

Eurocode 6: Design of masonry structures - Part 1-1: Common rules for reinforced and reinforced masonry structures (EN 1996-1-1:2004)

1.5.2 Terms and Definitions

1.5.2.5 confined masonry

masonry provided with reinforced concrete or reinforced masonry confining elements in the vertical and horizontal direction

6.9 Confined masonry

6.91 General

(1)P The design of confined masonry members shall be based on similar assumptions to those set out for unreinforced and for reinforced masonry members.

6.9.2 Verification of members

(1) In the verification of confined masonry members subjected to bending and/or axial loading, the assumptions given in this EN 1996-1-1 for reinforced masonry members should be adopted. In determining the design value of the moment of resistance of a section a rectangular stress distribution may be assumed, based on the strength of the masonry, only. Reinforcement in compression should also be ignored.

(2) In the verification of confined masonry members subjected to shear loading the shear resistance of the member should be taken as the sum of the shear resistance of the masonry and of the concrete of the confining elements. In calculating the shear resistance of the masonry the rules for unreinforced masonry walls subjected to shear loading should be used, considering for l_c the length of the masonry element. Reinforcement of confining elements should not be taken into account.

(3) In the verification of confined masonry members subjected to lateral loading, the assumptions set out for unreinforced and reinforced masonry walls should be used. The contribution of the reinforcement of the confining elements should be considered.

7.5 Confined masonry members

(1)P Confined masonry members shall not exhibit flexural cracking nor deflect excessively under serviceability loading conditions.

(2)P The verification of confined masonry members at the serviceability limit states shall be based on the assumptions given for unreinforced masonry members.

8.4 Confined masonry details

(1)P Confined masonry walls shall be provided with vertical and horizontal reinforced concrete or reinforced masonry confining elements so that they act together as a single structural member when subjected to actions.

(2)P Top and sides confining elements shall be cast after the masonry has been built so that they will be duly anchored together.

(3) Confining elements should be provided at every floor level, at every interception between walls and at both sides of every opening having an area of more than 1,5 m². Additional confining elements may be required in the walls so that the maximum spacing, both horizontal and vertical is 4 m.

(4) Confining elements should have a cross-sectional area not less than 0,02 m², with a minimum dimension of 150 mm in the plan of the wall, and be provided with longitudinal reinforcements with a minimum area equivalent to 0,8 % of the cross-sectional area of the confining element, but not less than 200 mm². Stirrups not less than 6 mm diameter, spaced not more than 300 mm should also be provided. The detailing of the reinforcements should be in accordance with 8.2.

(5) In confined masonry walls where Group 1 and Group 2 Units are used, the units adjacent to the confining elements should be overlapped according to the rules prescribed in the clause 8.1.4 for bonding of masonry. Alternatively, reinforcement not less than 6 mm diameter bars or equivalent and spaced not more than 300 mm, duly anchored in the concrete infill and in the mortar joints, should be adopted.

Eurocode 8: Eurocode 8 : Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings (EN 1998-1:2003)

9 SPECIFIC RULES FOR MASONRY BUILDINGS

9.1 Scope

(1)P This section applies to the design of buildings of unreinforced, confined and reinforced masonry in seismic regions.

(2)P For the design of masonry buildings EN 1996 applies. The following rules are additional to those given in EN 1996.

9.2 Materials and bonding patterns

9.2.1 Types of masonry units

(1) Masonry units should have sufficient robustness in order to avoid local brittle failure.

NOTE The National Annex may select the type of masonry units from EN 1996-1:2004, Table 3.1 that satisfy (1).

9.2.2 Minimum strength of masonry units

(1) Except in cases of low seismicity, the normalised compressive strength of masonry units, derived in accordance with EN 772-1, should be not less than the minimum values as follows:

- normal to the bed face: $f_{b,min}$;
- parallel to the bed face in the plane of the wall: $f_{bh,min}$.

NOTE The values ascribed to $f_{b,min}$ and $f_{bh,min}$ for use in a country may be found in its National Annex of this document. The recommended values are $f_{b,min} = 5 \text{ N/mm}^2$ $f_{bh,min} = 2 \text{ N/mm}^2$.

9.2.3 Mortar

(1) A minimum strength is required for mortar, $f_{m,min}$, which generally exceeds the minimum specified in EN 1996.

NOTE The value ascribed to $f_{m,min}$ for use in a country may be found in its National Annex of this document. The recommended value is $f_{m,min} = 5 \text{ N/mm}^2$ for unreinforced or confined masonry and $f_{m,min} = 10 \text{ N/mm}^2$ for reinforced masonry.

9.2.4 Masonry bond

(1) There are three alternative classes of perpend joints:

- a) joints fully grouted with mortar;
- b) ungrouted joints;
- c) ungrouted joints with mechanical interlocking between masonry units.

NOTE The National Annex may specify which ones among the three classes above will be allowed to be used in a country or parts of the country.

9.3 Types of construction and behaviour factors

(1) Depending on the masonry type used for the seismic resistant elements, masonry buildings should be assigned to one of the following types of construction:

- a) unreinforced masonry construction;
- b) confined masonry construction;

c) reinforced masonry construction;

NOTE 1 Construction with masonry systems which provide an enhanced ductility of the structure is also included (see Note 2 to Table 9.1).

NOTE 2 Frames with infill masonry are not covered in this section.

(2) Due to its low tensile strength and low ductility, unreinforced masonry that follows the provisions of EN 1996 alone is considered to offer low-dissipation capacity (DCL) and its use should be limited, provided that the effective thickness of walls, t_{ef} , is not less than a minimum value, $t_{ef,min}$.

NOTE 1 The conditions under which unreinforced masonry that follows the provisions of EN 1996 alone may be used in a country, may be found in its National Annex to this document. Such use is recommended only in low seismicity cases (see 3.2.1(4))

NOTE 2 The value ascribed to $t_{ef,min}$ for use in a country of unreinforced masonry that follows the provisions of EN 1996 alone, may be found in its National Annex of this document. The recommended values of $t_{ef,min}$ are those in the 2nd column, 2nd and 3rd rows of Table 9.2.

(3) For the reasons noted in (2) of this subclause, unreinforced masonry satisfying the provisions of the present Eurocode may not be used if the value of $a_{g,S}$, exceeds a certain limit, $a_{g,urm}$.

NOTE The value ascribed to $a_{g,urm}$ for use in a country may be found in its National Annex of this document. This value should not be less than that corresponding to the threshold for the low seismicity cases. The value ascribed to $a_{g,urm}$ should be consistent with the values adopted for the minimum strength of masonry units, $f_{b,min}$, $f_{bh,min}$ and of mortar, $f_{m,min}$. For the values recommended in the Notes to 9.2.2 and 9.2.3, the recommended value of $a_{g,urm}$ is 0,20 g.

(4) For types a) to c) the ranges of permissible values of the upper limit value of the behaviour factor q are given in Table 9.1.

Table 9.1: Types of construction and upper limit of the behaviour factor

Type of construction	Behaviour factor q
Unreinforced masonry in accordance with EN 1996 alone (recommended only for low seismicity cases).	1,5
Unreinforced masonry in accordance with EN 1998-1	1,5 - 2,5
Confined masonry	2,0 – 3,0
Reinforced masonry	2,5 - 3,0

NOTE 1 The upper limit values ascribed to q for use in a country (within the ranges of Table 9.1) may be found in its National Annex. The recommended values are the lower limits of the ranges in Table 9.1.

NOTE 2 For buildings constructed with masonry systems which provide an enhanced ductility of the structure, specific values of the behaviour factor q may be used, provided that the system and the related values for q are verified experimentally. The values ascribed to q for use in a country for such buildings may be found in its National Annex of these document.

(5) If the building is non-regular in elevation (see **4.2.3.3**) the q -values listed in Table 9.1 should be reduced by 20%, but need not be taken less than $q = 1,5$ (see **4.2.3.1(7)** and Table 4.1)

9.4 Structural analysis

(1)P The structural model for the analysis of the building shall represent the stiffness properties of the entire system.

(2)P The stiffness of the structural elements shall be evaluated taking into account both their flexural and shear flexibility and, if relevant, their axial flexibility. Uncracked elastic stiffness may be used for analysis or, preferably and more realistically, cracked stiffness in order to account for the influence of cracking on deformations and to better approximate the slope of the first branch of a bilinear force-deformation model for the structural element.

(3) In the absence of an accurate evaluation of the stiffness properties, substantiated by rational analysis, the cracked bending and shear stiffness may be taken as one half of the gross section uncracked elastic stiffness.

(4) In the structural model masonry spandrels may be taken into account as coupling beams between two wall elements if they are regularly bonded to the adjoining walls and connected both to the floor tie beam and to the lintel below.

(5) If the structural model takes into account the coupling beams, a frame analysis may be used for the determination of the action effects in the vertical and horizontal structural elements.

(6) The base shear in the various walls, as obtained by the linear analysis described in Section 4, may be redistributed among the walls, provided that:

a) the global equilibrium is satisfied (i.e. the same total base shear and position of the force resultant is achieved);

b) the shear in any wall is neither reduced more than 25 %, nor increased by more than 33%; and

c) the consequences of the redistribution for the diaphragm(s) are taken into account.

9.5 Design criteria and construction rules

9.5.1 General

(1)P Masonry buildings shall be composed of floors and walls, which are connected in two orthogonal horizontal directions and in the vertical direction.

(2)P The connection between the floors and walls shall be provided by steel ties or reinforced concrete ring beams.

(3) Any type of floors may be used, provided that the general requirements of continuity and effective diaphragm action are satisfied.

(4)P Shear walls shall be provided in at least two orthogonal directions.

(5) Shear walls should conform to certain geometric requirements, namely:

a) the effective thickness of shear walls, t_{ef} , may not be less than a minimum value, $t_{ef,min}$;

b) the ratio h_{ef}/t_{ef} of the effective wall height (see EN 1996-1-1:2004) to its effective thickness may not exceed a maximum value, $(h_{ef}/t_{ef})_{max}$; and

c) the ratio of the length of the wall, l , to the greater clear height, h , of the openings adjacent to the wall, may not be less than a minimum value, $(l/h)_{min}$.

NOTE The values ascribed to $t_{ef,min}$, $(h_{ef}/t_{ef})_{max}$ and $(l/h)_{min}$, for use in a country may be found in its National Annex of this document. The recommended values of $t_{ef,min}$, $(h_{ef}/t_{ef})_{max}$ and $(l/h)_{min}$ are listed in Table 9.2.

Table 9.2: Recommended geometric requirements for shear walls

Masonry type	$t_{ef,min}$ (mm)	$(h_{ef}/t_{ef})_{max}$	$(l/h)_{min}$
Unreinforced, with natural stone units	350	9	0,5
Unreinforced, with any other type of units	240	12	0,4
Unreinforced, with any other type of units, in cases of low seismicity	170	15	0,35
Confined masonry	240	15	0,3
Reinforced masonry	240	15	No restriction
Symbols used have the following meaning: t_{ef} thickness of the wall (see EN 1996-1-1:2004); h_{ef} effective height of the wall (see EN 1996-1-1:2004); h greater clear height of the openings adjacent to the wall; l length of the wall.			

(6) Shear walls not conforming to the minimum geometric requirements of (5) of this subclause may be considered as secondary seismic elements. They should conform to 9.5.2(1) and (2).

9.5.2 Additional requirements for unreinforced masonry satisfying EN 1998-1

(1) Horizontal concrete beams or, alternatively, steel ties should be placed in the plane of the wall at every floor level and in any case with a vertical spacing not more than 4 m. These beams or ties should form continuous bounding elements physically connected to each other .

NOTE Beams or ties continuous over the entire periphery are essential.

(2) The horizontal concrete beams should have longitudinal reinforcement with a cross-sectional area of not less than 200 mm^2 .

9.5.3 Additional requirements for confined masonry

(1)P The horizontal and vertical confining elements shall be bonded together and anchored to the elements of the main structural system.

(2)P In order to obtain an effective bond between the confining elements and the masonry, the concrete of the confining elements shall be cast after the masonry has been built.

(3) The cross-sectional dimensions of both horizontal and vertical confining elements may not be less than 150 mm. In double-leaf walls the thickness of confining elements should assure the connection of the two leaves and their effective confinement.

(4) Vertical confining elements should be placed:

- at the free edges of each structural wall element;
- at both sides of any wall opening with an area of more than $1,5 \text{ m}^2$;
- within the wall if necessary in order not to exceed a spacing of 5 m between the confining elements;
- at the intersections of structural walls, wherever the confining elements imposed by the above rules are at a distance larger than 1,5 m.

(5) Horizontal confining elements shall be placed in the plane of the wall at every floor level and in any case with a vertical spacing of not more than 4 m.

(6) The longitudinal reinforcement of confining elements may not have a cross-sectional area less than 300 mm^2 , nor than 1% of the cross-sectional area of the confining element.

(7) Stirrups not less than 5 mm in diameter and spaced not more than 150 mm should be provided around the longitudinal reinforcement.

(8) Reinforcing steel should be of Class B or C in accordance with EN 1992-1-1:2004, Table C.1.

(9) Lap splices may not be less than 60 bar diameters in length.

9.5.4 Additional requirements for reinforced masonry

(1) Horizontal reinforcement should be placed in the bed joints or in suitable grooves in the units, with a vertical spacing not exceeding 600 mm.

(2) Masonry units with recesses should accommodate the reinforcement needed in lintels and parapets.

(3) Reinforcing steel bars of not less than 4 mm diameter, bent around the vertical bars at the edges of the wall, should be used.

(4) The minimum percentage of horizontal reinforcement in the wall, normalised with respect to the gross area of the section, should not be less than 0,05 %.

(5)P High percentages of horizontal reinforcement leading to compressive failure of the units prior to the yielding of the steel, shall be avoided.

(6) The vertical reinforcement spread in the wall, as a percentage of the gross area of the horizontal section of the wall, should not be less than 0,08%.

(7) Vertical reinforcement should be located in pockets, cavities or holes in the units.

(8) Vertical reinforcements with a cross-sectional area of not less than 200 mm² should be arranged:

- at both free edges of every wall element;
- at every wall intersection;
- within the wall, in order not to exceed a spacing of 5 m between such reinforcements.

(9) **9.5.3(7), (8) and (9)** apply.

(10)P The parapets and lintels shall be regularly bonded to the masonry of the adjoining walls and linked to them by horizontal reinforcement.

9.6 Safety verification

(1)P The verification of the building's safety against collapse shall be explicitly provided, except for buildings satisfying the rules for "simple masonry buildings" given in **9.7.2**.

(2)P For the verification of safety against collapse, the design resistance of each structural element shall be evaluated in accordance with EN 1996-1-1:2004.

(3) In ultimate limit state verifications for the seismic design situation, partial factors γ_m for masonry properties and γ_s for reinforcing steel should be used.

NOTE The values ascribed to the material partial factors γ_m and γ_s for use in a country in the seismic design situation may be found in its National Annex of this document. The recommended value for γ_m is 2/3 of the value specified in the National Annex to EN 1996-1-1:2004, but not less than 1,5. The recommended value for γ_s is 1,0.

9.7 Rules for “simple masonry buildings”

9.7.1 General

(1) Buildings belonging to importance classes I or II and conforming to **9.2, 9.5** and **9.7.2** may be classified as “simple masonry buildings”.

(2) For such buildings an explicit safety verification in accordance with 9.6 is not mandatory.

9.7.2 Rules

(1) Depending on the product $a_g \cdot S$ at the site and the type of construction, the allowable number of storeys above ground, n , should be limited and walls in two orthogonal directions with a minimum total cross-sectional area A_{\min} , in each direction, should be provided. The minimum cross-sectional area is expressed as a minimum percentage, $p_{A,\min}$, of the total floor area per storey.

NOTE The values ascribed to n and $p_{A,\min}$ for use in a country may be found in its National Annex of this document. Recommended values are given in Table 9.3. These values, which depend also on a corrective factor k , are based on a minimum unit strength of 12 N/mm² for unreinforced masonry and 5 N/mm² for confined and reinforced masonry, respectively.

For buildings where at least 70% of the shear walls under consideration are longer than 2m, the factor k is given by $k = 1 + (l_{av} - 2)/4 \leq 2$ where l_{av} is the average length, expressed in m, of the shear walls considered. For other cases $k = 1$.

Independently of the value of k , the limitation of use of unreinforced masonry presented in 9.3(3) should be respected.

A further distinction for different unit strengths, types of construction and use of k may be found in the National Annex.

Table 9.3: Recommended allowable number of storeys above ground and minimum area of shear walls for "simple masonry buildings".

Acceleration at site $a_g \cdot S$		$\leq 0,07 k \cdot g$	$\leq 0,10 k \cdot g$	$\leq 0,15 k \cdot g$	$\leq 0,20 k \cdot g$
Type of construction	Number of storeys (n)**	Minimum sum of cross-sections areas of horizontal shear walls in each direction, as percentage of the total floor area per storey ($p_{A,\min}$)			
Unreinforced masonry	1	2,0%	2,0%	3,5%	n/a
	2	2,0%	2,5%	5,0%	n/a
	3	3,0%	5,0%	n/a	n/a
	4	5,0 %	n/a*	n/a	n/a
Confined masonry	2	2,0%	2,5%	3,0%	3,5%
	3	2,0%	3,0%	4,0%	n/a
	4	4,0%	5,0%	n/a	n/a
	5	6,0%	n/a	n/a	n/a
Reinforced masonry	2	2,0%	2,0%	2,0%	3,5%
	3	2,0%	2,0%	3,0%	5,0%
	4	3,0%	4,0%	5,0%	n/a
	5	4,0%	5,0%	n/a	n/a

* n/a means "not acceptable".

** Roof space above full storeys is not included in the number of storeys.

(2) The plan configuration of the building should fulfil all the following conditions:

a) The plan should be approximately rectangular;

b) The ratio between the length of the small side and the length of the long side in plan should be not less than a minimum value, λ_{\min} ;

NOTE The value to be ascribed to λ_{\min} for use in a country may be found in its National Annex of this document. The recommended value of λ_{\min} is 0,25.

c) The area of projections of recesses from the rectangular shape should be not greater than a percentage p_{\max} of the total floor area above the level considered.

NOTE The value to be ascribed to p_{\max} for use in a country may be found in its National Annex of this document. The recommended value is 15%.

(3) The shear walls of the building should fulfil all of the following conditions:

a) the building should be stiffened by shear walls, arranged almost symmetrically in plan in two orthogonal directions;

b) a minimum of two parallel walls should be placed in two orthogonal directions, the length of each wall being greater than 30 % of the length of the building in the direction of the wall under consideration;

c) at least for the walls in one direction, the distance between these walls should be greater than 75 % of the length of the building in the other direction;

d) at least 75 % of the vertical loads should be supported by the shear walls;

e) shear walls should be continuous from the top to the bottom of the building.

(4) In cases of low seismicity (see **3.2.1(4)**) the wall length required in **(3)b** of this subclause may be provided by the cumulative length of the shear walls (see **9.5.1(5)**) in one axis, separated by openings. In this case, at least one shear wall in each direction should have a length, l , not less than that corresponding to twice the minimum value of l/h defined in **9.5.1(5)c**.

(5) In both orthogonal horizontal directions the difference in mass and in the horizontal shear wall cross-sectional area between adjacent storeys should be limited to a maximum value of $\Delta_{m,\max}$ and $\Delta_{A,\max}$.

NOTE The values to be ascribed to $\Delta_{m,\max}$ and to $\Delta_{A,\max}$ for use in a country may be found in its National Annex to this document. The recommended values are $\Delta_{m,\max} = 20\%$, $\Delta_{A,\max} = 20\%$.

(6) For unreinforced masonry buildings, walls in one direction should be connected with walls in the orthogonal direction at a maximum spacing of 7 m.