4 Masonry elements

4.1 Structural design of masonry

The structural design of masonry is carried out in accordance with the guidance given in BS 5628 ‘Code of practice for use of masonry’. This is divided into the following three parts:

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 design of masonry dealt with in this manual is based on Part 1, which gives design recommendations for unreinforced masonry constructed of bricks, concrete blocks or natural stone.

When an unreinforced wall is found to be inadequate, consideration may be given to adding reinforcement or even prestressing the masonry. In such circumstances the calculations would be based upon the recommendations given in Part 2 of the code.

Guidance is given in the code on the design of walls to resist lateral loading, such as that resulting from wind loads, as well as vertical loading. However, this manual will concentrate on the design of vertically loaded walls.

4.2 Symbols

Those symbols used in BS 5628 that are relevant to this manual are as follows:

- $A$: horizontal cross-sectional area
- $b$: width of column
- $e_x$: eccentricity at top of a wall
- $f_k$: characteristic compressive strength of masonry
- $G_k$: characteristic dead load
- $g_A$: design vertical load per unit area
- $g_d$: design vertical dead load per unit area
- $h$: clear height of wall or column between lateral supports
- $h_{ef}$: effective height of wall or column
- $K$: stiffness coefficient
- $L$: length
- $l_{ef}$: effective length of wall
- $Q_k$: characteristic imposed load
- $t$: overall thickness of a wall or column
- $t_{ef}$: effective thickness of a wall or column
- $t_p$: thickness of a pier
- $t_i$: thickness of leaf 1 of a cavity wall
4.3 Definitions

The following definitions which are relevant to this manual have been abstracted from BS 5628 Part 1:

**Column** An isolated vertical load bearing member whose width is not more than four times its thickness, as illustrated in Figure 4.1.

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

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

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

**Load bearing walls** Walls primarily designed to carry an imposed vertical load in addition to their own weight.

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

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

**Slenderness ratio** The ratio of the effective height or effective length to the effective thickness.

**Structural units** Bricks or blocks, or square dressed natural stone.

**Single leaf wall** A wall of bricks or blocks laid to overlap in one or more directions and set solidly in mortar.

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

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

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

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

The fundamental properties of the individual materials that comprise a masonry wall are well understood and documented. Sadly, however, a designer’s intentions may sometimes be frustrated by a lack of understanding of their combined behaviour. To use masonry successfully the designer must select bricks or blocks of appropriate quality, choose suitable mortar, specify their use correctly and devise appropriate details.

It is pointed out in Part 1 of the code that wall thicknesses derived from strength considerations may be insufficient to satisfy other performance requirements. Reference should therefore be made to BS 5628 Part 3 for guidance on such matters as durability, fire resistance, thermal insulation, sound insulation, resistance to damp penetration and provision for thermal movement, together with material, component and workmanship specification matters.

The main constituent materials and components used in the construction of masonry walls are as follows:

(a) Bricks
(b) Blocks
(c) Mortar
(d) Wall ties
(e) Damp proof courses.

Each will now be discussed in more detail.

4.4.1 Bricks

Bricks are walling units not exceeding 337.5 mm in length, 225 mm in width and 112.5 mm in height. They are produced from a range of materials, such as clay, concrete and sometimes a mixture of lime and sand or crushed stone. The mixture types are referred to as either calcium silicate bricks or sand lime bricks.

The standard format of clay bricks is given in BS 3921 ‘Specification for clay bricks’ as $225 \times 112.5 \times 75$ mm. This includes an allowance for a $10$ mm mortar joint; thus the work size of the actual brick is $215 \times 102.5 \times 65$ mm.

Concrete bricks in accordance with BS 6073 Part 2 ‘Precast concrete masonry units’ may be within any of the format ranges indicated in Table 4.1, which is based on BS 6073 Table 2.

Calcium silicate bricks in accordance with BS 187 ‘Specification for calcium silicate (sand lime and flint lime) bricks’ have the same standard format as clay bricks.

Bricks can be classified in a number of ways with respect to their variety, type, quality and so on. However, for the purpose of this manual it will suffice to divide them into the following three general categories:

**Facing bricks** These are clay or concrete bricks manufactured to satisfy aesthetic requirements. They are available in a wide range of strengths, colours and textures.
Table 4.1 Format range of concrete bricks (based on BS 6073 Part 2 1981 Table 2)

<table>
<thead>
<tr>
<th>Work size of concrete bricks</th>
<th>Coordinating size of concrete bricks (including 10 mm mortar joints)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length × thickness × height</td>
<td>Length × thickness × height</td>
</tr>
<tr>
<td>290 × 90 × 90</td>
<td>300 × 100 × 100</td>
</tr>
<tr>
<td>215 × 103 × 65</td>
<td>225 × 113 × 75</td>
</tr>
<tr>
<td>190 × 90 × 90</td>
<td>200 × 100 × 100</td>
</tr>
<tr>
<td>190 × 90 × 65</td>
<td>200 × 100 × 75</td>
</tr>
</tbody>
</table>

Common bricks. These are clay or concrete bricks produced for general building work and not to provide an attractive appearance. The term ‘common’ covers a wide variety of bricks and is not a guide to structural quality. Many common bricks have excellent strength properties.

Engineering bricks. These are clay bricks produced with defined compressive strength qualities. They are available in two classes: engineering A and engineering B.

4.4.2 Blocks

Blocks are walling units that exceed in length, width or height the sizes specified for bricks. They are generally produced from concrete.

In accordance with BS 6073 ‘Precast concrete masonry units’ the purchaser of the blocks should specify their size from Table 1 in Part 2 of that standard, reproduced here as Table 4.2. To obtain the coordinating size of blockwork the nominal mortar joint, usually 10mm, should be added to the length and height dimensions given in the table; the thickness remains unchanged. It should be noted that not every manufacturer will produce the complete range of work sizes given in the table.

Table 4.2 Work sizes of blocks (BS 6073 Part 2 1981 Table 1)

| Length (mm) | Height (mm) | 60 | 75 | 90 | 100 | 115 | 125 | 140 | 150 | 175 | 190 | 200 | 215 | 220 | 225 | 250 |
|-------------|-------------|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 390         | 190         | ×  | ×  | ×  | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   |
| 440         | 140         | ×  | ×  | ×  | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   |
| 440         | 190         | ×  | ×  | ×  | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   |
| 440         | 215         | ×  | ×  | ×  | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   |
| 440         | 290         | ×  | ×  | ×  | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   |
| 590         | 140         | ×  | ×  | ×  | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   |
| 590         | 190         | ×  | ×  | ×  | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   |
| 590         | 215         | ×  | ×  | ×  | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   | ×   |
The types of block generally available are as follows:

**Facing blocks**  Blocks with a finish suitable to provide an attractive appearance.

**Ordinary or common blocks**  Blocks suitable for internal use or, if rendered, for external use.

**Solid blocks**  These are primarily voidless, having no formal holes or cavities other than those inherent in the block material.

**Hollow blocks**  These are blocks which have cavities passing right through the unit, but the volume of such cavities must not exceed 50 per cent of the total unit volume.

**Cellular blocks**  These are similar to hollow blocks, but the cavities are effectively closed at one end. They are laid with the closed end uppermost in the wall to provide a good bed for the next layer of mortar.

**Insulating blocks**  These are usually cellular blocks faced with polystyrene or having the cavities filled with UF foam or polystyrene to improve their thermal qualities.

### 4.4.3 Mortar

Whilst masonry walls may be constructed from bricks, blocks or stone, in each of these the mortar is the common factor. The mortar serves several purposes in the construction, and must satisfy a number of requirements in both the newly mixed and the hardened state. During construction, mortar should have good workability to enable efficient use by the bricklayer. It must spread easily so as to provide a level bed on which to align the masonry units of brick, block or stone. This in turn will ensure that the applied loads will be spread evenly over the bearing area of such units. When used with absorbent bricks it should retain moisture to avoid drying out and stiffening too quickly. Finally, it should harden in a reasonable time to prevent squeezing out under the pressure of the units laid above.

In the hardened state, mortar must be capable of transferring the stresses developed in the masonry units. Ideally, however, it should not be stronger than the masonry units themselves, so that any movement that occurs will be accommodated in the joints. This should ensure that any cracking that does develop will be in the mortar and not the masonry units.

Traditionally lime-sand mortars, relying on the loss of water and the action of carbonation to slowly gain strength, were employed for masonry construction. Whilst these offered excellent workability, their slow construction rate led to the adoption of cement mortars. The addition of cement promotes a faster gain of strength, resulting in more rapid construction. Lime may still be included in the mix for workability, giving cement-lime-sand mortar. Ready mixed lime with sand may be obtained in specified proportions to which the cement is then added on site prior to use. Plasticized mortar is produced by replacing the lime...
with a proprietary plasticizer additive to provide the workability, giving a mix of cement and sand with plasticizer.

Mortar to which the cement has been added should generally be used within two hours of mixing. Ready mixed retarded mortars are available which contain a retarding agent to delay the set and prolong the working life of the mortar. These should not be used without the prior approval of the designer.

BS 5628 Part 1 Table 1 gives requirements for mortar designations in relation to their constituent proportions and compressive strength; this is reproduced here as Table 4.3. In general the lowest grade of mortar practicable should be used. Thus for general purpose masonry construction a 1 : 1 : 6 cement : lime : sand mortar will be sufficient. For high strength load bearing masonry a 1 : 1½ : 3 cement : lime : sand mortar is more appropriate. For reinforced masonry a mix not weaker than 1 : 1½ : 4½ cement : lime : sand should normally be specified.

The bond of the mortar with the masonry units is equally as important as its compressive strength. Adequate bond depends on a number of factors such as sand quality, the type and absorption rate of the masonry units at the time of laying, and attention to curing.

Ready mixed lime with sand for mortar should comply with the requirements of BS 4721 ‘Specification for ready mixed building mortars’. The mixing and use of mortars should be in accordance with the recommendations given in BS 5628 Part 3.

### 4.4.4 Wall ties

The two leaves of a cavity wall should be tied together by metal wall ties embedded at least 50 mm into the horizontal mortar joints. Their overall length should be chosen to suit the cavity width.

The ties should comply with the requirements of BS 1243 ‘Metal ties for cavity wall construction’. This code gives recommendations for three types of tie: the wire butterfly, the double triangle and the vertical twist. Ties can be manufactured from either galvanized or stainless steel.

The traditional butterfly tie has limited structural strength and is usually confined to domestic construction. Vertical twist wall ties are structurally the most substantial and are suitable for the most highly stressed load bearing cavity walls. Double triangle wall ties are less substantial than the vertical twist but better than the butterfly tie.

The minimum spacing and the selection of wall ties is dealt with in BS 5628 Part 3 Table 9, reproduced here as Table 4.4. Additional ties should be provided adjacent to wall openings in accordance with the recommendations given in the standard.

### 4.4.5 Damp proof courses

Whilst the main purpose of a damp proof course (DPC) is to provide a moisture barrier, in structural terms it must not squeeze out under vertical load or induce sliding under horizontal loading.
<table>
<thead>
<tr>
<th>Properties</th>
<th>Mortar designation</th>
<th>Type of mortar (proportion by volume)</th>
<th>Mean compressive strength at 28 days (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cement:lime:sand</td>
<td>Masonry cement:sand</td>
</tr>
<tr>
<td>Increasing strength to accommodate movement, e.g. due to settlement, temperature and moisture changes</td>
<td>(i) 1:0 to 1:3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ii) 1:0 1/4 to 4 1/2</td>
<td>1:2 1/2 to 3 1/2</td>
<td>1:3 to 4</td>
<td>6.5</td>
</tr>
<tr>
<td>(iii) 1:1.5 to 6</td>
<td>1:4 to 5</td>
<td>1:5 to 6</td>
<td>3.6</td>
</tr>
<tr>
<td>(iv) 1:2.8 to 9</td>
<td>1:5 1/2 to 6 1/2</td>
<td>1:7 to 8</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Increasing resistance to frost attack during construction

Improvement in bond and consequent resistance to rain penetration
Table 4.4 Wall ties (BS 5628 Part 3 1985 Table 9)

(a) Spacing of ties

<table>
<thead>
<tr>
<th>Least leaf thickness (mm)</th>
<th>Type of tie</th>
<th>Cavity width (mm)</th>
<th>Equivalent no. of ties per square metre</th>
<th>Spacing of ties (mm) Horizontally</th>
<th>Vertically</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 to 90</td>
<td>All</td>
<td>50 to 75</td>
<td>4.9</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>90 or more</td>
<td>See table (b)</td>
<td>50 to 150</td>
<td>2.5</td>
<td>900</td>
<td>450</td>
</tr>
</tbody>
</table>

(b) Selection of ties

<table>
<thead>
<tr>
<th>Type of tie in BS 1243</th>
<th>Cavity width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing strength</td>
<td>Increasing flexibility and sound insulation</td>
</tr>
<tr>
<td></td>
<td>Vertical twist</td>
</tr>
<tr>
<td></td>
<td>Double triangle</td>
</tr>
<tr>
<td></td>
<td>Butterfly</td>
</tr>
</tbody>
</table>

A DPC can be made from a wide variety of materials, and therefore the choice should be based on the required performance in relation to the known behaviour of the materials. Advice on the physical properties and performance of DPC materials is given in BS 5628 Part 3.

4.5 Design philosophy

The design approach employed in BS 5628 is based on limit state philosophy. In the context of load bearing masonry its objective is to ensure an acceptable probability that the ultimate limit state will not be exceeded. Thus for a masonry member, which will be either a wall or a column,

\[
\text{Ultimate design strength} \geq \text{ultimate design load}
\]

4.6 Safety factors

As previously explained in relation to concrete design, partial safety factors are applied separately to both the loads and the material stresses in limit state design.

4.7 Loads

The basic or characteristic load is adjusted by a partial safety factor to arrive at the ultimate design load acting on a wall.

4.7.1 Characteristic loads

The characteristic loads applicable to masonry design are the same as those defined for concrete design:

Characteristic dead load \(G_k\) The weight of the structure complete with finishes, fixtures and partitions, obtained from BS 648 ‘Schedule of weights of building materials’. 
Characteristic imposed load $Q_k$ The live load produced by the occupants and usage of the building, obtained from BS 6399 ‘Design loading for buildings’, Part 1 for floors or Part 3 for roofs.

Characteristic wind load $W_k$ The wind load acting on the structure, obtained from CP 3 Chapter V Part 2 ‘Wind loads’, eventually to become Part 2 of BS 6399.

4.7.2 Partial safety factors for load

As mentioned in relation to concrete design, the applied load may be greater in practice than the characteristic load for a number of reasons. To allow for such eventualities the respective characteristic loads are multiplied by a partial safety factor $\gamma_l$ to give the ultimate design load appropriate to the load combination being considered. That is,

$$\text{Ultimate design load} = \gamma_l \times \text{characteristic load}$$

Values of $\gamma_l$ are given in BS 5628 Part 1 for the following load combinations:

(a) Dead and imposed load
(b) Dead and wind load
(c) Dead, imposed and wind load
(d) Accidental damage.

Those for the dead and imposed load combination which would usually apply to vertically loaded walls are as follows:

Design dead load: $\gamma_l = 1.4G_k$
Design imposed load: $\gamma_l = 1.6Q_k$

4.7.3 Ultimate design load

The ultimate design load acting vertically on a wall will be the summation of the relevant characteristic load combinations multiplied by their respective partial safety factors. Therefore the ultimate design load for the dead plus imposed load combination on a vertically loaded wall would be expressed as follows:

$$\text{Ultimate design load dead + imposed} = \gamma_l G_k + \gamma_l Q_k = 1.4G_k + 1.6Q_k$$

4.8 Material properties

Like concrete, the strength of masonry materials in an actual wall can differ from their specified strength for a number of reasons. The characteristic strength $f_k$ of the masonry units is therefore divided by a partial safety factor $\gamma_u$ to arrive at the ultimate design strength of the units. In
relation to vertically loaded walls it is the compressive strength we are usually concerned with.

### 4.8.1 Characteristic compressive strength of masonry units

The characteristic compressive strength $f_k$ for various masonry units is given in BS 5628 Part 1 Table 2a–d, reproduced here as Table 4.5a–d. It depends on the basic compressive strength of particular masonry units in conjunction with the designated mortar mix.

<table>
<thead>
<tr>
<th>Table 4.5</th>
<th>Characteristic compressive strength of masonry $f_k$ (N/mm²) (BS 5628 Part 1 1978 Table 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Constructed with standard format bricks</td>
<td>(b) Constructed with blocks having a ratio of height to least horizontal dimension of 0.6</td>
</tr>
</tbody>
</table>

#### (a) Constructed with standard format bricks

<table>
<thead>
<tr>
<th>Mortar designation</th>
<th>Compressive strength of unit (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5  10  15  20  27.5  35  50  70  100</td>
</tr>
<tr>
<td>(i)</td>
<td>2.5  4.4  6.0  7.4  9.2  11.4  15.0  19.2  24.0</td>
</tr>
<tr>
<td>(ii)</td>
<td>2.5  4.2  5.3  6.4  7.9  9.4  12.2  15.1  18.2</td>
</tr>
<tr>
<td>(iii)</td>
<td>2.5  4.1  5.0  5.8  7.1  8.5  10.6  13.1  15.5</td>
</tr>
<tr>
<td>(iv)</td>
<td>2.2  3.5  4.4  5.2  6.2  7.3  9.0  10.8  12.7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Mortar designation</th>
<th>Compressive strength of unit (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.8  3.5  5.0  7.0  10  15  20  35 or greater</td>
</tr>
<tr>
<td>(i)</td>
<td>1.4  1.7  2.5  3.4  4.4  6.0  7.4  11.4</td>
</tr>
<tr>
<td>(ii)</td>
<td>1.4  1.7  2.5  3.2  4.2  5.3  6.4  9.4</td>
</tr>
<tr>
<td>(iii)</td>
<td>1.4  1.7  2.5  3.2  4.1  5.0  5.8  8.5</td>
</tr>
<tr>
<td>(iv)</td>
<td>1.4  1.7  2.2  2.8  3.5  4.4  5.2  7.3</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Mortar designation</th>
<th>Compressive strength of unit (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.8  3.5  5.0  7.0  10  15  20  35 or greater</td>
</tr>
<tr>
<td>(i)</td>
<td>2.8  3.5  5.0  5.7  6.1  6.8  7.5  11.4</td>
</tr>
<tr>
<td>(ii)</td>
<td>2.8  3.5  5.0  5.5  5.7  6.1  6.5  9.4</td>
</tr>
<tr>
<td>(iii)</td>
<td>2.8  3.5  5.0  5.4  5.5  5.7  5.9  8.5</td>
</tr>
<tr>
<td>(iv)</td>
<td>2.8  3.4  4.4  4.8  4.9  5.1  5.3  7.3</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Mortar designation</th>
<th>Compressive strength of unit (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.8  3.5  5.0  6.8  8.8  12.0  14.8  22.8</td>
</tr>
<tr>
<td>(i)</td>
<td>2.8  3.5  5.0  6.4  8.4  10.6  12.8  18.8</td>
</tr>
<tr>
<td>(ii)</td>
<td>2.8  3.5  5.0  6.4  8.2  10.0  11.6  17.0</td>
</tr>
<tr>
<td>(iii)</td>
<td>2.8  3.5  4.4  5.6  7.0  8.8  10.4  14.6</td>
</tr>
</tbody>
</table>

The basic compressive strength of the individual masonry units given in each part of the table is based upon tests which take into account the presence of any voids or perforations in the unit. Thus the structural calculations for a wall constructed from either solid or hollow units can be made in exactly the same way.

The designation of mortar types is given in BS 5628 Part 1 Table 1, reproduced earlier as Table 4.3.

To obtain the respective value of $f_k$, reference should be made to the relevant part of Table 4.5 as explained in the following sections.

#### Bricks

Generally for bricks of standard dimensional format, $f_k$ is obtained directly from Table 4.5a.
However, if a solid wall or the loaded inner leaf of a cavity wall is constructed with standard format bricks, and the wall or leaf thickness is equal to the width of a single brick, then the value of \( f_k \) from Table 4.5a may be multiplied by 1.15. This increase in the compressive strength is based upon tests which have shown that such walls are stronger owing to the absence of vertical mortar joints within the wall thickness. It should be noted that this factor of 1.15 does not apply to cavity walls where both leaves are loaded.

**Blocks**

When a wall is constructed with blockwork, the increased size of the individual masonry units means that there are fewer joints compared with an equivalent wall of standard format bricks. Fewer joints result in a stronger wall, and hence the characteristic compressive strength of blockwork is influenced by the shape of the individual units.

The shape factor of a block is obtained by dividing its height by its lesser horizontal dimension. For example, for the block shown in Figure 4.2,

\[
\text{Shape factor} = \frac{\text{height}}{\text{lesser horizontal dimension}} = \frac{200}{100} = 2
\]

**Figure 4.2 Dimensions of a typical block**

Depending on the shape factor and the type of block, \( f_k \) is then obtained from the relevant part of Table 4.5:

(a) For hollow and solid blocks having a shape factor not greater than 0.6, \( f_k \) is obtained directly from Table 4.5b.

(b) For hollow blocks having a shape factor between 2.0 and 4.0, \( f_k \) is obtained directly from Table 4.5c.

(c) For solid blocks having a shape factor between 2.0 and 4.0, \( f_k \) is obtained directly from Table 4.5d.
In certain circumstances interpolation between the tables may be necessary as follows:

(d) For hollow block walls having a shape factor between 0.6 and 2.0, \( f_k \) is obtained by interpolation between the values in Table 4.5b and Table 4.5c.

(e) For solid block walls having a shape factor between 0.6 and 2.0, \( f_k \) is obtained by interpolation between the values in Table 4.5b and 4.5d.

**Natural stone**

For natural stone, \( f_k \) should generally be taken as that for solid concrete blocks of equivalent strength.

**Random rubble masonry**

For random rubble masonry \( f_k \) should be taken as 75 per cent of that for the corresponding strength of natural stone.

**Modification to characteristic strength for shell bedding**

Hollow concrete blocks are sometimes laid on a mortar bed consisting of two strips along the outer edges of the block. This is termed ‘shell bedding’ and is illustrated in Figure 4.3.

![Figure 4.3 Shell bedding to hollow blocks](image)

If such a construction procedure is to be permitted then the design calculations should be adjusted accordingly by reducing the characteristic strength. This is done by multiplying the value of \( f_k \) obtained from either Table 4.5b or Table 4.5c by a factor equal to the bedded area divided by the net area of the block:

\[
\text{Shell bedded } f_k = f_k \text{ from table} \times \frac{\text{bedded area}}{\text{net area of block}}
\]
Modification to characteristic strength for small plan areas

When the horizontal cross-sectional area of a loaded wall or column is less than 0.2 m², the value of \( f_k \) obtained from the tables should be multiplied by the following modification factor:

\[
\text{Small plan area modification factor} = 0.7 + 1.5A
\]

where \( A \) is the loaded horizontal cross-sectional area of the wall or column (m²).

4.8.2 Partial safety factors for materials

The partial safety factor \( \gamma_m \) for materials in masonry design is obtained from BS 5628 Part 1 Table 4, reproduced here as Table 4.6.

<table>
<thead>
<tr>
<th>Category of manufacturing control of structural units</th>
<th>Category of construction control</th>
<th>Normal</th>
<th>Special</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special</td>
<td>2.5</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>2.8</td>
<td>3.5</td>
<td></td>
</tr>
</tbody>
</table>

The factor is related to the standard of quality control exercised during both the manufacture and construction stages. In each case two levels of control are recognized, normal category or special category, and these apply as follows.

Normal category of manufacturing control

This should be assumed when the materials to be supplied will simply comply with the compressive strength requirements of the relevant British Standard.

Special category of manufacturing control

This may be assumed when the manufacturer agrees to supply materials that comply with a specified strength limit. Furthermore, the supplier must operate a quality control system to provide evidence that such a limit is being consistently met.

Normal category of construction control

This should be assumed when the standard of workmanship is in accordance with the recommendations given in BS 5628 Part 3, and appropriate
4.8 Factors influencing the load bearing capacity of masonry members

4.9 Factors influencing the load bearing capacity of masonry members

There are a number of interrelated factors that influence the load bearing capacity of masonry walls and columns.

- (a) Slenderness ratio
- (b) Lateral support
- (c) Effective height $h_{ef}$
- (d) Effective length $l_{ef}$
- (e) Effective thickness $t_{ef}$
- (f) Capacity reduction factor for slenderness.

The principal factor is the slenderness ratio; all the others are related to it. Let us therefore consider the effect of each factor on walls and columns.
4.9.1 Slenderness ratio

Vertically loaded walls and columns can fail by crushing due to direct compression or, if they are slender, by lateral buckling. A measure of the tendency to fail by buckling before crushing is the slenderness ratio (SR).

In accordance with BS 5628 the slenderness ratio of a wall should be calculated as follows:

$$SR_{wall} = \frac{\text{effective height}}{\text{effective thickness}} \quad \text{or} \quad \frac{\text{effective length}}{\text{effective thickness}}$$

$$= \frac{h_{ef}}{t_{ef}} \quad \text{or} \quad \frac{l_{ef}}{t_{ef}}$$

The effective length is only used when this would give a lesser slenderness ratio value.

For masonry columns the effective height is always used when calculating the slenderness ratio:

$$SR_{column} = \frac{\text{effective height}}{\text{effective thickness}} = \frac{h_{ef}}{t_{ef}}$$

The slenderness ratio of a member should generally not exceed 27. However, should the thickness of a wall be less than 90 mm, in a building of two storeys, then the slenderness ratio value must not exceed 20.

4.9.2 Lateral support

The effective height and the effective length are influenced by the degree of any lateral support that may be provided. With respect to the height this will be provided in the horizontal direction by the floors or roof. In the case of the length it will be provided in the vertical direction by any intersecting or return walls.

BS 5628 defines the degree of resistance to lateral movement as either ‘simple’ or ‘enhanced’ depending on the construction details adopted. Examples of horizontal lateral support that only provide simple resistance are illustrated in Figure 4.4; those capable of providing enhanced resis-

![Figure 4.4 Examples of horizontal lateral support only capable of providing simple resistance](image-url)
tance are illustrated in Figure 4.5. Similarly, examples of vertical lateral support that only provide simple resistance are shown in Figure 4.6; those that provide enhanced resistance are shown in Figure 4.7.

**Figure 4.5**  Examples of horizontal lateral support capable of providing enhanced resistance

**Figure 4.6**  Examples of vertical lateral support only capable of providing simple resistance

**Figure 4.7**  Examples of vertical lateral support capable of providing enhanced resistance
**4.9.3 Effective height**

The effective height $h_{ef}$ depends on the degree of horizontal lateral support provided and may be defined as follows for walls and columns.

For walls it should be taken as

(a) 0.75 times the clear distance between lateral supports which provide enhanced resistance, as depicted in Figure 4.8a; or

(b) The clear distance between lateral supports which only provide simple resistance, as depicted in Figure 4.8b.

For columns it should be taken as

(a) The distance between lateral supports in respect of the direction in which lateral support is provided, shown as $h_{ef} = h$ in Figure 4.9a and b; or

(b) Twice the height of the column in respect of a direction in which lateral support is not provided, shown as $h_{ef} = 2h$ in Figure 4.9b.

It should be noted that BS 5628 suggests that lateral support to columns should preferably be provided in both horizontal directions.

**4.9.4 Effective length**

The effective length $l_{ef}$ is a consideration that only applies to walls, and depends on the degree of vertical lateral support provided. It may be taken as

(a) 0.75 times the clear distance between lateral supports which provide enhanced resistance, as illustrated in Figure 4.10a
(b) Twice the distance between a lateral support which provides enhanced resistance and a free edge, as illustrated in Figure 4.10b.

(c) The clear distance between lateral supports which only provided simple resistance, as illustrated in Figure 4.10c.

(d) 2.5 times the distance between a lateral support which provides simple resistance and a free edge, as illustrated in Figure 4.10d.

It should be appreciated that the slenderness ratio of a wall without any vertical lateral supports must be based upon its effective height.
4.9.5 Effective thickness

The effective thickness \( t_{ef} \) parameters for walls and columns are illustrated in Figure 2 of BS 5628. They are basically divided into two categories in relation to whether stiffening piers or intersecting walls are present or not.

**Category 1: walls and columns not stiffened by piers or intersecting walls**

- (a) Columns as shown in Figure 4.11: \( t_{ef} = t \) or \( b \) depending in which direction the slenderness is being considered.
- (b) Single leaf walls as shown in Figure 4.12: \( t_{ef} = t \) the actual thickness \( t \).
- (c) Cavity walls as shown in Figure 4.13: \( t_{ef} = \) the greatest of \( 2(t_1 + t_2)/3 \) or \( t_1 \) or \( t_2 \).

**Category 2: walls stiffened by piers or intersecting walls**

- (a) Single leaf wall with piers shown in Figure 4.14: \( t_{ef} = tK \), where \( K \) is the appropriate stiffness coefficient from BS 5628 Table 5, reproduced here as Table 4.7.
- (b) Cavity wall with piers as shown in Figure 4.15: \( t_{ef} = \) the greatest of \( 2(t_1 + Kt_2)/3 \) or \( t_1 \) or \( Kt_2 \), where \( K \) is again the appropriate stiffness coefficient from Table 4.7.

For the purpose of category 2 an intersecting wall may be assumed to be equivalent to a pier with the dimensions shown in Figure 4.16.
Table 4.7  Stiffness coefficient for walls stiffened by piers (BS 5628 Part 1 1978 Table 5)

<table>
<thead>
<tr>
<th>Ratio of pier spacing (centre to centre) to pier width</th>
<th>Ratio $t_p/t$ of pier thickness to actual thickness of wall to which it is bonded</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1.0 1.4 2.0</td>
</tr>
<tr>
<td>10</td>
<td>1.0 1.2 1.4</td>
</tr>
<tr>
<td>20</td>
<td>1.0 1.0 1.0</td>
</tr>
</tbody>
</table>

Note: Linear interpolation between the values given in table is permissible, but not extrapolation outside the limits given.

**Figure 4.15**  Plan on a cavity wall with piers

**Figure 4.16**  Plan on an intersecting wall considered as an equivalent pier

### 4.9.6 Capacity reduction factor for slenderness

As stated earlier, the slenderness ratio is a measure of the tendency of a wall or column to fail by buckling before crushing. To take this into account, the design strength of a wall or column is reduced using a capa-
city reduction factor $\beta$ which is based upon the slenderness ratio value. It is obtained from BS 5628 Part 1 Table 7, reproduced here as Table 4.8.

A load applied eccentrically will increase the tendency for a wall or column to buckle and reduce the load capacity further. This is catered for by using a modified capacity reduction factor $\beta$ from Table 4.8 which depends on the ratio of the eccentricity $e_x$ to the member thickness.

Table 4.8  Capacity reduction factor $\beta$ (BS 5628 Part 1 1978 Table 7)

<table>
<thead>
<tr>
<th>Slenderness ratio $h_{ef}/t_{ef}$</th>
<th>Eccentricity at top of wall $e_x$ up to 0.05$t$ (see note 1)</th>
<th>0.1$t$</th>
<th>0.2$t$</th>
<th>0.3$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.00</td>
<td>0.88</td>
<td>0.66</td>
<td>0.44</td>
</tr>
<tr>
<td>6</td>
<td>1.00</td>
<td>0.88</td>
<td>0.66</td>
<td>0.44</td>
</tr>
<tr>
<td>8</td>
<td>1.00</td>
<td>0.88</td>
<td>0.66</td>
<td>0.44</td>
</tr>
<tr>
<td>10</td>
<td>0.97</td>
<td>0.88</td>
<td>0.66</td>
<td>0.44</td>
</tr>
<tr>
<td>12</td>
<td>0.93</td>
<td>0.87</td>
<td>0.66</td>
<td>0.44</td>
</tr>
<tr>
<td>14</td>
<td>0.89</td>
<td>0.83</td>
<td>0.66</td>
<td>0.44</td>
</tr>
<tr>
<td>16</td>
<td>0.83</td>
<td>0.77</td>
<td>0.64</td>
<td>0.44</td>
</tr>
<tr>
<td>18</td>
<td>0.77</td>
<td>0.70</td>
<td>0.57</td>
<td>0.44</td>
</tr>
<tr>
<td>20</td>
<td>0.70</td>
<td>0.64</td>
<td>0.51</td>
<td>0.37</td>
</tr>
<tr>
<td>22</td>
<td>0.62</td>
<td>0.56</td>
<td>0.43</td>
<td>0.30</td>
</tr>
<tr>
<td>24</td>
<td>0.53</td>
<td>0.47</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>0.45</td>
<td>0.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>0.40</td>
<td>0.33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note 1: It is not necessary to consider the effects of eccentricities up to and including 0.05$t$.

Note 2: Linear interpolation between eccentricities and slenderness ratios is permitted.

Note 3: The derivation of $\beta$ is given in Appendix B of BS 5628.

Whilst ideally the actual eccentricity should be calculated, BS 5628 allows it to be assumed at the discretion of the designer. Thus for a wall supporting a single floor or roof it may be assumed that the load will act at one-third of the bearing length from the edge of the supporting wall or leaf, as illustrated in Figure 4.17. When a floor of uniform thickness is continuous over a supporting wall, each span of the floor may be taken as being supported on half the total bearing area, as shown in Figure 4.18.

**Figure 4.17**  Assumed load eccentricity from a single floor or roof spanning on to a wall

**Figure 4.18**  Assumed load eccentricity from a floor or roof continuous over a wall
Where joist hangers are used the resultant load should be assumed to be applied at a distance of 25 mm from the face of the wall, as shown in Figure 4.19.

**Figure 4.19** Assumed load eccentricity from joist hangers

### 4.10 Vertical load resistance

The design vertical resistance of a wall per unit length is given by the following expression:

\[
\text{Vertical design strength per unit length of wall} = \frac{\beta tf_{k}}{\gamma_{m}} \quad (4.1)
\]

where

- $\beta$ is the capacity reduction factor from Table 4.8
- $f_{k}$ is the characteristic strength of masonry units from the appropriate part of Table 4.5
- $\gamma_{m}$ is the material partial safety factor from Table 4.6
- $t$ is the actual thickness of the leaf or wall

For a rectangular masonry column the design vertical load resistance is given by the following expression:

\[
\text{Vertical design strength of column} = \frac{\beta bt f_{k}}{\gamma_{m}} \quad (4.2)
\]

where $b$ is the width of the column, $t$ is the thickness of the column, and the other symbols are the same as those defined after expression 4.1 for walls.

The design vertical load resistance of a cavity wall or column is determined in relation to how the vertical load is applied. When the load acts on the centroid of the two leaves (Figure 4.20a) it should be replaced by two statically equivalent axial loads acting on each of the leaves (Figure 4.20b). Each leaf should then be designed to resist the equivalent
axial load it supports using the appropriate expression 4.1 or 4.2; the effective thickness of the wall for the purpose of obtaining the capacity reduction factor from Table 4.8 is that of the cavity wall or column.

The load from a roof or floor is often only supported by one leaf of a cavity wall, as shown in Figure 4.21. Then the design strength should be calculated using the thickness of that leaf alone in the relevant expression 4.1 or 4.2. The effective thickness used for obtaining the capacity reduction factor is again that of the cavity wall, thus taking into account the stiffening effect of the other leaf.

The general procedure for determining the vertical design strength of a wall or column may be summarized as follows.

4.10.1 Design summary for a vertically loaded wall or column

(a) Calculate the slenderness ratio for the wall or column under consideration.
(b) Obtain the capacity reduction factor $\beta$ from Table 4.8 corresponding to the slenderness ratio and taking into account any eccentricity of loading.
(c) Obtain the characteristic compressive strength $f_k$ of the masonry units from the relevant part of Table 4.5, adjusting if necessary for the plan area or shell bedding.
(d) Select the material partial safety factor $\gamma_m$ from Table 4.6 in relation to the standard of quality control that will be exercised.
(e) Calculate the vertical load resistance using expression 4.1 for walls or expression 4.2 for columns.

Whilst following this procedure, particular care needs to be exercised by the designer to ensure that all the factors that can influence the slenderness ratio are taken into consideration. Let us therefore look at a number of examples using this procedure which attempt to highlight those various factors.

Example 4.1

A 102.5 mm thick single skin brick wall, as shown in Figure 4.22, is built between the concrete floors of a multi-storey building. It supports an ultimate axial load,
including an allowance for the self-weight, of 250 kN per metre run. What brick and mortar strengths are required if normal manufacturing and construction controls apply and the wall is first 10 m long and secondly only 1 m long?

**Wall 10 m long**

Since the wall in this instance is not provided with any vertical lateral supports along its 10 m length, the slenderness ratio should be based upon its effective height. Furthermore, as the concrete floor is continuous over the wall, by reference to Figure 4.5 enhanced lateral resistance will be provided in the horizontal direction.

The effective height of the wall \( h_{ef} = 0.75h = 0.75 \times 3000 = 2250 \) mm, and the effective thickness of a solid wall is the actual thickness of 102.5 mm. Thus the slenderness ratio is given by

\[
SR = \frac{h_{ef}}{t_{ef}} = \frac{2250}{102.5} = 21.95 < 27
\]

Thus the slenderness ratio is acceptable. From Table 4.8, the capacity reduction factor \( \beta \) is 0.62.

Since the wall is 10 m long, the plan area is 10 \( \times \) 0.1025 = 1.025 m\(^2\). This is greater than 0.2 m\(^2\) and therefore the plan area reduction factor does not apply.

Now the ultimate vertical load is 250 kN per metre run or 250 N per millimetre run. The expression for the vertical design strength of a wall is \( \frac{b_t f_k}{m} \). Therefore

\[
250 = \frac{BF_k}{\gamma_m}
\]

The material partial safety factor \( \gamma_m \) is selected from Table 4.6 in relation to the standard of manufacture and construction control. In this instance it is normal for both manufacture and construction, and \( \gamma_m \) will therefore be 3.5. Furthermore, since the thickness of the wall is equal to the width of a single brick, the value of \( f_k \) may be multiplied by 1.15. Hence

\[
f_k \text{ required} = \frac{250 \gamma_m}{\beta t \times 1.15} = \frac{250 \times 3.5}{0.62 \times 102.5 \times 1.15} = 11.97 \text{ N/mm}^2
\]

Comparing this value with the characteristic strength of bricks given in Table 4.5a, suitable bricks and mortar can be chosen:

Use 50 N/mm\(^2\) bricks in grade (ii) mortar (\( f_k = 12.2 \) N/mm\(^2\)).

**Wall 1 m long**

In this instance the plan area of the wall is 1 \( \times \) 0.1025 = 0.1025 m\(^2\). This is less than 0.2 m\(^2\), and hence the small plan area modification factor should be applied:

Modification factor = \( (0.7 + 1.5A) = (0.7 + 1.5 \times 0.1025) = 0.854 \)
The characteristic strength $f_k$ obtained from Table 4.5a should be multiplied by this factor in addition to the single skin factor of 1.15. Thus

$$250 \text{ N per mm run} = \frac{\beta f_k \times 1.15 \times 0.854}{\gamma_m}$$

from which

$$f_k \text{ required} = \frac{250\gamma_m}{\beta \times 1.15 \times 0.854} = \frac{250 	imes 3.5}{0.62 \times 102.5 \times 1.15 \times 0.854} = 14.02 \text{ N/mm}^2$$

Again by reference to Table 4.5a:

Use 50 N/mm$^2$ bricks in grade (i) mortar ($f_k = 15$ N/mm$^2$), or use 70 N/mm$^2$ bricks in grade (ii) mortar ($f_k = 15.1$ N/mm$^2$).

**Example 4.2**

A single skin wall constructed from 390 mm long $\times$ 190 mm high $\times$ 100 mm thick solid concrete blocks is built between concrete floors as shown in Figure 4.23. The ultimate axial load carried by the wall, including an allowance for the self-weight, is 125 kN per metre run. If the wall is 5 m long, what block and mortar strengths are required if special manufacturing control and normal construction control will apply?

Since there are no intersecting walls the effective height will govern the slenderness. The effective height $h_{ef} = 0.75h = 0.75 \times 2500 = 1875$ mm, and the effective thickness $t_{ef}$ is the actual thickness of 100 mm. Thus

$$\text{SR} = \frac{h_{ef}}{t_{ef}} = \frac{1875}{100} = 18.75 < 27$$

Thus the slenderness ratio is acceptable. By interpolation from Table 4.8, the capacity reduction factor $\beta$ is 0.74.

The plan area of the 5 m long wall is $5 \times 0.1 = 0.5 \text{ m}^2$. This is greater than 0.2 m$^2$ and therefore the plan area reduction factor does not apply. Furthermore, it should be appreciated that the single skin factor used for the brick wall in Example 4.1 does not apply to walls constructed from blocks.

The vertical design strength is $\beta f_k / \gamma_m$. Thus

$$125 = \frac{\beta f_k}{\gamma_m}$$

from which

$$f_k \text{ required} = \frac{125\gamma_m}{\beta} = \frac{125 \times 3.1}{0.74 \times 100} = 5.24 \text{ N/mm}^2$$

Now the blocks to be used are solid concrete 390 mm long $\times$ 190 mm high $\times$ 100 mm thick, for which the ratio of the block height to the lesser horizontal dimension is $390/100 = 3.9$. Therefore $f_k$ should be obtained from Table 4.5d:

Use 7 N/mm$^2$ solid blocks in grade (iv) mortar ($f_k = 5.6$ N/mm$^2$).
Example 4.3
A ground floor wall in a three-storey building supports the loads indicated in Figure 4.24. Choose suitable bricks and mortar for the wall. Partial safety factors are given as follows: for materials, $\gamma_m = 2.8$; for dead loads, $\gamma_f = 1.4$; for imposed loads, $\gamma_f = 1.6$. The manufacturing control is to be normal and the construction control is to be special.

Floor characteristic dead load = 4.8 \text{kN/m}^2
Floor characteristic imposed load = 5 \text{kN/m}^2

250 \text{kN ultimate axial load from upper storeys}

Consider a 1 m length of wall for the purpose of design.

The ultimate design load from the upper storey has been given, but to this must be added the first-floor loading and the self-weight of the ground floor wall itself. Hence the characteristic dead load $G_k$ is calculated as follows:

Floor: $4.8 \times 7.5 \times 1 = 36$
Wall SW: $2200 \times 3.5 \times 0.125 \times 1 = 16.56$
Total $G_k$: $52.56 \text{kN}$

The characteristic imposed load will be $Q_k = 5 \times 7.5 \times 1 = 37.5 \text{kN}$. Hence

Ultimate design dead and imposed load

$= \gamma_f G_k + \gamma_f Q_k = 1.4 \times 52.56 + 1.6 \times 37.5 = 73.58 + 60 = 133.58 \text{kN per metre run}$

To this must be added the ultimate design load from the upper storeys of 250 kN per metre run. Hence

Total ultimate axial load = 250 + 133.58 = 383.58 kN/m = 383.58 N per mm run

The effective height $h_{ef} = 0.75h = 0.75 \times 3500 = 2625 \text{ mm}$. The effective thickness $t_{ef}$ is the actual thickness of 215 mm. Note that since the thickness of this brick wall is greater than a standard format brick, the thickness factor 1.15 does not apply. Thus the slenderness ratio is given by

$\frac{h_{ef}}{t_{ef}} = \frac{2625}{215} = 12.2 < 27$

This is satisfactory. From Table 4.8, the capacity reduction factor $\beta$ is 0.93.
The plan area of the 4 m long wall is $4 \times 0.215 = 0.86 \text{m}^2$. This is greater than 0.2 m$^2$, and therefore the plan area reduction factor does not apply.

The expression for the vertical design strength per unit length of walls is $\beta f_k / \gamma_m$. Therefore

$$383.58 = \frac{\beta f_k}{\gamma_m}$$

from which

$$f_k \text{ required} = \frac{383.58 \times 2.8}{0.93 \times 215} = 5.37 \text{ N/mm}^2$$

By reference to Table 4.5a:

Use 20 N/mm$^2$ bricks in grade (iii) mortar ($f_k = 5.8$ N/mm$^2$).

**Example 4.4**

The brick cavity wall shown in Figure 4.25 supports an ultimate load on the inner leaf of 75 kN/m, the outer leaf being unloaded. Select suitable bricks and mortar if both the manufacturing and construction control are to be normal.

The effective height $h_{ef} = 0.75h = 0.75 \times 4000 = 3000 \text{mm}$. The effective thickness $t_{ef}$ is the greatest of $2(t_1 + t_2)/3 = 2(102.5 + 102.5)/3 = 136.7 \text{ mm}$, or $t_1 = 102.5 \text{ mm}$, or $t_2 = 102.5 \text{ mm}$. Thus the slenderness ratio is given by

$$SR = \frac{h_{ef}}{t_{ef}} = \frac{3000}{136.7} = 21.95 < 27$$

This is satisfactory. The load from the roof slab will be applied eccentrically as shown in Figure 4.26; that is, the eccentricity is given by

$$e_x = \frac{t}{2} - \frac{t}{3} = \frac{t}{6}$$

Hence from Table 4.8 the capacity reduction factor $\beta$ is 0.473.

The vertical design strength per unit length of wall is $\beta f_k / \gamma_m$. Therefore

$$75 \text{ N/mm} = \frac{\beta f_k \times 1.15}{\gamma_m}$$

from which

$$f_k \text{ required} = \frac{75 \gamma_m}{\beta \times 1.15} = \frac{75 \times 3.5}{0.473 \times 102.5 \times 1.15} = 4.7 \text{ N/mm}^2$$

By reference to Table 4.5a:

Use 15 N/mm$^2$ bricks in grade (iii) mortar ($f_k = 5$ N/mm$^2$).
Example 4.5

The brick cavity wall shown in Figure 4.27 supports an ultimate axial load of 150 kN/m shared equally by both leaves. Select suitable bricks and mortar if both the manufacturing and construction control are to be normal.

The effective height and thickness and hence the slenderness ratio are the same as in Example 4.4; that is, SR = 21.95. However in this example, since the two leaves of the wall share the load equally, there is no eccentricity. Hence from Table 4.8 the capacity reduction factor $\beta$ is 0.62.

The vertical design strength is $f_v = \beta f_k/\gamma_m$. Thus, for each leaf,

$$f_v \text{ required} = \frac{150\gamma_m}{\beta t} = \frac{150 \times 3.5}{0.62 \times 2 \times 102.5} = 4.13 \text{ N/mm}^2$$

It should be noted that the narrow brick wall factor of 1.15 does not apply in this instance since both leaves are loaded. From Table 4.5a:

Use 15 N/mm² bricks in grade (iv) mortar ($f_k = 4.4 \text{ N/mm}^2$).

Example 4.6

The wall shown in Figure 4.28 is built of 50 N/mm² clay bricks set in grade (i) mortar. Calculate the vertical design strength of the wall if it is 2.4 m high and is provided with simple lateral support at the top. The category of manufacturing control is to be normal and that for construction special.

The effective height with simple lateral resistance is $h_{ef} = h = 2400 \text{ mm}$. Since vertical lateral support is not provided, the effective height will govern the slenderness. The effective thickness will be influenced by the piers:

$$\frac{\text{Pier spacing}}{\text{Pier width}} = \frac{3600}{440} = 8.18$$
$$\frac{\text{Pier thickness}}{t} = \frac{327.5}{215} = 1.52$$

Therefore, by interpolation from Table 4.7, the stiffness coefficient $K = 1.151$. Hence the effective thickness $t_{ef} = tK = 215 \times 1.151 = 247.47 \text{ mm}$. Thus the slenderness ratio is given by

$$\frac{h_{ef}}{t_{ef}} = \frac{2400}{247.47} = 9.7 < 27$$
This is satisfactory. Hence by interpolation from Table 4.8 the capacity reduction factor $\beta$ is 0.975 without eccentricity.

From Table 4.5a, the masonry characteristic strength $f_k = 15 \text{ N/mm}^2$. The material partial safety factor $\gamma_m = 2.8$. Finally, the ultimate vertical design strength per unit length of wall is

$$\frac{\beta f_k}{\gamma_m} = \frac{0.975 \times 215 \times 15}{2.8} = 1122.99 \text{ N/mm} = 1122.99 \text{ kN per metre run}$$

**Example 4.7**

Calculate the vertical design strength of the wall shown in Figure 4.29, assuming simple lateral support is provided at the top. The wall is 3.45 m high and is constructed from 27.5 N/mm$^2$ bricks set in grade (iii) mortar, and both the manufacturing and construction control are normal.

![Plan on wall](image)

**Figure 4.29** Plan on wall

The effective height $h_{ef} = h = 3450 \text{ mm}$. The intersecting walls are not long enough (that is $d < 10t$) or thick enough (that is $t_1$ and $t_2 < t$) to provide enhanced lateral support in the vertical direction; therefore the effective height will govern the slenderness. However, the length of the intersecting walls is greater than $3t$ and they may therefore be considered as equivalent stiffening piers. That is,

\[
\begin{align*}
\text{Equivalent pier spacing} & = \frac{1575}{102.5} = 15.37 \\
\text{Equivalent pier width} & = \frac{d}{t_1} = \frac{900}{102.5} = 8.79 \\
\text{Equivalent pier thickness} & = \frac{t_2}{t_1} = \frac{102.5}{215} = 0.48 \\
\text{Wall thickness} & = \frac{t}{t_1} = \frac{215}{102.5} = 2.10
\end{align*}
\]

Therefore, by interpolation from Table 4.7, the stiffness coefficient $K$ is 1.19. The effective thickness $t_{ef} = tK = 215 \times 1.19 = 255.85 \text{ mm}$. Thus the slenderness ratio is given by

$$SR = \frac{h_{ef}}{t_{ef}} = \frac{3450}{255.85} = 13.48 < 27$$

This is satisfactory. By interpolation from Table 4.7, the capacity reduction factor $\beta$ is 0.90 without eccentricity.
From Table 4.5a, the masonry characteristic strength $f_k = 7.1 \text{ N/mm}^2$. The material partial safety factor $\gamma_m = 3.5$. Thus the ultimate vertical design strength is

$$\frac{0.9 \times 215 \times 7.1}{3.5} = 392.53 \text{ N/mm} = 392.53 \text{ kN per metre run}$$

**Example 4.8**

Determine the vertical design strength of the wall shown in Figure 4.30. The wall is 3.45 m high, restrained at the top, and constructed from 35 N/mm$^2$ bricks set in grade (iii) mortar. Both the manufacturing and construction control are to be normal.

---

**Figure 4.30** Plan on wall

The effective height $h_{ef} = 0.75h = 0.75 \times 3450 = 2587.5 \text{ mm}$. The length of the intersecting walls is greater than $10t = 10 \times 215 = 2150 \text{ mm}$ and their thickness is not less than the main wall, $t = 215 \text{ mm}$; therefore they may be considered to provide lateral support in the vertical direction. The degree of support will be simple since the intersecting walls are only tied and not bonded to the main wall. Therefore the effective length is the clear distance between simple lateral supports, that is $l_{ef} = L - t_1 = 2250 - 215 = 2035 \text{ mm}$. As the effective length of 2035 mm is less than the effective height of 2587.5 mm, it will govern the slenderness ratio.

Furthermore, since the length of the intersecting walls is greater than $3t$ they may be considered as equivalent stiffening piers for the purpose of determining the effective thickness:

$$\frac{2250}{215} = 10.47$$
Equivalent pier thickness \( t_p = 3t = 3 \times 215 = 645 \text{ mm} \)

Therefore, by interpolation from Table 4.7, the stiffness coefficient \( K \) is 1.38. The effective thickness \( t_{ef} = tK = 215 \times 1.38 = 296.7 \text{ mm} \). Thus the slenderness ratio is given by

\[
SR = \frac{\text{effective length}}{\text{effective thickness}} = \frac{l_{ef}}{t_{ef}} = \frac{2035}{296.7} = 6.86 < 27
\]

This is satisfactory. From Table 4.7, the capacity reduction factor \( \beta \) is 1.0 without eccentricity.

From Table 4.5a, the masonry characteristic strength \( f_k = 8.5 \text{ N/mm}^2 \). The material partial safety factor \( \gamma_m = 3.5 \). Thus the ultimate vertical design strength is

\[
\frac{\beta f_k}{\gamma_m} = \frac{1.0 \times 215 \times 8.5}{3.5} = 522.14 \text{ N/mm} = 522.14 \text{ kN per metre run}
\]

4.11 Concentrated loads

Concentrated loads can occur at beam, truss or lintel bearings. Whilst these produce relatively high stress concentrations over a small plan area, they are usually rapidly dispersed through the wall construction below. It is accepted that bearing stresses produced by concentrated loads of a purely local nature may safely exceed the allowable design stress for a uniformly distributed load.

Reference should be made to BS 5628 Part 1 for guidance on the three types of bearing condition which permit the normal design stresses to be exceeded by 1.25, 1.5 and 2 times respectively.

4.12 References

BS 187 1978 Specification for calcium silicate (sand lime and flint lime) bricks.
BS 1243 1978 Specification for metal ties for cavity wall construction.
BS 3921 1985 Specification for clay bricks.
BS 5628 Code of practice for use of masonry.
  Part 3 1985 Materials and components, design and workmanship.
BS 6073 1981 Precast concrete masonry units.
  Part 1 Specification for precast masonry units.
  Part 2 Method for specifying precast concrete masonry units.

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