

Code of practice for the use of masonry —

Part 2: Structural use of reinforced and prestressed masonry

ICS 91.080.30

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSI
Documents

AVA

Document Sharing Hub

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by Technical Committee B/525, Building and civil engineering structures, to Subcommittee B/525/6, Use of masonry, upon which the following bodies were represented:

- Association of Consulting Engineers
- Autoclaved Aerated Concrete Products Association
- British Ceramic Research Ltd
- British Masonry Society
- British Precast Concrete Foundation
- Construction Confederation
- Concrete Block Association
- Department of the Environment, Transport and the Regions (represented by the Building Research Establishment)
- Department of the Environment, Transport and the Regions (Construction Services Directorate)
- Institution of Civil Engineers
- National House Building Council
- Royal Institution of British Architects

This British Standard, having been prepared under the direction of the Building and Civil Engineering Sector Policy and Strategy Committee, was published under the authority of the Standards Committee and comes into effect on 15 November 2000

© BSI 11-2000

First published March 1985
Second edition October 1995
Third edition November 2000

The following BSI references relate to the work on this standard:
Committee reference B/525/6
Draft for comment 98/104044 DC

ISBN 0 580 33238 1

Amendments issued since publication

Amd. No.	Date	Comments

Contents

	Page
Committees responsible	Inside front cover
Foreword	iii
1 Scope	1
2 Normative references	1
3 Terms and definitions	2
4 Symbols	3
5 Alternative materials and methods of design and construction	5
6 Materials and components	5
7 Design objectives and general recommendations	8
8 Design of reinforced masonry	21
9 Design of prestressed masonry	37
10 Other design considerations	43
11 Work on site	47
Annex A (normative) Design method for walls incorporating bed joint reinforcement to enhance lateral load resistance	50
Annex B (informative) Wall tie for high-lift cavity walls	52
Annex C (informative) Estimation of deflection	52
Annex D (normative) Method for determination of characteristic strength of brick masonry, f_k	53
Annex E (informative) Durability recommendations for various construction types	56
Bibliography	57
Index	58
Figure 1 — Characteristic compressive strength, f_k , of masonry	13
Figure 2 — Short-term design stress-strain curve for reinforcement	23
Figure 3 — Moment of resistance factor, Q	26
Figure 4 — Hooks and bends	36
Figure 5 — Typical short-term design stress-strain curves for normal and low relaxation tendons	41
Figure 6 — Minimum concrete cover in pocket-type walls and in reinforced hollow blockwork walls	46
Figure B.1 — Wall tie for high-lift grouted-cavity wall	52
Figure D.1 — Typical prisms for determination of f_k	54
Table 1 — Requirements for mortar	7
Table 2 — Chloride content of mixes	8
Table 3 — Characteristic compressive strength, f_k , of masonry	16
Table 4 — Characteristic tensile strength of reinforcing steel, f_y	16
Table 5 — Characteristic anchorage bond strength	17
Table 6 — Elastic modulus for concrete infill, E_c	18
Table 7 — Partial safety factors, γ_{mm} , for strength of reinforced masonry in direct compression and bending: ultimate limit state	20
Table 8 — Partial safety factors γ_{mv} , γ_m and γ_{ms} : ultimate limit state	20
Table 9 — Limiting ratios of span to effective depth for laterally-loaded walls	22
Table 10 — Limiting ratios of span to effective depth for beams	22
Table 11 — Values of the moment of resistance factor, Q , for various values of f_k / γ_{mm} and lever arm factor, C	25
Table 12 — Effective height of walls and columns	29
Table 13 — Values of the coefficient j	32

	Page
Table 14 — Selection of reinforcement for durability	43
Table 15 — Minimum concrete cover for carbon steel reinforcement	44
Table 15a — Adjustments to minimum cement contents for aggregates other than 20 mm nominal maximum size	44
Table D.1 — Value of k	55
Table D.2 — Value of reduction factor to allow for ratio h/t	55
Table E.1 — Durability recommendations for various construction types	56

Foreword

This part of BS 5628 has been prepared under the direction of Technical Subcommittee B/525/6. It supersedes BS 5628-2:1995, which is withdrawn.

This edition of BS 5628-2 introduces technical changes but it does not reflect a full review or revision of the standard which will be undertaken in due course.

The recommendations in this code are based on existing experience and practice in the UK and overseas and on the results of recent research. However, compared with reinforced masonry, there are relatively few examples of prestressed masonry at present in this country.

Annex A of this code gives interim recommendations for the design of masonry incorporating bed joint reinforcement for enhancement of lateral load resistance, pending further research.

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.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 59 and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

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 square dressed natural stone.

NOTE 1 The partial safety factors given in this code are based on the assumption that the special category of construction control (see 3.1) will be specified by the designer. If this is considered to be impracticable, higher partial safety factors should be used.

NOTE 2 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 normative documents contain provisions which, through reference in this text, constitute provisions of this part of this British Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 12:1996, *Specification for Portland cement*.

BS 146:1996, *Specification for Portland blastfurnace cements*.

BS 187:1978, *Specification for calcium silicate (sandlime and flintlime) bricks*.

BS 410:1986, *Specification for test sieves*.

BS 729:1971, *Specification for hot dip galvanized coatings on iron and steel articles*.

BS 970-1:1996, *Specification for wrought steels for mechanical and allied engineering purposes — Part 1: General inspection and testing procedures and specific requirements for carbon, carbon manganese, alloy and stainless steels*.

BS 1014: 1975, *Specification for pigments for Portland cement and Portland cement products*.

BS 1243: 1978, *Specification for metal ties for cavity wall construction*.

BS 1881-102:1983, *Testing concrete — Part 102: Method for determination of slump*.

BS 1881-115:1986, *Testing concrete — Part 115: Specification for compression testing machines for concrete*.

BS 1881-116:1983, *Testing concrete — Part 116: Method for determination of compressive strength of concrete cubes*.

BS 3921:1985, *Specification for clay bricks*.

BS 4027:1996, *Specification for sulfate-resisting Portland cement*.

BS 4449:1997, *Specification for carbon steel bars for the reinforcement of concrete*.

BS 4466:1989, *Specification for scheduling, dimensioning, bending and cutting of steel reinforcement for concrete*.

BS 4482:1985, *Specification for cold reduced steel wire for the reinforcement of concrete*.

BS 4483:1985, *Specification for steel fabric for the reinforcement of concrete*.

BS 4486:1980, *Specification for hot rolled and hot rolled and processed high tensile alloy steel bars for the prestressing of concrete*.

BS 4721:1981, *Specification for ready-mixed building mortars*.

BS 4729:1990, *Specification for dimensions of bricks of special shapes and sizes*.

BS 4887-1:1986, *Mortar admixtures — Part 1: Specification for air-entraining (plasticizing) admixtures*.

BS 5075-1:1982, *Concrete admixtures — Part 1: Specification for accelerating admixtures, retarding admixtures and water reducing admixtures*.

BS 5075-2:1982, *Concrete admixtures — Part 2: Specification for air entraining admixtures*.

BS 5328-1:1997, *Concrete — Part 1: Guide to specifying concrete*.

BS 5328-2:1997, *Concrete — Part 2: Methods for specifying concrete mixes*.

BS 5390:1976, *Code of practice for stone masonry*.

BS 5628-1:1992, *Code of practice for use of masonry — Part 1: Structural use of unreinforced masonry*.

BS 5628-3:1985, *Code of practice for use of masonry — Part 3: Materials and components, design and workmanship*.

BS 5896:1980, *Specification for high tensile steel wire and strand for the prestressing of concrete*.

BS 6073-1:1981, *Precast concrete masonry units — Part 1: Specification for precast concrete masonry units*.

BS 6073-2:1981, *Precast concrete masonry units — Part 2: Method for specifying precast concrete masonry units*.

BS 6399-1:1996, *Loading for buildings — Part 1: Code of practice for dead and imposed loads*.

BS 6399-2:1997, *Loading for buildings — Part 2: Code of practice for wind loads*.

BS 6399-3:1998, *Loading for buildings — Part 3: Code of practice for imposed roof loads*.

BS 6457:1984, *Specification for reconstructed stone masonry units*.

BS 6649:1985, *Specification for clay and calcium silicate modular bricks*.

BS 8002:1994, *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*.

CP 3:Chapter V-2, *Code of basic data for the design of buildings — Chapter V — Part 2: Wind loads (obsolescent)*.

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 structural units, either laid in situ or constructed in prefabricated panels, in which the structural 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 6a)]

3.3.3

Quetta bond

masonry at least one and a half 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 6b)]

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 connector

bed joint connector used to bond structural 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 (in mm ²)
A_{ps}	area of prestressing tendons (in mm ²)
A_s	cross-sectional area of primary reinforcing steel (in mm ²)
A_{s1}	area of compression reinforcement in the most compressed face (in mm ²)
A_{s2}	area of reinforcement in the least compressed face (in mm ²)
A_{sv}	cross-sectional area of reinforcing steel resisting shear forces (in mm ²)
a	shear span (in mm)
a_v	distance from face of support to the nearest edge of a principal load (in mm)
b	width of section (in mm)
b_c	width of compression face midway between restraints (in mm)
b_t	width of section at level of the tension reinforcement (in mm)
c	lever arm factor
d	effective depth (in mm) (see 3.7)
d_c	depth of masonry in compression (in mm)
d_o	overall depth of section (in mm)
d_1	the depth from the surface to the reinforcement in the more highly compressed face (in mm)
d_2	the depth of the centroid of the reinforcement from the least compressed face (in mm)
E_c	modulus of elasticity of concrete (kN/mm ²)
E_m	modulus of elasticity of masonry (in kN/mm ²)
E_u	worst credible earth or water load (in N) (see 7.3)
E_s	modulus of elasticity of steel (in kN/mm ²)
e_x	resultant eccentricity in plane of bending (in mm)

f_b	characteristic anchorage bond strength between mortar or concrete infill and steel (in N/mm ²)
f_{ci}	strength of concrete at transfer (in N/mm ²)
f_k	characteristic compressive strength of masonry (in N/mm ²)
f_{kx}	characteristic flexural strength (tension) of masonry (in N/mm ²)
f_p	stress due to prestress at the centroid of the section (in N/mm ²)
f_{pb}	stress in tendon at the design moment of resistance of the section (in N/mm ²)
f_{pe}	effective prestress in tendon after all losses have occurred (in N/mm ²)
f_{pu}	characteristic tensile strength of prestressing tendons (in N/mm ²)
f_s	stress in the reinforcement (in N/mm ²)
f_{sl}	stress in the reinforcement in the most compressed face (in N/mm ²)
f_{s2}	stress in the reinforcement in the least compressed face (in N/mm ²)
f_t	diagonal tensile strength of masonry
f_v	characteristic shear strength of masonry (in N/mm ²)
f_y	characteristic tensile strength of reinforcing steel (in N/mm ²)
G_k	characteristic dead load (in N)
g_B	design load per unit area due to loads acting at right angles to the bed joints (in N/mm ²)
h	clear distance between lateral supports (in mm)
h_{ef}	effective height of wall or column (in mm)
j	a coefficient derived from Table 12
K_t	coefficient to allow for type of prestressing tendon
L	length of the wall (in mm)
l	distance between end anchorages (in mm)
l_t	transmission length (in mm)
M	bending moment due to design load (in N·mm)
M_a	increase in moment due to slenderness (in N·mm)
M_d	design moment of resistance (in N·mm)
M_x	design moment about the x axis (in N·mm)
M'_x	effective uniaxial design moment about the x axis (in N·mm)
M_y	design moment about the y axis (in N·mm)
M'_y	effective uniaxial design moment about the y axis (in N·mm)
N	design vertical load (N)
N_d	design vertical load resistance (in N)
p	overall section dimension in a direction perpendicular to the x axis (in mm)
Q	moment of resistance factor (in N/mm ²)
Q_k	characteristic imposed load (in N)
q	overall section dimension in a direction perpendicular to the y axis (in mm)
r	width of shear connector (in mm)
s	spacing of shear connectors (in mm)
s_v	spacing of shear reinforcement along member (in mm)
t	overall thickness of a wall or column (in mm)
t_{ef}	effective thickness of a wall or column (in mm)
t_f	thickness of a flange in a pocket-type wall (in mm)
u	thickness of shear connector (in mm)

V	shear force due to design loads (in N)
v	shear stress due to design loads (in N/mm ²)
W_k	characteristic wind load (in N)
Z	section modulus (in mm ⁴)
z	lever arm (in 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
ρ	A_s/bd
n	nominal diameter of tendon

5 Alternative materials and methods of design and construction

Where materials and methods are used that are not referred to in this code, their use 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 or BS 5390.

6.2 Structural units

Bricks and blocks intended for use in reinforced and prestressed masonry should be selected from the types listed below and should conform to the relevant British Standard.

Calcium silicate (sandlime and flintlime) bricks	BS 187
Clay bricks	BS 3921
Precast concrete masonry units	BS 6073-1
Reconstructed stone masonry units	BS 6457
Stone masonry	BS 5390
Clay and calcium silicate modular bricks	BS 6649
Dimensions of bricks of special shapes and sizes	BS 4729

Selection of units should follow the recommendations contained in BS 5628-3 or BS 5390, as appropriate, 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 more¹⁾. 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 follow the recommendations of this code for similar new materials.

¹⁾ Based on gross area for solid concrete blocks and net area for hollow concrete blocks (see C.2 of BS 6073-2:1981) and on the area of bed for clay, calcium silicate and concrete bricks.

6.3 Steel

6.3.1 Reinforcing steel

Reinforcing steel, including bed joint reinforcement, should conform to the relevant British Standard listed below.

Hot rolled steel bars	BS 4449
Cold worked deformed steel bars	BS 4449
Cold reduced steel wire	BS 4482
Steel fabric	BS 4483
Austenitic stainless steel	BS 6744, types 304S31 and 316S33 BS 970-1, types 304S15, 304S31 or 316S33, excluding free machining specifications

Reinforcement may be galvanized after manufacture in accordance with BS 729 or clad with a layer of austenitic stainless steel of nominal thickness not less than 1 mm.

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.) should conform to one of the British Standards, as appropriate, specified in BS 5628-3:1985, clause 10.

Designers should pay particular attention to the characteristics of the materials chosen for d.p.c. 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. In general, advice on the resistance to compression, tension, sliding and shear should be sought from the manufacturers of the d.p.c.

6.5 Wall ties

Wall ties for low-lift grouted-cavity construction (see 11.2.2.2) should be the vertical-twist type conforming to the requirements of BS 1243, except for those for length.

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

Cement should conform to BS 12, BS 146 or BS 4027. Masonry cement or high alumina cement should never be used.

6.7 Aggregate

Aggregate for mortar should follow the recommendations of BS 5628-3:1985, 6.3.

Aggregate for concrete should be in accordance with BS 5328-1.

6.8 Mortars

6.8.1 General

The mixing and use of mortars should follow the recommendations of BS 5628-3 or BS 5390, as appropriate. 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 BS 5628-1:1992, A.1.

Table 1 — Requirements for mortar

Mortar designation (see note 1)	Type of mortar (proportions by volume) (see note 2)		Mean compressive strength at 28 days	
	Cement:lime:sand	Cement:sand with plasticizer (see 6.11.1)	Preliminary (laboratory) tests N/mm ²	Site tests N/mm ²
(i)	1:0 to ¼:3	—	16.0	11.0
(ii)	1:½:4 to 4½ (see note 3)	1:3 to 4 (see note 3)	6.5	4.5

NOTE 1 Designation (iii) mortar (see BS 5628-1:1992, Table 1) may be used in walls incorporating bed joint reinforcement to enhance lateral resistance (see annex A).

NOTE 2 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 3 In general, the lower proportion of sand applies to grade G of BS 1200 whilst the higher proportion applies to grade S of BS 1200.

6.8.2 Ready-mixed mortars

Ready-mixed lime:sand for mortar should conform to BS 4721. The appropriate addition of cement should be gauged on site.

Ready-to-use retarded cement:lime:sand mortars should conform to BS 4721 and be used only with the written permission of the designer.

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 5328. Specification may be by Designed, Prescribed, Standard 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 1881-102. 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 plasticised 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 1881-116. Sand for grout should pass a 1.18 mm sieve conforming to BS 410.

6.10 Colouring agents for mortar

Colouring agents should conform to BS 1014 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

For the purposes of this code an admixture is taken to be as defined in BS 4887 or BS 5075-1, including superplasticizers for infill concrete and mortar plasticizer.

Calcium chloride should never be used. Other admixtures should be used only with the written permission of the designer. If admixtures are used, it is important to ensure that the manufacturer’s instructions about quality and mixing times are carefully followed.

Admixtures should conform to the relevant British Standard listed below.

Concrete admixtures:	
accelerating admixtures, retarding admixtures and water reducing admixtures	BS 5075-1
Air-entraining admixtures	BS 5075-2
Mortar plasticizers	BS 4887

Where there is no appropriate British Standard, the suitability and effectiveness of an admixture should be to the satisfaction of the designer.

If two or more admixtures are to be used simultaneously in the same mix, data should be sought to assess their interaction and to ensure their compatibility.

The effect of admixtures on durability of concrete or mortar should be carefully assessed, with particular reference to whether they will combine with the ingredients to form harmful compounds or increase the risk of corrosion of the reinforcement.

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 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 % (<i>m/m</i>)
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 12 or BS 146	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.

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 length/125 for cantilevers or 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 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 span/300 unless uniformity of camber between adjacent 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 4 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 5628-3:1985, clause 20) 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 5628-1:1992, annex C.
- 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. 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.

7.2.2 Earth-retaining and foundation structures

The overall dimensions and stability of earth-retaining and foundation 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 3.3 and 3.5.2.1, 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, the designer should consider the effect of misuse or accident. No structure can necessarily 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 or chemical plant, 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, etc. should be considered.

Buildings of five storeys and above (category 2 buildings as defined in BS 5628-1) should be designed following the additional recommendations of BS 5628-1:1992, clause 37 except that mortar designation (iii) is recommended only for plain masonry containing bed joint reinforcement designed in accordance with annex A.

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.
- 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, CP 3:Chapter V -2 or BS 6399-2.

For the purposes of this code, worst credible earth and water loads, E_w , should be obtained in accordance with BS 8002:1994. (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 brick masonry, f_k

The characteristic compressive strength of brick masonry may be obtained from tests as described in annex D.

7.4.1.1.3 *Value of f_k where the compressive force is perpendicular to the bed face of the 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 structural units and the mortar designation may be taken to be the characteristic compressive strength of masonry constructed with 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 neglected (see Table 3 and Figure 1).

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

a) Table 3a) and Figure 1a) apply to masonry built with bricks or other structural units with a ratio of height to least horizontal dimension (aspect ratio) of 0.6.

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

b) Table 3b) and Figure 1b) apply to masonry built with solid concrete blocks with a ratio of height to least horizontal dimension of 1.0 and they make due allowance for the enhancement in strength resulting from the unit shape.

c) Table 3c) and Figure 1c) apply to masonry built with 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 they make due allowance for the enhancement in strength resulting from the unit shape.

d) Table 3d) and Figure 1d) apply to masonry built with structural units, other than solid concrete blocks, with a ratio of height to least horizontal dimension of between 2.0 and 4.0 and they make due allowance for the enhancement in strength resulting from the unit shape.

e) When masonry is built of hollow blocks having a ratio of height to least horizontal dimension between 0.6 and 2.0, the value of f_k should be obtained by interpolation between the values given in Tables 3a) and 3d).

f) When masonry is 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 Table 3a) and 3c). To assist the designer, Table 3b) gives values of f_k for solid concrete blocks having a ratio of height to least horizontal dimension of 1.0.

g) When masonry is built with hollow concrete blocks and the vertical cavities are filled completely with in situ concrete, the value of f_k should be obtained as if the blocks were solid [see f)] provided that:

- 1) the compressive strength of the blocks is assessed on their net area as defined in BS 6073-2:1981, annex C;
- 2) the characteristic concrete cube strength of the infill is not less than the compressive strength of the blocks derived from 1) and in no case less than the appropriate minimum strength given in 6.9.

Where the infill concrete is less strong than the concrete in the block, the characteristic compressive strength of the masonry should be obtained as if the blocks were solid and of compressive strength equal to the cube strength of the infill concrete.

h) When masonry is built with square dressed natural stone, the value of f_k should be obtained as if the units were solid concrete blocks of an equivalent compressive strength.

Linear interpolation within the tables is permitted.

7.4.1.1.4 *Value of f_k where the compressive force is parallel to the bed face of the 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 holes, frogged bricks where the frogs are filled and filled hollow blocks, the strength obtained from the appropriate item of 7.4.1.1.3;
- b) for cellular bricks 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 unfilled hollow and cellular blocks, 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 unit.

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

The value of f_k for masonry constructed with 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 defined in terms of the compressive strength of the structural 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 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 designation (i) or (ii) (see Table 1), the characteristic shear strength, f_v , may be taken as 0.35 N/mm^2 .

NOTE 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 3.6) to the effective depth 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 5628-1:1992, clause 25).

- 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:

$$f_v = 0.35 + 17.5p$$

where

$$p = A_s/bd;$$

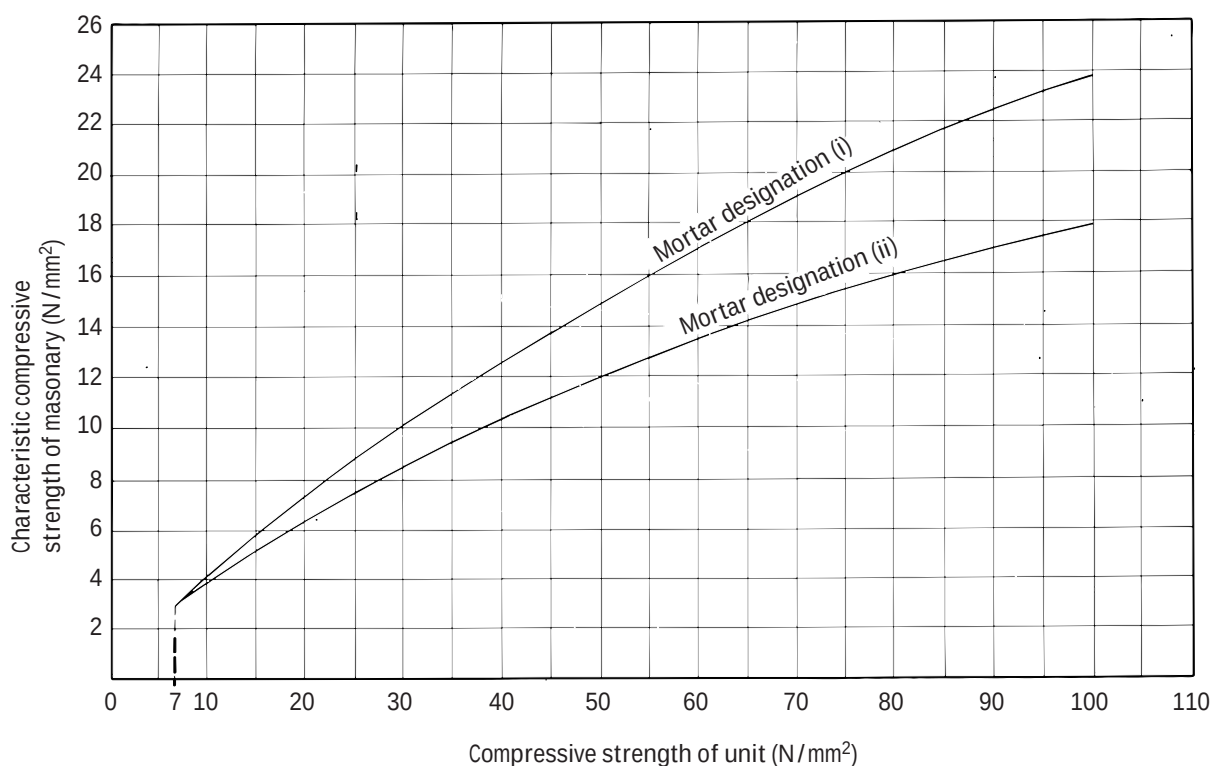
A_s is the cross-sectional area of primary reinforcing steel;

b is the width of section;

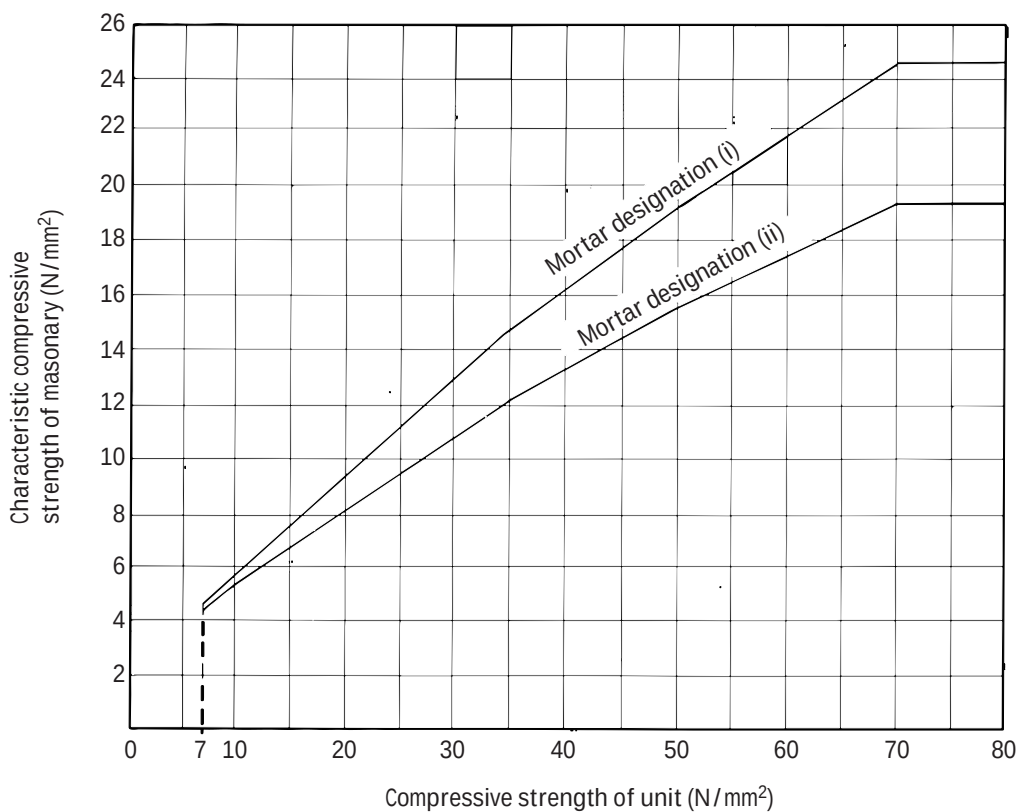
d is the effective depth see 3.4);

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 , (see 3.6) 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 .

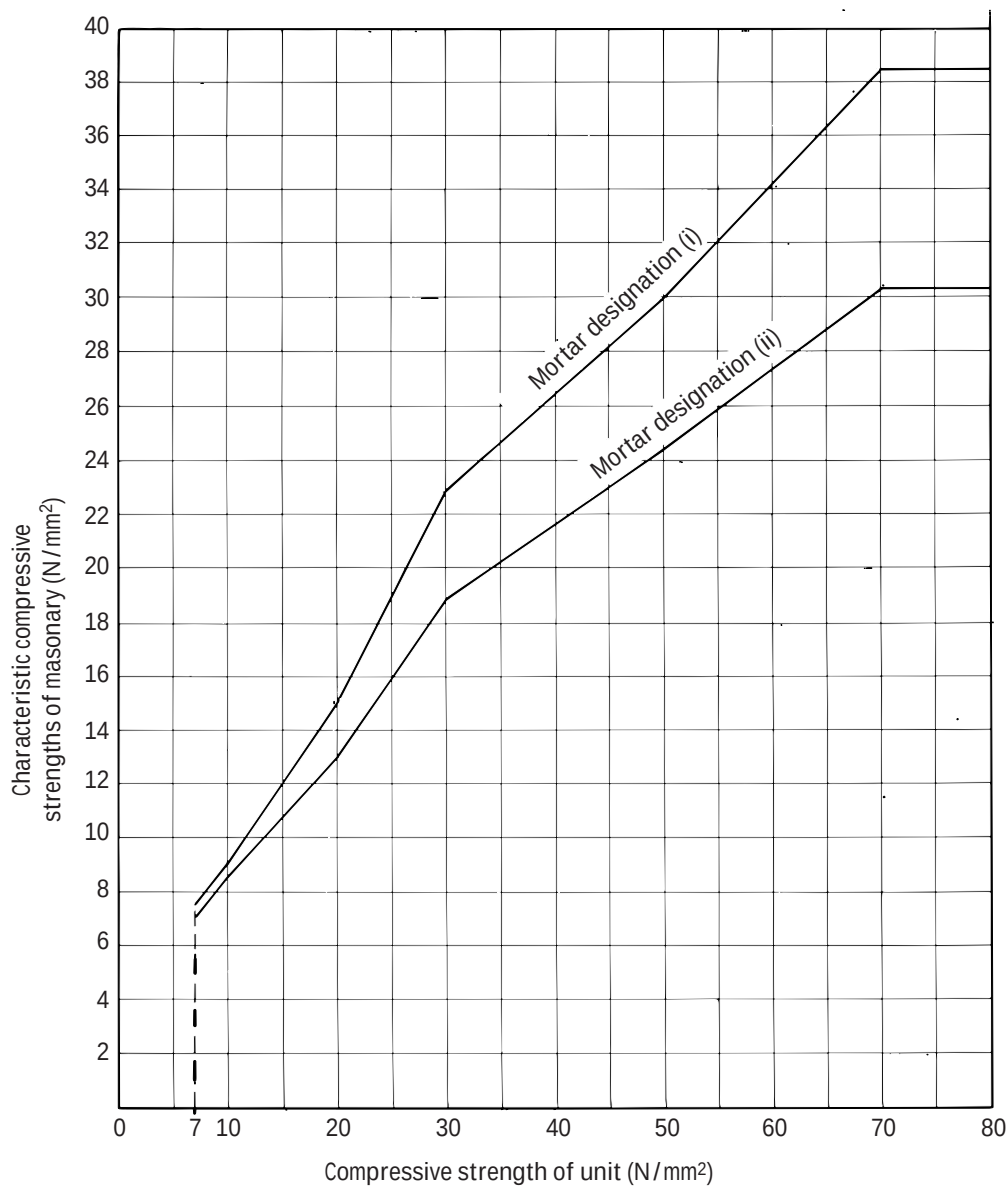


a) Masonry constructed with bricks or other units having a ratio of height to least horizontal dimension of 0.6 [see Table 3a)]



b) Block masonry constructed with solid blocks having a ratio of height to least horizontal dimension of 1.0 [see Table 3b)]

Figure 1 — Characteristic compressive strength, f_k , of masonry



c) Block masonry constructed with solid blocks having a ratio of height to least horizontal dimension of between 2.0 and 4.0 [see Table 3c)]

Figure 1 — Characteristic compressive strength, f_k , of masonry (continued)