

Code of practice for the use of masonry —

Part 2: Structural use of reinforced and prestressed masonry

ICS 91.080.30

Committees responsible for this British Standard

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- Brick Development Association
- British Masonry Society
- British Precast Concrete Federation
- CERAM Research Ltd.
- Concrete Block Association
- Construction Federation
- Institution of Civil Engineers
- Institution of Structural Engineers
- Mortar Industry Association Ltd.
- National House Building Council
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Foreword

This part of BS 5628 has been prepared under the direction of Technical Subcommittee B/525/6. It supersedes BS 5628-2:2000, which will be withdrawn on 31 March 2006.

The start and finish of text introduced or altered by Corrigendum No. 1 is indicated in the text by tags **[C1]** **<C1]**.

This edition of BS 5628-2 introduces changes to reflect the recent publication of related European product standards. It does not reflect a full review or revision of the standard, although the opportunity has been taken to make minor technical changes in order to keep the standard up-to-date.

It has been assumed in the drafting of this code that the design of reinforced and prestressed masonry is entrusted to appropriately qualified and experienced persons, and the execution of the work is carried out under the direction of appropriately qualified supervisors.

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Annexes A and D are normative. Annexes B, C and E are informative.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iii, a blank page, pages 1 to 60, an inside back cover and a back cover.

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1 Scope

This part of BS 5628 gives recommendations for the structural design of reinforced and prestressed masonry constructed of brick or block masonry or masonry of manufactured stone or square dressed natural stone.

NOTE The dimensions of a member determined from strength considerations may not always be sufficient to satisfy requirements for other properties of the member such as resistance to fire and thermal insulation, and reference should be made to other appropriate standards.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

- BS 410-1, *Test sieves — Technical requirements and testing — Test sieves of metal wire cloth.*
- BS 410-2, *Test sieves — Technical requirements and testing — Test sieves of perforated metal plate.*
- BS 3892-1, *Pulverized-fuel ash — Specification for pulverized-fuel ash for use with Portland cement.*
- BS 4027, *Specification for sulfate-resisting Portland cement.*
- BS 4449:1997, *Specification for carbon steel bars for the reinforcement of concrete.*
- BS 4482, *Specification for cold reduced steel wire for the reinforcement of concrete.*
- BS 4483, *Specification for steel fabric for the reinforcement of concrete.*
- BS 4486, *Specification for hot rolled and hot rolled and processed high tensile alloy steel bars for the prestressing of concrete.*
- BS 4729, *Specification for dimensions of bricks of special shapes and sizes.*
- BS 4887-1, *Mortar admixtures — Part 1: Specification for air-entraining (plasticizing) admixtures.*
- BS 5502-22, *Buildings and structures for agriculture. Code of practice for design, construction and loading.*
- BS 5628-1:2005, *Code of practice for use of masonry — Part 1: Structural use of unreinforced masonry.*
- BS 5628-3:2005, *Code of practice for use of masonry — Part 3: Materials and components, design and workmanship.*
- BS 5896, *Specification for high tensile steel wire and strand for the prestressing of concrete.*
- BS 6399-1, *Loading for buildings — Part 1: Code of practice for dead and imposed loads.*
- BS 6399-2, *Loading for buildings — Part 2: Code of practice for wind loads.*
- BS 6399-3, *Loading for buildings — Part 3: Code of practice for imposed roof loads.*
- BS 6699, *Specification for ground granulated blastfurnace slag for use with Portland cement.*
- BS 6744:2001, *Stainless steel bars for the reinforcement of and use in concrete — Requirements and test methods.*
- BS 7979, *Specification for limestone fines for use with Portland cement.*
- BS 8002, *Code of practice for earth retaining structures.*
- BS 8110-1:1997, *Structural use of concrete — Part 1: Code of practice for design and construction.*
- BS 8110-2:1985, *Structural use of concrete — Part 2: Code of practice for special circumstances.*
- BS 8215, *Code of practice for design and installation of damp-proof courses in masonry construction.*
- BS 8500-1, *Concrete — Complementary British Standard to BS EN 206-1 — Method of specifying and guidance for the specifier.*
- BS 8500-2, *Concrete — Complementary British Standard to BS EN 206-1 — Specification for constituent materials and concrete.*
- BS 8666, *Specification for scheduling, dimensioning, bending and cutting of steel reinforcement for concrete.*
- BS EN 197-1:2000, *Cement — Composition, specifications and conformity criteria for common cements.*

- BS EN 450-1, *Fly ash for concrete — Definition, specifications and conformity criteria.*
- BS EN 771-1, *Specification for masonry unit — Clay masonry units.*
- BS EN 771-2, *Specification for masonry units — Calcium silicate masonry units.*
- BS EN 771-3, *Specification for masonry units — Aggregate concrete masonry units (dense and light-weight aggregates).*
- BS EN 771-4, *Specification for masonry units — Autoclaved aerated concrete masonry units.*
- BS EN 771-5, *Specification for masonry units — Manufactured stone masonry units.*
- BS EN 771-6, *Specification for masonry units — Natural stone masonry units.*
- BS EN 772-1, *Methods of test for masonry units — Determination of compressive strength.*
- BS EN 772-2, *Methods of test for masonry units — Determination of percentage area of voids in aggregate concrete masonry units (by paper indentation).*
- BS EN 772-11, *Methods of test for masonry units — Determination of water absorption of aggregate concrete, manufactured stone and natural stone masonry units due to capillary action and the initial rate of water absorption of clay masonry units.*
- BS EN 772-16, *Methods of test for masonry units — Determination of dimensions.*
- BS EN 845-1, *Specification for ancillary components for masonry — Ties, tension straps, hangers and brackets.*
- BS EN 845-3, *Specification for ancillary components for masonry — Bed joint reinforcement of steel meshwork.*
- BS EN 934-3, *Admixtures for concrete, mortar and grout — Admixtures for masonry mortar — Definitions, requirements, conformity, marking and labelling.*
- BS EN 998-2, *Specification for mortar for masonry — Masonry mortar.*
- BS EN 1015-2, *Methods of test for mortar for masonry — Bulk sampling of mortars and preparation of test mortars.*
- BS EN 1015-11, *Methods of test for mortar for masonry — Determination of flexural and compressive strength of hardened mortar.*
- BS EN 1052-1, *Methods of test for masonry — Determination of compressive strength.*
- BS EN 1052-4, *Methods of test for masonry — Determination of shear strength including damp proof course.*
- BS EN 10025-1, *Hot rolled products of structural steels — General technical delivery conditions.*
- BS EN 10088-1, *Stainless steels — List of stainless steels.*
- BS EN 12350-2, *Testing fresh concrete — Slump test.*
- BS EN 12390-3, *Testing hardened concrete — Compressive strength of test specimens.*
- BS EN 12878, *Pigments for the colouring of building materials based on cement and/or lime — Specifications and methods of test.*
- BS EN 13877-3, *Concrete pavements — Specification for dowels to be used in concrete pavements.*
- BS EN ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles — Specifications and test methods.*
- DD 86-1, *Damp-proof courses — Methods of test for flexural bond strength and short term shear strength.*
- DD 86-2, *Damp-proof courses — Methods of test for creep deformation.*

3 Terms and definitions

For the purpose of this part of BS 5628 the definitions given in BS 5628-1 apply, together with the following.

3.1

masonry

assemblage of masonry units, either laid in situ or constructed in prefabricated panels, in which the masonry units are bonded and solidly put together with concrete and/or mortar so as to act compositely

3.2 Types of masonry

3.2.1

reinforced masonry

masonry in which steel reinforcement is incorporated to enhance resistance to tensile, compressive or shear forces

3.2.2

prestressed masonry

masonry in which pre-tensioned or post-tensioned steel is incorporated to enhance resistance to tensile or shear forces

3.3 Types of reinforced masonry

3.3.1

grouted-cavity

two parallel single-leaf walls spaced at least 50 mm apart, effectively tied together with wall ties. The intervening cavity contains steel reinforcement and is filled with infill concrete so as to result in common action with the masonry under load

3.3.2

pocket-type

masonry reinforced primarily to resist lateral loading where the main reinforcement is concentrated in vertical pockets formed in the tension face of the masonry and is surrounded by in situ concrete [see Figure 5a)]

3.3.3

Quetta bond

masonry at least one and a half masonry units thick in which vertical pockets containing reinforcement and mortar or concrete infill occur at intervals along its length

3.3.4

reinforced hollow blockwork

hollow blockwork that may be reinforced horizontally or vertically and subsequently wholly or partly filled with concrete [see Figure 5b)]

3.4 Types of geometric cross-section wall

3.4.1

diaphragm wall

two single-leaf walls structurally connected together by a series of cross webs of masonry

3.4.2

fin wall

wall with extended piers (fins) at frequent intervals constructed of masonry

3.5

prestressing tendon

high tensile steel wire, strand or bar pre-tensioned or post-tensioned to prestress masonry

3.6

shear tie

bed joint connector used to bond masonry units together in a cross-section in lieu of masonry bonding

3.7

effective depth

depth, in members in bending, from the compression face to the centroid of the longitudinal tensile reinforcement or prestressing tendons

3.8

shear span

ratio of maximum design bending moment to maximum design shear force

4 Symbols

The following symbols are used in this standard.

A_m	cross-sectional area of masonry (mm^2)
A_{ps}	area of prestressing tendons (mm^2)
A_s	cross-sectional area of primary reinforcing steel (mm^2)
A_{s1}	area of compression reinforcement in the most compressed face (mm^2)
A_{s2}	area of reinforcement in the least compressed face (mm^2)
A_{sv}	cross-sectional area of reinforcing steel resisting shear forces (mm^2)
A	shear span (mm)
a_v	distance from face of support to the nearest edge of a principal load (mm)
B	width of section (mm)
b_c	width of compression face midway between restraints (mm)
b_t	width of section at level of the tension reinforcement (mm)
C	lever arm factor
D	effective depth (mm) (see 3.7)
d_c	depth of masonry in compression (mm)
d_o	overall depth of section (mm)
d_1	the depth from the surface to the reinforcement in the more highly compressed face (mm)
d_2	the depth of the centroid of the reinforcement from the least compressed face (mm)
E_c	modulus of elasticity of concrete (kN/mm^2)
E_m	modulus of elasticity of masonry (kN/mm^2)
E_u	worst credible earth or water load (N) (see 7.3)
E_s	modulus of elasticity of steel (kN/mm^2)
e_x	resultant eccentricity in plane of bending (mm)
f_b	characteristic anchorage bond strength between mortar or concrete infill and steel (N/mm^2)
f_{ci}	strength of concrete at transfer (N/mm^2)
f_k	characteristic compressive strength of masonry (N/mm^2)
f_{kx}	characteristic flexural strength (tension) of masonry (N/mm^2)
f_p	stress due to prestress at the centroid of the section (N/mm^2)
f_{pb}	stress in tendon at the design moment of resistance of the section (N/mm^2)
f_{pe}	effective prestress in tendon after all losses have occurred (N/mm^2)
f_{pu}	characteristic tensile strength of prestressing tendons (N/mm^2)
f_s	stress in the reinforcement (N/mm^2)
f_{s1}	stress in the reinforcement in the most compressed face (N/mm^2)
f_{s2}	stress in the reinforcement in the least compressed face (N/mm^2)
f_t	diagonal tensile strength of masonry (N/mm^2)
f_v	characteristic shear strength of masonry (N/mm^2)
f_y	characteristic tensile strength of reinforcing steel (N/mm^2)
G_k	characteristic dead load (N)
g_B	design load per unit area due to loads acting at right angles to the bed joints (N/mm^2)
H	clear distance between lateral supports (in mm)
h_{ef}	effective height of wall or column (mm)
J	coefficient derived from Table 13

K_t	coefficient to allow for type of prestressing tendon
L	length of the wall (mm)
L	distance between end anchorages (mm)
l_t	transmission length (mm)
M	bending moment due to design load (N.mm)
M_a	increase in moment due to slenderness (N.mm)
M_d	design moment of resistance (N.mm)
M_x	design moment about the x axis (N.mm)
M'_x	effective uniaxial design moment about the x axis (N.mm)
M_y	design moment about the y axis (N.mm)
M'_y	effective uniaxial design moment about the y axis (N.mm)
N	design vertical load (N)
N_d	design vertical load resistance (N)
P	overall section dimension in a direction perpendicular to the x axis (mm)
Q	moment of resistance factor (N/mm ²)
Q_k	characteristic imposed load (N)
Q	overall section dimension in a direction perpendicular to the y axis (mm)
R	width of shear connector (mm)
S	spacing of shear connectors (mm)
s_v	spacing of shear reinforcement along member (mm)
T	overall thickness of a wall or column (mm)
t_{ef}	effective thickness of a wall or column (mm)
t_f	thickness of a flange in a pocket-type wall (mm)
U	thickness of shear connector (mm)
V	shear force due to design loads (N)
V	shear stress due to design loads (N/mm ²)
W_k	characteristic wind load (N)
Z	section modulus (mm ³)
Z	lever arm (mm)
γ_f	partial safety factor for load
γ_m	partial safety factor for material
γ_{mb}	partial safety factor for bond strength between mortar or concrete infill and steel
γ_{mm}	partial safety factor for compressive strength of masonry
γ_{ms}	partial safety factor for shear strength of masonry
γ_{mt}	partial safety factor for wall ties (including shear ties)
P	A_s/bd
Φt	nominal diameter of tendon

5 Alternative materials and methods of design and construction

The use of materials and methods that are not referred to in this code is acceptable, provided that the materials conform to the appropriate British Standards and that the methods of design and construction are such as to ensure that the strength and durability are at least equal to that recommended in this code.

Alternatively, the materials or methods may be proven by test. The test assembly should be representative as to materials, workmanship and details of the intended design and construction, and should be built under conditions representative of the conditions in the actual building construction.

6 Materials and components

6.1 General

Unless otherwise stated, the materials and components used in the construction of loadbearing walls should conform to the appropriate clause of BS 5628-3.

6.2 Masonry units

Masonry units intended for use in reinforced and prestressed masonry should be selected from the types listed below and should conform to the appropriate clause in the relevant British Standards:

clay masonry units	BS EN 771-1
calcium silicate masonry units	BS EN 771-2
aggregate concrete masonry units	BS EN 771-3
autoclaved aerated concrete masonry units	BS EN 771-4
manufactured stone masonry units	BS EN 771-5
natural stone masonry units	BS EN 771-6
bricks of special shapes and sizes	BS 4729

Selection of masonry units should follow the recommendations contained in BS 5628-3 in respect of durability and other considerations.

The tables and graphs in this part of BS 5628 cover masonry units of compressive strength 7 N/mm² or more, when tested in accordance with BS EN 772-1. However, this should not be taken to preclude the use of masonry units of lower strength for certain applications.

Masonry units that have been previously used should not be reused in reinforced and prestressed masonry unless they have been thoroughly cleaned and are generally in accordance with the recommendations of this code in respect of similar new materials.

6.3 Steel

6.3.1 Reinforcing steel

Reinforcing steel should conform to the relevant British Standard listed below.

Ribbed weldable steel reinforcing bars	BS 4449
Ribbed and plain round steel wire reinforcement	BS 4482
Steel fabric reinforcement	BS 4483
Plain round steel bars	BS EN 10025-2 or BS EN 13877-3
Stainless steel reinforcing bars	BS 6744, Designations 1.4301, 1.4429 or 1.4436 conforming to BS EN 10088-1
Plain round bars	BS EN 10025
Bedjoint reinforcement of welded wire meshwork	BS EN 845-3, excluding products not intended for structural (i.e. designed) applications

Reinforcement may be galvanized after manufacture in accordance with BS EN ISO 1461.

6.3.2 Prestressing steel

Prestressing wire, strands and bars should conform to BS 4486 or BS 5896.

6.4 Damp-proof courses

Damp-proof courses (d.p.c.s) should conform to one of the British Standards, as appropriate, specified in BS 5628-3:2005, 4.7.

Designers should pay particular attention to the characteristics of the materials chosen for d.p.c.s. Materials that squeeze out are undesirable in highly stressed walls, and the effect of sliding at the d.p.c. should be considered especially in relation to lateral loading.

Guidance on structural considerations affecting the selection of d.p.c.s is given in BS 8215 and characteristic strengths for some d.p.c. materials are given in DD 86-3. In general, advice on the resistance to compression, tension, sliding and shear should be sought from the manufacturers of the d.p.c.

Tests to determine the shear strength of d.p.c. materials should be in accordance with BS EN 1052-4. Tests to determine the flexural strength should be in accordance with DD 86-1, and tests to determine the deformation due to creep should be in accordance with DD 86-2.

6.5 Wall ties

Wall ties for low-lift grouted-cavity construction (see 11.2.2.2) should conform to BS EN 845-1 and have a declared tensile load capacity not less than 5 000 N.

Details of a tie for high-lift grouted cavity walls that is suitable for resisting the bursting forces which occur during the cavity filling and compaction operations are given in Annex B. Protection against corrosion should follow the recommendations of 10.1.2.8.

6.6 Cements

The following cements, or combination of cements, are suitable for use in mortars:

Cements:

Portland cement	BS EN 197-1 Notation CEM I
Limestone cement	BS EN 197-1 Notation CEM II/A-L and CEM II/A-LL
Sulfate-resisting Portland cement	BS 4027
Portland-slag cement	BS EN 197-1 Notation CEM or II/A-S or II/B-S
Portland-fly ash cement	BS EN 197-1 Notation CEM II/A-V or II/B-V

Combinations of cements:

- Combinations produced in the mortar mixer from Portland cement CEM I conforming to BS EN 197-1 and ground granulated blastfurnace slag conforming to BS 6699 where the proportions and properties conform to CEM II/A-S or CEM II/B-S of BS EN 197-1: 2000, except Clause 9 of that standard.
- Combinations produced in the mortar mixer from Portland cement CEM I conforming to BS EN 197-1 and limestone fines conforming to BS 7979 where the proportions and properties conform to CEM II/A-L or CEM II/A-LL of BS EN 197-1:2000, except Clause 9 of that standard.
- Combinations produced in the mortar mixer from Portland cement CEM I conforming to BS EN 197-1 and pulverized fuel ash conforming to BS 3892-1, or to BS EN 450-1, where the proportions and properties conform to CEM II/A-V or CEM II/B-V of BS EN 197-1:2000, except Clause 9 of that standard.

The use of masonry cement and high alumina cement is not permitted.

6.7 Aggregate

Aggregate for mortar should follow the recommendations of BS 5628-3:2005, 4.3.

Aggregate for concrete should be in accordance with BS 8500.

6.8 Masonry mortars

6.8.1 General

Mortars intended for use in reinforced and prestressed masonry should conform to BS EN 998-2. The use of mortars should be in accordance with the recommendations given in BS 5628-3. For site made mortars, the mixing of the mortar should be in accordance with BS 5628-3.

Mortars should be designed or prescribed. For designed mortars, the compressive strength of the mortar provides the control of the hardened mortar quality. When samples are taken from a designed mortar in accordance with BS EN 1015-2, and tested in accordance with BS EN 1015-11, the compressive strength of the mortar should not be less than the declared compressive strength. Table 1 shows the relationship of compressive strength classes to strength.

Table 1 — Masonry mortars

Mortar designation	Compressive strength class	Prescribed mortars (proportion of materials by volume) (see notes 1 and 2)		Compressive strength at 28 days
		cement ^a : lime : sand with or without air entrainment	cement ^a : sand with or without air entrainment	
(i)	M12	1 : 0 to ¼ : 3	—	12
(ii)	M6	1 : ½ : 4 to 4½	1 : 3 to 4	6

^a Cement or combinations of cement in accordance with Clause 13

NOTE 1 Proportioning by mass will give more accurate batching than proportioning by volume, provided that the bulk densities of the materials are checked on site.

NOTE 2 When the sand portion is given as, for example, 5 to 6, the lower figure should be used with sands containing a higher proportion of fines whilst the higher figure should be used with sands containing a lower proportion of fines.

NOTE 3 Mortar of strength class M4 may only be used in walls incorporating bed joint reinforcement to enhance lateral load resistance (see Annex A). See BS 5628-1:2005, Table 1 for details of the mortar M4.

6.8.2 Semi-finished factory made and pre-batched mortars

Semi-finished factory made and pre-batched mortars should conform to the requirements of BS EN 998-2. For designed mortars, the manufacturer should declare the strength that he is offering; for prescribed mortars, the provisions given in 6.8.1 apply.

Where pre-mixed lime-sand mortars are used, the specified addition of cement on site should be gauged.

6.9 Concrete infill and grout

6.9.1 For certain reinforced masonry applications (see 10.1.2.5 and 10.1.2.6) the concrete infill may comprise a mix consisting of the following proportions by volume of materials:

1 : 0 to ¼ : 3 : 2 cement : lime : sand : 10 mm nominal maximum size aggregate,

otherwise the concrete infill for reinforced masonry, pre-tensioned masonry and post-tensioned masonry should be specified in accordance with BS 8500-1. Specification may be by Designed, Prescribed, Standardized or Designated mix as appropriate to the requirements of use.

The maximum size of aggregate for concrete infill should not exceed the cover to any reinforcement, less 5 mm.

The recommendations for infill concrete, to ensure adequate reinforcement durability, are given in 10.1.

6.9.2 The workability of all mixes should be appropriate to the size and configuration of the void to be filled and where slumps are specified these should be between 75 mm and 175 mm for unplasticized mixers, when tested in accordance with BS EN 12350-2. In order to ensure that complete filling and compaction is achieved, designers should consider the workability of the infill concrete appropriate to the height and least width of the pour. For small or narrow width sections, the use of plasticized or superplasticized mixes should be considered.

6.9.3 Where tendons are used in narrow ducts which cannot be filled using the appropriate infill concrete described in 6.9.1, the ducts may be filled with a neat cement grout or a sand : cement grout with a minimum cube strength of 17 N/mm² at 7 days, when tested in accordance with BS EN 12390-3. Sand for grout should pass a 1.18 mm sieve conforming to BS 410-1 or -2.

6.10 Colouring agents for mortar

Colouring agents should conform to BS EN 12878 and their content by mass should not exceed 10 % (m/m) of the cement in the mortar. Carbon black colouring agent should be limited to 3 % (m/m) of the cement. The colouring agent should be evenly distributed throughout the mortar.

6.11 Admixtures

6.11.1 General

Admixtures should conform to BS EN 943-3.

Calcium chloride should never be added to masonry mortar or infill concrete.

The chloride ion content by mass of admixtures should not exceed 2 % (m/m) of the admixtures or 0.03 % (m/m) of the cement.

6.11.2 Chlorides

6.11.2.1 Chlorides in sands

The chloride ion content by mass of dry building sand should not exceed 0.15 % (m/m) of the cement.

6.11.2.2 Chlorides in mixes

The total chloride ion content of concrete and mortar mixes arising from aggregates and any other sources should not exceed the limits given in Table 2.

Table 2 — Chloride content of mixes

Type or use of concrete or mortar	Maximum total chloride content by mass of cement % (m/m)
Prestressed concrete; heat-cured concrete containing embedded metal	0.1
Concrete or mortar made with cement conforming to BS 4027	0.2
Concrete or mortar containing embedded metal and made with cement conforming to BS EN 197-1	0.4

7 Design objectives and general recommendations

7.1 Basis of design

7.1.1 *Limit state design*

7.1.1.1 The design of reinforced and prestressed masonry should provide an adequate margin of safety against the ultimate limit state. This is achieved by ensuring that the design strength is greater than or equal to the design load.

The design should be such that serviceability limit state criteria are met. Consideration should be given to the limit states of deflection and cracking and others where appropriate, e.g. fatigue.

7.1.1.2 Designers should consider whether the proportion of concrete infill in a given cross-section is such that the recommendations of BS 8110-1 would be more appropriate than the recommendations of this code.

7.1.2 *Limit states*

7.1.2.1 *Ultimate limit state*

The strength of the structure should be sufficient to withstand the design loads, taking due account of the possibility of overturning or buckling. The design loads and the design strengths of materials should be those recommended in **7.3** and **7.4** respectively, modified by the partial safety factors appropriate to the ultimate limit state given in **7.5.2**.

7.1.2.2 *Serviceability limit states*

7.1.2.2.1 *Deflection*

The deflection of the structure or any part of it should not adversely affect the performance of the structure or any applied finishes, particularly in respect of weather resistance.

The design should be such that deflections are not excessive, with regard to the requirements of the particular structure, taking account of the following recommendations.

- a) The final deflection (including the effects of temperature, creep and shrinkage) of all elements should not, in general, exceed $\text{length}/125$ for cantilevers or $\text{span}/250$ for all other elements.
- b) Consideration should be given to the effect on partitions and finishes of that part of the deflection of the structure taking place after their construction. A limiting deflection of $\text{span}/500$ or 20 mm, whichever is the lesser, is suggested.
- c) If finishes are to be applied to prestressed masonry members, the total upward deflection, before the application of finishes, should not exceed $\text{span}/300$ unless uniformity of camber between adjacent masonry units can be ensured.

In any calculation of deflections (see Annex C) the design loads and the design properties of materials should be those recommended for the serviceability limit state in **7.3** to **7.5**. For reinforcement, stresses lower than the characteristic strengths given in Table 3 may need to be used to reduce deflection or control cracking.

7.1.2.2.2 *Cracking*

Fine cracking or opening up of joints can occur in reinforced masonry structures. However, cracking should not be such as to adversely affect the appearance or durability of the structure. The effects of temperature, creep, shrinkage and moisture movement will require the provision of movement joints (see BS 5628-3:2005, **5.4.2**) or other precautions.

7.2 Stability

7.2.1 *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 as to who has responsibility for overall stability when some or all of the design and detailing is carried out by more than one designer.

To ensure a robust and stable design it will be necessary to consider the layout of the structure on plan, the interaction of the masonry elements and their interaction with other parts of the structure.

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

- a) Buildings should be designed so that at any level they are capable of resisting a uniformly distributed horizontal load equal to 1.5 % of the total characteristic dead load above that level. This force may be apportioned between the structural elements according to their stiffness.
- b) Robust connections should be provided between elements of the structure, particularly at floors and roofs. For guidance, see BS 5628-1:2005, Annex D.
- c) Consideration should be given to connections between elements of different materials to ensure that any differences in their structural behaviour do not adversely affect the stability of the elements.

When bed joints are to be raked out for pointing, the designer should allow for the resulting loss of strength.

7.2.2 Earth-retaining and foundation structures

The overall dimensions and stability of earth-retaining and foundations structures, e.g. the area of pad footings, should be determined by appropriate geotechnical procedures which are not considered in this code. However, in order to establish section sizes and reinforcement areas which will give adequate safety and serviceability without undue calculation, it is appropriate in normal design situations to apply values of the partial safety factor for load, γ_f , comparable to other forms of loading. The partial safety factor load, γ_f , should be applied to all earth and water loads unless they derive directly from loads which have already been factored in alternative ways to those described in 7.3 and 7.5.2.1, in which case the loads should be derived to achieve equilibrium with other design loads. When applying γ_f no distinction is made between adverse and beneficial loads.

7.2.3 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 members of the structure in the ground floor, the provision of bollards, walls, retaining earth banks, etc. should be considered.

All buildings should be robust against misuse and accidental forces that could arise. For Class 1 buildings (see BS 5628-1:2005, Table 11), no additional measures are likely to be necessary other than design to this code of practice and to BS 5628-1 as appropriate.

For Class 2A buildings (see BS 5628-1:2005, Table 11) the recommendations for Class 1 buildings are appropriate with the additional provision that effective horizontal ties, or effective anchorage of suspended floors to walls, should be installed. BS 5628-1 gives guidance on meeting these provisions.

For Class 2B buildings (see BS 5628-1:2005, Table 11) the recommendations for Class 1 buildings are appropriate with the additional provision that either effective horizontal ties and effective vertical ties to supporting walls and columns should be installed, or the notional removal of vertical loadbearing elements of the construction, one at a time, should be demonstrated to be possible without causing collapse. In the event that the notional removal of vertical loadbearing members cannot be accepted, such members should be designed as key elements. BS 5628-1 gives guidance on meeting these provisions.

7.2.4 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 elements during construction.

7.3 Loads

Ideally, the characteristic load on a structure should be determined statistically. Since it is not yet possible to express 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 6399-1.
- b) *Characteristic imposed load.* The characteristic imposed load, Q_k , should be taken as equal to the imposed load as defined in, and calculated in accordance with, BS 6399-1 and -3.
- c) *Characteristic wind load.* The characteristic wind load, W_k , should be taken as equal to the wind load as defined in, and calculated in accordance with BS 6399-2.

For the purposes of this code, worst credible earth and water loads, E_u , should be obtained in accordance with BS 8002. (See also 7.5.2.1)

7.4 Structural properties and analysis

7.4.1 Structural properties

7.4.1.1 Characteristic compressive strength of masonry, f_k

7.4.1.1.1 General

The characteristic compressive strength of masonry, f_k , used in the design of a member should be that appropriate to the direction of the compressive force in the member.

7.4.1.1.2 Direct determination of the characteristic compressive strength of masonry, f_k

The characteristic compressive strength of masonry may be obtained from tests undertaken in accordance with BS EN 1052-1.

7.4.1.1.3 Value of f_k where the compressive force is perpendicular to the bed face of the masonry unit

Where no specific tests are carried out (see 7.4.1.1.2), the value of f_k for a given masonry defined in terms of the compressive strength of the masonry units and the mortar strength class may be taken to be the characteristic compressive strength of masonry constructed with masonry units laid in the normal way under laboratory conditions and tested at an age of 28 days under axial compression in such a manner that the effects of slenderness may be ignored (see Table 3).

The value of f_k should be taken from the appropriate section of the table, using the following guidelines.

Table 3a) applies to masonry built with standard format bricks of clay or calcium silicate, conforming to the requirements of BS EN 771-1 or -2, and having no more than 25% formed voids (perforations) or 20% frogs.

The characteristic compressive strength of masonry of walls constructed with bricks of clay or calcium silicate that have more than 25% and less than 55% of formed voids (perforations), may be taken from the values given in Table 3a) multiplied by 0.8, provided that the compressive strength of the units does not exceed 55 N/mm².

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 3a) may be multiplied by 1.15.

NOTE This table is intended to cover normal size bricks which have an aspect ratio ≈ 0.63 .

Table 3b) applies to masonry built with autoclaved aerated concrete blocks having a ratio of height to least horizontal dimension of 0.6.

Table 3c) applies to masonry built with aggregate concrete blocks and a ratio of height to least horizontal dimension of 0.6.

Table 3d) applies to masonry built with aggregate concrete blocks having not more than 25% of formed voids and a ratio of height to least horizontal dimension of between 2.0 and 4.5.

Table 3e) applies to masonry built with autoclaved aerated concrete blocks having a ratio of height to least horizontal dimension of between 2.0 and 4.5.

Table 3f) applies to masonry built with aggregate concrete blocks having more than 25% but less than 60% of formed voids and a ratio of height to least horizontal dimension of between 2.0 and 4.5.

Table 3g) applies to masonry built with solid aggregate concrete blocks having a block height/wall thickness ratio of between 1.0 and 1.2 as a collar jointed wall

Table 3h) applies to masonry built with solid aggregate concrete blocks laid flat having an as laid height/wall thickness ratio of between 0.4 and less than 0.6

The characteristic compressive strength of masonry bonded with thin layer mortar may be taken as the values given for mortar strength class M12 (mortar designation (i)) in Table 3.

7.4.1.1.4 *Value of f_k where the compressive force is parallel to the bed face of the masonry unit*

The value of f_k for masonry in which the compressive forces act parallel to the bed faces may be taken as follows:

- a) for masonry units without formed voids, frogged bricks where the frogs are filled, and blocks with filled formed voids, the strength obtained from the appropriate item of **7.4.1.1.3**;
- b) for bricks with formed voids and bricks with perforations, the characteristic compressive strength determined in accordance with **7.4.1.1.2** or, where no test data are available, one-third of the strength obtained from the appropriate item of **7.4.1.1.3**;
- c) for blocks with unfilled formed voids, the characteristic compressive strength given in Table 3, using the strength of the block determined in the direction parallel to the bed face of the masonry unit.

7.4.1.1.5 *Value of f_k for masonry units of unusual format or for unusual bonding patterns*

The value of f_k for masonry constructed with masonry units of unusual formats, or with an unusual bonding pattern, may be taken as follows:

- a) for brick masonry, the values determined by test in accordance with **7.4.1.1.2**, provided that the value of f_k is not taken to be greater than the appropriate value given in Table 3;
- b) for block masonry, the value given in Table 3, using the strength of the block determined in the appropriate aspect.

7.4.1.2 *Characteristic compressive strength of masonry in bending*

For a given masonry construction defined in terms of the compressive strength of the masonry units and mortar designation, the value of f_k derived from **7.4.1.1** may be taken to be the characteristic compressive strength of masonry in bending.

7.4.1.3 *Characteristic shear strength of masonry, f_v*

7.4.1.3.1 *General*

When designing masonry for shear, care should be taken in the use of d.p.c. materials that might reduce the bending and shear strengths of the masonry. Recommended test methods are given in DD 86-1 and BS EN 1052-4.

When it is proposed to use masonry units containing greater than 40 % formed voids, the designer should be satisfied that the required characteristic shear strength can be achieved.

7.4.1.3.2 *Shear in bending (reinforced masonry)*

Characteristic shear strength may be calculated by one of two alternative methods appropriate to whether reinforcement is contained in mortar or in concrete infill.

- a) For reinforced sections in which the reinforcement is placed in bed or vertical joints, including Quetta bond and other sections where the reinforcement is wholly surrounded with mortar strength class M12 or M6 (see Table 1), the characteristic shear strength, f_v , may be taken as 0.35 N/mm^2 .

No enhancement of characteristic shear strength, f_v , is to be used for the area of primary reinforcing steel provided or for situations where the ratio of the shear span to the effective depth is 2 or greater.

For simply supported beams or cantilevers where the ratio of the shear span (see 3.8) to the effective depth (see 3.7) is less than 2, f_v may be increased by the following factor:

$$2d/a_v$$

where

d is the effective depth;

a_v is the distance from the face of the support to the nearest edge of a principal load;

provided that f_v is not taken to be greater than 0.7 N/mm^2 .

At sections in certain laterally loaded walls there may be substantial compressive stresses from vertical loads. In such cases the shear may be adequately resisted by the plain masonry (see BS 5628-1:2005, Clause 22).

b) For reinforced sections in which the main reinforcement is placed within pockets, cores or cavities filled with concrete infill as defined in 6.9.1, the characteristic shear strength of the masonry, f_v , may be obtained from the following equation:

$$f_v = 0.35 + 17.5 \rho$$

where

$$\rho = A_s/bd$$

A_s is the cross-sectional area of primary reinforcing steel;

b is the width of section;

d is the effective depth;

provided that f_v is not taken to be greater than 0.7 N/mm^2 .

For simply supported reinforced beams or cantilever retaining walls where the ratio of the shear span, a , to the effective depth, d , is six or less, f_v may be increased by a factor $\{2.5 - 0.25 (a/d)\}$ provided that f_v is not taken to be greater than 1.75 N/mm^2 .

7.4.1.3.3 Racking shear in reinforced masonry shear walls

When designing reinforced masonry shear walls the characteristic shear strength of masonry, f_v , may be taken to be:

$$0.35 + 0.6g_B, \text{ with a maximum of } 1.75 \text{ N/mm}^2$$

where

g_B is the design load per unit area normal to the bed joint due to the loads calculated for the appropriate loading condition detailed in 7.5.

Alternatively, for unreinforced sections in which the main reinforcement is placed within pockets, cores or cavities filled with concrete infill as defined in 6.9.1, the characteristic shear strength of masonry, f_v , may be taken to be 0.7 N/mm^2 provided that the ratio of height to length of the wall does not exceed 1.5.

7.4.1.3.4 Shear in prestressed sections

For prestressed sections with bonded or unbonded tendons, the design shear strength of masonry may be determined directly from a consideration of the characteristic diagonal tensile strength of masonry and the prestress (see 9.2.3.1).

Table 3 — Characteristic compressive strength masonry, f_k , in N/mm²

<i>a) — Constructed with standard format bricks of clay and calcium silicate having no more than 25% of formed voids, or 20% frogs</i>											
Mortar strength Class/Designation	Compressive strength of unit (N/mm ²) ^a										
	7	10	15	20	30	40	50	75	100	125	150
M12 / (i)	3.2	4.0	5.3	6.4	8.3	10.0	11.6	15.2	18.3	21.2	23.9
M6 / (ii)	3.1	3.8	4.8	5.6	7.1	8.4	9.5	12.0	14.2	16.1	17.9
<i>b) — Constructed with autoclaved aerated concrete blocks having a ratio of height to least horizontal dimension of 0.6</i>											
	Compressive strength of unit (N/mm ²) ^a										
	7.3	10.4									
M12 / (i)	3.4	4.4									
M6 / (ii)	3.2	4.2									
<i>c) — Constructed with aggregate concrete blocks having a ratio of height to least horizontal dimension of 0.6</i>											
	Compressive strength of unit (N/mm ²) ^a										
	7.3	10.4	17.5	22.5	30	40 or greater					
M12 / (i)	3.4	4.4	6.3	7.5	9.5	11.2					
M6 / (ii)	3.2	4.2	5.5	6.5	7.9	9.3					
<i>d) — Constructed with aggregate concrete blocks having not more than 25% of formed voids and a ratio of height to least horizontal dimension of between 2.0 and 4.5</i>											
	Compressive strength of unit (N/mm ²) ^a										
	7.3	10.4	17.5	22.5	30	40 or greater					
M12 / (i)	6.8	8.8	12.5	15.0	18.7	22.1					
M6 / (ii)	6.4	8.4	11.1	13.0	15.9	18.7					
<i>e) — Constructed with autoclaved aerated concrete blocks having a ratio of height to least horizontal dimension of between 2.0 and 4.5</i>											
	Compressive strength of unit (N/mm ²) ^a										
	7.3	10.4									
M12 / (i)	6.8	8.8									
M6 / (ii)	6.4	8.4									
<i>f) — Constructed with aggregate concrete blocks having more than 25% but less than 60% of formed voids and a ratio of height to least horizontal dimension of between 2.0 and 4.5</i>											
	Compressive strength of unit (N/mm ²) ^a										
	7.3	10.4	17.5	22.5	30	40 or greater					
M12 / (i)	6.6	8.1	11.2	13.1	16.0	19.4					
M6 / (ii)	6.4	7.5	9.9	11.6	14.0	16.7					
[C₁] <i>g) — Constructed with aggregate concrete blocks having not more than 25% formed voids and having a block height / wall thickness ratio of between 1.0 and 1.2 as a collar jointed wall [C₁]</i>											
	Compressive strength of unit (N/mm ²) ^a										
	7.3	10.4	17.5	22.5	30	40 or greater					
M12 / (i)	5.5	7.0	9.7	11.6	14.2	16.5					
M6 / (ii)	4.5	5.7	7.9	9.4	11.6	13.5					
[C₁] <i>h) — Constructed with solid aggregate concrete blocks laid flat having an as laid height/ wall thickness ratio of between 0.4 and 0.6 [C₁]</i>											
	Compressive strength of unit (N/mm ²) ^a										
	7.3	10.4	17.5	22.5	30	40 or greater					
M12 / (i)	5.6	7.2	9.7	11.3	13.5	15.4					
M6 / (ii)	4.6	5.9	7.9	9.1	10.8	12.3					
^a Measured in normal direction of test for units											