SECTION 7 STRUCTURAL DESIGN OF UNREINFORCED MASONRY

7.1 SCOPE OF SECTION

This Section sets out particular requirements for the structural design of unreinforced masonry for the strength and serviceability limit states. These requirements are in addition to the general requirements of Section 4.

Masonry, contains reinforcement that does not comply with the structural design requirements of Section 8 for strength assessment purposes, shall be regarded as unreinforced masonry, and shall be in accordance with the requirements of this Section.

7.2 GENERAL BASIS OF DESIGN

Each unreinforced masonry member shall be designed to comply with Clauses 7.3 to 7.5, as appropriate, taking into account the strength of the material and the further provisions in Clauses 7.6 to 7.9, as applicable, for the relevant type of member.

The value of the design bending moment shall include the bending moments, if any, resulting from load eccentricities or bending moments applied at the ends of the member.

For a member to be designed to comply with Clause 7.4, the loads and forces on the wall shall be such that—

(a) any bending moments acting on the wall, other than those arising from the laterally applied loads, are small enough to be ignored; and

(b) the compressive stresses on any bed joint in the wall from any simultaneously acting loads do not exceed 3 f'_{mt} in magnitude.

In addition, the member shall be designed to comply with Clause 7.3 for all forces and moments other than those resulting from short-term out-of-plane loads.

7.3 DESIGN FOR MEMBERS IN COMPRESSION

7.3.1 General

Unreinforced masonry members resisting compressive forces, with or without simultaneously acting bending moments, shall be designed to comply with Clause 7.3.3 or Clause 7.3.4. Members with concentrated loads shall be designed to comply with Clause 7.3.5, and lightly loaded members under the action of transient out-of-plane forces shall be designed to comply with Clause 7.4.

The compressive capacity of a masonry member depends upon the following factors:

(a) Slenderness.

(b) Effective eccentricity of loading at each end.

(c) Characteristic compressive strength of the masonry.

(d) Cross-sectional area of the masonry.

In a wall or isolated pier subject to compression and bending, the vertical and bending forces shall be considered at top and bottom of the member by regarding the vertical force as acting at statically equivalent effective eccentricities, (e_1) and (e_2) respectively, at each end. In this calculation, the most unfavourable disposition of live loads shall be considered. These conditions shall be deemed to be satisfied if the provisions of Clause 7.3.3 or 7.3.4 are applied.

Although it is assumed in cavity wall construction that each leaf can give support to the other leaf for robustness purposes (see Clause 4.6) or for withstanding lateral loads (see Clause 7.8.3), no such mutual support shall be assumed or relied upon with respect to buckling actions under compressive forces.

7.3.2 Basic compressive capacity

The basic compressive capacity of the cross-section (F_o) shall be taken as follows:

(a) For ungrouted masonry—

$$F_o = \phi f'_m A_b \qquad \ldots 7.3.2(1)$$

(b) For grouted masonry—

(i) if no testing is done—

$$F_o = \phi\left(f'_m A_b + k_c \sqrt{\left(\frac{f'_{cg}}{1.3}\right)} A_c\right) \qquad \ldots 7.3.2(2)$$

(ii) if testing is done—

$$F_o = \phi f'_{mg} A_d \qquad \ldots 7.3.2(3)$$

where

ϕ = the capacity reduction factor (see Clause 4.4)

f'_m = the characteristic compressive strength of the masonry (see Clause 3.3.2)

A_b = the bedded area of a masonry cross-section (see Clause 4.5.4)

k_c = a strength factor for grout in compression

= 1.4 for hollow concrete masonry units of density greater than 2000 kg/m^3

= 1.2 for all other masonry

f'_{cg} = the design characteristic compressive strength of grout in megapascals (see Clause 3.5)

A_c = the design cross-sectional area of grout (see Clause 4.5.7)

f'_{mg} = the characteristic compressive strength of grouted masonry specimens manufactured and tested in accordance with Appendix C and determined in accordance with Appendix B

A_d = the design cross-sectional area of the member (see Clause 4.5.6).

7.3.3 Design by simple rules

7.3.3.1 *General*

Clauses 7.3.3.1 to 7.3.3.3 apply to unreinforced masonry walls with or without engaged piers, and to isolated piers of rectangular cross-section. The possibility of buckling about each of the two principal axes of the cross-section of the member shall be assessed.

The resistance to lateral loading shall be checked independently, in accordance with Clause 7.4. It is not necessary to consider the interaction of vertical and lateral loads acting simultaneously.

If the member under consideration has insufficient capacity under the simplified rules, its capacity may be determined under refined calculations as specified in Clause 7.3.4.

7.3.3.2 *Compression on uniform symmetrical members*

A member shall be designed such that the following relationship is satisfied:

$$F_d \leq k F_o \qquad \ldots 7.3.3.2$$

where

F_d = the design compressive force which acts on the cross-section of member simultaneously with a bending moment, shear force or other load action

F_o = the basic compressive strength capacity (see Clause 7.3.2)

k = a reduction factor for slenderness and eccentricity given as follows

(a) For a wall or pier supporting a concrete slab as defined in Table 7.1, k is the lesser of—

(i) $0.67 - 0.02(S_{rs} - 14)$; or

(ii) 0.67

(b) For a wall or pier supporting other systems as defined in Table 7.1, k is the lesser of—

(i) $0.67 - 0.025(S_{rs} - 10)$; or

(ii) 0.67

(c) For a wall with the load applied to the face as defined in Table 7.1, k is the lesser of—

(i) $0.067 - 0.002(S_{rs} - 14)$; or

(ii) 0.067

The following requirements shall apply:

(A) For masonry not reinforced for vertical bending, the wall shall extend at least one storey above the point of load application.

(B) For single leaf walls, the minimum thickness shall be 140 mm.

(C) For cavity walls, the thickness of the loaded leaf shall be not less than 100 mm and the sum of the thicknesses of the two leaves not less than 200 mm. (Since the floor line is a line of lateral support, cavity wall ties in this region shall be at 300 mm centres maximum).

(D) If a load is applied to both faces, the wall shall be designed for the difference between the two loads.

In Items (a)(i), (b)(i) and (c)(i), S_{rs} is the simplified slenderness ratio determined in accordance with Clause 7.3.3.3.

The values of k given in Table 7.1 shall be deemed to satisfy the equations in this Clause. In all cases the capacity of the wall shall be checked for the total load on the wall at any level.

Where the load is applied directly on to an engaged pier, the capacity of the pier shall be determined in accordance with Clauses 7.3.4 and 7.3.5, as appropriate.

7.3.3.3 *Slenderness ratio*

The slenderness ratio of a member about a given principal axis shall be as follows:

(a) Other than for a wall that is laterally supported along one or both of its vertical edges—

$$S_{rs} = \frac{a_v H}{k_t t} \qquad \text{. . . 7.3.3.3(1)}$$

(b) For a wall that is laterally supported along one or both of its vertical edges, the lesser of—

$$S_{rs} = \frac{a_v H}{k_t t}\text{; or} \qquad \text{. . . 7.3.3.3(2)}$$

$$S_{rs} = \frac{0.7}{t}\sqrt{a_v H a_h L} \qquad \text{. . . 7.3.3.3(3)}$$

where

S_{rs} = the simplified slenderness ratio

a_v = a slenderness coefficient

= 1 if the member is laterally supported along its top edge

= 2.5 if the member is not laterally supported along its top edge

H = the clear height of a member between horizontal lateral supports; or

= for a member without top horizontal support, the overall height from the bottom lateral support

k_t = a thickness coefficient derived from Table 7.2

= 1 if there are no engaged piers

If the engagement of a pier to the wall does not meet the requirements of Clause 4.11 for bonding or tying, the value of k_t shall be taken as 1.0

a_h = a slenderness coefficient

= 1 if the member is laterally supported along both its vertical edges

= 2.5 if the member is laterally supported along one vertical edge

L = the clear length of a wall between vertical lateral supports; or

= for a wall without a vertical support at one end or at a control joint or for walls containing openings, the length to that unsupported end or control joint or edge of opening

A control joint in a wall, or an edge to an support at that edge opening in a wall, shall be regarded as an unsupported edge to that wall unless specific measures are taken to provide adequate lateral support at that edge.

t = the overall thickness of the member's cross-section perpendicular to the principal axis under consideration; for members of cavity wall construction, each leaf is assessed separately and individually for thickness and for slenderness ratio

t_{wp} = the overall thickness of a masonry wall plus an engaged pier or buttress

7.3.4 Design by refined calculation

7.3.4.1 *General*

Clauses 7.3.4.1 to 7.3.4.5 apply to unreinforced masonry walls with or without engaged piers, and to isolated piers. The possibility of buckling about each of the two principal axes of the cross-section of the member shall be assessed.

The provisions of this Clause are for uniform symmetrical members in uniaxial bending and compression. Other cases may be designed using the same general principles with appropriate modification based on the principles of structural mechanics.

7.3.4.2 *Uniaxial bending and compression on uniform symmetrical members*

A member shall be designed such that the following relationship is satisfied:

$$F_d \leq kF_o \qquad \ldots 7.3.4.2$$

where

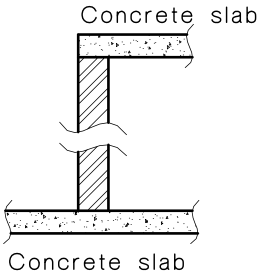
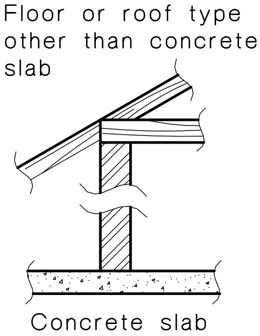
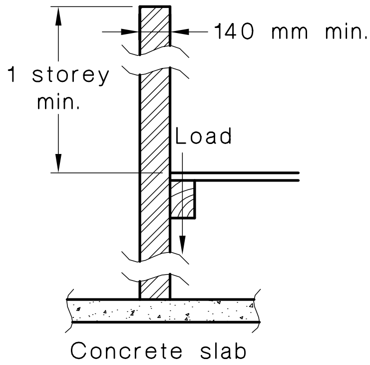
F_d = the design compressive force that acts on the cross-section of a member simultaneously with a bending moment, shear force or other load action

k = a reduction factor for slenderness and eccentricity (see Clause 7.3.4.5)

F_o = the basic compressive strength capacity (see Clause 7.3.2).

TABLE 7.1

REDUCTION FACTOR (*k*) FOR DESIGN BY SIMPLE RULES

S_{rs}	**Reduction factor (*k*)**		
			
≤8	0.67	0.67	0.067
10	0.67	0.67	0.067
12	0.67	0.63	0.067
14	0.67	0.58	0.067
16	0.63	0.53	0.063
18	0.59	0.48	0.059
20	0.55	0.43	0.055
22	0.51	0.38	0.051
24	0.47	0.33	0.047
26	0.43	0.28	0.043
28	0.39	0.23	0.039
30	0.35	0.18	0.035
32	0.31	0.13	0.031
34	0.27	0.08	0.027
36	0.23	0.03	0.023

NOTES:

1 Linear interpolation within each category is permitted.

2 This Table does not cover the case of load applied to one face of the wall at roof level. Because of the low precompression at this level, a detail that minimizes the load eccentricity should be used.

TABLE 7.2

THICKNESS COEFFICIENTS (k_t) FOR WALLS STIFFENED BY MONOLITHICALLY ENGAGED PIERS

Pier spacing/pier width (see Note 1)	Thickness coefficient (k_t) Pier thickness ratio (t_{wp}/t)		
	1	2	3
6	1.0	1.4	2.0
8	1.0	1.3	1.7
10	1.0	1.2	1.4
15	1.0	1.1	1.2
20 or more	1.0	1.0	1.0

NOTES:

1 Pier spacing is taken as the distance between centre-lines of piers.

2 Linear interpolation may be used.

7.3.4.3 *Slenderness ratio*

The slenderness ratio of a member about a given principal axis shall be as follows:

(a) Other than for a wall that is laterally supported along one or both of its vertical edges—

$$S_r = \frac{a_v H}{k_t t} \qquad \text{. . . 7.3.4.3(1)}$$

(b) for a wall that is laterally supported along one or both of its vertical edges, the lesser of—

$$S_r = \frac{a_v H}{k_t t}\text{; or} \qquad \text{. . . 7.3.4.3(2)}$$

$$S_r = \frac{0.7}{t}\sqrt{a_v H a_h L} \qquad \text{. . . 7.3.4.3(3)}$$

where

S_r = The slenderness ratio

a_v = A slenderness coefficient

= 0.75 for a member laterally supported and partially rotationally restrained at both top and bottom

= 0.85 for a member laterally supported at top and bottom and partially rotationally restrained at one of them

= 1.0 for a member laterally supported at both top and bottom

= 1.5 for a member laterally supported and partially rotationally restrained at the bottom and partially laterally supported at the top

= 2.5 for a freestanding wall

the situations shown and described in Figures 7.1 to 7.5 shall be deemed to provide the appropriate values.

H = The clear height of a member between horizontal lateral supports; or

= for a member without top horizontal support, the overall height from the bottom lateral support

k_t = a thickness coefficient derived from Table 7.2

if the engagement of a pier to the wall does not meet the requirements of Clause 4.11 for bonding or tying, the value of k_t shall be taken as 1.0.

t = the overall thickness of the member's cross-section perpendicular to the principal axis under consideration; for members of cavity wall construction, each leaf is assessed separately and individually for thickness and for slenderness ratio

a_h = a slenderness coefficient

= 1.0 for a member laterally supported along both vertical edges (regardless of the rotational restraint along these edges); or

= 2.5 for a member laterally supported along one vertical edge, and unsupported along its other vertical edge

the situations shown and described in Figure 7.6 are deemed to provide the appropriate values.

L = the clear length of a wall between vertical lateral supports; or

= for a wall without a vertical support at its end or at a control joint, the length to that unsupported end or control joint.

A member shall not be regarded as being laterally supported at an edge unless that lateral support meets the requirements of Clause 2.6.3 in the direction perpendicular to the principal axis under consideration.

A control joint in a wall, or an edge to an opening in a wall, shall be regarded as an unsupported edge to that wall unless specific measures are taken to provide adequate lateral support at that edge.

Where an engaged pier or buttress is of such dimension that t_{wp} exceeds 0.25 H in value, it shall be designed as a member providing lateral support to the wall, and shall not then be used in evaluating k_t.

Where a wall contains openings, the assessment of the slenderness ratio shall take account of the extent and position of openings in relation to applied loads and support conditions, with each side of the opening being considered to be an unsupported vertical edge.

Where the openings are such that the masonry between any two consecutive openings is by definition an isolated pier, the slenderness ratio of that isolated pier shall be taken as the lesser of the following:

(i) $$S_r = \frac{2H_1}{t} \quad \ldots 7.3.4.3(4)$$

where

S_r = the slenderness ratio

H_1 = the height of the taller opening

t = the overall thickness or depth of the member's cross-section perpendicular to the principal axis under consideration; for members of cavity wall construction, each leaf is assessed separately and individually for thickness and for slenderness ratio

(ii) The value for the pier assessed in accordance with this Clause.

7.3.4.4 *Effective eccentricity*

The effective load eccentricity shall be determined taking into account the relative stiffness of the masonry members (or member) and floor slabs or beams that the masonry supports, the relative rotation of the slab or beams and the supporting masonry member and any other factors that affect the interaction of the components framing into the joint.

This requirement shall be deemed to be satisfied if the effective eccentricity is calculated assuming that the load transmitted to a wall by a single floor or roof acts at one third of the depth of the bearing area from the loaded face of the wall or loadbearing leaf. Where a supported floor or roof is continuous over a wall, each side of the floor or roof shall be taken as being individually supported on one half of the total bearing area. The resulting eccentricity of load at any level shall be calculated on the assumption that the total vertical load on the wall above the plane under consideration is axial immediately above the horizontal plane under consideration.

Alternatively, for walls with a (minimum) design compressive stress immediately above the joint under consideration greater than 0.25 MPa, a rigid frame analysis may be used with the appropriate allowance for relative slab wall rotation at the joints.

7.3.4.5 *Reduction factor for slenderness and eccentricity for refined calculation*

The reduction factor (k) shall be the lesser of the values calculated in Items (a) and (b), as follows:

(a) For lateral instability—

(i) for e_1/t_w 0.05—

$$k = 1.18 - 0.03\,S_r \qquad \text{. . . 7.3.4.5(1)}$$

but not greater than one.

(ii) for $e_1/t_w > 0.05$—

$$k = 0.5\left(1+\frac{e_2}{e_1}\right)\left[\left(1-2.083\frac{e_1}{t_w}\right)-\left(0.025-0.037\frac{e_1}{t_w}\right)(1.33S_r-8)\right] + 0.5\left(1-0.6\frac{e_1}{t_w}\right)\left(1-\frac{e_2}{e_1}\right)(1.18-0.03S_r) \qquad \text{. . . 7.3.4.5(2)}$$

Where the slenderness ratio (S_r) has been assessed in accordance with Clause 7.3.4.3(b), k is evaluated on the assumption that $e_2/e_1 = 1$.

The values given in Table 7.3 shall be deemed to satisfy Equations 7.3.4.5(1) and 7.3.4.5(2).

(b) For local crushing, a value of k given as follows:

(i) For members of solid cross-section with full bedding or walls fully grouted—

$$k = 1 - 2\frac{e_1}{t_w} \qquad \text{. . . 7.3.4.5(3)}$$

(ii) For members with face shell bedding or a diaphragm wall, the lesser of—

$$k = \frac{1-\dfrac{t_{fs}}{t_w}}{1-\dfrac{t_{fs}}{t_w}+2\dfrac{e_1}{t_w}} \qquad \text{. . . 7.3.4.5(4)}$$

and

$$k = \frac{1}{2\frac{t_{fs}}{t_w}}\left(1 - 2\frac{e_1}{t_w}\right) \qquad \ldots 7.3.4.5(5)$$

where

e_1 = the larger eccentricity of the vertical force, at either top or bottom of the member

e_2 = the smaller eccentricity of the vertical force at the other end and is negative when the eccentricities are on opposite sides of the member

t_w = the overall thickness of wall or isolated pier

t_{fs} = the thickness of the face shell for hollow block masonry or flange thickness for diaphragm walls.

NOTE: Concrete floor systems spanning from one side only shall bear on at least of the thickness of the supporting wall or leaf and the bearing width shall be not less than 85 mm.

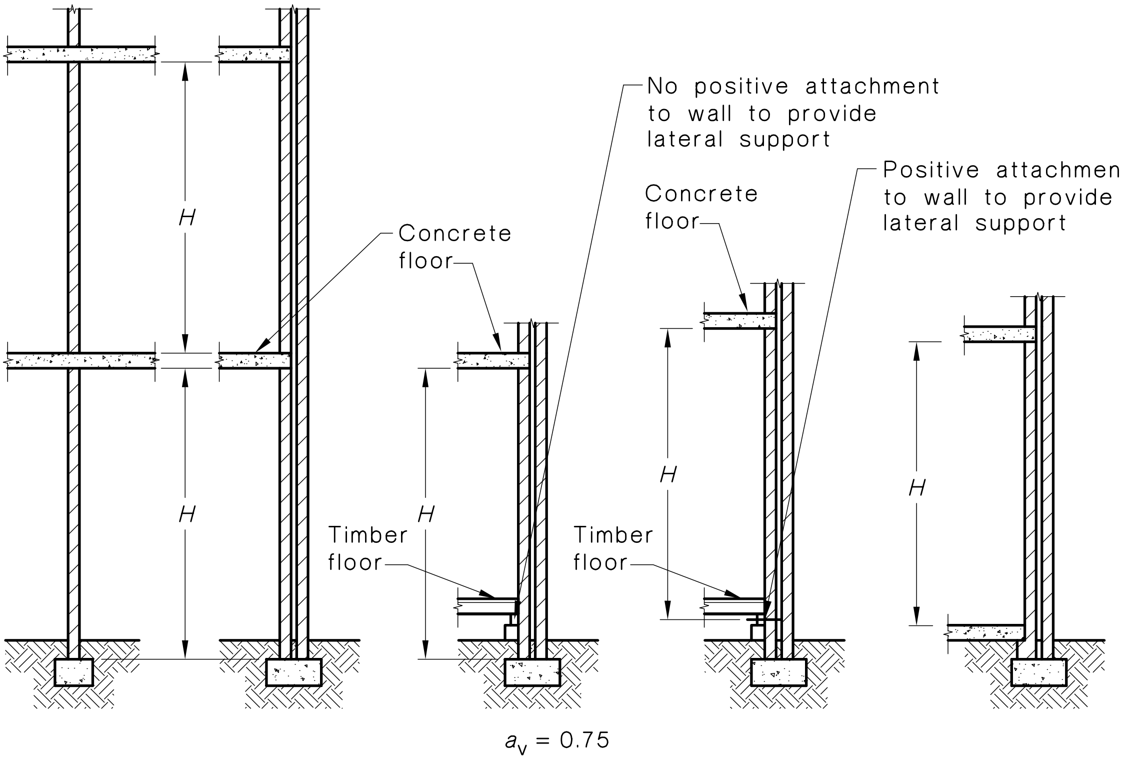


FIGURE 7.1 LATERAL SUPPORT AND PARTIAL ROTATIONAL RESTRAINT AT TOP AND BOTTOM (FULLY BRACED CONSTRUCTION)