References

www.brick.org.uk
• Materials
• Basic Principles
• Design
• Case Studies
• Other Buildings
Materials

• Units
  – Clay bricks
  – Calcium silicate bricks
  – Concrete blocks
  – Stone masonry (natural or manufactured)
  – Compressed earth

• Mortar
  – Cement mortar
  – Lime mortar
Materials

• Clay bricks
  – Density 23-28KN/m3
  – Strengths 5-100N/mm2
  – Tendency to expand
  – Varying porosity
  – Varying durability

• Concrete blocks
  – Density 5-20KN/m3
  – Strengths 3-30N/mm2
  – Tendency to shrink
  – New low carbon blocks emerging

www.greenspec.co.uk/bricks.php  www.greenspec.co.uk/blocks.php
Basic principles

- Masonry is good in compression but has limited flexural or tensile strength
- Tend to rely on gravity to stabilise masonry structures
Pinnacles
November 2009

ABRIDGED

An ancient Roman bridge spanned the Wadi al Murr near Mosul, Iraq, in the 1920s. Credited to German archaeologist Max von Oppenheim, this image never ran in the Geographic—nor did his manuscript for a story about his work at Tell Halaf, Syria, found with it in the photographic file. Von Oppenheim discovered the site (which dates from the sixth millennium B.C.) in 1899 and conducted excavations there over the next three decades. He shipped several treasures from the dig home to Berlin for exhibition in his personal museum, but many were destroyed in an Allied bombing raid in 1943. Objects salvaged from the rubble have recently been restored and are scheduled to go on display next year.
Anaconda stack, US
St. Martin's Church, Germany

- Completed 1500
- 130m
Basic principles

- Masonry is 3x weaker in bending parallel to bed joints than it is perpendicular
- Strengthen masonry by sitting heavy slab on it or using buttressing

[Diagram showing failure planes parallel and perpendicular to bed joints, with numerical values indicating strength ratios.]
Design

- Design
  - Design Codes
  - Factors of Safety
  - Strength
    - Brick, Block and Stone
    - Mortar
    - Combined
  - Stability / Slenderness
  - Movement
  - Durability
  - Robustness
  - Preliminary Sizing
  - Non-loadbearing masonry
Design codes

- BS5628 Parts 1-3 : 2005
- Eurocode 6
- Limit State Codes
  - Factored loads
  - Ultimate stresses
Factors of safety

- Loads

<table>
<thead>
<tr>
<th>Load combination</th>
<th>Load type</th>
<th>Dead</th>
<th>Imposed</th>
<th>Wind</th>
<th>Earth and water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead and imposed</td>
<td>1.4 or 0.9</td>
<td>1.6</td>
<td>–</td>
<td>–</td>
<td>1.2</td>
</tr>
<tr>
<td>Dead and wind</td>
<td>1.4 or 0.9</td>
<td>–</td>
<td>1.4*</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Dead and wind (freestanding</td>
<td>1.4 or 0.9</td>
<td>–</td>
<td>1.2*</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>walls)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dead, imposed or wind</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2*</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Accidental damage</td>
<td>0.95 or 1.05</td>
<td>0.35</td>
<td>0.35</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

*Buildings should be capable of resisting a horizontal load equal to 1.5% of the total characteristic dead load (i.e. 0.015G₀) above any level. In some instances 0.015G₀ can be greater than the applied wind loadings.

- Materials

<table>
<thead>
<tr>
<th></th>
<th>Category of masonry units</th>
<th>Category of construction control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compression, ( \gamma_m )</strong></td>
<td>Category I</td>
<td>Category I and II</td>
</tr>
<tr>
<td></td>
<td>Category II</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.8</td>
</tr>
<tr>
<td><strong>Flexure, ( \gamma_m )</strong></td>
<td>Category I and II</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0</td>
</tr>
</tbody>
</table>

Table 4 — Partial safety factors for material strength
Unit strength

- Unit or brick/block strength can be quite high but mortar is the weakest link.
- With thinner mortars and large units the wall compressive strength approaches that of the unit.
Unit strength

- Strength of natural stone can be highly dependant on bedding direction.

<table>
<thead>
<tr>
<th></th>
<th>Crushing N/mm²</th>
<th>Tension N/mm²</th>
<th>Shear N/mm²</th>
<th>Bending N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basalt</td>
<td>8.5</td>
<td>8.6</td>
<td>4.3</td>
<td>—</td>
</tr>
<tr>
<td>Chalk</td>
<td>1.1</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Granite</td>
<td>96.6</td>
<td>3.2</td>
<td>5.4</td>
<td>10.7</td>
</tr>
<tr>
<td>Limestone</td>
<td>53.7</td>
<td>2.7</td>
<td>4.3</td>
<td>6.4</td>
</tr>
<tr>
<td>Limestone soft</td>
<td>10.7</td>
<td>1.0</td>
<td>3.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Marble</td>
<td>64.4</td>
<td>3.2</td>
<td>5.4</td>
<td>—</td>
</tr>
<tr>
<td>Sandstone</td>
<td>53.7</td>
<td>1.1</td>
<td>3.2</td>
<td>5.4</td>
</tr>
<tr>
<td>Sandstone soft</td>
<td>21.5</td>
<td>0.5</td>
<td>1.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Slate</td>
<td>85.8</td>
<td>1.1</td>
<td>3.2</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Compressed earth units

Ecoterre™ Earth Bricks

A range of unfired clay bricks intended for most internal non load-bearing applications.

Unfired clay bricks have excellent sustainability credentials – low energy input, very low waste and high recyclability and Ecoterre™ is manufactured in the UK. When incorporated into a building they give thermal mass and acoustic insulation, inhibit condensation and regulate the relative humidity of the atmosphere.

<table>
<thead>
<tr>
<th>Earth Brick Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
</tr>
<tr>
<td>Size</td>
</tr>
<tr>
<td>Configuration</td>
</tr>
<tr>
<td>Compressive Strength</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Density</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Earth Brick Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
</tr>
<tr>
<td>Size</td>
</tr>
<tr>
<td>Configuration</td>
</tr>
<tr>
<td>Compressive Strength</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Density</td>
</tr>
</tbody>
</table>
Mortar strength

<table>
<thead>
<tr>
<th>Mortar designation</th>
<th>Compressive strength class</th>
<th>Prescribed mortars (proportion of materials by volume)</th>
<th>Compressive strength at 28 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) M12</td>
<td>1:0 to ¼:3</td>
<td>---</td>
<td>12 N/mm²</td>
</tr>
<tr>
<td>(ii) M6</td>
<td>1:½:4 to 4½</td>
<td>1:3 to 4</td>
<td>6 N/mm²</td>
</tr>
<tr>
<td>(iii) M4</td>
<td>1:1:5 to 6</td>
<td>1:5 to 6</td>
<td>4 N/mm²</td>
</tr>
<tr>
<td>(iv) M2</td>
<td>1:2:8 to 9</td>
<td>1:7 to 8</td>
<td>2 N/mm²</td>
</tr>
</tbody>
</table>

---

* Cement, or combination of cements, in accordance with Clause 13, except masonry cements
  
* Masonry cement in accordance with Clause 13, (inorganic filler other than lime)
  
* Masonry cement in accordance with Clause 13, (lime)

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

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

Non-hydraulic lime mortar mixes for masonry

<table>
<thead>
<tr>
<th>Mix constituents</th>
<th>Approximate proportions by volume</th>
<th>Notes on general application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime putty: coarse sand</td>
<td>2:5</td>
<td>Used where dry weather and no frost are expected for several months</td>
</tr>
<tr>
<td>Pozzolanic*: lime putty: coarse sand</td>
<td>1:2–3:2</td>
<td>Used where an initial mortar set is required within a couple of days</td>
</tr>
</tbody>
</table>

* Pozzolanic material can be cement, fired china dust or ground granulated blast furnace slag (ggbfs).

The actual amount of lime putty used depends on the grading of the sand and the volume of voids. Compressive strength values for non-hydraulic lime mortar masonry can be approximated using the values for Class IV cement mortar. Due to the flexibility of non-hydraulic lime mortar, thermal and moisture movements can generally be accommodated by the mortar without cracking of the masonry elements or the use of movement joints. This flexibility also means that resistance to lateral load relies on mass and dead load rather than flexural strength. The accepted minimum thickness of walls with non-hydraulic lime mortar is 215 mm and therefore the use of lime mortar in standard single leaf cavity walls is not appropriate.
Combined strength

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

<table>
<thead>
<tr>
<th>Mortar strength Class/Designation</th>
<th>Compressive strength of unit (N/mm$^2$)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>M12 / (i)</td>
<td>2.5</td>
</tr>
<tr>
<td>M6 / (ii)</td>
<td>2.5</td>
</tr>
<tr>
<td>M4 / (iii)</td>
<td>2.5</td>
</tr>
<tr>
<td>M2 / (iv)</td>
<td>2.2</td>
</tr>
</tbody>
</table>

---

d) — Constructed with aggregate concrete blocks having not more than 25% of formed voids and a ratio of height to least horizontal dimension of between 2.0 and 4.5

<table>
<thead>
<tr>
<th>Mortar strength Class/Designation</th>
<th>Compressive strength of unit (N/mm$^2$)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.9</td>
</tr>
<tr>
<td>M12 / (i)</td>
<td>2.8</td>
</tr>
<tr>
<td>M6 / (ii)</td>
<td>2.8</td>
</tr>
<tr>
<td>M4 / (iii)</td>
<td>2.8</td>
</tr>
<tr>
<td>M2 / (iv)</td>
<td>2.8</td>
</tr>
</tbody>
</table>

---

19.1.10 Natural stone masonry

The characteristic compressive strength of stone masonry with bed joints 10 mm thick or less, and in mortar designation (iii) or stronger, may be taken as 0.35 times the mean compressive strength of the natural stone masonry units or representative cubes when prepared in accordance with BS EN 771-6 and tested in accordance with BS EN 772-1. Where the strength is derived from cubes, consideration should be given to the direction of any bedding planes, see BS EN 771-6.
Stability & slenderness

- Strength of a masonry wall dependant on slenderness and type of load applied. *(ie concentric or eccentric)*
- The slenderness ratio should not exceed 27 (building more than 2 storey it should not exceed 20)
Stability & slenderness

- As height of wall increases, strength of wall reduces.
- Rate of reduction in strength to increase in height is not necessarily linear.

1N/mm² = 215KN/m
5 storey building supporting 7.5m office floor
- 125KN/m floor load
- 75KN/m brick self weight
Movement

- Clay brickwork tends to expand over time
- Concrete blockwork tends to shrink over time

---

**Movement joints in masonry with cement-based mortar**

Movement joints to limit the lengths of walls built in cement mortar are required to minimize cracking due to deflection, differential settlement, temperature change and shrinkage or expansion. In addition to long wall panels, movement joints are also required at points of weakness, where stress concentrations might be expected to cause cracks (such as at steps in height or thickness or at the positions of large chases). Typical movement joint spacings are as follows:

<table>
<thead>
<tr>
<th>Material</th>
<th>Approximate horizontal joint spacing* and reason for provision</th>
<th>Typical joint thickness mm</th>
<th>Maximum suggested panel length:height ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay bricks</td>
<td>12 m for expansion</td>
<td>16</td>
<td>3:1</td>
</tr>
<tr>
<td></td>
<td>15–18 m with bed joint reinforcement at 450 mm c/e</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18–20 m with bed joint reinforcement at 225 mm c/e</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Calcium silicate bricks</td>
<td>7.5–9 m for shrinkage</td>
<td>10</td>
<td>3:1</td>
</tr>
<tr>
<td>Concrete bricks</td>
<td>6 m for shrinkage</td>
<td>10</td>
<td>2:1</td>
</tr>
<tr>
<td>Concrete blocks</td>
<td>6–7 m for shrinkage</td>
<td>10</td>
<td>2:1</td>
</tr>
<tr>
<td></td>
<td>15–18 m with bed joint reinforcement at 450 mm c/e</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18–20 m with bed joint reinforcement at 225 mm c/e</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Natural stone cladding</td>
<td>6 m for thermal movements</td>
<td>10</td>
<td>3:1</td>
</tr>
</tbody>
</table>

**Notes:**
1. Consider bed joint reinforcement for ratios beyond the suggested maximum.
2. The horizontal joint spacing should be halved for joints which are spaced off corners.

Vertical joints are required in cavity walls every 9 m or three storeys for buildings over 12 m or four storeys. This vertical spacing can be increased if special precautions are taken to limit the differential movements caused by the shrinkage of the internal block and the expansion of the external brick. The joint is typically created by supporting the external skin on a proprietary stainless steel shelf angle fixed back to the internal structure. Normally 1 mm of joint width is allowed for each metre of masonry (with a minimum of 10 mm) between the top of the masonry and underside of the shelf angle support.
Durability

‘Stronger’ bricks and mortars are more durable than weaker ones.

- F = frost resistant
- M = Moderate frost resistant
- N = No frost resistant
- L = Low soluble salt content
- N = Normal soluble salt content
Robustness

Ronan Point collapse

16.3 Accidental forces

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

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

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

- Whilst slenderness and strength are not always linear relationship, preliminary sizing of masonry is still based on height/depth ratios (which are linear).

<table>
<thead>
<tr>
<th>Description</th>
<th>Freestanding/cantilever</th>
<th>Element supported on two sides</th>
<th>Panel supported on four sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral loading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid wall with no piers - uncracked section</td>
<td>H/6–8.5¹</td>
<td>H/20 or L/20</td>
<td>H/22 or L/25</td>
</tr>
<tr>
<td>Solid wall with no piers - cracked section</td>
<td>H/4.5–6.4¹</td>
<td>H/10 or L/20</td>
<td>H/12 or L/25</td>
</tr>
<tr>
<td>External cavity wall² panel</td>
<td>–</td>
<td>H/20 or L/30</td>
<td>H/22 or L/35</td>
</tr>
<tr>
<td>External cavity wall² panel with bed joint reinforcement</td>
<td>–</td>
<td>H/20 or L/35</td>
<td>H/22 or L/40</td>
</tr>
<tr>
<td>External diaphragm wall panel</td>
<td>H/10</td>
<td>H/14</td>
<td></td>
</tr>
<tr>
<td>Reinforced masonry retaining wall (bars in pockets in the walls)</td>
<td>H/10–15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid masonry retaining wall (thickness at base)</td>
<td>H/2.5–4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical loading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid wall</td>
<td>H/8</td>
<td>H/18–22</td>
<td>–</td>
</tr>
<tr>
<td>Cavity wall</td>
<td>H/11</td>
<td>H/5.5</td>
<td>–</td>
</tr>
<tr>
<td>Masonry arch/vault</td>
<td>H/20–30</td>
<td>L/10–15</td>
<td>L/30–60</td>
</tr>
</tbody>
</table>

NOTES:
1. Depends on the wind exposure of the wall.
2. The spans or distances between lateral restraints are L in the horizontal direction and H in the vertical direction.
3. In cavity walls, the thickness is the sum of both leaves excluding the cavity width.
Non-loadbearing masonry

Figure 6 — Limiting dimensions of walls for stability
Case studies

• Baker Street
• The Forum
• Winterton House
• 30 Finsbury Square
Baker Street, London
Typical Baseplate

Fabricated Pin

Cast-in detail

Possible web stiffen rigid

Accommodates rotation
Minimise eccentricity
Robust detail
Low maintenance
Buildability
Cost

Possible web stiffen rigid

Accommodates rotation
Minimise eccentricity
Robust detail
Low maintenance
Buildability
Cost

Accommodate rotation
Minimise eccentricity
Robust detail
Low maintenance
Buildability
Cost

Proprietary Bearing

Thin Embedded

Possible web stiffen rigid

Site bolt end plate or welded end plate with bolt down baseplate

Accommodate rotation
Minimise eccentricity
Robust detail
Low maintenance
Buildability
Cost

Accommodate rotation
Minimise eccentricity
Robust detail
Low maintenance
Buildability
Cost

Main issues that bearing detail must address:
- Accommodate support rotation
- Minimise eccentric loading to wall
- Provide robust detail (ie disproportionate collapse)
- Low maintenance detail (ventilated bearing)

Note: possible lack of lateral restraint to wall

Whitby Bird & Partners

20-32 Baker St.

1994

90m

12.00
Note: see also SK/131
The Forum, Norwich
Other projects

• The Landmark, Ilfracombe
• World of Glass, St Helens
• SSEES UCL, London
• Inland Revenue, Nottingham
• St Pauls Church, London N4
• Institute of Technology, Cork
• Office for SAHRC, New Delhi
• King Willem College, Netherlands
• Bryanston Science School, Dorset
The Landmark, Ilfracombe
World of Glass, St Helens
St Pauls Church, London N4
Institute of Technology, Cork
SAHRC, New Delhi
The animated wall. The dynamic skin changes character as per surrounding light conditions. In the day time it casts shadow patterns on the staircase and at night it gives out light to form patterns outside. On its own the patterns forming on the wall rotate with stay light.

The wall is a modern interpretation of the traditional carved jali by repeating a single module to create an apparently complicated pattern.

To cut down on false ceiling costs the slab has been cast in the form of a vault to avoid beams crossing the office space. With brick cladding on the ceiling and only nominal filling the slab provides acoustic insulation between floors and thermal insulation on the roof.

Masons were trained on site to lay bricks in a 20 course brick bond. No specialist skilled labour was hired and the masons showed interest and enthusiasm in learning a new technique.

OFFICE FOR SAHRDC at SAFDARJUNG EXTENSION NEW DELHI INDIA
King Willem School, Netherlands
National Assembly, Bangladesh
IIM, Ahmedabad
MARTa Herford, Germany