



BS 5628 : Part 1 : 1978

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Code of practice for

Use of masonry

Part 1. Structural use of unreinforced masonry

Code de bonne pratique pour maçonnerie
Partie 1. Usage structurel de la maçonnerie non renforcée

Leitfaden für Mauerwerk im Hochbau
Teil 1. Unbewehrtes Mauerwerk

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BS 5628 : Part 1 : 1978

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Foreword

BS 5628 is a new code of practice and is published in accordance with BSI policy whereby all new and revised codes of practice are published in the general series of British Standards. It is intended ultimately to replace CP 111 : 1970, which will, however, continue to exist until it is withdrawn following the publication of BS 5628 : Part 2. This new code may be used in place of CP 111, but it is essential that clauses from both codes are not used together in the same design.

In this Part 1, the opportunity has been taken to use limit state philosophy, in accordance with recent practice in other codes. The 1948, 1964 and 1970 editions of CP 111 were in permissible stress terms, and a section on reinforced masonry walls was included. Reinforced masonry has been excluded from this Part of BS 5628, as the subject will be dealt with in Part 2. Plain concrete walls are now covered in CP 110.

The use of limit state enables the degree of risk to be varied by the choice of different partial safety factors. It has been recognized in this Part that masonry is built to

differing standards of workmanship and, therefore, the partial safety factors have reflected this. For the lowest standard of workmanship and quality of structural unit, the results of design in accordance with this Part of BS 5628 for axial loading will be similar to those obtainable from CP 111; for eccentric loading, somewhat higher strengths will be obtained from this code.

In view of the widespread demand for guidance on the design of walls to resist lateral loading, a section on this subject has been incorporated in this code. This is based on a large volume of recent research work.

It has become necessary, in structural design, to ensure explicitly that a building will not collapse catastrophically as the result of misuse or accident. The recommendations dealing with this requirement reflect the available theoretical and research studies on the behaviour of elements and structures under extreme conditions. Whilst some aspects of the work require further study, the guidance given represents a balanced combination of facts and engineering judgment.

Code of practice for

Use of masonry

Part 1. Structural use of unreinforced masonry

Section one. General

1. Scope

This Part of BS 5628 gives recommendations for the structural design of unreinforced masonry constructed of brick masonry, block masonry, masonry of square dressed natural stone, and random rubble masonry.

The thickness of a wall determined from strength considerations may not always be sufficient to satisfy requirements for other properties of the wall such as resistance to fire, thermal insulation, sound insulation or resistance to damp penetration and reference should be made to BS 5628 : Part 3 or BS 5390, as appropriate.

It has been assumed in the drafting of this code that the design of masonry is entrusted to chartered structural or civil engineers or other appropriately qualified persons, for whose guidance it has been prepared, and that the execution of the work is carried out under the direction of appropriately qualified supervisors.

2. References

The titles of the standards publications referred to in this code are listed on the inside back cover.

3. Definitions

For the purposes of this Part of BS 5628 the following definitions apply.

- 3.1 actual dimension.** Either the work size of the unit or, where applicable for solid walls, the sum of the work size of the units together with the work size of the joints between them.
- 3.2 category 1 building.** A building having four storeys (including basement storeys), or less.
- 3.3 category 2 building.** A building having five storeys (including basement storeys), or more.
- 3.4 characteristic load.** Ideally, where the load acts unfavourably, the load which has a probability of not more than 5 % of being exceeded or, where the load acts favourably, the load which has a probability of at least 95 % of being exceeded. In practice, the load obtained from the appropriate British Standard.
- 3.5 characteristic strength of masonry.** The value of the strength of masonry below which the probability of test results falling is not more than 5 %.
- 3.6 compressive strength of structural units.** For the normal category of manufacturing control, the strength of a sample tested according to the appropriate British Standard.

NOTE. When manufacturing control is within the special category, as defined in 27.2.1.2, compressive strength is taken as the acceptance limit, therein defined.

3.7 column. An isolated vertical loadbearing member whose width is not more than four times its thickness.

3.8 design load. The characteristic load multiplied by a partial safety factor for loads.

3.9 design strength. The characteristic strength divided by a partial safety factor for material strength.

3.10 effective height or length. The height or length of a wall, pier or column assumed for calculating the slenderness ratio.

3.11 effective thickness. The thickness of a wall, pier or column assumed for calculating the slenderness ratio.

3.12 laterally loaded wall panels. Walls subjected mainly to loads normal to the face of the wall.

3.13 lateral support. The support, in relation to a wall or pier, which will restrict movement in the direction of the thickness of the wall or, in relation to a column, which will restrict movement in the direction of its thickness or width. Lateral supports may be horizontal or vertical.

3.14 loadbearing walls. Walls primarily designed to carry an imposed vertical load in addition to their own weight.

3.15 masonry. An assemblage of structural units, either laid in-situ or constructed in prefabricated panels, in which the structural units are bonded and solidly put together with mortar or grout. Masonry may be reinforced or unreinforced.

3.16 orthogonal ratio. The ratio of the flexural strength of masonry when failure is parallel to the bed joints to that when failure is perpendicular to the bed joints.

3.17 pier. A member which forms an integral part of a wall, in the form of a thickened section placed at intervals along the wall.

3.18 protected member. A structural member capable of resisting a specified pressure.

NOTE. See section five.

3.19 slenderness ratio. The ratio of the effective height or length to the effective thickness.

3.20 structural units. Bricks or blocks or square dressed natural stone.

3.21 types of wall

3.21.1 single-leaf wall. A wall of bricks or blocks laid to overlap in one or more directions and set solidly in mortar.

3.21.2 double-leaf (collar-jointed) wall. Two parallel single-leaf walls, with a space between not exceeding 25 mm, filled solidly with mortar and so tied together as to result in common action under load.

3.21.3 cavity wall. Two parallel single-leaf walls, usually at least 50 mm apart, and effectively tied together with wall ties, the space between being left as a continuous cavity or filled with non-loadbearing material.

3.21.4 grouted cavity wall. Two parallel single-leaf walls, spaced at least 50 mm apart, effectively tied together with wall ties and with the intervening cavity filled with fine aggregate concrete (grout), which may be reinforced, so as to result in common action under load.

3.21.5 faced wall. A wall in which the facing and backing are so bonded as to result in common action under load.

3.21.6 veneered wall. A wall having a facing which is attached to the backing, but not so bonded as to result in common action under load.

3.22 walette. A small masonry panel constructed for test purposes.

4. Symbols

The following symbols are used in this code:

A	horizontal cross-sectional area
B	width of a bearing under a concentrated load
b	width of column
E_n	nominal earth or water load (see clause 21)
e_a	additional eccentricity due to deflection in walls
e_x	eccentricity at top of a wall
e_t	total design eccentricity in the mid-height region of a wall
e_m	the larger of e_x or e_t
F_k	characteristic load
F_m	average of the maximum loads carried by two test panels
F_t	tie force
f_k	characteristic compressive strength of masonry
f_{kx}	characteristic flexural strength (tension) of masonry
f_v	characteristic shear strength of masonry
G_k	characteristic dead load
g_A	design vertical load per unit area
g_d	design vertical dead load per unit area
h	clear height of wall or column between lateral supports
h_a	clear height of wall between concrete surfaces or other construction capable of providing adequate resistance to rotation across the full thickness of a wall
h_L	clear height of wall to point of application of a lateral load
h_{ef}	effective height or length of wall or column
k	multiplication factor for lateral strength of axially loaded walls
K	stiffness coefficient
L	length
L_a	a span in accidental damage calculation
N_s	number of storeys in a building
n	axial load per unit length of wall, available to resist an arch thrust
n_w	design vertical load per unit length of wall
p_{lim}	acceptance limit for compressive strength of units
p_o	specified compressive strength of units
p_u	mean compressive strength of units
Q_k	characteristic imposed load
q_{lat}	design lateral strength per unit area
t	overall thickness of a wall or column
t_{ef}	effective thickness of a wall or column
t_p	thickness of a pier

t_1	thickness of leaf 1 of a cavity wall
t_2	thickness of leaf 2 of a cavity wall
v_h	design shear stress
W_k	characteristic wind load
v_u	deflection of test wall in the mid-height region
Z	section modulus
α	bending moment coefficient for laterally loaded panels
β	capacity reduction factor for walls allowing for effects of slenderness and eccentricity
γ_f	partial safety factor for load
γ_m	partial safety factor for material
γ_{mv}	partial safety factor for material in shear
μ	orthogonal ratio
ψ_m	reduction factor for strength of mortar
ψ_u	unit reduction factor

5. Alternative materials and methods of design and construction

Where materials and methods are used that are not referred to by this code, their use is not discouraged, provided that the materials comply with the requirements of the appropriate British Standards and that the methods of design and construction are such as to ensure a standard of strength and durability at least equal to that recommended in this code.

Where materials or methods are used that are not referred to by this code or any other British Standard, they should be proven by test, and the test assembly should be representative, as to materials, workmanship and details, of the design and construction for which approval is desired, and should be built under conditions truly representative of the conditions in the actual building construction. Details of the testing procedures to determine the characteristic compressive strength and characteristic flexural strength of masonry are set out in A.2 and A.3 respectively.

Section two. Materials, components and workmanship

6. General

The materials, components and workmanship used in the construction of loadbearing walls should comply with the appropriate clause in BS 5628 : Part 3 or BS 5390.

7. Structural units

The following structural units should comply with the appropriate clauses in the relevant British Standard:

Calcium silicate (sandlime and flintlime) bricks	BS 187
Clay bricks and blocks	BS 3921
Stone masonry	BS 5390
Precast concrete masonry units	BS 6073 : Part 1
Reconstructed stone masonry units	BS 6457

Materials that have been previously used should not be re-used in masonry construction unless they have been thoroughly cleaned and conform to the code recommendations for similar new materials.

8. Laying of structural units

8.1 General. Structural units will normally be laid on their bed faces. In circumstances where units are used under load

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in another aspect, laid on stretcher or on end, the strength of the units should be determined for this aspect in accordance with the appropriate clauses of BS 187, BS 6073 : Part 1 and BS 3921.

8.2 Bricks with frogs. Bricks should normally be laid on a full bed of mortar* with the frog or larger frog uppermost, which should be filled with mortar as the work proceeds.

8.3 Perforated bricks. Perforated bricks and bricks defined as solid according to BS 187 and BS 3921, but having perforations passing through them, should be laid on a full width bed of mortar*. The bedding mortar for divided joint units should be laid by means of a mortar tray in accordance with the brickmaker's recommendations. The perforations should only be filled with mortar as required in BS 5628 : Part 3 or when specified by the designer.

8.4 Hollow and cellular blocks

8.4.1 Hollow clay blocks. Hollow clay blocks as defined in BS 3921 may have horizontal or vertical perforations. The blocks should be laid on a full bed of mortar*, except those with vertical perforations which are designed to be laid with a divided bed joint in accordance with the manufacturer's recommendations.

8.4.2 Hollow and cellular concrete blocks. Hollow and cellular concrete blocks complying with the requirements of BS 6073 : Part 1 are normally laid on a full bed of mortar*. Occasionally such blocks are laid with the bed joint separated into two parallel strips.

9. Rate of laying

The maximum height that should normally be built in a day is 1.5 m.

10. Forming of chases and holes

Chasing of completed walls or the formation of holes should be carried out only when approved by the designer and then in accordance with BS 5628 : Part 3.

11. Pallet slips

Timber pallet slips or other material for fixings should not be built into walls without the approval of the designer.

*When bed joints are raked out for pointing allowance should be made in design for the resulting loss of strength.

12. Damp proof courses

Damp proof courses should comply with the requirements of one of the British Standards, as appropriate, specified in clause 10 of BS 5628 : Part 3 : 1985.

Designers should pay particular attention to the characteristics of the materials chosen for damp proof courses. Materials which squeeze out are undesirable in highly stressed walls, and the effect of sliding at the damp proof course should be considered especially in relation to lateral loading. In general, advice on the resistance to compression, tension, sliding and shear should be sought from the manufacturers of the damp proof course.

Methods of test for damp proof courses are described in DD 86 : Parts 1 and 2.

13. Wall ties

Wall ties should comply with the requirements of BS 1243. Vertical twist ties provide the maximum interaction between leaves, but in situations where large differential movements are likely to occur, or other factors predominate (e.g. sound insulation), a more flexible type of tie may be more appropriate.

In situations of severe exposure, or where required by building regulations, stainless steel or suitable non-ferrous ties should be used.

14. Cements

Cement should comply with the requirements of one of the following British Standards: BS 12, BS 146, BS 4027 and BS 5224.

The use of high alumina cement is not permitted.

15. Mortars

15.1 General. The mixing and use of mortars should be in accordance with the recommendations given in BS 5628 : Part 3 or BS 5390. The proportions of the materials and mean compressive strengths required are given in table 1. When testing is required, it should be in accordance with A.1.

15.2 Ready mixed mortars. Ready-mixed lime : sand for mortar should comply with the requirements of BS 4721. The appropriate addition of cement should be gauged on site.

Wet ready-mixed retarded cement : lime : sand mixes should be used only with the written permission of the designer.

Table 1. Requirements for mortar

		Mortar designation	Type of mortar (proportion by volume)			Mean compressive strength at 28 days	
			Cement : lime : sand	Masonry cement : sand	Cement : sand with plasticizer	Preliminary (laboratory) tests	Site tests
↑ Increasing strength Increasing ability to accommodate movement, e.g. due to settlement, temperature and moisture changes ↓	Direction of change in properties is shown by the arrows	(i)	1 : 0 to ¼ : 3	—	—	N/mm ² 16.0	N/mm ² 11.0
		(ii)	1 : ½ : 4 to 4½	1 : 2½ to 3½	1 : 3 to 4	6.5	4.5
		(iii)	1 : 1 : 5 to 6	1 : 4 to 5	1 : 5 to 6	3.6	2.5
		(iv)	1 : 2 : 8 to 9	1 : 5½ to 6½	1 : 7 to 8	1.5	1.0
					Increasing resistance to frost attack during construction → Improvement in bond and consequent resistance to rain penetration ←		

16. Colouring agents

Pigments should comply with the requirements of BS 1014 and should not exceed 10 % by mass of the cement in the mortar. Care should be taken to ensure that the pigment is evenly distributed throughout the mortar and that the strength of the mortar remains adequate. Carbon black should be limited to 3 % by mass of the cement.

17. Plasticizers

Plasticizers should comply with the requirements of BS 4887 and should be used only with the written permission of the designer.

If plasticizers are used, it is important to ensure that the manufacturer's instructions about quantity and mixing time are carefully followed.

18. Frost inhibitors

The use of calcium chloride or frost inhibitors based on calcium chloride is not permitted in mortars.

Section three. Design: objectives and general recommendations

19. Basis of design

The design of loadbearing masonry members should be undertaken primarily to ensure an adequate margin of safety against the ultimate limit state being reached. Generally, this is achieved by ensuring that the design strength of a member is greater than or equal to the design load. However, for some design situations, for example freestanding walls with no allowable flexural strength or axially loaded walls subject to lateral loads, the fundamental relationship which governs the design will be independent of the material strength and the partial safety factors associated with it.

The assessment of the characteristic compressive strength may be based either on the results of laboratory tests carried out on representative wall panels, as outlined in A.2, or on the information given in clause 23.

The factor γ_m makes allowance for the variation in the quality of the materials and for the possible difference between the strength of masonry constructed under site conditions and that of specimens built in the laboratory for the purpose of establishing its physical properties.

The partial safety factors for loads (γ_f), used in this code for the ultimate limit state, are based on those adopted in CP 110.

γ_f is introduced to take account of:

- (a) possible unusual increases in load beyond those considered in deriving the characteristic load,
- (b) inaccurate assessment of effects of loading, and unforeseen stress redistribution within the structure,
- (c) the variations in dimensional accuracy achieved in construction.

The structural design should also ensure that there is an adequate margin of safety against a serviceability limit state being reached. In the case of the serviceability limit state of cracking due to axially applied service loads, an adequate margin may be assumed to exist when the design satisfies the ultimate limit state.

The risk of adverse effects on the structure, including non-loadbearing elements such as partitions, arising from

expansion or contraction due to temperature and moisture changes, creep, settlement or deformation of flexural members, should be assessed. Where necessary, suitable details should be employed to maintain an adequate margin of safety against a limit state being reached.

20. Stability

20.1 General considerations. The designer responsible for the overall stability of the structure should ensure the compatibility of the design and details of parts and components. There should be no doubt of this responsibility for overall stability when some or all of the design and details are not made by the same designer.

To ensure a robust and stable design it will be necessary to consider the layout of structure on plan, returns at the ends of walls, interaction between intersecting walls and the interaction between masonry walls and the other parts of the structure.

The design recommendations in section four assume that all the lateral forces acting on the whole structure are resisted by walls in planes parallel to these forces, or by suitable bracing.

As well as the above general considerations, attention should be given to the following recommendations:

(a) buildings should be designed to be capable of resisting a uniformly distributed horizontal load equal to 1.5 % of the total characteristic dead load above any level (see clause 22(b) and (c));

(b) connections of the type indicated in appendix C should be provided as appropriate at floors and roofs.

20.2 Earth retaining and foundation structures. The overall dimensions and stability of earth retaining and foundation structures (e.g. the area of pad footings, etc.) should be determined by appropriate geotechnical procedures, which are not considered in this code. However, in order to establish section sizes and strengths which will give adequate safety and serviceability without undue calculation, it is appropriate in normal design situations to apply values of γ_f comparable to those applied to other forms of loading.

The factor γ_f should be applied to all earth and water loads unless they derive directly from loads which have already been factored, in which case the loads should be derived to achieve equilibrium with other design loads. When applying the factor, no distinction is made between adverse and beneficial loads.

20.3 Accidental forces. In addition to designing the structure to support loads arising from normal use, there should be a reasonable probability that it will not collapse catastrophically under the effect of misuse or accident. No structure can be expected to be resistant to the excessive loads or forces that could arise due to an extreme cause, but it should not be damaged to an extent disproportionate to the original cause.

Furthermore, owing to the nature of a particular occupancy or use of a structure (e.g. flour mill, chemical plant, etc.), it may be necessary in the design concept or a design appraisal to consider the effect of a particular hazard and to ensure that, in the event of an accident, there is an acceptable probability of the structure remaining after the event, even if in a damaged condition.

Where there is the possibility of vehicles running into and damaging or removing vital loadbearing elements of the structure in the ground floor, the provision of bollards, walls, retaining earth banks, etc. should be considered.

20.4 During construction. The designer should consider whether special precautions or temporary propping are necessary to ensure the overall stability of the structure or of individual walls during construction.

21. Loads

Ideally, the characteristic load on a structure should be determined statistically.

Since it is not yet possible to determine loads in this way, the following should be used as characteristic loads.

(a) *Characteristic dead load.* The characteristic dead load G_k is the weight of the structure complete with finishes, fixtures and partitions and should be taken as equal to the dead load as defined in and calculated in accordance with BS 6399 : Part 1.

(b) *Characteristic imposed load.* The characteristic imposed load Q_k should be taken as the imposed load as defined in and calculated in accordance with BS 6399 : Part 1.

(c) *Characteristic wind load.* The characteristic wind load W_k should be taken as the wind load calculated in accordance with CP 3 : Chapter V : Part 2.

For the purposes of this standard, nominal earth loads, E_n , should be obtained in accordance with current practice, e.g. as described in Civil Engineering Code of Practice No. 2*.

22. Design loads: partial safety factor, γ_f

When using the design relationship for the ultimate limit state given in sections four and five, the design load should

be taken as the sum of the products of the component characteristic loads multiplied by the appropriate partial safety factor, as shown below. Where alternative values are shown, that producing the more severe conditions should be selected.

(a) *Dead and imposed load*

design dead load = $0.9G_k$ or $1.4G_k$
 design imposed load = $1.6Q_k$
 design earth and water load = $1.4 E_n$

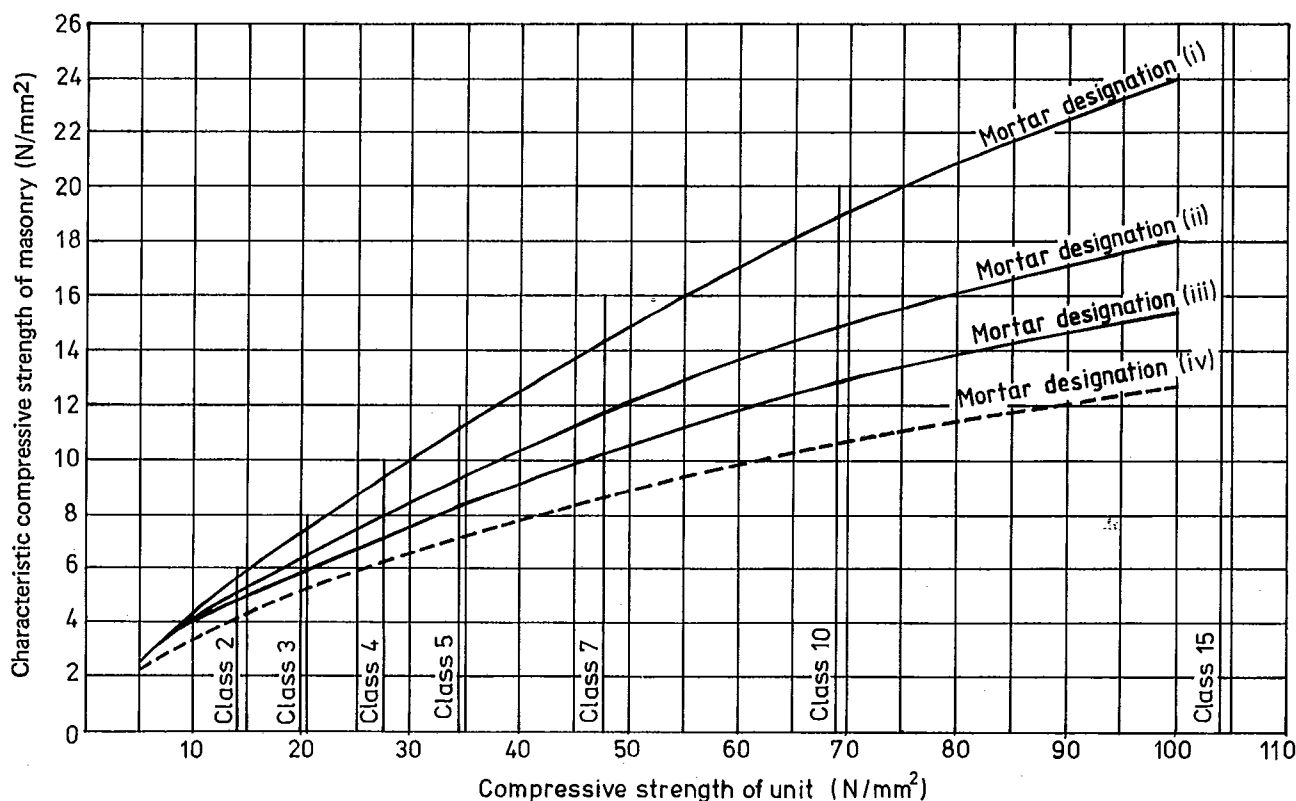
(b) *Dead and wind load*

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 = $1.4 E_n$

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.

(c) *Dead, imposed and wind load*

design dead load = $1.2G_k$
 design imposed load = $1.2Q_k$
 design wind load = $1.2W_k$ or $0.015G_k$ whichever is the larger.
 design earth and water load = $1.2 E_n$



Interpolation for classes of loadbearing bricks not on the graph may be used for average crushing strengths intermediate between those given on the graph, as described in clause 10 of BS 3921 : 1974 and clause 7 of BS 187 : 1978.

Figure 1(a). Characteristic compressive strength of brick masonry, f_k , (see table 2(a))

*'Earth retaining structures' Civil Engineering Code of Practice No. 2, published in 1951 by the Civil Engineering Codes of Practice Committee of the Institution of Structural Engineers.

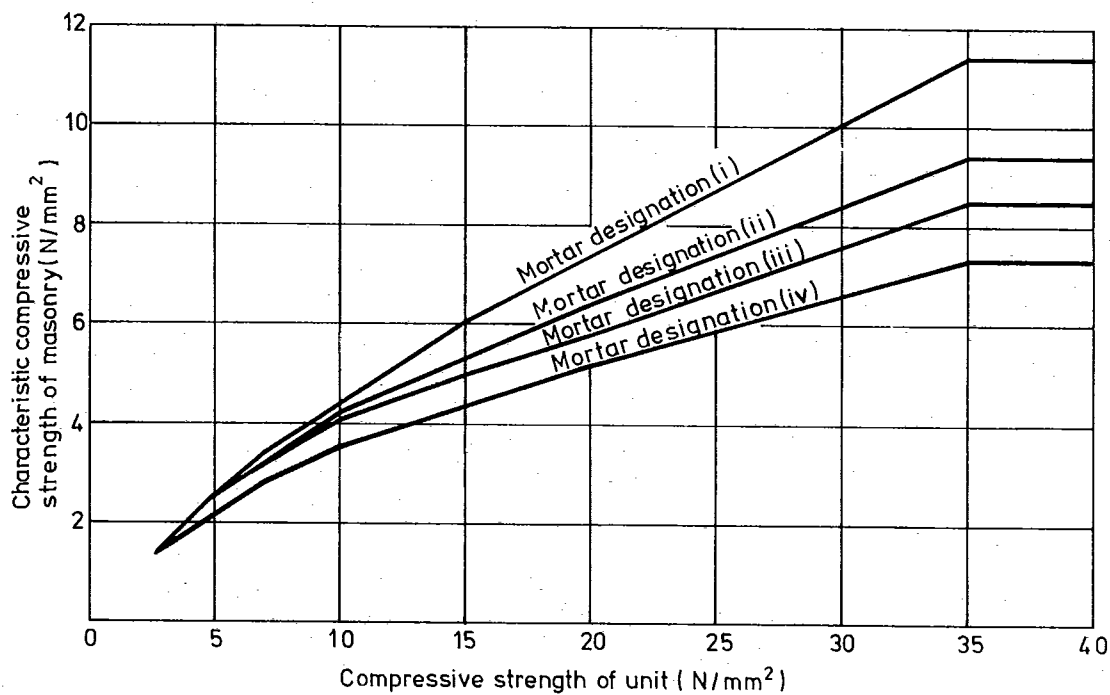


Figure 1(b). Characteristic compressive strength, f_k , of block masonry constructed with blocks having a ratio of height to least horizontal dimension of 0.6 (see table 2(b))

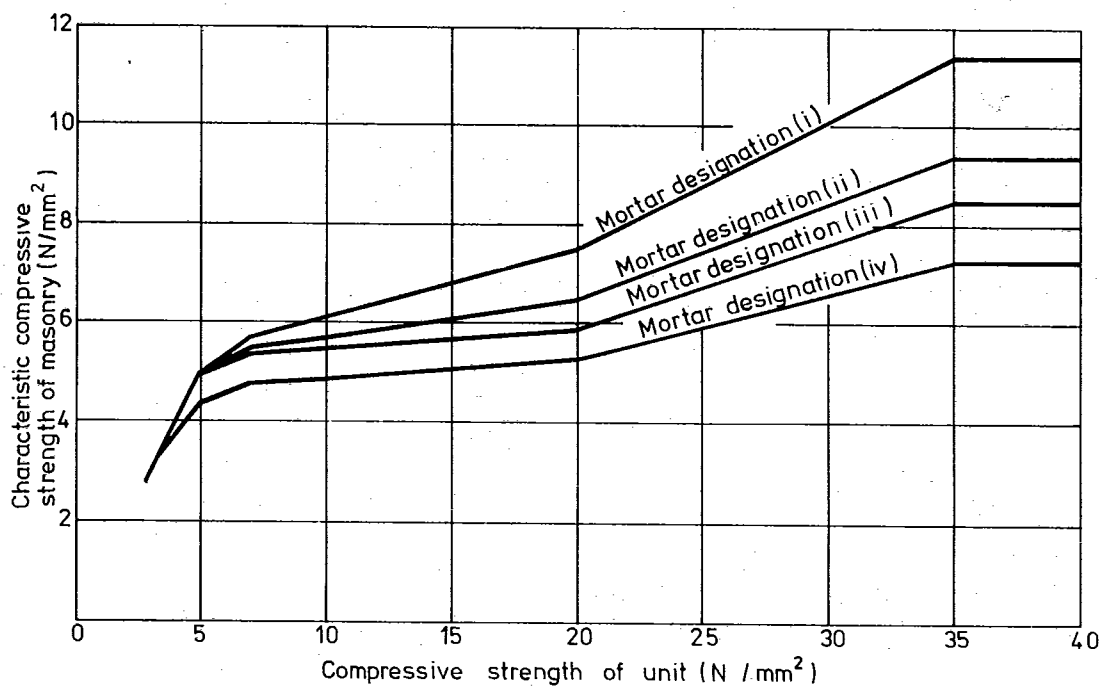


Figure 1(c). Characteristic compressive strength, f_k , of block masonry constructed with hollow blocks having a ratio of height to least horizontal dimension of between 2.0 and 4.0 (see table 2(c))

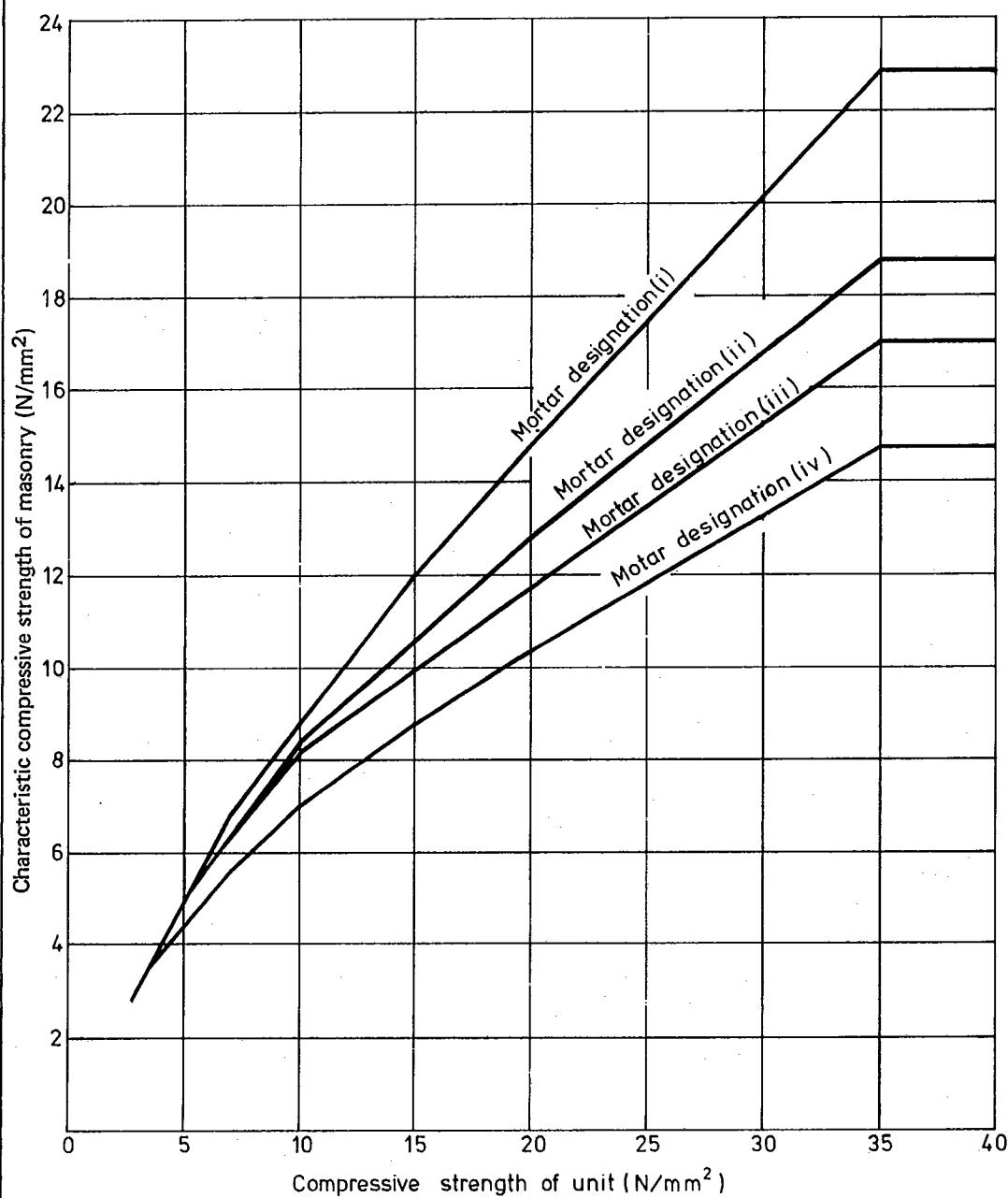


Figure 1(d). Characteristic compressive strength, f_k , of block masonry constructed from solid concrete blocks having a ratio of height to least horizontal dimension of between 2.0 and 4.0 (see table 2(d))

(d) *Accidental damage (see clause 37)*

design dead load = $0.95G_k$ or $1.05G_k$
 design imposed load = $0.35Q_k$ except that, in the case of buildings used predominantly for storage, or where the imposed load is of a permanent nature, $1.05Q_k$ should be used.
 design wind load = $0.35W_k$

where

G_k is the characteristic dead load,

Q_k is the characteristic imposed load,

W_k is the characteristic wind load,

and the numerical values are the appropriate γ_f factors.

In design, each of the load combinations (a) to (d) should be considered and that giving the most severe conditions should be adopted.

In certain circumstances, other values of γ_f may be appropriate, e.g. in farm buildings. Reference should be made to the relevant British Standards, e.g. BS 5502 : Part 1 : Section 1.2.

23. Characteristic compressive strength of masonry, f_k

23.1 Normal masonry. The characteristic compressive strength, f_k , of any masonry may be determined by tests on wall specimens, following the procedures laid down in A.2.

For normally bonded masonry, defined in terms of the shape and compressive strength of the structural units and the designation of the mortar (see table 1), the values given in table 2 inclusive may be taken to be the characteristic compressive strength, f_k , of walls constructed under laboratory conditions tested at an age of 28 days under axial compression in such a manner that the effects of slenderness may be neglected. Linear interpolation within the tables is permitted; facilitated by the graphs (figures 1(a) to 1(d)).

Table 2(a) applies to masonry built with standard format bricks complying with the requirements of BS 187, BS 1180 or BS 3921.

Table 2(b) applies to masonry built with structural units with a ratio of height to least horizontal dimension of 0.6.

Table 2(c) applies to structural units, other than solid concrete blocks, with a ratio of height to least horizontal dimension of between 2.0 and 4.0, and makes due allowance for the enhancement in strength resulting from the unit shape.

Table 2(d) applies to solid concrete blocks, i.e. those without cavities, with a ratio of height to least horizontal dimension of between 2.0 and 4.0, and makes due allowance for the enhancement in strength resulting from the unit shape.

23.1.1 Walls or columns of small plan area. Where the horizontal cross-sectional area of a loaded wall or column is less than 0.2 m^2 , the characteristic compressive strength should be multiplied by the factor:

$$(0.70 + 1.5A)$$

where

A is the horizontal loaded cross-sectional area of the wall or column (m^2).

Table 2. Characteristic compressive strength of masonry, f_k , in N/mm^2

(a) Constructed with standard format bricks

Mortar designation	Compressive strength of unit (N/mm ²)								
	5	10	15	20	27.5	35	50	70	100
(i)	2.5	4.4	6.0	7.4	9.2	11.4	15.0	19.2	24.0
(ii)	2.5	4.2	5.3	6.4	7.9	9.4	12.2	15.1	18.2
(iii)	2.5	4.1	5.0	5.8	7.1	8.5	10.6	13.1	15.5
(iv)	2.2	3.5	4.4	5.2	6.2	7.3	9.0	10.8	12.7

(b) Constructed with blocks having a ratio of height to least horizontal dimension of 0.6

Mortar designation	Compressive strength of unit (N/mm ²)							
	2.8	3.5	5.0	7.0	10	15	20	35 or greater
(i)	1.4	1.7	2.5	3.4	4.4	6.0	7.4	11.4
(ii)	1.4	1.7	2.5	3.2	4.2	5.3	6.4	9.4
(iii)	1.4	1.7	2.5	3.2	4.1	5.0	5.8	8.5
(iv)	1.4	1.7	2.2	2.8	3.5	4.4	5.2	7.3

(c) Constructed with hollow blocks having a ratio of height to least horizontal dimension of between 2.0 and 4.0

Mortar designation	Compressive strength of unit (N/mm ²)							
	2.8	3.5	5.0	7.0	10	15	20	35 or greater
(i)	2.8	3.5	5.0	5.7	6.1	6.8	7.5	11.4
(ii)	2.8	3.5	5.0	5.5	5.7	6.1	6.5	9.4
(iii)	2.8	3.5	5.0	5.4	5.5	5.7	5.9	8.5
(iv)	2.8	3.5	4.4	4.8	4.9	5.1	5.3	7.3

(d) Constructed from solid concrete blocks having a ratio of height to least horizontal dimension of between 2.0 and 4.0

Mortar designation	Compressive strength of unit (N/mm ²)							
	2.8	3.5	5.0	7.0	10	15	20	35 or greater
(i)	2.8	3.5	5.0	6.8	8.8	12.0	14.8	22.8
(ii)	2.8	3.5	5.0	6.4	8.4	10.6	12.8	18.8
(iii)	2.8	3.5	5.0	6.4	8.2	10.0	11.6	17.0
(iv)	2.8	3.5	4.4	5.6	7.0	8.8	10.4	14.6

23.1.2 Narrow brick walls. When brick walls are constructed so that the thickness of the wall or loaded inner leaf of a cavity wall is equal to the width of a standard format brick, the values of f_k obtained from table 2(a) may be multiplied by 1.15.

23.1.3 Walls constructed in modular bricks. For 90 mm wide x 90 mm high modular bricks complying with the requirements of BS 6073 : Part 1 or as detailed in DD 34 or DD 59, the values of f_k in table 2(a) may be multiplied by the following factors:

- (a) masonry thickness equal to width of brick: 1.25;
- (b) other thicknesses: 1.10.

23.1.4 Walls constructed of wide bricks. When walls are constructed with bricks having a ratio of height to least horizontal dimension of less than 0.6, the value of f_k should have been obtained from wall tests carried out in accordance with A.2.

23.1.5 Hollow block walls. When walls are built of hollow blocks having a ratio of height to least horizontal dimension of between 0.6 and 2.0, the value of f_k should be obtained by interpolation between the values given in tables 2(b) and 2(c).

23.1.6 Solid concrete block walls. When walls are built of solid concrete blocks, i.e. those without any cavities, having a ratio of height to least horizontal dimension of between 0.6 and 2.0, the value of f_k should be obtained by interpolation between the values given in tables 2(b) and 2(d).

23.1.7 Walls of hollow concrete blocks filled with in-situ concrete. When walls are built with hollow concrete blocks and the vertical cavities are completely filled with in-situ concrete, the characteristic compressive strength of the masonry should be obtained as if the blocks were solid (see 23.1.6), provided that:

- (a) the compressive strength of the blocks is assessed on their net area;
- (b) the 28-day cube strength of the concrete infilling is not less than the compressive strength of the blocks derived from (a) above.

23.1.8 Natural stone masonry. Natural stone masonry should be designed on the basis of solid concrete blocks of an equivalent compressive strength. Where masonry is constructed from large, carefully shaped pieces with relatively thin joints, its loadbearing capacity is more closely related to the intrinsic strength of the stone than is the case where small structural units are used. Design stresses in excess of those obtained from this code may be allowed in such massive stone masonry, provided that the designer is satisfied that the properties of the stone warrant an increase.

23.1.9 Random rubble masonry. The characteristic strength of random rubble masonry may be taken as 75 % of the corresponding strength of natural stone masonry built with similar materials. In the case of rubble masonry built with lime mortar, the characteristic strength may be taken as one-half of that for masonry in mortar designation (iv).

23.2 Structural units laid other than on the normal bed face. Where structural units are laid other than on the normal bed face, the compressive strength of the unit as determined for that direction (see clause 8) should be adopted when using table 2.

23.3 Perforated bricks and hollow blocks. The compressive strength of perforated bricks and hollow blocks is determined by dividing the ultimate load by the gross plan area of the unit, as if it were solid. This compressive strength should therefore be used in obtaining the value of f_k from tables 2(a), 2(b) and 2(c). Hollow concrete blocks are sometimes laid with mortar on the two outer strips of block (shell bedding), in which case the value of f_k should be obtained as usual from tables 2(b) and 2(c), but the design strength of the wall should be reduced by the ratio of the bedded area to the net area of block.

24. Characteristic flexural strength of masonry, f_{kx}

24.1 General. The characteristic flexural strength, f_{kx} , should be used only in the design of masonry in bending. In general, no direct tension should be allowed in masonry. However, at the designer's discretion half the values in table 3 may be allowed in direct tension when suction forces arising from wind loads on roof structures are transmitted to masonry walls, or when the probable effects of misuse or accidental damage (see section five) are being considered. In no circumstances may the combined flexural and direct tensile stresses exceed the values given in table 3.

Flexural tension should be relied on at a damp proof course only if the damp proof course consists of a material which has been proved by tests (see DD 86 : Part 1) to permit the joint to transmit tension or if it is of bricks complying with the requirements of BS 743.

24.2 Flexural strength. The characteristic flexural strength values given in table 3 may be used for the categories of brick, block and mortar shown or, alternatively, tests may be carried out in accordance with A.3.

Linear interpolation between entries in table 3 is permitted for:

- (a) concrete block walls of thickness between 100 mm and 250 mm;
- (b) concrete blocks of compressive strength between 2.8 N/mm² and 7.0 N/mm² in a wall of given thickness.

25. Characteristic shear strength of masonry, f_v

The characteristic shear strength, f_v , of masonry may be taken as $0.35 + 0.6g_A$ N/mm² with a maximum of 1.75 N/mm² for walls built in mortar designations (i), (ii) or (iii) or $0.15 + 0.6g_A$ N/mm² with a maximum of 1.4 N/mm² for walls built in mortar designation (iv), where

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 22.

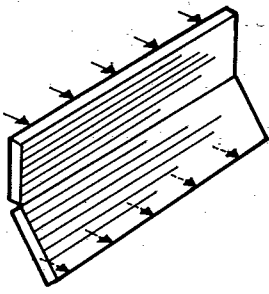
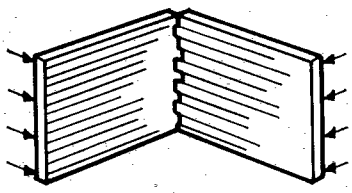
26. Coefficient of friction

The coefficient of friction between clean concrete and masonry faces may be taken as 0.6.

27. Partial safety factors for material strength, γ_m

27.1 General. The value of γ_m to be used in the application of the design procedures given in sections four and five should be related to the quality control exercised.

Table 3. Characteristic flexural strength of masonry, f_{kx} , N/mm²

	Plane of failure parallel to bed joints			Plane of failure perpendicular to bed joints		
						
Mortar designation	(i)	(ii) and (iii)	(iv)	(i)	(ii) and (iii)	(iv)
Clay bricks having a water absorption less than 7 % between 7 % and 12 % over 12 %	0.7 0.5 0.4	0.5 0.4 0.3	0.4 0.35 0.25	2.0 1.5 1.1	1.5 1.1 0.9	1.2 1.0 0.8
Calcium silicate bricks	0.3		0.2	0.9		0.6
Concrete bricks	0.3		0.2	0.9		0.6
Concrete blocks (solid or hollow) of compressive strength in N/mm ² :						
2.8 } 3.5 } used in walls of thickness* 7.0 } up to 100 mm	0.25		0.2	0.40 0.45 0.60	0.4 0.4 0.5	
2.8 } 3.5 } used in walls of thickness* 7.0 } 250 mm	0.15		0.1	0.25 0.25 0.35	0.2 0.2 0.3	
10.5 } 14.0 } used in walls of any and over } thickness*	0.25		0.2	0.75 0.90†	0.6 0.7†	

*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.

†When used with flexural strength in parallel direction, assume the orthogonal ratio $\mu = 0.3$.

27.2 Quality control. The value of γ_m adopted should be commensurate with the degree of control exercised both during the manufacture of the structural units and in the site supervision, and also with the quality of the mortar used during construction. Two levels of control are recognized in each case, as detailed in 27.2.1 and 27.2.2.

27.2.1 Manufacturing control

27.2.1.1 Normal category. Normal category should be assumed when the supplier is able to meet the requirements for compressive strength in the appropriate British Standard, but does not meet the requirements for the special category detailed in 27.2.1.2.

27.2.1.2 Special category. Special category may be assumed where the manufacturer:

- (a) agrees to supply consignments of structural units to a specified strength limit, referred to as the 'acceptance limit', for compressive strength, such that the average

compressive strength of a sample of structural units, taken from any consignment and tested in accordance with the appropriate British Standard specification, has a probability of not more than 2.5 % of being below the acceptance limit, and

(b) operates a quality control scheme, the results of which can be made available to demonstrate to the satisfaction of the purchaser that the acceptance limit is consistently being met in practice, with the probability of failing to meet the limit being never greater than that stated in 27.2.1.2(a).

27.2.2 Construction control

27.2.2.1 Normal category. Normal category should be assumed whenever the work is carried out following the recommendations for workmanship in section four of BS 5628 : Part 3 : 1985, or BS 5390, including appropriate supervision and inspection.

27.2.2.2 Special category. Special category of construction control may be assumed where the requirements of the normal category control are complied with 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 table 4;
- (b) preliminary compressive strength tests carried out on the mortar to be used, in accordance with A.1, indicate compliance with the strength requirements given in table 1 and regular testing of the mortar used on site, in accordance with A.1, shows that compliance with the strength requirements given in table 1 is being maintained.

27.3 Values of γ_m for normal and accidental loads.

The value of γ_m to be used in clauses 32, 34 and 36 should be obtained from table 4. When considering the probable effects of misuse or accident (section five), the values given in table 4 may be halved, except where otherwise required in 37.1.1.

Table 4. Partial safety factors for material strength, γ_m

		Category of construction control	
		Special	Normal
Category of manufacturing control of structural units	Special	2.5	3.1
	Normal	2.8	3.5

Where wall tests in accordance with A.2 and A.3 have been carried out, the γ_m factors to be applied to the characteristic strengths determined in accordance with A.2 and A.3 may be taken as 0.9 times the values given in table 4, provided the masonry complies in all respects with the recommendations given in this code.

Where the specimen tested incorporates constructional details or units not covered by this code, a similar procedure may be applied but the characteristic strength so obtained should be used only to design walls which incorporate the same constructional details or units.

27.4 Values of γ_{mv} for shear loads. The partial safety factor for masonry strength in shear, γ_{mv} , should be taken as 2.5 when mortar not weaker than designation (iv) is used. When considering the probable effects of misuse or accident (section five) the value of γ_{mv} may be reduced to 1.25.

27.5 Values of γ_m for use with ties. The partial safety factor to be applied to the strength of wall ties (36.2) should be 3.0. When considering the probable effects of misuse or accidental damage, this value may be halved.

Section four. Design: detailed considerations

28. Consideration of slenderness of walls and columns

28.1 Slenderness ratio. The slenderness ratio should not exceed 27, except in the case of walls less than 90 mm thick, in buildings of more than two storeys, where it should not exceed 20.

28.2 Lateral support. A lateral support may be provided along either a horizontal or a vertical line, depending on whether the slenderness ratio is based on a vertical or horizontal dimension.

28.2.1 Horizontal or vertical lateral supports. Horizontal or vertical lateral supports should be capable of transmitting to the elements of construction that provide lateral stability to the structure as a whole, the sum of the following design lateral forces:

- (a) the simple static reactions to the total applied design horizontal forces at the line of lateral support, and
- (b) 2.5 % of the total design vertical load that the wall or column is designed to carry at the line of lateral support; the elements of construction that provide lateral stability to the structure as a whole need not be designed to support this force.

However, the designer should satisfy himself that loads applied to lateral supports will be transmitted to the elements of construction providing stability, e.g. by the floors or roofs acting as horizontal girders.

28.2.2 Horizontal lateral supports

28.2.2.1 Simple resistance to lateral movement may be assumed in the case of houses of not more than three storeys where timber floor members, spaced apart at a distance of not more than 1.2 m, are connected by suitable joist hangers effectively fixed to the joist, as indicated in appendix C. In all other cases, including buildings of more than three storeys, a connection capable of providing simple resistance to lateral movement may be assumed where connections are of the form illustrated in appendix C.

28.2.2.2 Enhanced resistance to lateral movement may be assumed where:

- (a) floors or roofs of any form of construction span on to the wall or column from both sides at the same level;
- (b) an in-situ concrete floor or roof, or a precast concrete floor or roof giving equivalent restraint, irrespective of the direction of span, has a bearing of at least one-half the thickness of the wall or inner leaf of a cavity wall or column on to which it spans but in no case less than 90 mm;
- (c) in the case of houses of not more than three storeys, a timber floor spans on to a wall from one side and has a bearing of not less than 90 mm.

Preferably, columns should be provided with lateral support in both horizontal directions.

28.2.3 Vertical lateral supports

28.2.3.1 Simple resistance to lateral movement may be assumed where an intersecting or return wall not less than the thickness of the supported wall or loadbearing leaf of a cavity wall extends from the intersection at least ten times the thickness of the supported wall or loadbearing leaf and is connected to it by metal anchors calculated in accordance with 28.2.1 and evenly distributed throughout the height at not more than 300 mm centres.

28.2.3.2 Enhanced resistance to lateral movement may be assumed where an intersecting or return wall as described in 28.2.3.1 is properly bonded to the supported wall or loadbearing leaf of a cavity wall.

28.2.3.3 In all other cases of vertical lateral support, simple or enhanced resistance to lateral movement may be established by calculation.

28.3 Effective height or length. The effective height or length of a loadbearing wall or column should be assessed taking account of the relative stiffness of the elements of structure connected to the wall or column and the efficiency of the connections. In the absence of detailed calculations, the designer may take the effective height or length from 28.3.1 or 28.3.2.

28.3.1 Effective height

28.3.1.1 Walls. The effective height of a wall may be taken as:

- (a) 0.75 times the clear distance between lateral supports which provide enhanced resistance to lateral movement, or
- (b) the clear distance between lateral supports which provide simple resistance to lateral movement.

28.3.1.2 Columns. The effective height of a column should be taken as the distance between lateral supports or twice the height of the column in respect of a direction in which lateral support is not provided.

28.3.1.3 Columns formed by adjacent openings in walls. Where openings occur in a wall such that the masonry between any two openings is, by definition, a column, the effective height of the column should be taken as follows.

- (a) Where an enhanced resistance to lateral movement of the wall containing the column is provided, the effective height should be taken as 0.75 times the distance between the supports plus 0.25 times the height of the taller of the two openings.
- (b) Where a simple resistance to lateral movement of the wall containing the column is provided, the effective height should be taken as the distance between the supports.

28.3.1.4 Piers. Where the thickness of a pier is not greater than 1.5 times the thickness of the wall of which it forms a part, it may be treated as a wall for effective height consideration; otherwise the pier should be treated as a column in the plane at right angles to the wall.

NOTE. The thickness of a pier, t_p , is the overall thickness including the thickness of the wall or, when bonded into one leaf of a cavity

wall, the thickness obtained by treating this leaf as an independent wall.

28.3.2 Effective length. The effective length of a wall may be taken as:

- (a) 0.75 times the clear distance between vertical lateral supports or twice the distance between a support and a free edge, where lateral supports provide enhanced resistance to lateral movement;
- (b) the clear distance between lateral supports or 2.5 times the distance between a support and a free edge where lateral supports provide simple resistance to lateral movement.

28.4 Effective thickness. The effective thickness of a wall, column or pier is given in 28.4.1 and 28.4.2 and is illustrated in figure 2.

28.4.1 Walls and columns not stiffened by piers or intersecting walls. For single leaf walls and columns the effective thickness is the actual thickness.

For cavity walls and columns the effective thickness should be taken as two-thirds the sum of the actual thicknesses of the two leaves or the actual thickness of the thicker leaf, whichever is the greater.

28.4.2 Walls stiffened by piers or intersecting walls. Where a wall, which may be one leaf of a cavity wall, is stiffened by piers, the effective thickness, t_{ef} , of the wall, or leaf of a cavity wall, is:

$$t_{ef} = t \times K$$

where

- t is the actual thickness of the wall or leaf
- t_{ef} is the effective thickness of the wall or leaf
- K is the appropriate stiffness coefficient taken from table 5.

For a wall stiffened by intersecting walls, the appropriate stiffness coefficient may be determined from table 5 on the assumption that the intersecting walls are equivalent to piers of width equal to the thickness of the intersecting wall and of thickness equal to 3 times the thickness of the stiffened wall.

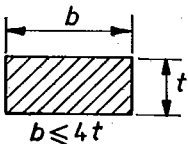
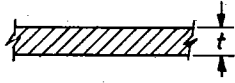
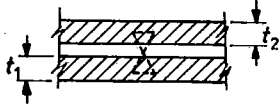
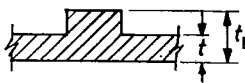
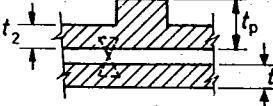
Column	Single leaf wall	Cavity wall	Walls stiffened by piers	
			Single leaf	Cavity
Plan shapes				
				
Effective thickness				
t or b , depending on direction of bending	t	the greatest of (a) $2/3 (t_1 + t_2)$ or (b) t_1 or (c) t_2	$t \times K$ where K is the stiffness coefficient from table 5	the greatest of (a) $2/3 (t_1 + Kt_2)$ or (b) t_1 or (c) Kt_2

Figure 2. Effective thickness of columns and walls