COMPRESSIVE LOADING
Barry Haseltine

Minimum thickness of walls

Clause 8.1.2 gives the minimum thickness of a wall as a symbol, with the value or values to be given in the National Annex. The UK National Annex, for example, gives the minimum thickness of a single leaf loadbearing wall as 90mm and the leaves of a cavity wall as 75mm.

Calculation models

Clause 5.1 requires that a calculation model of the structure should be set up based on the geometry of the structure, the materials being used and the environment in which it is built, in order to obtain (**Clause 5.1 (5)**):

- axial loads due to vertical and horizontal actions;
- shear loads due to vertical and/or horizontal actions;
- bending moments due to vertical and/or lateral actions;
- torsional moments, if applicable.

Analysis of walls under vertical loading

For analysis of walls under vertical loading, the following are required (**Clause 5.5.1.1 (1)**)

- vertical loads directly applied to the wall;
- second order effects;
- eccentricities calculated from a knowledge of the layout of the walls, the interaction of the floors and the stiffening walls;
- eccentricities resulting from construction deviations and differences in the material properties of individual components.

Effective Height

The effective height, h_{ef}, is derived from the clear storey height, h, using the formula

$$h_{ef} = \rho_n h$$

where ρ is a reduction factor on which guidance is given as to the values to be used for the number of edges, n, of the wall that are restrained or stiffened. For example in the case of a wall with two free vertical edges but restrained at both top and bottom n = 2.

For walls restrained at the top and bottom by reinforced concrete floors or roofs, mostly,

$$\rho_2 = 0.75$$

For walls restrained at the top and bottom and stiffened on one vertical edge (with one free vertical edge):

when $h \leq 3.5\, l$,

$$\rho_3 = \frac{1}{1 + {\frac{\rho_2 h}{3 l}}^{2}} \rho_2$$

For walls restrained at the top and bottom and stiffened on two vertical edges:

when $h \leq 1.15\, l$,

$$\rho_4 = \frac{1}{1 + {\frac{\rho_2 h}{l}}^{2}} \rho_2$$

or

when $h > 1.15\, l$,

$$\rho_4 = \frac{0.5\, l}{h}$$

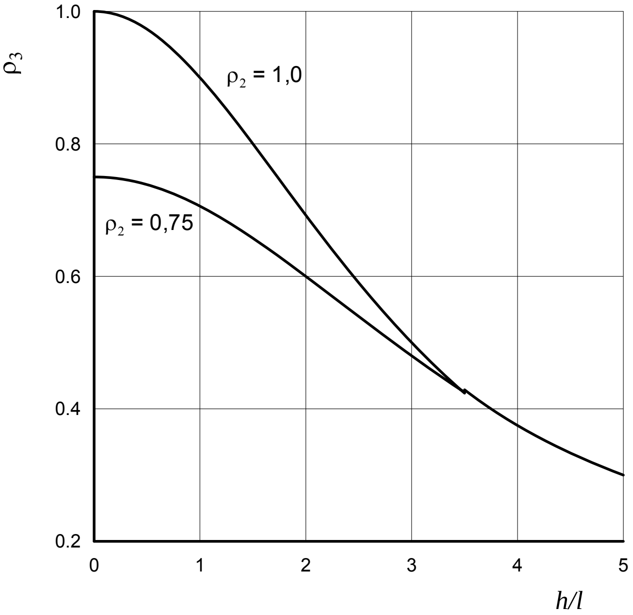


Figure D.1 — Graph showing values of ρ_3

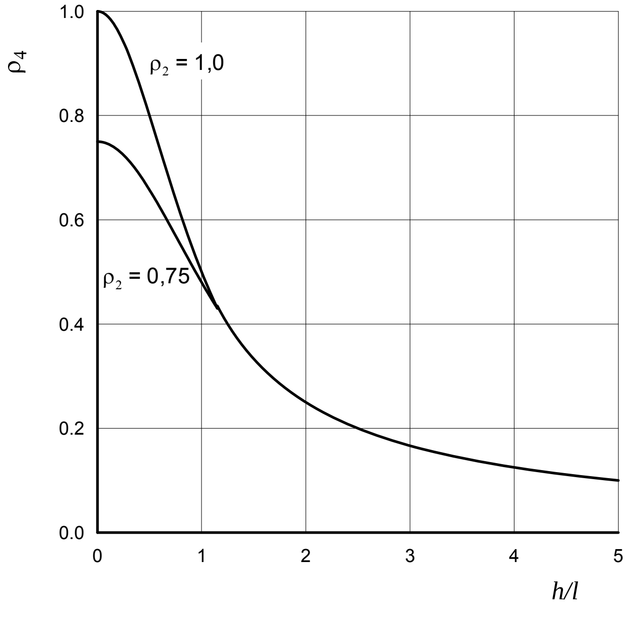


Figure D.2 — Graph showing values of ρ_4

Effective thickness of walls

Clause 5.5.1.3 deals with effective thickness; in most cases the effective thickness of a wall is taken to be the actual thickness. However, if the wall is weakened by the presence of chases and recesses greater in size than those permitted in **Clauses 8.6.2 and 8.6.3,** then either the residual thickness should be used or alternatively the chase or recess should be considered as a free edge to the wall. Similarly, if there are openings greater in height or width than one quarter of the wall height or width, respectively, and having an area greater than one tenth of that of the wall, they should be considered as providing a free edge.

In the case of cavity walls, **Clause 5.5.1.3 (3)** permits the effective thickness to be calculated using the equation

$$t_{ef} = \sqrt[3]{k_{tef} t_1^3 + t_2^3}$$

where t_1 and t_2 are the thicknesses of the two leaves and k_{tef} is a factor to allow for the relative E values of the leaves t_1 and t_2. The value of k_{tef} is to be given in the National Annex, and in the UK it is to be taken as 1.0.

Eccentricity at right angles to the wall

Calculation of structural eccentricity

Clause 5.5.1.1 and **Annex C** require that structural eccentricity at right angles to the wall, or out-of-plane eccentricity as it is called, should be calculated.

How this is done is left to the Code user, but the method in **C(1)** is adequate for most cases, but caution in its use is advisable where the wall panels, loads and spans in a building do not follow a simple common repetitive pattern. In such cases a more rigorous analysis is recommended.

6.1.2.1 Design load and resistance

At the ultimate limit state, the design vertical load on a masonry wall, N_{Ed}, should be less than or equal to the design vertical load resistance of the wall, N_{Rd}, such that,

$$N_{Ed} \leq N_{Rd}$$

The design should allow for the long term effects of loading, second order effects, and eccentricities calculated from knowledge of the layout of the walls, the interaction of the floors and the stiffening of the walls, and from construction deviations and differences in the material properties of individual components.

Clause 6.1.2.1(2) gives the design vertical load resistance of a single leaf wall per unit length, N_{Rd}, as

$$N_{Rd} = \Phi_{i,m}\, t\, f_d$$

where:

Φ	is the capacity reduction factor, Φ_i , at the top or bottom of the wall, or Φ_m in the middle of the wall, as appropriate, allowing for the effects of slenderness and eccentricity of loading, obtained from **Clause 6.1.2.2**.
f_d	is the design compressive strength of the masonry
t	is the thickness of the wall.

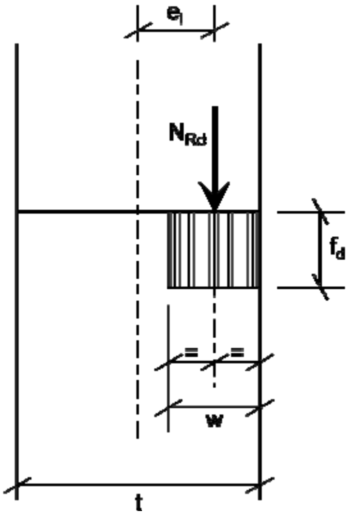


Figure 6.1: Stress block assumed in Clause 6.1.2.2 and Annex G

$$\Phi_i = 1 - \frac{2e_i}{t}$$

where

e_i is the eccentricity at the top or the bottom of the wall, as appropriate, calculated using the **Equation (6.5)**:

$$e_i = \frac{M_{id}}{N_{id}} + e_{he} + e_{init} \;\text{¡Ý}0.05\,t$$

M_{id} is the design value of the bending moment at the top or the bottom of the wall resulting from the eccentricity of the floor load at the support, analysed according to **Clause 5.5.1** (see **Figure 6.1**); N_{id} is the design value of the vertical load at the top or bottom of the wall;

e_{he} is the eccentricity at the top or bottom of the wall, if any, resulting from horizontal loads (for example, wind);

e_{init} is the initial eccentricity (see **5.5.1.1**);

Note. The assumed value of initial eccentricity is used in **Equations (6.6)** and **(6.7)**, and it may take a positive or negative sign to increase or reduce the absolute value of the resultant eccentricity, e_i or e_{mk}, at the particular level in the wall. For design purposes it is only meaningful to consider the case where the absolute value of the resultant eccentricity is increased.

t is the thickness of the wall.

6.1.2.7 Reduction for slenderness in the middle of the wall

Informative **Annex G**, allowed to be used in the UK, gives the reduction factor for slenderness to be used in the middle of the wall height. The appropriate symbols are given below.

e_{mk} is the eccentricity at the mid height of the wall, calculated using **Equations (6.5)** and **(6.7)**:

$$e_{mk} = e_m + e_k \geq 0.05\ t$$

$$e_m = \frac{M_{md}}{N_{md}} + e_{hm} \pm e_{init}$$

e_m is the eccentricity due to loads;

M_{md} is the design value of the largest moment in the middle of the height of the wall resulting from the moments at the top and bottom of the wall (see **Figure 6.1**), including any load applied eccentrically to the face of the wall (e. g. brackets);

N_{md} is the design value of the vertical load at the middle height of the wall, including any load applied eccentrically to the face of the wall (e. g. brackets);

e_{hm} is the eccentricity at mid-height resulting from horizontal loads (for example, wind);

NOTE. The inclusion of e_{hm} depends on the load combination being used for the verification; its sign relative to that of M_{md}/N_{md} should be taken into account.

e_{init} is the initial eccentricity with sign that increases the absolute value of e_m (see **5.5.1.1**);

h_{ef} is the effective height, obtained from **5.5.1.2** for the appropriate restraint or stiffening condition;

t_{ef} is the effective thickness of the wall, obtained from 5.7;

e_k is the eccentricity due to creep, calculated from the Equation **(6.8)**:

$$e_k = 0.002\ \varphi_{\infty} \frac{h_{ef}}{t_{ef}} \sqrt{t\ e_m}$$

φ_{∞} is the final creep coefficient (see note under **3.7.4(2)**)

Equation (3.1) $f_k = K f_b^{\alpha} f_m^{\beta}$

For general purpose mortar:	α = 0.7 and β = 0.3
For lightweight mortar:	α = 0.7 and β = 0.3
For thin layer mortar (in bed joints of thickness 0.5mm to 3mm):	
a) using clay units of Group 1, Calcium silicate and aggregate concrete units of Group 1 and 2 and autoclaved concrete units of Group 1	α = 0.85 and β = 0
b) using clay units of Group 2	α = 0.7and β = 0

Masonry Unit		General purpose mortar	Thin layer mortar (bed joint ≥ 0.5mm and ≤ 3mm)	Lightweight mortar of density	
				$600 \le \rho_d \le 800 kg/m^3$	$800 < \rho_d \le 1\,300 kg/m^3$
Clay	Group 1	0.50	0.75	0.30	0.40
	Group 2	0.40	0.70	0.25	0.30
	Group 3	(1)	(1)	(1)	(1)
	Group 4	(1)	(1)	(1)	(1)
Calcium silicate	Group 1	0.50	0.80	(2)	(2)
	Group 2	0.40	0.70	(2)	(2)
Aggregate concrete	Group 1	0.55	0.80	0.45	0.45
	Group 1[(3)] (units laid flat)	0.50	0.70	0.40	0.40
	Group 2	0.52	0.76	0.45	0.45
	Group 3	(1)	(1)	(1)	(1)
	Group 4	(1)	(1)	(1)	(1)
Autoclaved aerated concrete	Group 1	0.55	0.80	0.45	0.45
Manufactured stone	Group 1	0.45	0.75	(2)	(2)
Dimensioned natural stone	Group 1	0.45	(2)	(2)	(2)

(1) Group 3 and 4 units have not traditionally been used in the UK, so no values are available.

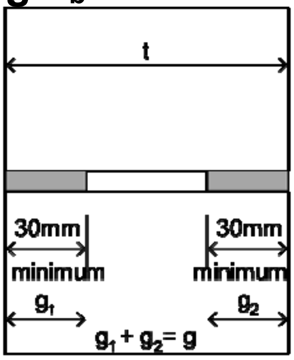
(2) These masonry unit and mortar combinations are not normally used in the UK, so no values are available.

(3) If Group 1 units contain formed vertical voids multiply K by (100-n)/100, where n is the percentage of voids, maximum 25%.

NOTE f_b is the normalised strength of a unit; if concrete blocks are to be laid flat, then the normalised strength is still used for the design, even if that strength was obtained by testing blocks in the upright position.

Value of constant K to be used in calculation of f_k with

Value of K to be used with shell bedding when ‘full bedding’ f_b is used



For g/t ≤ 045, K = half that for normal bedding
For g/t = 1.0, K = that for normal bedding
For intermediate values of g/t K may be obtained by linear interpolation.

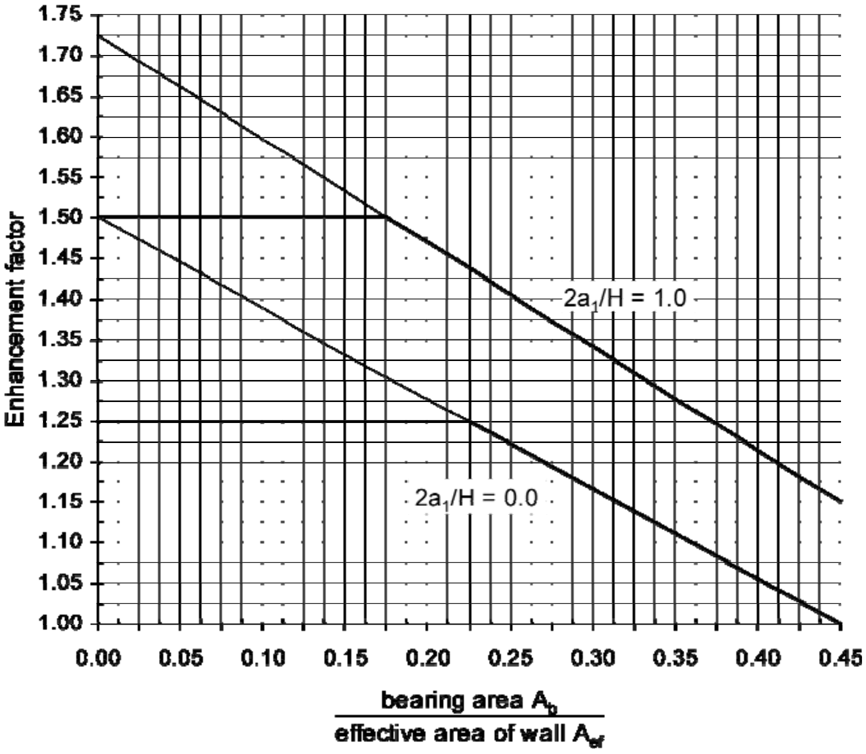


Figure 6.3: Enhancement factor for concentrated loads

Values of γ_M for UK

	Values of γ_M for ultimate limit state	
Class of execution control:	**1 (1)**	**2 (1)**
Material:		
Masonry		
when in a state of direct or flexural compression		
Unreinforced masonry made with:		
units of category I	2.3 (2)	2.7 (2)
units of category II	2.6 (2)	3.0 (2)
Reinforced masonry made with:		
units of category I	2.0 (2)	(2)
units of category II	2.3 (2)	(3)
when in a state of flexural tension		
units of category I and II	2.3 (2)	2.7 (2)
when in a state of shear		
Unreinforced masonry made with:		
units of category I and II	2.5 (2)	2.5 (2)
Reinforced masonry made with:		
units of category I and II	2.0 (2)	(3)
Steel and other components:		
Anchorage of reinforcing steel	1.5 (4)	(3)
Reinforcing steel and prestressing steel	1.15 (4)	(3)
Ancillary components - wall ties	3.5 (2)	3.5 (2)
Ancillary components - straps	1.5 (5)	1.5 (5)
Lintels in accordance with BS EN 845-2	See NA to BS EN 845-2	See NA to BS EN 845-2

(1) Class 1 of execution control should be assumed whenever the work is carried out following the recommendations for workmanship in BS EN 1996-2, including appropriate supervision and inspection, and in addition:

a) the specification, supervision and control ensure that the construction is compatible with the use of the appropriate partial safety factors given in BS EN 1996-1-1;

b) the mortar conforms to BS EN 998-2, if it is factory made mortar. If it is site mixed mortar, preliminary compression strength tests carried out on the mortar to be used, in accordance with BS EN 1015-2 and BS EN 1015-11, indicate conformity with the strength requirements given in BS EN 1996-1-1 and regular testing of the mortar used on site, in accordance with BS EN 1015-2 and BS EN 1015-11, shows that the strength requirements of BS EN 1996-1-1 are being maintained.

Class 2 of execution control should be assumed whenever the work is carried out following the recommendations for workmanship in BS EN 1996-2, including appropriate supervision.

(2) When considering the effects of misuse or accident these values may be halved.

(3) Class 2 of execution control is not considered appropriate for reinforced masonry and should not be used. However, masonry wall panels reinforced with bed joint reinforcement used:

a) to enhance the lateral strength of the masonry panel;

b) to limit or control shrinkage or expansion of the masonry,

can be considered to be unreinforced masonry for the purpose of class of execution control and the unreinforced masonry direct or flexural compression γ_M values are appropriate for use.

(4) When considering the effects of misuse or accident these values should be taken as 1.0.

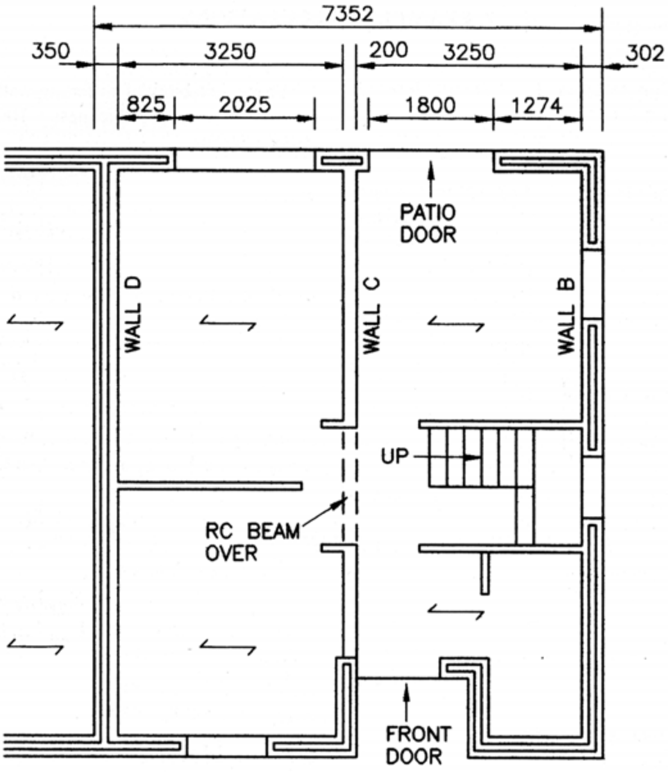
(5) For horizontal restraint straps, unless otherwise specified, the declared ultimate load capacity depends on there being a design compressive stress in the masonry of at least 0.4N/mm^2. When a lower stress due to design loads may be acting, for example when autoclaved aerated concrete or lightweight aggregate concrete masonry is used, the manufacturer's advice should be sought and a partial safety factor of 3 should be used.

Chases and recesses on walls

(1)P Chases and recesses shall not impair the stability of the wall.

Unreinforced masonry design example - 4 storey domestic house

Ground floor plan of four storey domestic house



DESIGN WALL D
(350MM THICK CAVITY WALL 150 +150 + 50MM CAVITY)

ACTIONS

Permanent

Roof- finishes and trussed rafters at 600c/c on plan = 0.83kN/m^2
Ceiling- Insulation on plasterboard = 0.25kN/m^2

Floors- floating chipboard finish on 102mm deep prestressed concrete slabs (hollow cored type) with plaster finish = 2.30kN/m^2

Stairs- 100mm reinforced concrete waist and steps and finishes = 5.23kN/m^2

External walls- 302.5mm thick; 102.5mm outer brick skin, 150mm inner blockwork skin, plaster finish = 4.74kN/m^2

Internal walls (loadbearing) 200mm blockwork, plaster finish both sides = 3.5kN/m^2

Internal partition (non-loadbearing) 100mm blockwork, plaster finish both sides = 1.27kN/m^2

Internal party wall- 350mm thick 150mm blockwork skins, finish on both sides = 5.00kN/m^2

Variable

Roof- 0.75kN/m^2 plus 0.25kN/m^2 ceiling = 1.00kN/m^2

Floors = 1.50kN/m^2

Permanent load G_k on wall at ground storey:

from third floor ` $= 2.3\times\frac{3.25}{2}$ = 3.74kN/m on each leaf

from second floor $= 2.3\times\frac{3.25}{2}$ = 3.74kN/m on each leaf

from first floor $= 2.3\times\frac{3.25}{2}$ = 3.74kN/m on each leaf

from internal partitions $= 1.27\times\frac{3.25}{2}\times\frac{7.2}{4.8}$

= 3.10kN/m on each leaf

from own weight of wall $= \frac{5}{2}\times 10.5$ = 26.25kN/m on each leaf

ΣG_k = 40.57kN/m²

Variable load Q_k on wall at ground storey:

from third floor $= 1.5\times\frac{3.25}{2}$ = 2.44kN/m on each leaf

from second floor $=1.5\times\frac{3.25}{2}$ = 2.44kN/m on each leaf

from first floor $= 1.5\times\frac{3.25}{2}$ = 2.44kN/m on each leaf

ΣQ_k = 7.32kN/m on each leaf

As there is only one variable load in this example Ψ_0 is not used, and the design value of the combination of loads is

$$\Sigma\gamma_{Gj}G_{kj} + \gamma_{Qj}\, Q_{kj}$$

where $\gamma_G = 1.35$ and $\gamma_Q = 1.5$

$$(1.35 \times 40.57) + (1.5 \times 7.32) = 65.75\text{kN/m} = N_{Ed}$$

Effective height of wall $h_{ef} = \rho_n h$ (see **Clause 5.5.1.2 (10)**) where ρ_n is a reduction factor to allow for edge restraint on the wall. Assume ground slab is suspended and not cast on the ground.

With reference to **Clause 5.5.1.2** and **Annex D**

$$\frac{h}{l} = \frac{2550}{4700} = 0.54$$

Therefore

ρ_4 = 0.64 (from **Graph D2)** for ρ_2 = 0.75 and

h_{ef} = 0.64×2550 = 1630mm.

Check suitability of stiffening wall (see **Clause 5.5.1.2**):

thickness = 100

which exceeds

$$0.3 \times t_{ef} = 56\text{mm}$$

where

$t_{ef} = \sqrt[3]{150^3 + 150^3}$

$= 189\text{mm}$

Length of stiffening wall also exceeds 1/5 × 2550.

Check slenderness ratio

$\frac{l}{t} = \frac{4700}{189}$

$= 25.74 \ (< 30)$

(assuming $t = t_{ef}$ in the case of a cavity wall.)

Design vertical load resistance (See **Clause 6.1.2.1(2)**)

$N_{Rd} = \Phi \, t \, f_d$ (for each leaf)

Consider a metre length of the wall:

$E_{slab} = 30.5 \times 1000 = 30500\text{N/mm}^2$

$E_{wall} = 1000 \, f_k = 5100\text{N/mm}^2$ (see below)

$I_{slab} = \frac{1000 \times 100^3}{12} = 83.33 \times 10^6 \text{mm}^4$

$I_{wall} = \frac{1000 \times 150^3}{12} = 281 \times 10^6 \text{mm}^4$

$h_{wall} = 2550\text{mm}$

$l_{slab} = 3400\text{mm}$

$f_k = K \times f_b^{0.70} \times f_m^{0.30}$

$= 5.1\text{N/mm}^2$ for 10.4N/mm^2 blocks, 150mm thick, and M4 mortar interpolating from the tables below.

e) 215mm high x 100mm thick Group 1 concrete blocks: Wall without longitudinal joint

δ =1.38 K = 0.55 (that is wall thickness = block thickness)

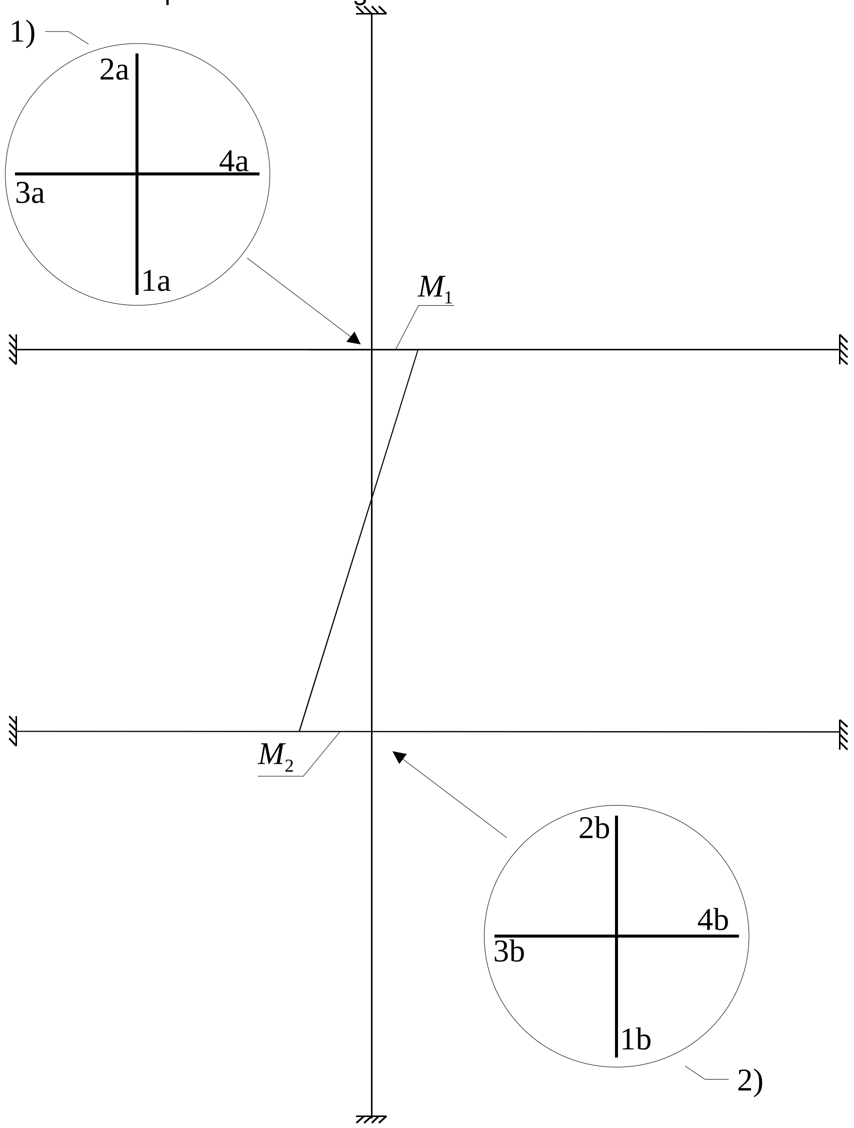
Mortar		**Mean Compressive strength of unit (N/mm²) to BS EN 771-3 or 4 (not normalised)**								
UK designation	**EN1996-1-1 class**	**2.9**	**3.6**	**5.2**	**7.3**	**10.4**	**17.5**	**22.5**	**30**	**40**
(i)	M12	2.7	3.4	4.6	5.8	7.5	10.8	12.8	15.7	19.2
(ii)	M6	2.5	2.9	3.7	4.7	6.1	8.7	10.4	12.8	15.6
(iii)	M4	2.2	2.6	3.3	4.2	5.4	7.7	9.2	11.3	13.8
(iv)	M2	1.8	2.1	2.7	3.4	4.4	6.3	7.5	9.2	11.2

f) 215mm high x 200mm thick Group 1 concrete blocks: Wall without longitudinal joint

δ =1.18 K = 0.55 (that is wall thickness = block thickness)

Mortar		Mean Compressive strength of unit (N/mm²) to BS EN 771-3 or 4 (not normalised)								
UK designation	EN1996-1-1 class	2.9	3.6	5.2	7.3	10.4	17.5	22.5	30	40
(i)	M12	2.3	2.9	4.1	5.2	6.7	9.7	11.5	14.1	17.2
(ii)	M6	2.2	2.6	3.4	4.3	5.4	7.8	9.3	11.4	14.0
(iii)	M4	2.0	2.3	3.0	3.8	4.8	6.9	8.3	10.1	12.4
(iv)	M2	1.6	1.9	2.4	3.1	3.9	5.6	6.7	8.2	10.1

Figure C.1 — Simplified frame diagram



Key

1	Frame a
2	Frame b

NOTE Moment M_1 is found from frame a and moment M_2 from frame b

Floor fixed end moment = $(1.35 \times 2.3 + 1.5 \times 1.5) \times \frac{3.25 \times 3.4}{12}$

= 4.8kNm

Following **Annex C** with 3 members

for slab, $\frac{EI}{l}$ = 0.75×10^9Nmm

for one leaf of wall, $\frac{EI}{h}$ = 562×10^6Nmm

M_1 = $\frac{4.8 \times 10^6 \times 562 \times 10^6}{(0.75 \times 10^9) + 2(562 \times 10^6)}$

= 1.439×10^6Nmm on the one metre length

N_1 = $\frac{65.75 \times 10^3}{150 \times 10^3}$

= 0.44N/mm² (>0.25N/mm²)

k_m = $\frac{0.75 \times 10^3}{2 \times 562 \times 10^6}$

= 0.667

Therefore $M_{1(reduced)}$ is = $M_1\left(1 - \frac{k_m}{4}\right)$

= $1.439 \;\; 1 \;\; \frac{0.667}{4}$ = 1.20kNm/m

$\frac{M_{1(reduced)}}{N_{Ed}}$ = $\frac{1.20}{65.75}$

= 0.01825m or 18.25mm at top and bottom of wall

Initial eccentricity (**Clause 5.5.1.1 (4)**)

e_{init} = $\frac{h_{ef}}{450}$ = $\frac{1630}{450}$

= ±3.62mm

over full height of wall.

At top and bottom of the wall therefore:

e_i = 18.25 + 3.62

= 21.87mm

> 0.05t (0.05t = 7.5mm)

e_{he} = 0

Φ_i = $1 - 2 \times \frac{21.87}{150}$

= 0.70

In the middle of the wall height:

M_1 = M_2

M_{md} = 0

N_M = 65.75kN/m

e_m = $\frac{0}{65.75} + 3.62$

= 3.62mm

Slenderness of wall

$\frac{h_{ef}}{t_{ef}}$ = $\frac{1630}{189}$

= 8.62(<27)

therefore $e_k = 0$.

Therefore $e_{mk} = e_m + e_k$,

so

e_{mk} = 3.62mm

$\frac{e_{mk}}{t}$ = $\frac{3.62}{150}$

= 0.024 < 0.05t

From **Figure G.1** Φ_m = 0.85 for e=0.05t

Therefore top and bottom of wall governs (Φ_i).

Wall capacity

γ_M = 2.3 for Category I masonry units and Class 1 execution control

γ_M = 3.0 for Category II masonry units and Class 2 execution control

f_d $= \dfrac{5.1}{2.3}$ $= 2.2\text{N/mm}^2$
(Execution 1)

or

f_d $= \dfrac{5.1}{3.0}$ $= 1.7\text{N/mm}^2$
(Execution 2)

N_{Rd} = 0.70 × 2.2 × 150
= 231kN/m (Execution 1)

or = 0.70 × 1.7 × 150
= 178.5kN/m (Execution 2)

Note both values of N_{Rd} exceed the value of N_{Ed} (65.75kN/m) by a substantial margin, therefore consider using 3.6N/mm² units in M4 mortar.

By reducing the f_k value of the masonry to 2.45N/mm² the slab/wall stiffness ratio will increase resulting in reduced moment transfer into the wall and correspondingly less eccentricity.

N_{Rd} $> \dfrac{0.70 \times 150 \times 2.45}{2.3}$
> 111.81kN/m (for Execution 1.)

or > 85.75kN/m (for Execution 2.)

Both values of N_{Rd} exceed N_{Ed} of 65.75.