EUROCODE 6

Design of masonry structures

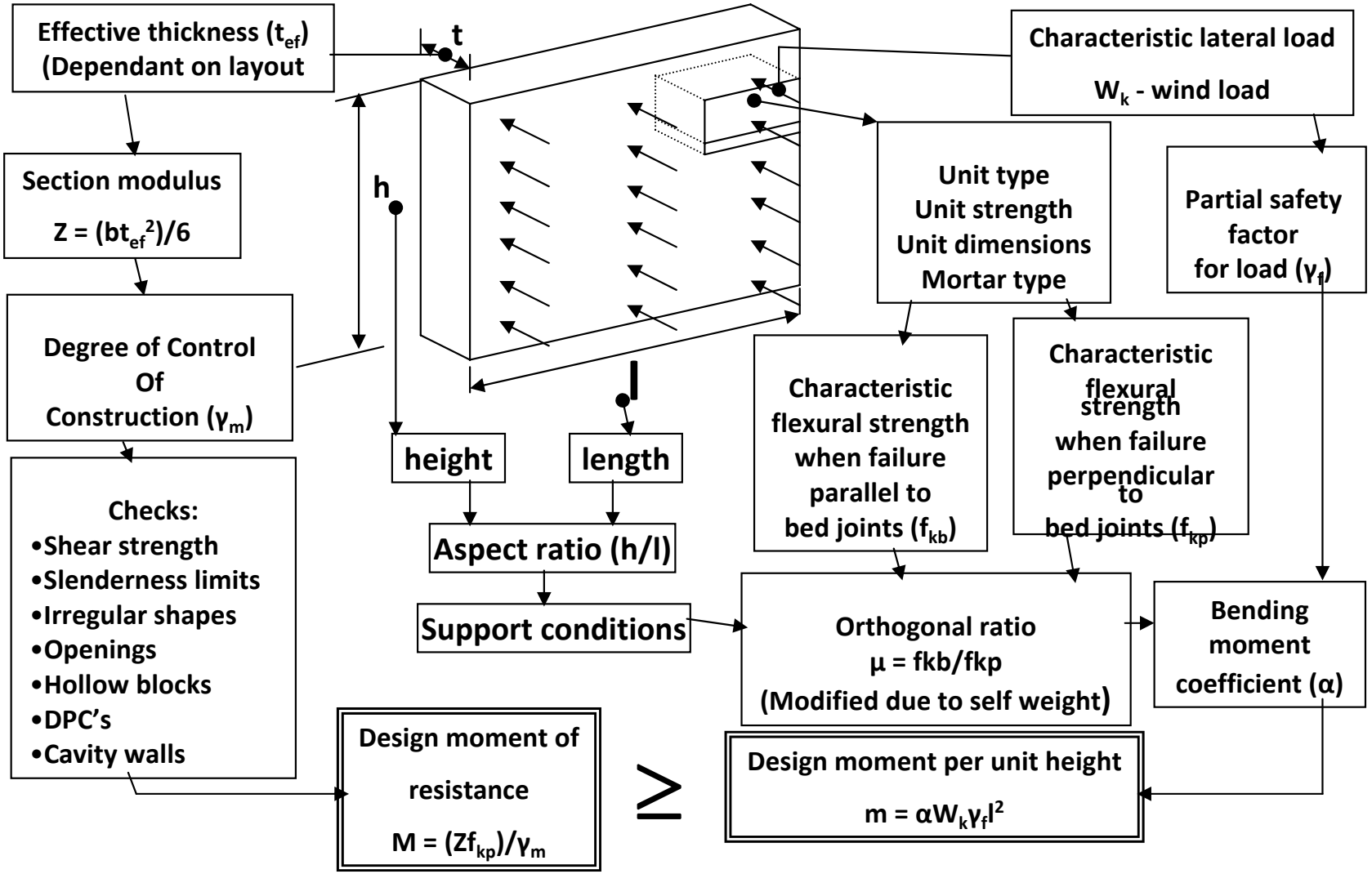
Laterally Loaded Masonry

Introduction

U.K. Walls slender in comparison to most of Europe

Design

- EC6: Pt. 1.1 – Calculation methods
- EC6: Pt. 3 - Empirical guidance and
  - Simplified calculation - methods


Effective thickness (t_{ef}) (Dependant on layout
t
Characteristic lateral load
W_k - wind load
Section modulus
$Z = (bt_{ef}^2)/6$
h
Unit type
Unit strength
Unit dimensions
Mortar type
Partial safety factor for load (γ_f)
Degree of Control Of Construction (γ_m)
l
Characteristic flexural strength when failure parallel to bed joints (f_{kb})
Characteristic flexural strength when failure perpendicular to bed joints (f_{kp})
height
length
Checks:
•Shear strength
•Slenderness limits
•Irregular shapes
•Openings
•Hollow blocks
•DPC's
•Cavity walls
Aspect ratio (h/l)
Support conditions
Orthogonal ratio
μ = fkb/fkp
(Modified due to self weight)
Bending moment coefficient (α)
Design moment of resistance
$M = (Zf_{kp})/\gamma_m$
≥
Design moment per unit height
$m = \alpha W_k \gamma_f l^2$

Combinations of Actions

Combinations of Actions	Load Type				
	Permanent Actions G_k		Variable Actions Q_{k1}		Additional Variable Actions Q_{ki}
	Unfavourable γ_F	Favourable γ_F	Unfavourable γ_G	Favourable γ_G	Favourable $\gamma_{Qi}\Psi_0$
Permanent plus Variable (leading only)	1.35	1.0	1.5	0	-
Permanent plus Variable (wind)	1.35	1.0	1.5	-	-
Permanent plus Variable (leading) plus Variable (additional) wind	1.35	1.0	1.5	-	1.5x0.5

NOTE Wind may be either a leading or additional variable load.

Clause 18 of BS5628 Part 1

(b) *Dead and wind load*

design dead load	$= 0.9G_k$ or $1.4G_k$
design wind load	$= 1.4W_k$ or $0.015G_k$ whichever is the larger
design earth and water load	$= 1.4E_n$

In the particular case of freestanding walls and laterally loaded wall panels, whose removal would in no way affect the stability of the remaining structure, γ_f applied on the wind load may be taken as 1.2.

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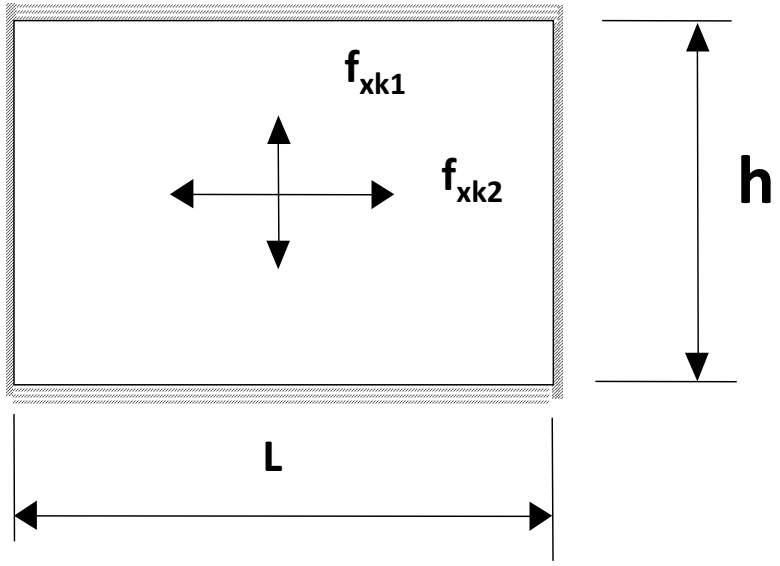
(Flexural strength approach - Clauses 5.5.5 & 6.3.1, Annex E & Annex F)



- Characteristic flexural - strength

Applied moments
Moments of resistance
Design procedure
Shear design
Slenderness limits

Characteristic Flexural Strength

- f_{xk1} (About an axis parallel to bed joints)

f_{xk2} (About an axis perpendicular to bed - joints)

Table NA.6 of UK National Annex (strengths)

Annex E of EC6 Pt. 1.1 (panel coefficients)

- Annex F of EC6 Pt. 1.1 (size limitations)

Applied Bending Moment

- **Preliminaries**
  - **Orthogonal strength ratio $\mu = f_{xk1}/f_{xk2}$**
  - **Panel aspect ratio = h/L**

Bending moment coefficient obtained - using

μ and h/L from Annex E of EC6 Pt. 1.1

Applied Bending Moments

Vertically spanning walls

$$M_{Ed1} = \alpha W_{Ed} h^2$$

m = design moment per unit length wall
W_{Ed} = design lateral (wind) load unit area
h = height between horizontal supports
α = bending moment coefficient

- With simple supports, α = 0.125 (1/8)

Applied Bending Moments

Horizontally spanning walls

$M_{Ed2} = \alpha W_{Ed} L^2$

M_{Ed2} = design moment per unit height wall
W_{Ed} = design lateral (wind) load unit area
L = length between vertical supports
α = bending moment coefficient

- With simple supports, $\alpha = 0.125$ (1/8)
- With fixed supports, $\alpha = 0.063$ (1/16)

Applied Bending Moments

Two way spanning walls

$M_{Ed1} = \alpha_1 W_{Ed} L^2$

M_{Ed1} = design lateral (wind) load unit area

L = length between vertical supports

α_1 = bending moment coefficient

And $\alpha_1 = \mu \alpha_2$

Moment Of Resistance

- $M_{Rd} = f_{xd} z$ or $(f_{xd1} + \sigma_d)z$

where:

M_{Rd} = Design moment of resistance

f_{xd} = Design flexural strength about - relevant direction of bending – (NA.6)

f_{xd1} = Design flexural strength with - plane of failure parallel to bed - joints

z = Section modulus ($bt^2/6$)

σ_d = Design vertical dead load ($\leq 0.2f_d$)

Walls with Piers - Assessing z

Take outstanding length of flange from face of pier as lesser of:

- h/10 for vertically spanning walls
- h/5 for cantilever walls
- half the clear distance between piers

And h is clear height of wall

Design Procedure

1. Assume support conditions
2. Assume strength and thickness of - unit required
3. Find orthogonal strength ratio - $\mu = f_{xk1}/f_{xk2}$
4. Find panel aspect ratio = h/L
5. Find moment coefficient, α (Annex E)
6. Determine bending moment applied to panel as: $M_{Ed} = \alpha W_{Ed} l^2$

Design Procedure

7. Check flexural capacity of wall, M_{Rd}
   as: $M_{Rd} = f_{xd}\, z$ self weight may - be included
8. If $M_{Rd} \geq M_{Ed}$ then wall acceptable
   If not, return to 1) or 2) and modify

Shear and panel dimensions still to be checked.

Shear Strength Of Panels

- **Shear must be controlled such that:**

$$V_{Rd} \geq V_{Ed}$$

Shear Strength Of Panels

Design shear strength of masonry (V_{Rd})

$f_{vk} = (f_{vko} + 0.4\sigma_d) \leq 0.065 f_b$

where, σ_d is design compressive stress, if any

And $V_{Rd} = (f_{vk} / \gamma_m) A_w$

- **Design shear applied (V_{Ed})**

  $V_{Ed} = W_{Ed} A_w$

  where W_{Ed} is design (wind) load per unit area

  A_w is effective cross-sectional area of wall. - Use 45° spread lines

BS5628 Clause 21

21 Characteristic shear strength of masonry, f_v

21.1 General

21.1.1 *Horizontal direction*

The characteristic shear strength of masonry in the horizontal direction of the horizontal plane (see Figure 1) is given by:

$$f_v = f_{vko} + 0.6g_A$$

where

f_{vko} is the characteristic initial shear strength in N/mm^2; and,

g_A is the design vertical load per unit area of wall cross-section due to the vertical loads calculated from the appropriate loading condition specified in Clause **18**.

f_v should be taken as not greater than 1.75 N/mm^2 for masonry built in thin layer mortar and mortar strength classes M12 and M6 / designations (i) and (ii) or 1.4 N/mm^2 for masonry built in mortar strength classes M4 and M2 / designations (iii) and (iv).

BS5628 Clause 21

21.1.2 *Characteristic initial shear strength of masonry, f_{vko}*

The characteristic initial shear strength of masonry, f_{vko}, may be:

a) determined by tests in accordance with BS EN 1052-3;

b) taken as 0.35 N/mm^2 with clay/cal silicate units having less than 40% formed voids and concrete units having less than 50% formed voids for masonry built in thin layer mortar and mortar strength classes M12 and M6 / designations (i) and (ii); or

c) taken as 0.15 N/mm^2 for masonry built in mortar strength classes M4 and M2 / designations (iii) and (iv).

BS 5628 Clause 21

21.2 Vertical direction

The characteristic shear strength f_v of bonded masonry in the vertical direction of the vertical plane (see Figure 1) may be taken as:

a) for brick:

1) 0.7 N/mm^2 (for mortar strength classes M12 and M6 / designations (i) and (ii));

2) 0.5 N/mm^2 (for mortar strength classes M4 and M2 / designations (iii) and (iv));

b) for dense aggregate solid concrete block with a minimum strength of 7 N/mm^2:

0.35 N/mm^2 (for mortar strength classes M12, M6 and M4 / designations (i), (ii) and (iii)).

BS 5628 Clause 21

21.2 Vertical direction

The characteristic shear strength f_v of bonded masonry in the vertical direction of the vertical plane (see Figure 1) may be taken as:

a) for brick:

1) 0.7 N/mm^2 (for mortar strength classes M12 and M6 / designations (i) and (ii));

2) 0.5 N/mm^2 (for mortar strength classes M4 and M2 / designations (iii) and (iv));

b) for dense aggregate solid concrete block with a minimum strength of 7 N/mm^2:

0.35 N/mm^2 (for mortar strength classes M12, M6 and M4 / designations (i), (ii) and (iii)).

EC6 NA Table NA.5

Table NA.5 – Values of the initial shear strength of masonry, f_{vko}

Masonry units	Strength class of general purpose mortar	f_{vko} (N/mm^2)		
		General purpose mortar	Thin layer mortar (bed joint ≤ 0,5 mm and ≥ 3 mm)	Lightweight mortar
Clay	M12	0,30	} 0,30	} 0,15
	M4 and M6	0,20		
	M2	0,10		
Calcium silicate	M12	0,20	} 0,40	} 0,15
	M4 and M6	0,15		
	M2	0,10		
Aggregate concrete, autoclaved aerated concrete, manufactured stone and dimensioned natural stone	M12	0,20	} 0,30	} 0,15
	M4 and M6	0,15		
	M2	0,10		

EC6 NA.2.5 & NA.2.6

NA.2.5 Characteristic shear strength of masonry [see BS EN 1996-1-1, **3.6.2**(3)]

The limit of f_{vk} should be taken as $0{,}065\, f_b$.

NA.2.6 Characteristic shear strength of masonry [see BS EN 1996-1-1, **3.6.2**(4)]

The limit of f_{vk} should be taken as $0{,}045\, f_b$.

For filled and unfilled perpend joints respectively

Cavity Walls To EC6 Pt. 1.1

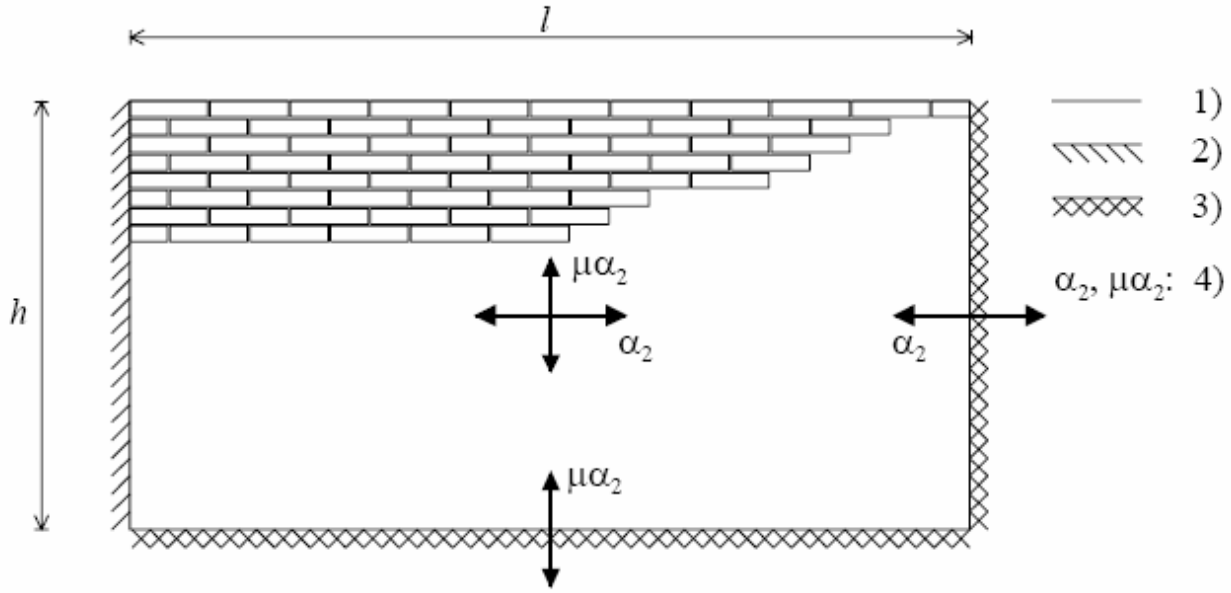
- **Design strength = sum of design lateral - strength of each wall**

$$M_{Rd} = M_{Rd1} + M_{Rd2}$$

OR

- **Design applied load W_{Ed} apportioned to - each leaf on a stiffness basis (W_{Ed1}; W_{Ed2})**

Eurocode 6 Part 1.1 Annex E



Key

1) free edge
2) simply supported edge
3) fully restrained/continuous edge
4) α_2, $\mu\alpha_2$: moment coefficients in the indicated directions

Figure E.1 — Key to support conditions used in tables

BS 5628 Pt.1 Slenderness Limits

- **Panel simply supported top and bottom**

$$\text{Height} \leq 40t_{ef}$$

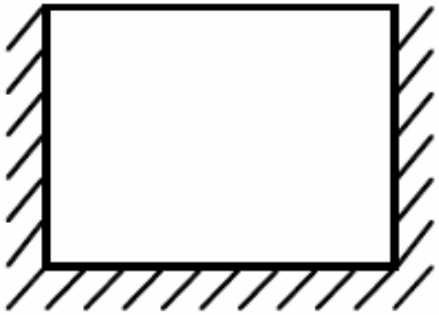
Free standing wall

$$\text{Height} \leq 12t_{ef}$$

Eurocode 6 Part 1.1 Annex E

Wall support condition

A

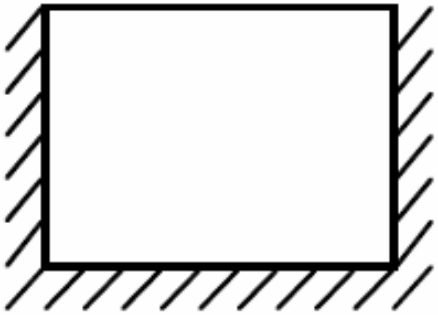


μ	h/l							
	0,30	**0,50**	**0,75**	**1,00**	**1,25**	**1,50**	**1,75**	**2,00**
1,00	0,031	0,045	0,059	0,071	0,079	0,085	0,090	0,094
0,90	0,032	0,047	0,061	0,073	0,081	0,087	0,092	0,095
0,80	0,034	0,049	0,064	0,075	0,083	0,089	0,093	0,097
0,70	0,035	0,051	0,066	0,077	0,085	0,091	0,095	0,098
0,60	0,038	0,053	0,069	0,080	0,088	0,093	0,097	0,100
0,50	0,040	0,056	0,073	0,083	0,090	0,095	0,099	0,102
0,40	0,043	0,061	0,077	0,087	0,093	0,098	0,101	0,104
0,35	0,045	0,064	0,080	0,089	0,095	0,100	0,103	0,105
0,30	0,048	0,067	0,082	0,091	0,097	0,101	0,104	0,107
0,25	0,050	0,071	0,085	0,094	0,099	0,103	0,106	0,109
0,20	0,054	0,075	0,089	0,097	0,102	0,105	0,108	0,111
0,15	0,060	0,080	0,093	0,100	0,104	0,108	0,110	0,113
0,10	0,069	0,087	0,098	0,104	0,108	0,111	0,113	0,115
0,05	0,082	0,097	0,105	0,110	0,113	0,115	0,116	0,117

Eurocode 6 Part 1.1 Annex E

Wall support condition

A



μ	h/l							
	0,30	**0,50**	**0,75**	**1,00**	**1,25**	**1,50**	**1,75**	**2,00**
1,00	0,031	0,045	0,059	0,071	0,079	0,085	0,090	0,094
0,90	0,032	0,047	0,061	0,073	0,081	0,087	0,092	0,095
0,80	0,034	0,049	0,064	0,075	0,083	0,089	0,093	0,097
0,70	0,035	0,051	0,066	0,077	0,085	0,091	0,095	0,098
0,60	0,038	0,053	0,069	0,080	0,088	0,093	0,097	0,100
0,50	0,040	0,056	0,073	0,083	0,090	0,095	0,099	0,102
0,40	0,043	0,061	0,077	0,087	0,093	0,098	0,101	0,104
0,35	0,045	0,064	0,080	0,089	0,095	0,100	0,103	0,105
0,30	0,048	0,067	0,082	0,091	0,097	0,101	0,104	0,107
0,25	0,050	0,071	0,085	0,094	0,099	0,103	0,106	0,109
0,20	0,054	0,075	0,089	0,097	0,102	0,105	0,108	0,111
0,15	0,060	0,080	0,093	0,100	0,104	0,108	0,110	0,113
0,10	0,069	0,087	0,098	0,104	0,108	0,111	0,113	0,115
0,05	0,082	0,097	0,105	0,110	0,113	0,115	0,116	0,117

Eurocode 6 Pt. 1.1 NA.2.8

NA.2.8 Characteristic flexural strength of masonry [see BS EN 1996-1-1, **3.6.3**(3)]

The values of f_{xk1} and f_{xk2} to be used for general purpose mortars are given in Table NA.7.

For thin layer mortars use the values given for M12 mortar.

For lightweight mortars use the values given for M2 mortar.

Values characteristic flexural strength from EC6

Values of f_{xk1}, for plane of failure parallel to bed joints

Masonry Unit	f_{xk1} (N/mm^2)			
	General purpose mortar		Thin layer mortar	Lightweight mortar
	$f_m < 5$ N/mm^2	$f_m \geq 5$ N/mm^2		
Clay	0,10	0,10	0,15	0,10
Calcium silicate	0,05	0,10	0,20	not used
Aggregate concrete	0,05	0,10	0,20	not used
Autoclaved aerated concrete	0,05	0,10	0,15	0,10
Manufactured stone	0,05	0,10	not used	not used
Dimensioned natural stone	0,05	0,10	0,15	not used

Values characteristic flexural strength from EC6

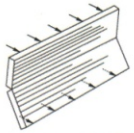
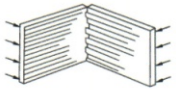
Values of f_{xk2}, for plane of failure perpendicular to bed joints

Masonry Unit		f_{xk2} (N/mm^2)			
		General purpose mortar		Thin layer mortar	Lightweight mortar
		$f_m < 5$ N/mm^2	$f_m \geq 5$ N/mm^2		
Clay		0,20	0,40	0,15	0,10
Calcium silicate		0,20	0,40	0,30	not used
Aggregate concrete		0,20	0,40	0,30	not used
Autoclaved aerated concrete	$\rho < 400$ kg/m^3	0,20	0,20	0,20	0,15
	$\rho \geq 400$ kg/m^3	0,20	0,40	0,30	0,15
Manufactured stone		0,20	0,40	not used	not used
Dimensioned natural stone		0,20	0,40	0,15	not used

EC6 NA Table NA.6

NA to BS EN 1996-1-1:2005

Table NA.6 **Characteristic flexural strength of masonry, f_{xk1} and f_{xk2}, in N/mm²**

	Values of f_{xk1} Plane of failure parallel to bed joints 			Values of f_{xk2} Plane of failure perpendicular to bed joints 		
Mortar strength class:	**M12**	**M6 and M4**	**M2**	**M12**	**M6 and M4**	**M 2**
Clay masonry units of groups 1 and 2 having a water absorption (see Note 1) of:						
less than 7%	0,7	0,5	0,4	2,0	1,5	1,2
between 7% and 12%	0,5	0,4	0,35	1,5	1,1	1,0
over 12%	0,4	0,3	0,25	1,1	0,9	0,8
Calcium silicate brick sized* masonry units	0,3		0,2	0,9		0,6
Aggregate concrete brick sized* masonry units	0,3		0,2	0,9		0,6
Aggregate concrete masonry units and manufactured stone of groups 1 and 2 and AAC masonry units used in walls of thickness up to 100 mm (see Note 2 and 3) of declared compressive strength:						
2,9	0,25		0,2	0,4		0,4
3,6				0,45		0,4
7,3				0,6		0,5
Aggregate concrete masonry units and manufactured stone of groups 1 and 2 and AAC masonry units used in walls of thickness of 250 mm or greater (see Note 2 and 3), of declared compressive strength:						
2,9	0,15		0,1	0,25		0,2
3,6				0,25		0,2
7,3				0,35		0,3
Aggregate concrete masonry units and manufactured stone of groups 1 and 2 and AAC masonry units used in walls of any thickness (see Note 2), of declared compressive strength:						
10,4	0,25		0,2	0,75		0,6
≥ 17,5				0,9 (see Note 4)		0,7 (see Note 4)

NOTE 1 *Tests to determine the water absorption of clay masonry units are to be conducted in accordance with BS EN 772-7.*

NOTE 2 *The thickness should be taken to be the thickness of the wall, for a single-leaf wall, or the thickness of the leaf, for a cavity wall.*

NOTE 3 *Linear interpolation may be used to obtain the values of f_{xk1} and f_{xk2} for:*

a) wall thicknesses greater than 100 mm and less than 250 mm;

b) compressive strengths between 2,9 N/mm² and 7,3 N/mm² in a wall of given thickness.

NOTE 4 *When used with flexural strength in the parallel direction, assume the orthogonal ratio $\mu = 0,3$.*

* units not exceeding 337.5 mm × 225 mm × 112.5 mm

EC6 NA Table NA.6 (Detail)

Mortar strength class:	M12	M6 and M4	M2	M12	M6 and M4	M 2
Clay masonry units of groups 1 and 2 having a water absorption (see Note 1) of:						
less than 7%	0,7	0,5	0,4	2,0	1,5	1,2
between 7% and 12%	0,5	0,4	0,35	1,5	1,1	1,0
over 12%	0,4	0,3	0,25	1,1	0,9	0,8
Calcium silicate brick sized* masonry units	0,3		0,2	0,9		0,6
Aggregate concrete brick sized* masonry units	0,3		0,2	0,9		0,6
Aggregate concrete masonry units and manufactured stone of groups 1 and 2 and AAC masonry units used in walls of thickness up to 100 mm (see Note 2 and 3) of declared compressive strength:						
2,9	0,25		0,2	0,4		0,4
3,6				0,45		0,4
7,3				0,6		0,5
Aggregate concrete masonry units and manufactured stone of groups 1 and 2 and AAC masonry units used in walls of thickness of 250 mm or greater (see Note 2 and 3), of declared compressive strength:						
2,9	0,15		0,1	0,25		0,2
3,6				0,25		0,2
7,3				0,35		0,3
Aggregate concrete masonry units and manufactured stone of groups 1 and 2 and AAC masonry units used in walls of any thickness (see Note 2), of declared compressive strength:						
10,4	0,25		0,2	0,75		0.6
≥ 17,5				0,9 (see Note 4)		0,7 (see Note 4)

BS 5628 Pt.1 Slenderness Limits (Clause 32.3 controls slenderness)

- **Panel supported on three sides**

  (i) Two or more sides continuous:

  height x length ≤ $1500t_{ef}^2$

  (ii) All other cases:

  height x length ≤ $1350t_{ef}^2$

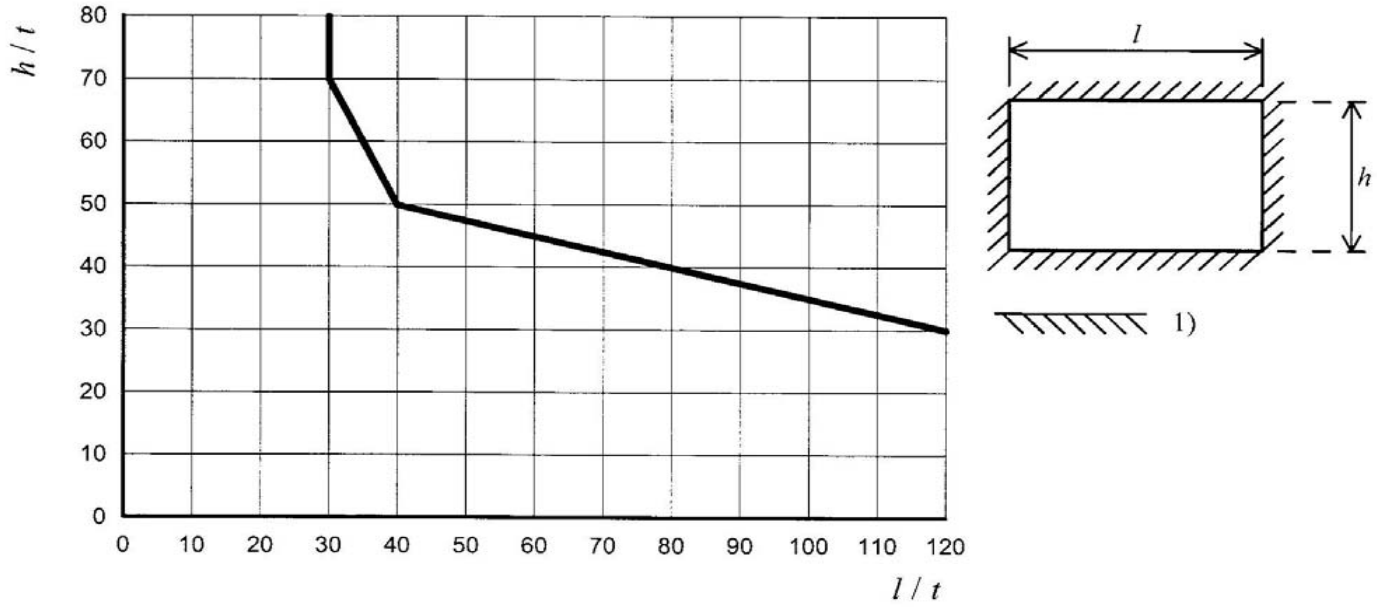
- **No dimension to exceed $50t_{ef}$**

BS 5628 Pt.1 Slenderness Limits

- **Panel supported on four sides**
  - **(i) Three or more sides continuous:**
    height x length ≤ $2250t_{ef}^2$
  - **(ii) All other cases:**
    height x length ≤ $2025t_{ef}^2$

- **No dimension to exceed $50t_{ef}$**

Eurocode 6 Pt. 1.1 Figure F.1

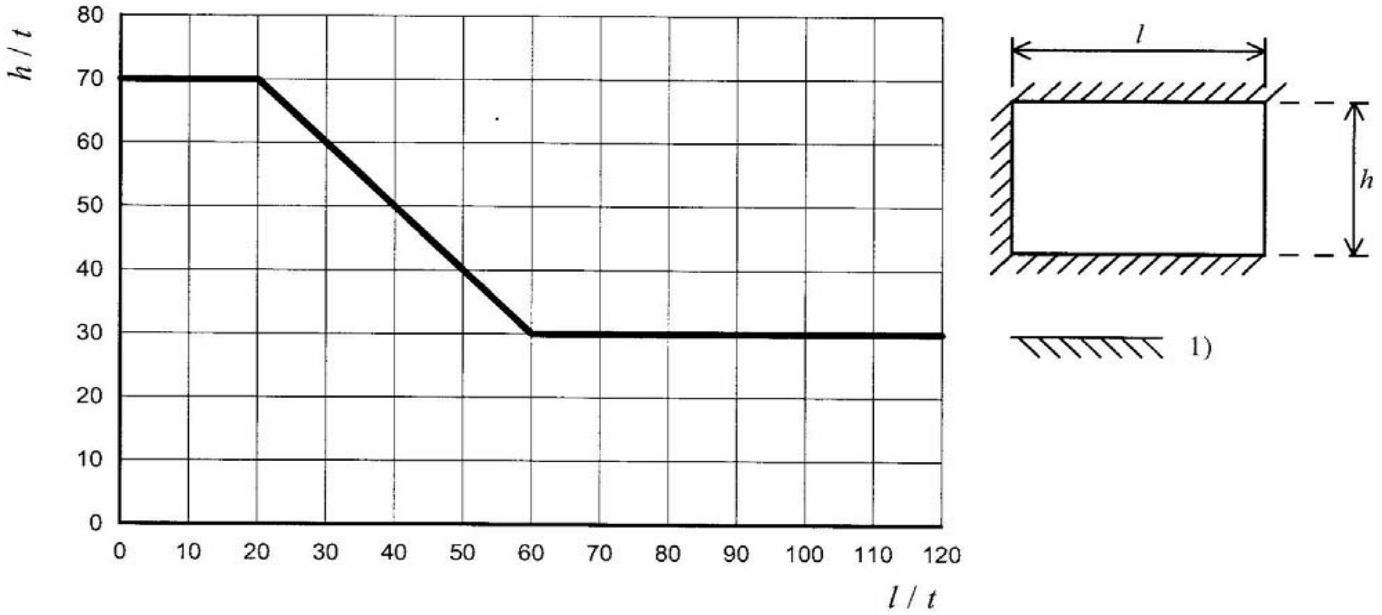


Key

1) simply supported or with full continuity

Figure F.1 — Limiting height and length to thickness ratios of walls restrained on all four edges

Eurocode 6 Pt. 1.1 Figure F.2

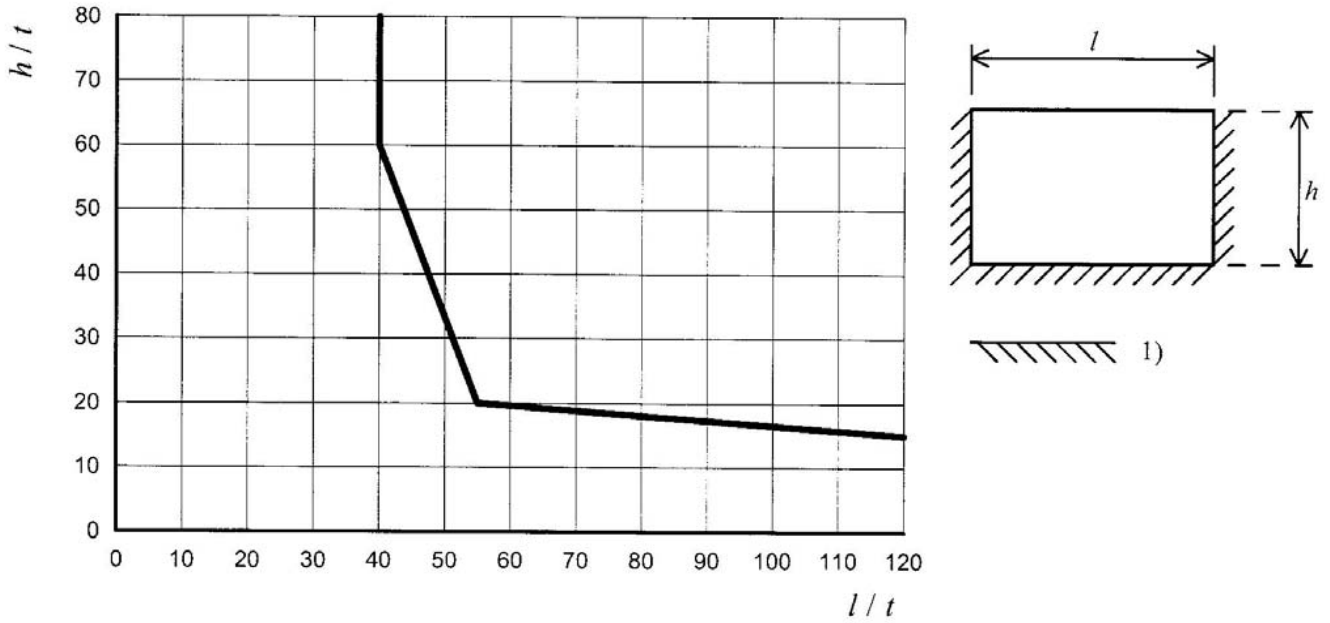


Key

1) simply supported or with full continuity

Figure F.2 — Limiting height and length to thickness ratios of walls restrained at the bottom, the top and one vertical edge

Eurocode 6 Pt. 1.1 Figure F.3



Key

1) simply supported or with full continuity

Figure F.3 — Limiting height and length to thickness ratios of walls restrained at the edges, the bottom, but not the top

Comparison of serviceability limits for Laterally Loaded Panels 2.7m high & 100mm thick

Description	Maximum panel length BS 5628	Maximum panel length EC6
Walls restrained top and bottom but not ends	4m	3m

Comparison of serviceability limits for Laterally Loaded Panels 2.7m high & 100mm thick

Description	Maximum panel length BS 5628	Maximum panel length EC6
Panels supported on four edges	5m	12m

Comparison of serviceability limits for Laterally Loaded Panels 2.7m high & 100mm thick

Description	Maximum panel length BS 5628	Maximum panel length EC6
Panels supported on three edges	5m	12m

Comparison of serviceability limits for Laterally Loaded Panels 2.7m high & 100mm thick

Description	Maximum panel length BS 5628	Maximum panel length EC6
Panels supported on three edges	5m	5,2m

Enhancing Lateral Load Performance

Bed joint reinforcement used to enhance lateral load resistance

Use partial safety factors from BS 5628 Part 1

Can use mortar designation (iii)

c.s.a. reinforcement at least 14mm^2 at vertical centres not exceeding 450mm.

Limiting Dimensions in BS 5628

Number of sides supported	Types of support	
3	Two or more sides continuous $1800\ t_{ef}^2$	All other cases $1600\ t_{ef}^2$
4	Three or more sides continuous $2700\ t_{ef}^2$	All other cases $2400\ t_{ef}^2$

N.B No dimension to exceed 60 t_{ef}

Four design methods in BS5628

1. Design as horizontally spanning wall
2. Design with reinforced section carrying extra load only
3. Design using modified orthogonal ratio
4. Design based on cracking load

Four design methods

1. Design as horizontally spanning wall
2. Design with reinforced section carrying extra load only
3. Design using modified orthogonal ratio
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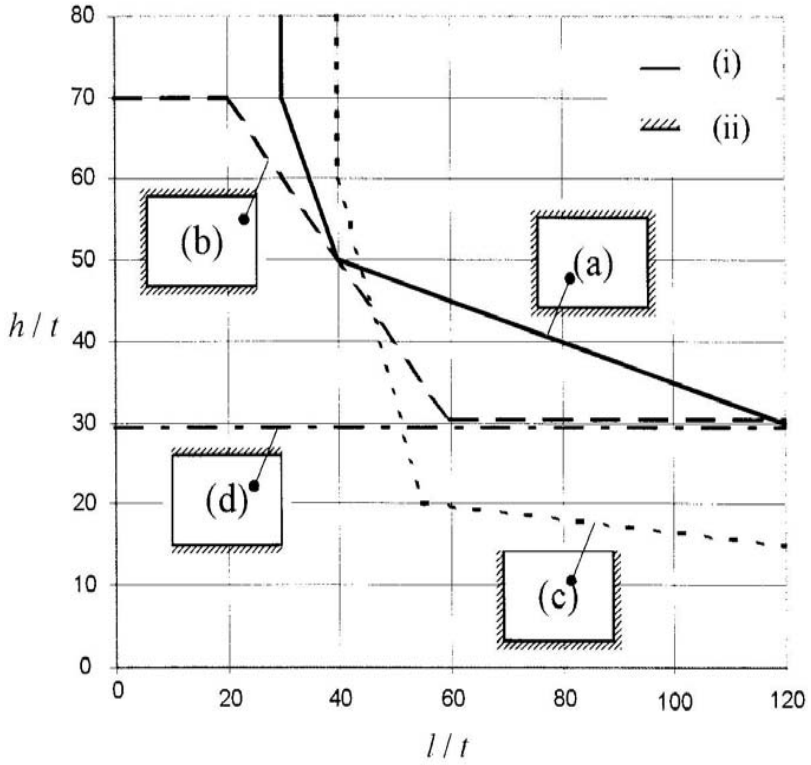
1996-3 Wall types

Type a walls restrained along 4 edges

Type b walls restrained along all edges, except for 1 vertical edge

Type c walls restrained along all edges, except at top edge

Type d walls restrained along the top and bottom edges only



Key:

(i) Free end
(ii) Restrained

(a) Type a wall
(b) Type b wall
(c) Type c wall
(d) Type d wall

Figure B.1 — Limitation of size thickness ratio of internal walls not subject to vertical load but with limited lateral load