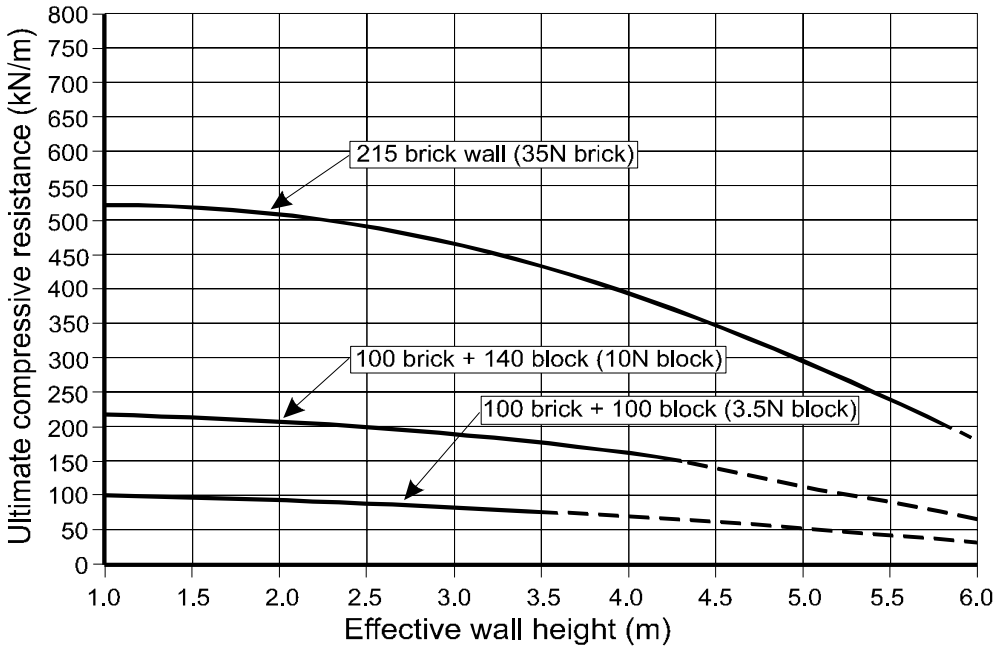
4.7 MASONRY

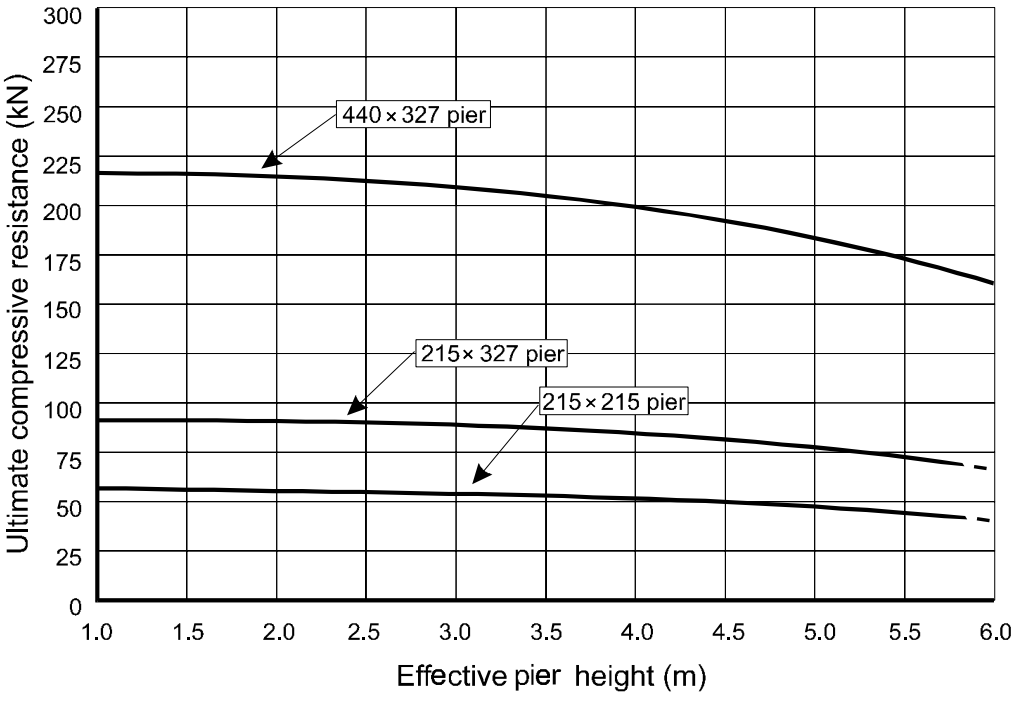
4.7.1 RULES OF THUMB

Ultimate resistances in compression

Wall sizing: e < 0.05 t ; grade (iii) mortar
(Note: For cavity walls load is applied to inner leaf only.)
BS 5628 : Pt 1 Cl 28.1. limits slenderness ratio to 27



Pier sizing : e < 0.05 t ; 20N brick ; grade (iii) mortar
BS 5628 : Pt 1 Cl 28.1. limits slenderness ratio to 27



ARUP

Initial sizing rules

Trial wall thicknesses:
For compressive loading only:

	Supported top and bottom	Supported at base only
Solid	H/16	H/8
Cavity*	H/11	H/5.5

H is wall height Min. leaf thickness 100mm
* Wall thickness is sum of leaf thickness

For lateral loading:
solid walls, Height = 1/40 distance between supports
cavity walls, Height = 1/30 distance between supports

4.7.2 LOAD FACTORS (From BS 5628 Part 1 Clause 22)

Load Combination (Including Earth and Water Loading Where Present)	Load Type					
	Dead, G_k		Imposed, Q_k		Earth and Water, E_n	Wind, W_k
	Adverse	Beneficial	Adverse	Beneficial		
1. Dead and Imposed	1.4	0.9	1.6	0	1.4	-
2. Dead and Wind	1.4	0.9	-	-	1.4	1.4*†
3. Dead, Imposed and Wind	1.2	1.2	1.2	1.2	1.2	1.2†

† Use $0.015G_k$ if greater than factored W_k.
* A partial factor of 1.2 may be used for freestanding walls and laterally loaded walls panel, whose removal would in no way affect the stability of the remaining structure.

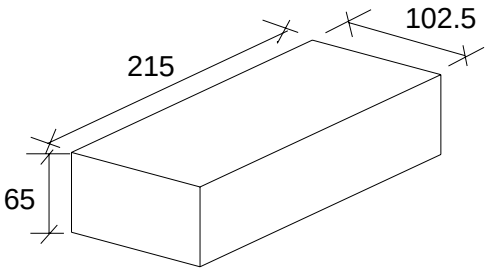
4.7.3 MATERIAL FACTORS (From BS 5628 Part 1 Table 4)

Partial safety factors for material strength

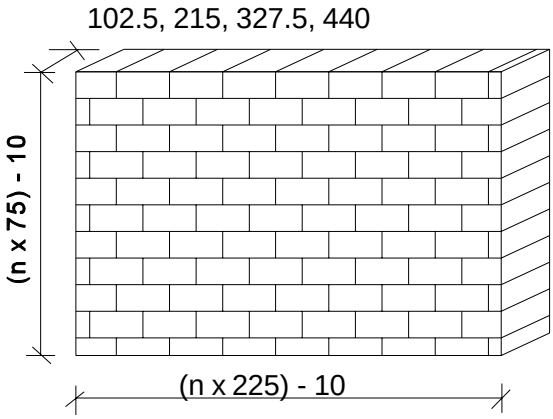
		Construction Control	
		Special	Normal
Manufacturing Control	Special	2.5	3.1
	Normal	2.8	3.5*

* Use for initial sizing
Note particular requirements for use of 'Special' catogory

4.7.4 MODULAR DIMENSIONS (Brickwork)



Mortar Thickness = 10mm



4.7.5 TYPICAL UNIT STRENGTHS

Material and BS	Class	Typical unit compressive strength (N/mm^2)
Fired-clay bricks (BS 3921)	Engineering A† Engineering B† Facing bricks† Common bricks	> 70 > 50 10 - 50 10 - 30
Calcium silicate bricks (BS187)	Class 7 Class 6 Class 5 Class 4 Class 3	48.5 41.5 34.5 27.5 20.5
Concrete bricks (BS 6073: Part 1)		7 - 20
Concrete blocks (BS 6073: Part 1)	Dense solid† Dense hollow† Lightweight†	7, 10 - 35 3.5, 7, 10 2.8, 3.5, 4, 7 (10)
Reconstructed stone† (BS 6457)	Dense solid	As dense solid concrete blocks
Natural stone† (BS 5390 and BS 8298)	Structural quality	15 - 100 (dependent on stone type, bed, location, etc.)
† These are often selected by client or architect for appearance or thermal performance - check this, and establish strength, before starting to size members.		

ARUP

4.7.6 MASONRY COMPRESSIVE STRENGTH (BS 5628, Pt. 1, Table 2)

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

(a) Constructed with standard format bricks

Mortar designation	Compressive strength of unit (N/mm^2)								
	5	**10**	**15**	**20**	**27.5**	**35**	**50**	**70**	**100**
(i)	2.5	4.4	6.0	7.4	9.2	11.4	15.0	19.2	24.0
(ii)	2.5	4.2	5.3	6.4	7.9	9.4	12.2	15.1	18.2
(iii)	2.5	4.1	5.0	5.8	7.1	8.5	10.6	13.1	15.5
(iv)	2.2	3.5	4.4	5.2	6.2	7.3	9.0	10.8	12.7

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

Mortar designation	Compressive strength of unit (N/mm^2)							
	2.8	**3.5**	**5.0**	**7.0**	**10**	**15**	**20**	**35** or greater
(i)	1.4	1.7	2.5	3.4	4.4	6.0	7.4	11.4
(ii)	1.4	1.7	2.5	3.2	4.2	5.3	6.4	9.4
(iii)	1.4	1.7	2.5	3.2	4.1	5.0	5.8	8.5
(iv)	1.4	1.7	2.2	2.8	3.5	4.4	5.2	7.3

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

Mortar designation	Compressive strength of unit (N/mm^2)							
	2.8	**3.5**	**5.0**	**7.0**	**10**	**15**	**20**	**35** or greater
(i)	2.8	3.5	5.0	5.7	6.1	6.8	7.5	11.4
(ii)	2.8	3.5	5.0	5.5	5.7	6.1	6.5	9.4
(iii)	2.8	3.5	5.0	5.4	5.5	5.7	5.9	8.5
(iv)	2.8	3.5	4.4	4.8	4.9	5.1	5.3	7.3

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

Mortar designation	Compressive strength of unit (N/mm^2)							
	2.8	**3.5**	**5.0**	**7.0**	**10**	**15**	**20**	**35** or greater
(i)	2.8	3.5	5.0	6.8	8.8	12.0	14.8	22.8
(ii)	2.8	3.5	5.0	6.4	8.4	10.6	12.8	18.8
(iii)	2.8	3.5	5.0	6.4	8.2	10.0	11.6	17.0
(iv)	2.8	3.5	4.4	5.6	7.0	8.8	10.4	14.6

NOTE TO TABLE OF f_k

1. For piers, columns, and short walls with plan area A (in m^2) ≤ 0.2m^2, multiply f_k by (0.7 + 1.5A).

2. For 'half-brick thick' brick walls, multiply Table (a) values by 1.15.

3. For 90 x 90mm section modular bricks, multiply the Table (a) values by:
1.25 if wall thickness = brick width, 1.1 otherwise

4. For unfilled hollow blocks, interpolate between Tables (b) and (c) as necessary.

5. For solid and concrete-filled hollow blocks, with height:least horizontal dimension between 0.6 and 2.0, interpolate between Tables (b) and (d) as necessary.

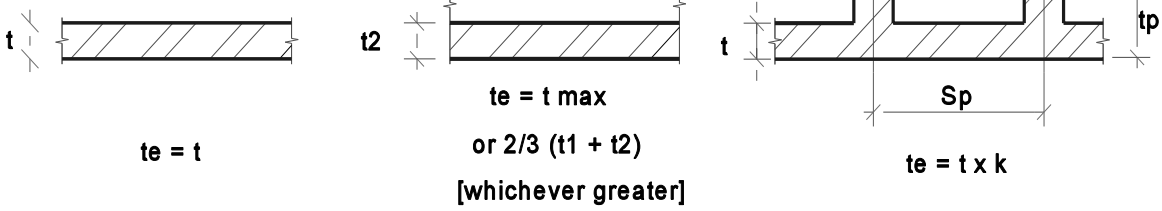
6. For squared natural stone and reconstructed stone, interpolate between Tables (b) and (d) as necessary.

7. For random rubble natural stone, take 75% of squared natural stone values. If using lime mortar, take 50% of strength for grade (iv) mortar.

MORTAR STRENGTHS

Desig-nation	Cement:Lime:Sand
(i)	1 : 0 - ¼ : 3
(ii)	1 : ½ : 4 - 4½
(iii)	1 : 1 : 5-6
(iv)	1 : 2 : 8-9
Pure lime	0 : 1 : 3

See also Section 4.7.12, and BS 5628, Pt 1, Table 1.



te = t

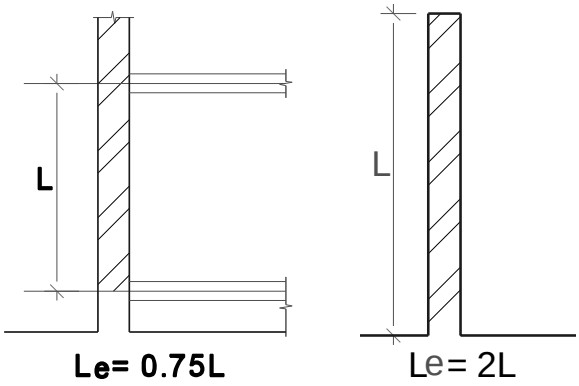
te = t max
or 2/3 (t1 + t2)
[whichever greater]

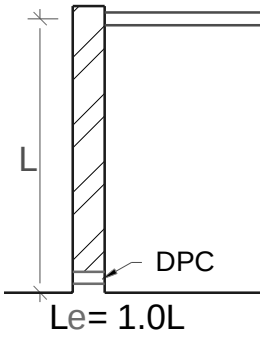
te = t x k

Values of K for the design of piers (From BS 5628, Pt. 1, Table 5)			
Ratio of pier spacing (centre-to-centre) to pier width (s_p / w_p)	Ratio of pier thickness to actual thickness of wall or leaf (t_p / t)		
	1	2	3 and thicker
6 (or less)	1	1.4	2
10	1	1.2	1.4
20 (or more)	1	1	1

Reduction factor β (From BS 5628, Pt. 1, Table 7)

Capacity reduction factor, β †				
Slenderness ratio: l_e/t_e	Eccentricity at top of wall, e			
	Up to 0.05t	0.1t	0.2t	0.3t
0	1.00	0.88	0.66	0.44
6	1.00	0.88	0.66	0.44
8	1.00	0.88	0.66	0.44
10	0.97	0.88	0.66	0.44
12	0.93	0.87	0.66	0.44
14	0.89	0.83	0.66	0.44
16	0.83	0.77	0.64	0.44
18	0.77	0.70	0.57	0.44
20	0.70	0.64	0.51	0.37
22	0.62	0.56	0.43	0.30
24	0.53	0.47	0.34	
26	0.45	0.38		
27	0.40	0.33		
† Linear interpolation between eccentricities and slenderness ratios is permitted				





Vertical load resistance of wall or column per unit length:

$$P = \frac{\beta t f_k}{\gamma_m}$$

where β = capacity reduction factor from above table
t = actual wall, column, or leaf thickness
f_k = characteristic compressive strength from table
γ_m = partial safety factor for material from Table 4.7.3 - use 3.5 for sizing.

ARUP

4.7.7 SIZING EXTERNAL WALL PANELS

- Walls in buildings up to four storeys high and subject only to lateral loads may be sized as below. Gravity stresses generally improve capacity to resist wind, and so thickness may be guesstimated for higher loadbearing walls.
- Applicable only in areas with many windbreaks (cities, towns, woodland etc.) within the defined wind zones.
- Thickness of wall should be at least:
  For solid wall: 1/40th of distance between supports
  For cavity wall: total thickness 1/30th of distance between supports; each leaf min. 100mm thick; cavity width 100mm max; wall ties 900 x 450mm spacing; mortar grade (i), (ii) or (iii)
- Treat pitched gable walls as rectangular panels with height taken at mid-height of roof slope.
- Openings (windows, doors, etc.) only if either:
  - Openings are entirely framed by lateral restraints (floors, roof, crosswalls, etc.)
    or
  - (a) the total area of openings is less than the lesser of
    10% of the maximum tabulated area
    25% of the actual wall area
    and
  - (b) no opening is less than half its maximum dimension from any edge of the wall panel (other than its base) and from any adjacent opening.
- If above conditions not satisfied, calculate wind forces and use Table in 4.7.8 or design to BS 5628: Part 1.

Maximum permitted areas of certain walls

Wind zone	Height	A		B		C		D		E		F		G		H		I	
		Cavity wall	190mm solid wall	Cavity wall	190mm solid wall	Cavity wall	190mm solid wall	Cavity wall	190mm solid wall	Cavity wall	190mm solid wall	Cavity wall	190mm solid wall	Cavity wall	190mm solid wall	Cavity wall	190mm solid wall	Cavity wall	190mm solid wall
	m	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2
1	5.4	11.0	13.5	17.5	19.0	26.5	28.5	20.5	29.0	32.0	41.0	32.0	41.0	8.5	10.0	14.0	19.0	19.5	30.5
	10.8	9.0	11.5	13.0	15.5	17.5	21.5	15.5	23.5	24.0	32.5	32.0	41.0	7.0	8.0	10.0	14.5	15.5	21.5
2	5.4	9.5	12.0	14.0	17.0	21.0	24.0	17.5	25.5	27.0	35.5	32.0	41.0	7.5	8.5	10.5	16.5	17.0	24.5
	10.8	8.0	9.5	11.5	14.0	13.5	17.5	13.0	20.5	19.0	28.5	28.0	36.5	6.0	7.0	9.0	11.0	13.0	17.5
3	5.4	8.5	10.5	12.5	15.0	15.5	20.0	14.5	22.5	22.0	31.0	30.5	40.5	6.5	7.5	9.5	13.5	14.5	20.0
	10.8	7.0	8.5	10.0	12.0	11.5	15.5	11.0	17.5	14.5	24.5	24.5	31.5	5.0	6.0	7.5	9.0	11.5	15.0
4	5.4	8.0	9.5	11.0	13.5	13.0	17.0	12.5	19.5	18.0	27.5	27.0	35.0	6.0	6.5	8.5	10.5	12.5	17.0
	10.8	6.5	7.5	9.0	11.0	10.5	13.5	9.5	14.5	12.5	21.0	21.5	27.5	4.0	5.5	6.5	7.5	10.0	12.5

Notes:
1. Cavity wall: 100mm outer leaf (any bricks or blocks not less than 14.0 N/mm²)
   100mm inner leaf (any bricks or blocks not less than 3.5 N/mm²).
   If either leaf is increased to 140mm, increase the areas by 20%
2. Solid walls: Single leaf, collar-jointed, grouted cavity.
   Any bricks or blocks not less than 3.5 N/mm²
3. Wind zones: As BS 5628 Part 3 Figure 1.

ARUP

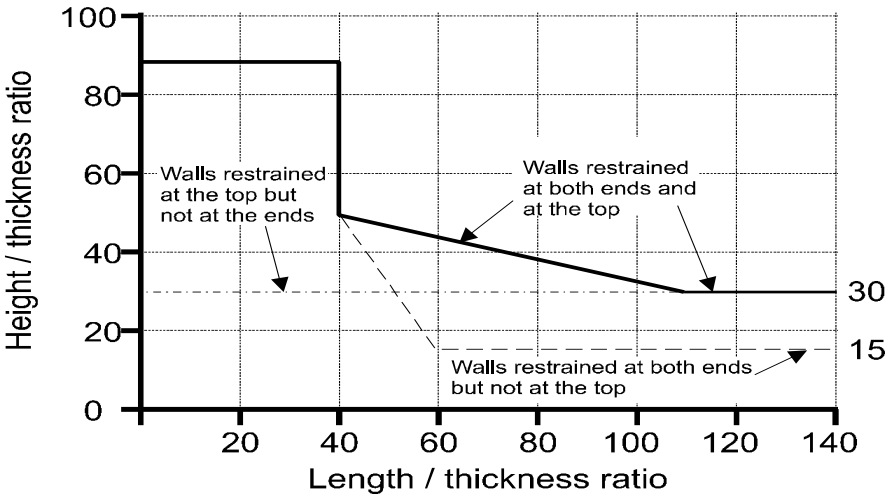
4.7.8 FLEXURAL STRENGTH OF MASONRY

Characteristic Flexural Strength of Masonry, f_{kx}, in N/mm^2						
	Plane of failure parallel to bed joints (spanning vertically)			Plane of failure perpendicular to bed joints (spanning horizontally)		
Mortar designation	(i)	(ii) and (iii)	(iv)	(i)	(ii) and (iii)	(iv)
Clay bricks having a water absorption:						
less than 7%	0.7	0.5	0.4	2.0	1.5	1.2
between 7% and 12%	0.5	0.4	0.35	1.5	1.1	1.0
over 12%	0.4	0.3	0.25	1.1	0.9	0.8
Calcium silicate bricks	0.3		0.2	0.9		0.6
Concrete bricks	0.3		0.2	0.9		0.6
Concrete blocks (solid or hollow) of compressive strength in N/mm^2:						
2.8 used in wall				0.40		0.4
3.5 thickness* up	0.25		0.2	0.45		0.4
7.0 to 100mm				0.60		0.5
2.8 used in wall				0.25		0.2
3.5 thickness* of	0.15		0.1	0.25		0.2
7.0 250mm				0.35		0.3
10.5 used in walls of				0.75		0.6
14.0 any thickness*	0.25		0.2	0.90†		0.7†
and over						

* The thickness should be taken to be the thickness of the wall, for a single leaf wall, or the thickness of the leaf, for a cavity wall. For concrete blocks 100-250mm thick, interpolate.
† When used with flexural strength in parallel direction, assume the orthogonal ratio μ=0.3
Note: Mortar designation as in Table 4.7.6

4.7.9 INTERNAL NON-LOADBEARING MASONRY WALLS

For single-leaf wall of length L and height H, with adequate lateral restraint. calculate the minimum thickness required from the graph:



Extract from BS5628: Part 3, figure 6.

Note:
This graph only applies where significant internal wind pressures cannot occur.

ARUP

For cavity wall with wall ties, sum of leaf thicknesses to be not less than 1½t where t is calculated as above.
Note that the presence of openings, chases, and movement joints may demand greater thickness and/or additional intermediate restraints.

4.7.10 FREESTANDING MASONRY WALLS

Thickness of freestanding walls (Single leaf, unstiffened by piers)

Wind zone	Max. ratio of height (above lateral restraint): actual thickness	Max. ratio of height (above d.p.c.†): actual thickness
1	8.5	6.4
2	7.5	5.6
3	6.5	4.9
4	6.0	4.5

† Assume d.p.c. cannot resist flexure.

Notes: 1. Unit compressive strength $\geq$ 3.5 N/mm^2, density $\geq$ 1400 kg/m^3.
2. Applicable only in areas with many windbreaks (cities, towns, woodland, etc.) - elsewhere calculate wind forces and design as gravity wall or to BS 5628: Part 1.
3. Wind zones as BS 5628 Part 3 Figure 1

4.7.11 JOINTS

Recommended Vertical Joints in Masonry			
Material	Max. joint spacing (m)†	Joint width (mm)	Max. aspect ratio*
Fired-clay bricks	15 12 (preferable)	1.3 x spacing in metres (minimum)	3:1 (suggested)
Calcium silicate (sand-lime) bricks	7.5 - 9	10 (typical)	3:1
Concrete blocks and bricks	6	10 (suggested)	2:1
Natural stone cladding in cement-based mortar	6	10	3:1 (suggested)

† Use max of half these values for joint nearest corner (Internal or External)

* Ratio of panel length:panel height for solid panel; if openings, check each sub-panel separately and consider reinforcement for ratios beyond max. value.

Horizontal joints in non-loadbearing masonry† (BS 5628 Part 1 Cl 29.2.2)		
Uninterrupted wall height	Joint spacing (m)	Joint width (m)
Multi-storey	9m or every third storey (whichever is less), but can omit if building is less than 12m with four or fewer storeys	Allow 1mm per metre between masonry support and top of masonry below; minimum 10mm
Storey-high	At head of wall	Allow 1mm per metre

† Consider also other requirements for joint (acoustic and thermal insulation, weathertightness, fire separation, etc) when selecting joint filler.

4.7.12 OTHER ISSUES

Non-structural issues influencing decisions on material strength, wall thickness, and mortar grade:

Issue	Influence on	Recommendation
Weathertightness	Wall thickness	Use cavity construction (min. 90mm thick outer leaf), or assume min. solid wall thickness for Sheltered/Moderate exposure (Table 11, BS 5628: Part 3): Rendered Clay/calcium silicate/dense concrete/reconstructed stone - 190mm; Lightweight concrete - 140mm. Unrendered 440mm
Durability	Material, strength, mortar grade. Conservatively, for sizing, choose lowest unit strength and mortar grade to satisfy durability	See Table 13 BS 5628: Part 3. For unrendered external walls with high [and low] risk of saturation: Fired-clay units - FL,FN [ML,MN] in (i), (ii),[iii] grade mortar; Calcium silicate units - classes 2-7 in (iii),[iv] mortar *; Concrete bricks $\geq$ 15 [7] N/mm^2 in (iii) mortar; Concrete blocks (any strength) in (iii), [iv] mortar*. For internal walls and inner leaves of cavity walls: Fired-clay units - any in (i)-(iv) mortar; Calcium silicate units - classes 2-7 in (iii) or (iv) mortar; Concrete bricks - $\geq$ 7N/mm^2 in (iv) mortar; Concrete blocks (any strength) in (iii) or (iv) mortar. * See remarks on table 13C for mortar grade (iv).
Fire resistance	Material and whether solid/perforated/hollow; thickness	See Table 16, BS 5628: Part 3. A 100mm unplastered wall or leaf of a cavity wall will give 2 hour fire resistance in all materials and loading conditions (sometimes conservatively) except: Fired-clay bricks/blocks with voids or perforations (75-100% solid - use min. 170mm thickness); Hollow concrete blocks with gravel or natural stone aggregate (limestone OK) - min. 200mm thickness with vermiculite-gypsum plaster. Pay attention to joints around panels.
Thermal insulation (and avoidance of condensation)	Material, strength, thickness of external walls	This often dictates use of cavity wall with lightweight/hollow - hence WEAK - concrete blocks, typically 2.8 - 7 N/mm^2 and 100-150mm min. thickness; this may be a problem on multi-storey loadbearing wall construction. Applied insulation in cavity or on inner [or outer] face may be used. This must be resolved with architect/service engineer EARLY in design.
Sound absorption and noise reduction	Material, strength, thickness	See Building Regulations Approved Document E1 Airborne sound resistance where necessary (e.g. between dwellings) is typically achieved by: Single leaf walls - 215mm plastered brickwork (min. density 1610kg/m^3) or dense blockwork (min. density 1840kg/m^3), or 190mm unplastered concrete (min. density 2200kg/m^3); Cavity walls - two 102mm leaves of plastered brickwork (min.density 1970kg/m^3), two 100mm leaves (50mm cavity) of plastered dense blockwork (min. density 1990kg/m^3), or two 100mm leaves (75mm cavity) of plastered dry-lined lightweight blockwork (max. density 1600 kg/m^3). Pay attention to joints aroud panels.
Appearance	Material, strength	Architect's choice - must be resolved EARLY as it profoundly influences structural design.
Health and safety	Thickness of unit	Units weighing more than 20kg should not be used if one-man laying is intended (which is normal). E.g. max. thickness dense blockwork at 2000kg/m^3 is 105mm (standard 440x215 block). Consider collar-jointed wall or blocks laid on side† if thicker wall required (†check strength with manufacturer).