SECTION 1. BS 5628:2005 – CODE OF PRACTICE FOR THE USE OF MASONRY

1.1 Overview of BS 5628:2005

BS 5628:2005 Code of practice for the use of masonry is the current British standard for the design of unreinforced and reinforced masonry structures of all kinds. There are three parts to the British standard as follows:

Part 1: Structural use of unreinforced masonry
Part 2: Structural use of reinforced and prestressed masonry
Part 3: Materials and components, design and workmanship

The Standard sets out the minimum requirements for the design and construction of masonry, including unreinforced, reinforced and prestressed, using manufactured units of clay, calcium silicate and aggregate concrete laid in mortar, autoclaved aerated concrete (AAC) laid in thin bed mortar, manufactured stone masonry units and natural stone masonry units laid in mortar, and bricks of special shapes and sizes.

Each Part of the Standard is a comprehensive document of about 70 pages arranged in the following Sections:

Part 1: Structural use of unreinforced masonry

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Section 2.	**Materials, components and workmanship**
Clause 6	General

The Standard assumes that the structural design of masonry and the execution of the Code recommendations will be entrusted to appropriately qualified and competent people. This is always essential.

It is also most importantly stated that British Standards do not purport to include all the necessary provisions of a contract, and that users are responsible for their correct application.

1.2 Scope of BS 5628:2005

The purpose of this section of the design manual is to show that the design of ***mortarless*** masonry structures clearly falls within the scope of BS 5628-1:2005, BS 5628-2:2005 and BS 5628-3:2005**.**

BS 5628-1:2005 states that this Part "…. gives recommendations for the design of unreinforced masonry units of bricks, blocks, manufactured stone, square dressed natural stone, and random rubble masonry." (Section 1 clause 1). Unlike the Australian Standard there is nothing in the scope clause that says the Standard only applies to masonry units laid in mortar. Notwithstanding this, similar to the Australian Standard, Section 1 clause 5 covering the design of unreinforced masonry states that:

> "*Where materials and methods are used that are not referred to in this British Standard, their use is not discouraged, provided that the materials conform to the requirements of the appropriate British Standards or other documents, 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 British Standard."*

Essentially the same words are written in BS 5628-2:2005 in Section 5 covering the design of reinforced masonry.

Mortarless masonry units are laid without mortar but this is the only difference between ***mortarless*** masonry and fully grouted hollow concrete block masonry. The ***mortarless*** masonry units are aggregate concrete units just like the units used in mortared masonry, and concrete core filling grout is used throughout just like fully grouted mortared masonry. The only real difference is the dry interface between each ***mortarless*** masonry unit and all neighboring masonry units (bed joints and perpends), and for the purposes of design this is treated as a raked mortar joint. On this basis it is most strongly considered there is no doubt that the BS 5628:2005 series of Standards can be appropriately applied to the design of ***mortarless*** masonry structures.

This is the approach taken in the design calculations used to prepare the design tables in Part 2 of this design manual.

It must be appreciated that ***mortarless*** masonry is not a new structural system. It is simply an alternative method of masonry construction that is different to the traditional method inasmuch as it does not make use of mortar to lay the masonry units and to bond them together. Another difference is that all ***mortarless*** masonry walls are always core filled (grouted) whereas traditional mortared masonry walls may be fully grouted, partially grouted or left ungrouted. Traditional mortared masonry walls are often ungrouted, and ungrouted walls are never as strong or as robust as fully grouted walls.

A finished ***mortarless*** masonry wall is essentially the same as any fully grouted hollow aggregate block wall. It is essentially a concrete wall in which masonry units are used as permanent formwork, and in which the masonry units also contribute to some extent to the total strength and robustness of the finished wall.

Note that BS 5628-1:2005 Section 2 clause 7 and BS 5628-2:2005 Section 6 clause 6.2 requires that aggregate concrete masonry units comply with the requirements of BS EN 771-3. It also specifically requires that any recycled materials used in masonry construction first be cleaned and conform to code recommendations for similar new materials.

1.3 Design objectives & general recommendations of BS 5628-1:2005 and BS 5628-2:2005

BS 5628-1:2005 Section 3 and BS 5628-2:2005 Section 7 set out the design objectives and general recommendations of unreinforced and reinforced masonry respectively.

1.3.1 Limit state design

BS 5628-1:2005 Clause 15 requires that the design of unreinforced masonry members be such that it is ensured there is an adequate margin of safety against the ultimate limit state being reached. It states that this is generally achieved by ensuring the **design strength** of a member is greater than or equal to the **design load**.

The **design strength** is defined as the characteristic strength divided by a partial safety factor for material strength, and the characteristic strength is defined as the value of the strength below which the probability of test results falling is not more than 5%.

The **design load** is defined as the characteristic load multiplied by a partial safety factor for loads (γ_f).

It is the responsibility of the designer to ensure there is an adequate margin of safety against the serviceability limit state being reached. With respect to cracking due to axially applied loads, it is deemed that an adequate margin of safety may be assumed to exist when the design satisfies the ultimate limit state.

BS 5628-2:2005 Clause 7.1.1 requires the same as BS 5628-1:2005 with respect to the ultimate limit state. It also requires that the serviceability limit state criteria are met, and that consideration be given to other aspects of serviceability such as fatigue.

BS 5628-2:2005 Clause 7.1.2 states that designers should give consideration as to whether the proportion of core fill is such that the recommendations of BS 8110 would be more appropriate than the recommendations of BS 5628-2:2005.

BS 5628-2:2005 Clause 7.1.2.2.1 requires that the deflections are not excessive, and the following recommendations are made:

- 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.
- 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 the lesser of span/500 or 20mm is recommended.

It is sated in this clause that when calculating deflections the design loads and the design properties of materials should be those recommended for the serviceability limit state, and it states that the stresses in the reinforcement may need to be lower than the recommended characteristic strengths in order to reduce deflection or control cracking.

In terms of cracking, the Standard states that cracking should not be such as to adversely affect the appearance or durability of the structure, and it states that the effects of temperature, creep and shrinkage will require the provision of movement joints or other precautions.

1.3.2 Stability

BS 5628-1:2005 Clause 16 requires that the designer responsible for the overall stability of the structure should also ensure the compatibility of the design and details of parts and components. It states that:

> *"To ensure a robust and stable design it will be necessary to consider the layout of the 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."*

It further states that:

> *"The design recommendations of section 4 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 (i.e. 0.015 G_k) above any level.*
>
> *b) Connections of the type indicated in Annex C (BS 5628-1:2005) should be provided as appropriate at floors and roofs."* (This is one of a number of mistakes discovered in the Standard. Annex D is clearly the Annex that should have been referred to.)

All walls constructed of ***mortarless*** masonry are fully grouted and they contain at least minimum amounts of vertical and horizontal reinforcement. As such structures built with ***mortarless*** masonry as load bearing walls are readily connected at junctions between walls and floor slabs etc. They therefore have far superior capability in transferring horizontal loads from floor diaphragms to shear walls and vice versa.

BS 5628-1:2005 Clause 16.3 requires that in addition to designing a structure to support loads arising from normal use, there should also be a reasonable probability that a structure will not collapse catastrophically under the effect of misuse or accident. It permits accidental damage from vehicles being addressed by the installation of bollards or earth banks.

BS 5628-1:2005 Clause 16.4 requires the designer to consider whether special precautions or temporary propping are necessary to ensure stability of the structure as a whole or of individual walls during construction.

BS 5628-2:2005 Clause 7.2 contains essentially the same requirements for stability as those outlined above, as would be expected. However a most important note is included at the end of clause 7.2.1 which states:

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

This is the provision that validates the design approach referred to above in 1.2 when discounting the dry joints between ***mortarless*** masonry units for the purposes of strength calculations.

There is a lot more detail provided in BS 5628-2:2005 Clause 7.2.3 with respect to designing for accidental forces, which is essentially as follows:

> *"All buildings should be robust against misuse and accidental forces that could arise.*
>
> *For Class 1 buildings no additional measures are likely to be necessary other than design to BS 5628-2:2005 and BS 5628-1:2005 as appropriate.*

> *For Class 2A buildings 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 5628-1:2005 gives guidance on meeting these provisions.*
>
> *For Class 2B buildings 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 load-bearing 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 load-bearing members cannot be accepted, such members should be designed as key elements. BS 5628-1:2005 gives guidance on meeting these provisions."*

Structures built with mortarless ***masonry*** load bearing walls fully tied to floor slabs have far greater capacity to cope with accidental damage. Reinforced mortarless ***masonry*** walls with continuity of reinforcement through floor slabs or full anchorage of wall reinforcement into floor slabs act in unison with the slabs to compensate for the accidental removal or damage on local load bearing elements. Slabs are capable of hanging from walls, and walls and slabs can behave as deep flanged wall beams to span greater distances and transfer loads to undamaged load bearing elements.

BS 5628-1:2005 provides the following detailed descriptions of the Classes of buildings:

Class 1 Building
- houses not exceeding four storeys;
- agricultural buildings;
- buildings into which people rarely go, provided no part of the building is closer than 1.5 times the building height to another building or to an area where people do go.

Class 2A Building
- five storey single occupancy houses;
- hotels not exceeding four storeys;
- flats, apartments and other residential buildings not exceeding four storeys;
- office buildings not exceeding four storeys;
- industrial buildings not exceeding three storeys;
- retailing premises not exceeding three storeys of less than 2,000 m^2 floor area in each storey;
- single storey educational buildings;
- all buildings not exceeding two storeys to which members of the public are admitted and which contain floor areas not exceeding 2,000 m^2 at each storey.

Class 2B Building
- hotels, flats, apartments and other residential buildings greater than four storeys but not exceeding 15 storeys;
- educational buildings greater than one storey but not exceeding 15 storeys;
- retailing premises greater than three storeys but not exceeding 15 storeys;
- hospitals not exceeding three storeys;
- office buildings greater than four storeys but not exceeding 15 storeys;
- all buildings to which members of the public are admitted which contain floors areas exceeding 2,000 m^2 but less than 5,000 m^2 at each storey;
- car parking not exceeding six storeys.

Clause 7.2.4 requires the designer to consider whether special precautions or temporary propping are necessary to ensure stability of the structure as a whole or of individual walls during construction. Tall lifts of ***mortarless*** construction may require temporary support to ensure the masonry stays in true horizontal and vertical alignment and to adequately cater for workplace safety.

1.3.3 Loads & Load Combinations

When designing in limit state (ultimate or serviceability) it is necessary to determine the actual loads that will or could be applied to the structure. These are called the characteristic loads. The characteristic loads are then multiplied by a partial safety factor (γ_f) which is different for both the ultimate and serviceability limit states, and which is varied to ensure that the worst action effect is being allowed for.

a) Characteristic Loads

G_k is the **characteristic dead load** which is the weight (dead load) of the structure complete with all finishes, fixtures and partitions.

Q_k is the **characteristic imposed load** which is the imposed load (live load) as defined in and calculated in accordance with BS 6399-1 and BS 6399-3.

W_k is the **characteristic wind load** the wind load and this should be calculated in accordance with BS 6399-2.

E_u is the **worst credible earth and water lateral loads** and this should be calculated in accordance with BS 8002.

BS 5628-1 also alerts designers to the need of considering other performance criteria. Clause 15 requires that designers also ensure there is an adequate margin of safety against a serviceability limit state being reached, and to consider the adverse effects on the structure including non-loadbearing elements arising from:

- Expansion or contraction due to temperature or moisture changes,
- Creep,
- Settlement or deformation of flexural members

b) Design Loads

For both unreinforced and reinforced masonry, the partial safety factors (γ_f) for each of the characteristic loads vary according to how the load is being combined, in order to produce a more severe design load:

Ultimate Strength Limit State design loads

The partial safety factors for each of the characteristic loads vary according to how the load is being combined in order to produce a more severe design load. Where alternative values are shown below, the value that produces a more severe design condition should be selected. (BS 5628-1:2005 clause 18):

a) Dead and imposed load
   i) design dead load = 0.9 G_k or 1.4 G_k
   ii) design imposed load = 1.6 Q_k
   iii) design earth & water load = 1.2 E_u

b) Dead and wind load
   i) design dead load = 0.9 G_k or 1.4 G_k
   ii) design wind load = 1.4 W_k
   iii) design earth & water load = 1.2 E_u

c) Dead, imposed and wind load
   i) design dead load = 1.2 G_k
   ii) design imposed load = 1.2 Q_k
   iii) design wind load = 1.2 W_k
   iv) design earth & water load = 1.2 E_u

d) Accidental damage
   i) design dead load = 0.95 G_k or 1.05 G_k
   ii) design imposed load = 0.35 Q_k generally,
   = 1.05 Q_k in the case of buildings used predominantly for storage, or where the imposed load is of a permanent nature.
   iii) design wind load = 0.35 W_k

Serviceability Limit State design loads

AS 5628-2 Clause 7.5.3 gives the following requirements for calculating serviceability limit state design loads:

a) Dead and imposed load
   j) design dead load = 1.0 G_k
   ii) design imposed load = 1.0 Q_k
   iii) design earth & water load = 1.0 E_u

b) Dead and wind load
   j) design dead load = 1.0 G_k
   ii) design wind load = 1.0 W_k
   iii) design earth & water load = 1.0 E_u

c) Dead, imposed and wind load
   i) design dead load = 1.0 G_k
   ii) design imposed load = 0.8 Q_k
   iii) design wind load = 0.8 W_k
   iv) design earth & water load = 1.0 E_u

Note again that each of the above load combinations should be considered when assessing short term deflections, and the load combination that gives the most severe condition should be adopted.

Long term thermal effects and creep movements should also be considered.

1.3.4 Structural properties

1.3.4.1 Characteristic compressive strength of *mortarless* masonry, f_k

a) Unreinforced masonry

BS 5628-1:2005 Clause 19 is devoted to the characteristic compressive strength of unreinforced masonry. Tables 2a) to 2h) tabulate values of f_k that correspond to different types of masonry units and different mortar strengths. For the purposes of determining the characteristic compressive strength of ***mortarless*** masonry using the tables, a mortar strength of 12 MPa is the most appropriate as it is the closest to the grout strength which is C16/20 minimum, and as extrapolation outside the table is not permitted.

For the purposes of this design manual, the compressive strength of the ***mortarless*** masonry units is either 15 MPa or 20 MPa.

In BS 5628-1:2005 Table 2c) is for ‘aggregate concrete blocks having a ratio of height to least horizontal dimension of 0.6’ while Table 2d) is for ‘aggregate concrete blocks having not more than 25% of formed voids and a ratio of height to least horizontal dimension of between 2 and 4.5.’

Clause 19.1.8 relates to concrete block walls having not more than 25% formed voids and having a ratio of height to least horizontal dimension of between 0.6 and 2.0. It states that the value of f_k should be obtained by interpolation between the values given in table 2c) and those given in Table 2d).

Clause 19.1.9 is for walls of hollow concrete blocks completely filled with insitu concrete. It states that the characteristic compressive strength should be obtained as if the blocks had not more than 25% formed voids, provided that the compressive strength of the masonry units is assessed on their net area, and provided that the 28-day cube strength of the core fill grout is not less than the compressive strength of the masonry unit. This refers back to Clause 19.1.8 and it results in the following values of f_k for the various ***mortarless*** masonry units fully grouted:

Mortarless **Masonry Units**	**Height of block / least horizontal dimension**	**Characteristic compressive strength** f_k (Mpa)	
		15 MPa blocks	**20 MPa blocks**
140	1.43	9.2	11.0
150	1.33	8.8	10.5
200	1.00	7.2	8.9

Note once more however that these values are conditional on the grout strength being not less than the block strength.

When the horizontal cross section of a wall or column is less than 0.2 m^2 then the characteristic compressive strength should be multiplied by the following factor (Clause 19.1.2):

(0.70 + 1.5A)

where A = the horizontal loaded cross sectional area of the wall or column in m^2.

b) Reinforced masonry

BS 5628-2:2005 Clause 7.4.1.1 is devoted to the characteristic compressive strength of reinforced masonry.

As with unreinforced ***mortarless*** masonry, for the purposes of this design manual the compressive strength of the masonry units is either 15 MPa or 20 MPa.

Table 3c is for ‘aggregate concrete blocks having a ratio of height to least horizontal dimension of 0.6.’

Table 3d is for ‘aggregate concrete blocks having not more than 25% of formed voids and a ratio of height to least horizontal dimension of between 2 and 4.5.’

Table 3e is for AAC blocks.

Table 3f is for ‘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 and 4.5.’

Surprisingly there is no Clause in BS 5628-2:2005 that provides guidance on how to calculate the characteristic compressive strength of fully grouted concrete block masonry. This is despite the fact that BS 5628-2:2005 is the reinforced masonry code.

For the purposes of this design manual therefore, the approach outlined in BS 5628-1:2005 has been adopted, only in this case Tables 3c and 3d have been used. The values of f_k were the same as those tabulated above for unreinforced masonry. This is as would be anticipated unless the reinforcement was included in the calculation, and as explained above this is not recommended as the reinforcement would be in compression and it should therefore be tied to prevent buckling. It is not realistic to attempt this in a typical reinforced ***mortarless*** wall.

1.3.4.2 Characteristic compressive strength of reinforced masonry in bending, f_k

BS 5628-2:2005 Clause 7.4.1.2 states that the values tabulated above for the characteristic compressive strength may also be used for the characteristic compressive strength of masonry in bending.

1.3.4.3 Characteristic shear strength, f_v (transverse shear)

BS 5628-2:2005 Clause 7.4.1.3.2b) provides the following formula for the calculation of characteristic shear strength:

$$f_v = 0.35 + 17.5\,p \quad \text{but not greater than 0.7 MPa, where } p = A_s / bd$$

For simply supported beams in which the clear span L does not exceed $7d$, f_v may be increased by the amount $2.75-0.25L/d$ provided that f_v is not taken as greater than 1.75MPa.

For cantilever retaining walls in which the length of the cantilever L does not exceed 6d+d/2, f_v may be increased by the amount $2.625-0.25L/d$ provided that f_v is not taken as greater than 1.75MPa.

1.3.4.4 Characteristic shear strength, f_v (in-plane shear or racking shear in shear walls)

BS 5628-2:2005 Clause 7.4.1.3.3 provides the following formula for the calculation of characteristic shear strength:

$$f_v = 0.35 + 0.6\,g_B$$

but not greater than 1.75 MPa, where g_B is the design load per unit area normal to the bed joint

Alternatively, for walls containing no shear reinforcement the characteristic shear strength f_v may be taken as 0.7MPa provided the ratio of the height to the length of the wall does not exceed 1.5.

1.3.4.5 Characteristic strength of reinforcing steel, f_y

BS 5628-2:2005 Clause 7.4.1.4 tabulates the characteristic tensile yield strength of reinforcing steel as 500 MPa for Grade 500 reinforcement conforming to BS 4449, and 235 MPA for plain dowel bars conforming to BS EN 10025-2 or BS EN 13877-3.

1.3.4.6 Characteristic anchorage bond strength, f_b

BS 5628-2:2005 Clause 7.4.1.6 refers to Table 5 for bond strength. For ribbed bars in reinforced hollow blockwork the recommended characteristic anchorage bond strength for C25/30 grout or stronger is 4.1 MPa.

1.3.4.7 Elastic Moduli

The short term elastic modulus of core filled concrete masonry $\boldsymbol{E_m = 900\, f_k}$ MPa.

The elastic modulus of the core fill grout (E_c) is as follows:

$\boldsymbol{E_c = 25{,}000}$ MPa for C20/25 Grout
$\boldsymbol{E_c = 26{,}000}$ MPa for C25/30 Grout
$\boldsymbol{E_c = 28{,}000}$ MPa for C32/40 Grout

The elastic modulus of steel reinforcement $\boldsymbol{E_s = 200{,}000}$ MPa.

1.3.5 Partial safety factors (γ)

The partial safety factors for load (γ_f) are given above for both the ultimate limit state and the serviceability limit state. These are introduced to take account of possible unusual increases in load beyond the characteristic load, inaccurate assessment of the effects of loading, unforeseen stress redistribution, and variations in dimensional accuracy of the built structure.

The design strength of a material or ancillary component is the characteristic strength by the appropriate partial safety factor.

BS 5628-1:2005 Clause 23 - When designing unreinforced masonry, the partial safety factor for material strength (γ_m) should be commensurate with the degree of control exercised both during manufacture of the ***mortarless*** masonry units and during construction. In the preparation of the design tables in Part 2 of this manual, it has been assumed that the category of the masonry units is Category I (refer Clauses 3.3 and 3.4), and that the category of construction control is normal (refer Clause 23.2.2). This results in partial safety factors as follows:

Compression γ_m = 3.1

Flexure γ_m = 3.0

(These could both reduce to as low as 2.5 with increased levels of control in both manufacture and construction.)

Shear γ_{mv} = 2.5 generally, or

= 1.25 when considering the possible effects of misuse or accident

Reinforced masonry - ultimate limit state

BS5628-2 Clause 7.5 - When designing reinforced masonry for ultimate limit state, the partial safety factors for material strengths are as follows:

Compression γ_{mm} = 2.0 for Category I masonry units

Flexure γ_{mm} = 2.0 for Category I masonry units

(Note that mortarless masonry units are considered Category I masonry units.)

Shear γ_{mv} = 2.0

Bond γ_{mb} = 1.5

Reinforcement γ_{ms} = 1.15

When designing for accidental loads or when considering the effects of localized damage, the values of γ_{mm} & γ_{mv} can be halved, and the values of γ_{mb} & γ_{ms} should then be taken as 1.0.

Reinforced masonry - serviceability limit state

When designing reinforced masonry for serviceability limit state, the partial safety factors for material strengths are as follows when calculating deflection or assessing the stresses or crack widths at any section within a structure:

Compression γ_{mm} = 1.5

Flexure γ_{mm} = 1.5

Reinforcement γ_{ms} = 1.0