effective lengths are covered in Eurocode 2 Cl. 5.8.3.2 and Exp. (5.15). The effective length of most columns will be $l/2 < l_0 < l$ (see Eurocode 2 Figure 5.7f). PD 6687[6] Cl. 2.10 suggests that using the procedure outlined in Eurocode 2 (5.8.3.2(3) and 5.8.3.2(5)) leads to similar effective lengths to those tabulated in BS 8110[7] and reproduced in Table 5.1 of *Concise Eurocode 2*[5] and in this publication as Table C16. For simplicity, tabular values are used in this example. However, experience suggests that these tabulated values are conservative.

Fig. 5.7
PD 6687[6]: Cl. 2.10
Cl. 5.8.3.2(3)
5.8.3.2(5)
Table C16

where

i = radius of gyration

= $h/12^{0.5}$ for rectangular sections

$\lambda = 3187 \times 3.46/300$ $\underline{= 36.8}$

5.1.2 Limiting slenderness, λ_{lim}

$\lambda_{lim} = 20\ ABC/n^{0.5}$ — Exp. (5.13N)

where

$A = 0.7$ (default) — Cl. 5.8.3.1(1)

$B = 1.1$ (default)

$C = 1.7 - r_m \quad = 1.7 - M_{01}/M_{02}$

$= 1.7 - 38.5/(-38.5) = 2.7$

$n = N_{Ed}/A_c f_{cd} \quad = 1620 \times 10^3/(300^2 \times 0.85 \times 30/1.5)$

$= 1.06$

$\lambda_{lim} = 20\ ABC/n^{0.5}$

$= 20 \times 0.7 \times 1.1 \times 2.7/1.06^{0.5}$

In this example $\lambda_{lim} = 40.4$ i.e. > 36.8 $\underline{\therefore \text{ Column not slender}}$

5.1.3 Design moments

$M_{Ed} = \max[M_{02}; M_{0Ed} + M_2; M_{01} + 0.5M_2]$ — Cl. 5.8.8.2(1)

where

$M_{02} = M + e_i N_{Ed} \geq e_0 N_{Ed}$ — Cl. 5.8.8.2, 6.1.4

where

$M = 38.5$ kNm

$e_i = l_0/400$ — Cl. 5.2.7, 5.2.9

$e_0 = \max[h/30; 20] = \max[300/30; 20] = 20$ mm — Cl. 6.1.4

$M_{02} = 38.5 + 1620 \times 3.187/400 \geq 0.02 \times 1620$

$= 38.5 + 12.9 \geq 32.4$ kNm

$= 51.4$ kNm

$M_{0Ed} = 0.6M_{02} + 0.4M_{01} \geq 0.4M_{02}$

$= 0.6 \times 51.4 + 0.4 \times (-38.5 + 12.9) \geq 0.4 \times 51.4$

$= 20.6 \geq 20.6$

$= 20.6$

$M_2 = 0$ (column is not slender)

$M_{01} = M_{02}$

$\therefore \max[M_{02}; M_{0Ed} + M_2; M_{01} + 0.5M_2] = 51.4$ kNm $\underline{\therefore M_{Ed} = 51.4 \text{ kNm}}$

5.1.4 Design using charts (see Appendix C)

$d_2 = c_{nom} + \text{link} + \phi/2 = 25 + 8 + 16 = 49$

$d_2/h = 49/300 = 0.163$

$\therefore$ interpolating between $d_2/h = 0.15$ and 0.20 — Figs. C5c), C5d)

for

$N_{Ed}/bhf_{ck} = 1620 \times 10^3/(300^2 \times 30) = 0.60$

$M_{Ed}/bh^2f_{ck} = 51.4 \times 10^6/(300^3 \times 30) = 0.063$
$A_sf_{yk}/bhf_{ck} = 0.24$
$A_s = 0.24 \times 300^2 \times 30/500 = 1296\ mm^2$

Try 4 no. H25 (1964 mm^2)

5.1.5 Check for biaxial bending

$\lambda_y/\lambda_z \approx 1.0$ — Cl. 5.8.9

i.e. $\lambda_y/\lambda_z \leq 2.0$ ∴ OK but check Exp. (5.38b) — Exp. (5.38a)

As a worst case M_{Edy} may coexist with e_ON_{Ed} about the orthogonal axis: — Cl. 6.1(4)

$$\frac{e_y/h_{eq}}{e_z/b_{eq}} = \frac{(M_{Edz}/N_{Ed})/h}{(M_{Edy}/N_{Ed})/b} = \frac{M_{Edz}}{M_{Edy}}$$ — Exp. (5.38b)

Imperfections need to be taken into account in one direction only. — Cl. 5.8.9(2)

∴ As a worst case for biaxial bending

$M_{Edz} = M + O = 38.5$ kNm
$M_{Edy} = e_ON_{Ed} = 32.4$ kNm

$$\frac{M_{Edz}}{M_{Edy}} = \frac{38.5}{32.4} = 1.19 \text{ i.e. } > 0.2 \text{ and } < 5.0$$ — Exp. (5.38b)

∴ Biaxial check required — Cl. 5.8.9(4)

Check whether
$(M_{Edz}/M_{Rdz})^a + (M_{Edy}/M_{Rdy})^a \leq 1.0$ — Exp. (5.39)

where
$M_{Edz} = 38.5$ kNm
$M_{Edy} = 32.4$ kNm
$M_{Rdz} = M_{Rdy}$ — Figs. C5c), C5d)

To determine M_{Rdz}, find M_{Ed}/bh^2f_{ck} (and therefore moment capacity) by interpolating between $d_2/h = 0.15$ (Figure C5c) and 0.20 (Figure C5d) for the proposed arrangement and co-existent axial load.

Assuming 4 no. H25,
$A_sf_{yk}/bhf_{ck} = 1964 \times 500/(300^2 \times 30) = 0.36$

Interpolating for $N_{Ed}/bhf_{ck} = 0.6$,
$M_{Ed}/bh^2f_{ck} = 0.094$
∴ $M_{Rdz} = M_{Rdy} = 0.094 \times 300^3 \times 30 = 76.1$ kNm

a is dependent on N_{Ed}/N_{Rd} — Cl. 5.8.9(4), Notes to Exp. (5.39)
where
$N_{Ed} = 1620$ kN as before