EN 1996-1-1 REINFORCED MASONRY DESIGN EXAMPLE 3
(NOTE: THIS USES THE UK NATIONAL ANNEX NDP VALUES)

Reinforced Masonry – Reinforced Hollow Concrete Blockwork Column Subjected To Uniaxial Bending

Design a 3,0m high reinforced hollow concrete blockwork column to carry a design vertical load of 400kN (N_{Ed})and a design bending moment of 45kN.m (M_{Ed}). If the height of the column is increased to 6,0m also assess the effect this has on the column section chosen?

The blocks to be used are dense aggregate concrete with a compressive strength (non-normalised) of 10,4N/mm^2. The concrete block masonry units are Group 2 of work size 440 by 215 by 215mm high with 35% voids ratio and of category I manufacturing control. The mortar is a class M6 (designation ii) General Purpose mortar with the work being constructed to class 1 execution control. The infill concrete is a C35/45. Trial column section is 440 by 440mm.

The exposure situation given is MX2 and therefore 25mm minimum concrete cover to main reinforcing steel is required from Table NA.9 of the UK National Annex (stainless steel will be used in column links which are partially bedded in mortar and in concrete infill and so 20mm minimum cover is appropriate to links to achieve bond and practical cover). Isolation of links and main steel required at isolated positions of contact by taping etc.

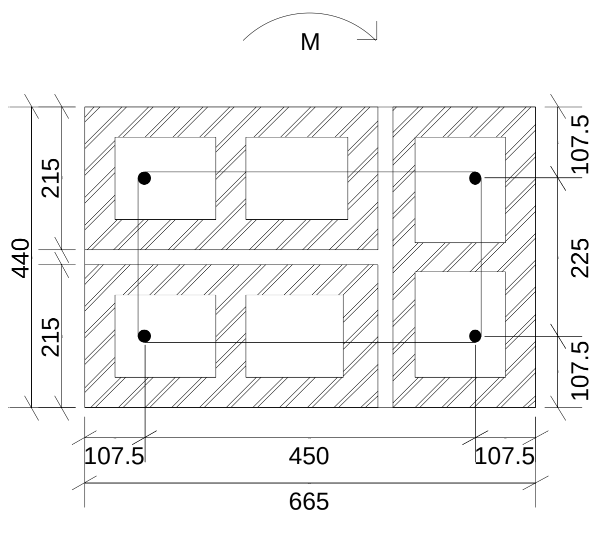

Figure: Steel positions in hollow concrete blocks

The guidance in BS EN 1996-1-1 on the design of columns when the design axial load, σ_d, exceeds 30% of the masonry design strength, f_d, is limited for combined bending and axially loading and reference to *clause 8.3.3 of BS 5628 Part 2* is required, although the partial safety factors, characteristic strengths, effective height, effective thickness and slenderness ratios should be those relevant to BS EN1996-1-1. In due course a BSI Provisional Draft (PD) will be produced to cover aspects not given by the Eurocode and these are likely to mainly based upon *BS 5628 Part 2* information.

The normalised compressive strength of the unit is given by:
f_b = 10,4 N/mm^2 x 1,0 x 1,16
f_b = 12,06 N/mm^2
where 1,0 is the conditioning factor and 1,16 is the shape factor both taken from BS EN 772 Part 1
The strength of the unit based on the net area is calculated as:
12,06 x 100%/65% = 18,55N/mm^2
As this strength is lower than that of the concrete infill to be used the masonry is designed as having an equivalent gross compressive strength based on that of a solid masonry unit (Group 1 solid) with a normalised compressive strength equal to that of the net area block strength as f_b = 18,55N/mm^2
Therefore $f_k = Kf_b^{0,7} f_m^{0,3}$ where K = 0,55 from UK National Annex, thus:
f_k = 0,55 x 18,55^{0,7} x 6,0^{0,3}
f_k = 7,27N/mm^2
Therefore $f_d = f_k/\gamma_M$ = 7,27/2,3 = 3,16N/mm^2 using category I units with class 1 execution control (γ_M = 2,3 for the unreinforced section capacity check)
And σ_d = 400kN x 10^3 / 440 x 440 = 2,07N/mm^2 (therefore $\sigma_d = 0,65f_d > 0,3f_d$)
Assume top and bottom of columns have lateral supports restricting movement in both directions with effective height factor, ρ_2 = 1,0.
Therefore h_{ef} = 3000 x 1,0 = 3000mm
t_{ef} = minimum thickness = 440mm
Slenderness ratio = 3000/440 = 6,82
This is less than 12, therefore column is short and can be designed using the additional principles from *clause 8.3.3.1 of BS5628 Part 2*.
Check whether only minimum reinforcement required from:
$N_{Rd} = f_d\, b(t_o - 2e_i)$ *interpreted from BS5628 Part 2*
Resultant eccentricity, e_i = (45,0 x 10^6) / (400,0 x 10^3) = 112,5mm
And $f_d = f_k/\gamma_M$ = 7,27/ 2,0 = 3,64N/mm^2 (γ_M = 2,0 for reinforced section capacity)
N_{Rd} = 3,64 x 440(440 – 2 x 112,5) x 10^{-3}
N_{Rd} = 344,3kN
This is less than design vertical load N_{Ed} of 400kN, therefore designed reinforcement is required.
Consider stress distribution across section
Assume $d_{cm} = t_o - d_2$ and f_{s2} = 0
Provide 2 no. 20mm diameter deformed Grade 500 steel bars each face (4no. total); area of 2 no. bars = 628mm^2
And f_{yd} = 500/1,15 = 435N/mm^2

From: $N_{Rd} = f_d\, bd_{cm} + (f_{s1}/\gamma_M)\, A_{s1} - (f_{s2}/\gamma_M)\, A_{s2}$ *interpreted from BS5628 Part 2*

N_{Rd} = (3,64 x 440 x 332,5 x 10^{-3}) + (0,83 x 500 x 628 x 10^{-3}/1,15) – 0 using 0,83f_{yk}/γ_M as 0,83f_{yd} *interpreted from BS5628 Part 2*
N_{Rd} = 532,5 + 226,6 kN
N_{Rd} = 759,1kN > 400kN

From:
$M_{Rd} = 0{,}5f_d\, b\, d_{cm}(t_o - d_{cm}) + 0{,}83f_{yd}\, A_{s1}(0{,}5t_o - d_1) + (f_{s2}/\gamma_M)\, A_{s2}(0{,}5t_o - d_2)$
using $0{,}83f_{yd}$ *interpreted from BS5628 Part 2*

$M_{Rd} = \{0{,}5 \times 3{,}64 \times 440 \times 332{,}5 \times (440 - 332{,}5) \times 10^{-6}\} + \{(0{,}83 \times 435 \times 628 \times (0{,}5 \times 440 - 107{,}5) \times 10^{-6}\} + 0$
$M_{Rd} = 28{,}6 + 25{,}5$
$M_{Rd} = 54{,}1\text{kN.m} > 45\text{kN.m}$
Thus N_{Rd} exceeds N_{Ed} and M_{Rd} *exceeds* M_{Ed} and the section is therefore adequate.

Column link reinforcement:
$A_s = 4 \times 314 = 1256\text{mm}^2$ for main vertical steel
Therefore steel % of section = (1256 x 100 / 440 x 440) = 0,65% which is greater than 0,25%
And vertical design load % = (400,0 x 100 / 759,1) = 53% which is greater than 25%

From Clause 8.2.6 links are required with vertical spacing as lesser of:
a) 440 mm
b) 300 mm
c) 12 x 20 = 240mm which therefore governs
Provide 6mm diameter plain bar strength Grade 200 Austenitic stainless steel column links at 225 mm vertical spacing to suit block coursing dimensions.

If actual and the effective height of column are increased to 6,0m
Slenderness ratio becomes 6000/440 = 13,6 and column becomes slender that is slenderness ratio greater than 12, but less than the limiting value of 27
An additional moment, M_{ad}, must therefore be allowed for as:
$M_{ad} = N_{Ed}\, h_{ef}^2 / 2000\, t$ Eqn. 6.25
$M_{ad} = (400{,}0 \times 6{,}0^2 / 2000 \times 0{,}440)$
$M_{ad} = 16{,}4$ kN.m

Design moment M_{Ed} becomes 45 + 16,4 = 61,4kN.m

From the above it will be seen that N_{Rd} unmodified still exceeds N_{Ed} for the slender column situation, but M_{Rd} is now less than M_{Ed} so reinforcement will be increased to 4 no. 25mm diameter reinforcing bars.

$M_{Rd} = \{0{,}5 \times 3{,}64 \times 440 \times 332{,}5 \times (440 - 332{,}5) \times 10^{-6}\} + \{(0{,}83 \times 435 \times 982 \times (0{,}5 \times 440 - 107{,}5) \times 10^{-6}\} + 0$
$M_{Rd} = 28{,}6 + 39{,}9$ kN
$M_{Rd} = 68{,}5\text{kN.m} > 61{,}4\text{kN.m}$
Thus M_{Rd} *exceeds* M_{Ed} and the section is therefore adequate using 4 no. 25mm diameter reinforcing bars.

The effect of the slender column is therefore to increase the reinforcement requirement from 20mm diameter to 25mm diameter bars in the reinforced masonry column. Column links for practical spacing purposes remain the same as before.

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