R3 Solution. Reinforced Hollow Concrete Blockwork Column Subjected To Uniaxial Bending

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.
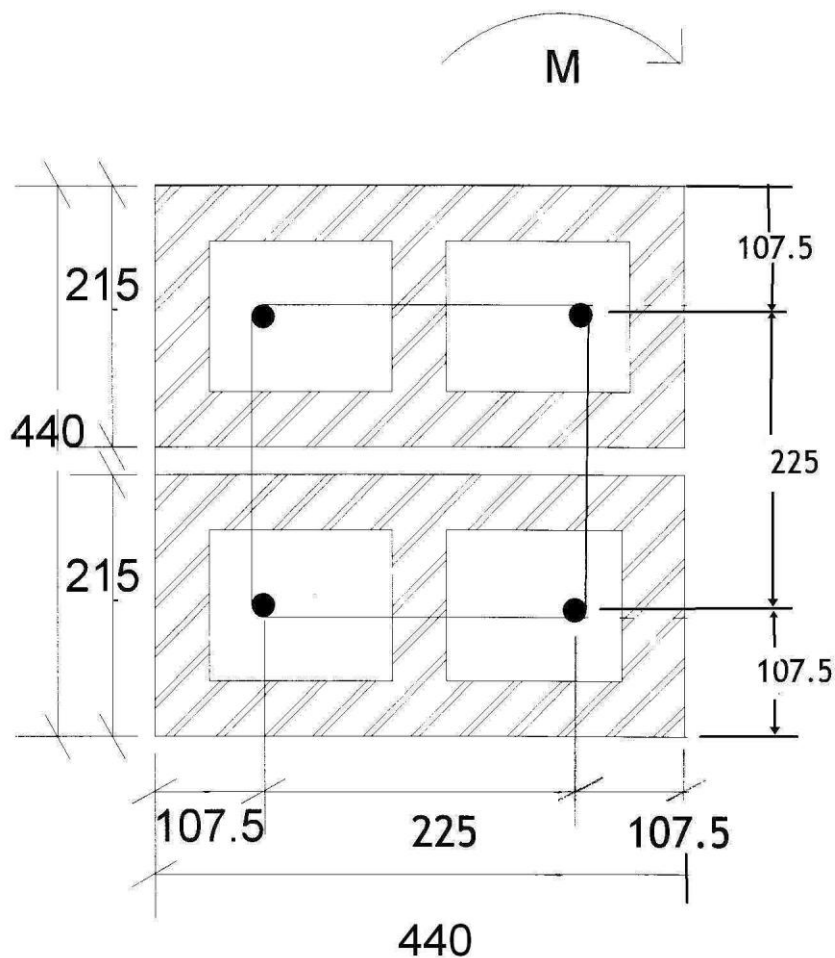

Figure 1: Position of reinforcement in column

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 axial loading and reference to clause 6.3.6.1 of PD 6697 is required.

The normalised compressive strength of the masonry unit is given by:
f_b = 7,3 N/mm^2 x 1,0 x 1,16
f_b = 8,47 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:
8,47 x 100%/70% = 12,10 N/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 = 12,10 N/mm^2

Therefore f_k = $K f_b^{0,7} f_m^{0,3}$ where K = 0,75 from UK National Annex, thus:
f_k = 0,8 x 0,75 x 12,10^{0,7} x 6,0^{0,3} (0,8 reduction to k because of mortar joints in masonry cross section).
f_k = 5,88 N/mm^2

Therefore f_d = f_k/γ_M = 5,88/2,3 = 2,56 N/mm^2 using category I units with class 1 execution control (γ_M = 2,3 for the unreinforced section capacity check)
And σ_d = 375kN x 10^3 / 440 x 440 = 1,94/mm^2 (therefore σ_d = 0,76f_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 6.3.6.1.1.1 of PD 6697.
Check whether only minimum reinforcement required from:

$$N_{Rd} = f_d b(t_o - 2e_i) \text{ [from PD 6697]}$$

Resultant eccentricity, e_i = (32,5 x 10^6) / (375,0 x 10^3) = 86,7mm
And f_d = f_k/γ_M = 5,88/ 2,0 = 2,94 N/mm^2 (γ_M = 2,0 for reinforced section capacity)
N_{id} = 2,94 x 440(440 – 2 x 86,7) x 10^{-3}
N_{id} = 344,9 kN [299,9 for an unreinforced section with γ_M at 2,3]
This is less than design vertical load N_{Ed} of 375kN, therefore designed reinforcement is required.

Consider stress distribution across section
d_d =2(220,0-86,7) = 266.6mm which lies between ($t-d_2$) = 332,5mm and $t/2$ =220,0mm.
Therefore f_{d2} =0,586 f_{yd} as f_{d2} varies linearly from 0 to f^{yd} between ($t-d_2$) and $t/2$

And $d_d > 2d_1$ min.(215mm).

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:
$$N_{Rd} = f_d\,bd_d + f_{d1}\,A_{s1} - f_{d2}\,A_{s2} \text{ [From PD 6697]}$$

N_{Rd} = (2,94 x 440 x 266,6 x 10^{-3}) + (0,83 x 435 x 628 x 10^{-3}) – (435 x 0,586 x 628 x 10^{-3}) [using $0,83f_{yk}$/ γ_M as 0,83 f_{yd} for steel in compression PD 6697]
N_{Rd} = 344,9 + 226,7-160 kN
N_{Rd} = 411,5 kN > 375 kN

From:
$$M_{Rd} = 0,5f_d bd_d(t_0 - d_d) + 0,83f_{d1}A_{s1}(0,5t - d_1) + f_{d2}A_{s2}(0,5t - d_2)$$

M_{Rd} = {0,5 x 2,94 x 440 x 266,6 x (440 – 266,6) x 10^{-6}} + {(0,83 x 435 x 628 x (0,5 x 440 – 107,5) x 10^{-6}} + {435 x 0,586 x 628 x (0,5 x 440-107,5) x 10^6} [using $0,83f_{yk}$/ γ_M as 0,83 f_{yd} for steel in compression PD 6697]
M_{Rd} = 29,9 + 25,5 + 18,0
M_{Rd} = 73,4kN.m > 32,5 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 x 314 = 1256mm^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 % = (375,0 x 100 / 411,5) = 91,1% 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. 6.26
M_{ad} = (375,0 x 6,0^2 / 2000 x 0,440)
M_{ad} = 15,3 kN.m

Design moment M_{Ed} becomes 32,5 + 15,3 = 47,8kN.m in the direction of the external bending moment being applied.

As the column is now slender it will be necessary to reconsider the design as a biaxial bending member following the guidance in PD 6697.
The effect of the slender column may therefore be to adjust the section design in respect of the masonry unit strength required (increased), to increase the size of the steel reinforcement required or to increase the column cross section- or a combination of these.