THINK BRICK
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Design of Free-Standing Clay Brick Walls

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1. Introduction

Before a masonry fence can be built, the building regulation authorities require that a permit be obtained. Many authorities require that fences be designed to resist the wind loads given in the Australian Standard Structural Design Actions Part 2 (AS 1170.2). The result is that traditional methods of construction and design, in which the mass of the brickwork has to be sufficient to provide the necessary stability, are often uneconomical or impracticable.

The buttresses or piers used with these fences only contribute to the stability of the wall when the wind blows from the side opposite to that in which they project. For the purposes of design, the vertical bending strength of such fences is ignored because brickwork, like concrete, although strong in compression is relatively weak in tension.

This manual advocates the use of piers which have reinforcement that extends into the footings. These piers are simple slender members in which the steel reinforcement resists the tensile stresses induced by wind loads. They work in the same manner as the posts in timber post and rail fences and, because the fence need no longer be high in mass to be stable, the wall panels can usually be a single leaf in thickness.

The amount of material used in this type of free-standing wall is often half that required by traditional methods which are likely to have inferior stability. The savings in the materials employed gives a corresponding reduction in construction costs and excavation of the foundations. It is not only those concerned with large or tall brick fences who can benefit from the design approach given in this manual.

The design method is described in detail in Section 5. Various moment-formulas and allowable stresses are given, but most users of this note will only wish to use the tabulated information given in Section 3 to obtain instant load and strength values for their particular application. In this way an economical and stable wall can be designed in a few minutes. Some design alternatives, including serpentine, staggered and hollow walls are also considered.

Because most free-standing walls will be exposed to the elements on all faces the quality of the materials and workmanship should be as high as possible. In addition to the structural requirements for free-standing walls this manual gives suitable construction details and material specifications.

Notation

The following notation has been used throughout this section:

Symbol	Meaning	Units
A_s	Cross-sectional area of steel reinforcement	mm^2
d	Distance from the centre of steel reinforcement in tension to the outside edge of compression zone in direction of bending	m
e	Estimated long-term (15 year) unrestrained expansion of brick	mm/m
f'_m	Characteristic unconfined compressive strength of brickwork	MPa
f'_{uc}	Characteristic unconfined compressive strength of bricks	MPa
H	Height of a free-standing wall above ground level	m
L	Length of a pier footing in the direction of the wall panel	m
l	Length of a wall perpendicular to the direction of the wind	m
m	Force due to mass of a material	(kN/m^3)
M	Applied moment due to wind pressure	kN.m/m
M_r	Moment of resistance or stability moment of a member	kN.m/m
p	Wind pressure	kPa
S_p	Spacing of piers or points of lateral support	m
t_p	Thickness of a wall plus the projection of a pier, buttress or intersecting wall	m
t_w	Thickness of a wall panel	m
T_w	Overall thickness of a wall section where $T_w \neq t_w$	m
V	Shear force	kN
w_p	Width of a pier or buttress	m

2. Structural design

This section enables the user to quickly determine the wind loads acting upon free-standing walls and to design them in accordance with the relevant Australian Standards. Information is provided in tabular and graphic form so that the users may experiment with different structural solutions. The limit states design method has been used throughout this note and each step of the design sequence is explained in detail.

A structurally sound brickwork fence is composed of the following elements:

- An adequate footing system;
- Brickwork panels which may or may not have adequate stability in themselves; and, if they do not;
- Lateral support in the form of piers, posts or return walls.

Table 5 (page 10) shows the ability of wall panels to span between points of lateral support. Unless the wind pressure is particularly high or the lateral support is to be widely spaced, single-leaf panels are usually adequate. If bonded twin-leaf or hollow walls are employed, additional lateral support will be unnecessary in some instances.

The only loads to which free-standing walls are subject result from self weight and from wind pressure. The wind loads and the properties of the brickwork and footings can be determined either by use of the tables in Section 3, computation or by a combination of both. Appropriate methods of computation are outlined in Section 5.

It is recommended that the design steps illustrated in Figure 1 be followed.

Figure 1. Design sequence

	Design problem	Quick solution	Detailed method
1	Determine the wind class for the site	Local authority or AS 4055	See AS 1170.2
2	Convert wind class to pressure	Table 1	See Section 5.2
3	Convert wind pressure to overturning moment and shear force	Tables 2 & 3	See Section 5.2.1 and 5.2.2
4	Determine the stability moment of the wall panels (per unit length)	Table 4	See Sections 5.3.1
5	Determine if additional lateral support is required (per unit length). If not, proceed to step 9.	Subtract the stability moment of the wall from the overturning moment of the wind (see Section 5.4.1(a)).	
6	Determine the maximum allowable spacing of lateral supports for the wall panel, according to wind pressure.	Table 5	See Section 5.4.1(b)
7	Determine the required lateral support at the spacings selected.	Multiply the lateral support moment and shear force required per unit length by the selected spacing between points of support.	
8	Select appropriate means of lateral support to satisfy the requirements for moment and shear force	Tables 6 or 7	See Section 5.4
9	Determine the required footings for the wall or piers (if used)	See Section 5.5 and AS 2870	
10	Choose appropriate construction details	See Section 4	

3. Design tables

The tables in this section can be used without reference to the related methods of calculation if desired. They should be used in the sequence described in Figure 1.

Where answers of greater accuracy are required, or details of the design calculations are needed, reference should be made to the appropriate parts of Section 5.
The notation is defined in Section 1.

Table 1. Design wind pressures (kPa) for free-standing walls

Wind class	Wind speed for ultimate limit state (m/s)	Gust pressure (kPa)	Wall length/height ratio (l/H)				
			1	2	3	4	≥5
			Design wind pressures (kPa)				
N1	34	0.69	0.88	0.86	0.85	0.84	0.83
N2	40	0.96	1.22	1.19	1.17	1.16	1.15
N3	50	1.50	1.91	1.86	1.83	1.81	1.80
N4	61	2.23	2.84	2.77	2.73	2.70	2.68
N5	74	3.29	4.17	4.07	4.02	3.97	3.94
N6	86	4.44	5.64	5.50	5.42	5.37	5.33
C1	50	1.50	1.91	1.86	1.83	1.81	1.80
C2	61	2.23	2.84	2.77	2.73	2.70	2.68
C3	74	3.29	4.17	4.07	4.02	3.97	3.94
C4	86	4.44	5.64	5.50	5.42	5.37	5.33

Notes:
1. For details and methods of calculation, refer to Section 5.2.
2. Interpolation for wall length/height ratio is permitted.

Table 2. Overturning moments on free-standing walls (kN.m/m)

Pressure (kPa)	Wall height (m)							
	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
	Overturning moment (kN m/n)							
0.8	0.3	0.6	0.9	1.3	1.8	2.3	2.9	3.6
0.9	0.4	0.6	1.0	1.5	2.0	2.6	3.3	4.1
1.0	0.4	0.7	1.1	1.6	2.2	2.9	3.6	4.5
1.1	0.4	0.8	1.2	1.8	2.4	3.2	4.0	5.0
1.2	0.5	0.9	1.4	1.9	2.6	3.5	4.4	5.4
1.3	0.5	0.9	1.5	2.1	2.9	3.7	4.7	5.9
1.4	0.6	1.0	1.6	2.3	3.1	4.0	5.1	6.3
1.5	0.6	1.1	1.7	2.4	3.3	4.3	5.5	6.8
1.6	0.6	1.2	1.8	2.6	3.5	4.6	5.8	7.2
1.7	0.7	1.2	1.9	2.8	3.7	4.9	6.2	7.7
1.8	0.7	1.3	2.0	2.9	4.0	5.2	6.6	8.1
1.9	0.8	1.4	2.1	3.1	4.2	5.5	6.9	8.6
2.0	0.8	1.4	2.3	3.2	4.4	5.8	7.3	9.0
2.2	0.9	1.6	2.5	3.6	4.9	6.3	8.0	9.9
2.4	1.0	1.7	2.7	3.9	5.3	6.9	8.7	10.8
2.6	1.1	1.9	2.9	4.2	5.7	7.5	9.5	11.7
2.8	1.1	2.0	3.2	4.5	6.2	8.1	10.2	12.6
3.0	1.2	2.2	3.4	4.9	6.6	8.6	10.9	13.5
3.2	1.3	2.3	3.6	5.2	7.1	9.2	11.7	14.4
3.4	1.4	2.4	3.8	5.5	7.5	9.8	12.4	15.3
3.6	1.5	2.6	4.1	5.8	7.9	10.4	13.1	16.2
3.8	1.5	2.7	4.3	6.2	8.4	10.9	13.9	17.1
4.0	1.6	2.9	4.5	6.5	8.8	11.5	14.6	18.0
4.2	1.7	3.0	4.7	6.8	9.3	12.1	15.3	18.9
4.4	1.8	3.2	5.0	7.1	9.7	12.7	16.0	19.8
4.6	1.9	3.3	5.2	7.5	10.1	13.2	16.8	20.7
4.8	1.9	3.5	5.4	7.8	10.6	13.8	17.5	21.6
5.0	2.0	3.6	5.6	8.1	11.0	14.4	18.2	22.5
5.2	2.1	3.7	5.9	8.4	11.5	15.0	19.0	23.4
5.4	2.2	3.9	6.1	8.7	11.9	15.6	19.7	24.3
5.6	2.3	4.0	6.3	9.1	12.3	16.1	20.4	25.2
5.8	2.3	4.2	6.5	9.4	12.8	16.7	21.1	26.1
6.0	2.4	4.3	6.8	9.7	13.2	17.3	21.9	27.0

Notes:
1. For details of the method of calculation, refer to Section 5.2.1.
2. Interpolation is permitted.

Table 3. Shear forces on free-standing walls (kN/m)

Pressure (kPa)	Height (m)							
	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
	Shear force kN/m							
0.8	0.7	1.0	1.2	1.4	1.7	1.9	2.2	2.4
0.9	0.8	1.1	1.4	1.6	1.9	2.2	2.4	2.7
1.0	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
1.1	1.0	1.3	1.7	2.0	2.3	2.6	3.0	3.3
1.2	1.1	1.4	1.8	2.2	2.5	2.9	3.2	3.6
1.3	1.2	1.6	2.0	2.3	2.7	3.1	3.5	3.9
1.4	1.3	1.7	2.1	2.5	2.9	3.4	3.8	4.2
1.5	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.5
1.6	1.4	1.9	2.4	2.9	3.4	3.8	4.3	4.8
1.7	1.5	2.0	2.6	3.1	3.6	4.1	4.6	5.1
1.8	1.6	2.2	2.7	3.2	3.8	4.3	4.9	5.4
1.9	1.7	2.3	2.9	3.4	4.0	4.6	5.1	5.7
2.0	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0
2.2	2.0	2.6	3.3	4.0	4.6	5.3	5.9	6.6
2.4	2.2	2.9	3.6	4.3	5.0	5.8	6.5	7.2
2.6	2.3	3.1	3.9	4.7	5.5	6.2	7.0	7.8
2.8	2.5	3.4	4.2	5.0	5.9	6.7	7.6	8.4
3.0	2.7	3.6	4.5	5.4	6.3	7.2	8.1	9.0
3.2	2.9	3.8	4.8	5.8	6.7	7.7	8.6	9.6
3.4	3.1	4.1	5.1	6.1	7.1	8.2	9.2	10.2
3.6	3.2	4.3	5.4	6.5	7.6	8.6	9.7	10.8
3.8	3.4	4.6	5.7	6.8	8.0	9.1	10.3	11.4
4.0	3.6	4.8	6.0	7.2	8.4	9.6	10.8	12.0
4.2	3.8	5.0	6.3	7.6	8.8	10.1	11.3	12.6
4.4	4.0	5.3	6.6	7.9	9.2	10.6	11.9	13.2
4.6	4.1	5.5	6.9	8.3	9.7	11.0	12.4	13.8
4.8	4.3	5.8	7.2	8.6	10.1	11.5	13.0	14.4
5.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0
5.2	4.7	6.2	7.8	9.4	10.9	12.5	14.0	15.6
5.4	4.9	6.5	8.1	9.7	11.3	13.0	14.6	16.2
5.6	5.0	6.7	8.4	10.1	11.8	13.4	15.1	16.8
5.8	5.2	7.0	8.7	10.4	12.2	13.9	15.7	17.4
6.0	5.4	7.2	9.0	10.8	12.6	14.4	16.2	18.0

Notes:

1. For details of the method of calculation, refer to Section 5.2.2.
2. Interpolation is permitted.

Table 4. Stability moments of free-standing clay brick walls (kN.m/m)

Wall type	Overall thickness (mm)	Height (m)							
		0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
		Stability moment kN m/m							
Single leaf (Note 1)	90	0.06	0.08	0.10	0.12	0.15	0.17	0.19	0.21
	110	0.09	0.12	0.16	0.19	0.22	0.25	0.28	0.31
Solid (Note 2)	190	0.28	0.37	0.46	0.56	0.65	0.74	0.83	0.93
	230	0.41	0.54	0.68	0.81	0.95	1.09	1.22	1.36
Diaphragm (Note 3)	290	0.40	0.54	0.67	0.80	0.94	1.07	1.21	1.34
	350	0.59	0.79	0.99	1.19	1.38	1.58	1.78	1.98

Notes:

1. A cavity wall using wall ties in accordance with AS 3700 has a stability moment equal to the sum of the moments of the individual leaves.
2. Two leaves bonded in accordance with AS 3700 with the collar joint filled with mortar.
3. Construction of diaphragm walls to be in accordance with Section 5.3.4.
4. For details of the method of calculation, refer to Sections 5.3.1 and 5.3.4.
5. Interpolation for wall height is permitted.

Table 5. Maximum horizontal spans (m) of wall panels between points of lateral support (S_p)

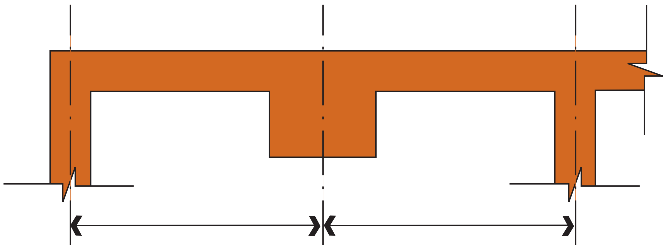
	Single leaf						Solid wall					
Thickness	90			110			190			230		
End condition	A	B	C	A	B	C	A	B	C	A	B	C
Pressure (kPa)	Maximum horizontal span (m)						Maximum horizontal span (m)					
0.8	2.4	1.9	1.0	2.9	2.4	1.2	5.0	4.1	2.0	6.1	5.0	2.5
0.9	2.2	1.8	0.9	2.7	2.2	1.1	4.7	3.9	1.9	5.7	4.7	2.3
1.0	2.1	1.7	0.9	2.6	2.1	1.1	4.5	3.7	1.8	5.4	4.4	2.2
1.1	2.0	1.7	0.8	2.5	2.0	1.0	4.3	3.5	1.7	5.2	4.2	2.1
1.2	1.9	1.6	0.8	2.4	1.9	1.0	4.1	3.3	1.7	5.0	4.0	2.0
1.3	1.9	1.5	0.8	2.3	1.9	0.9	3.9	3.2	1.6	4.8	3.9	1.9
1.4	1.8	1.5	0.7	2.2	1.8	0.9	3.8	3.1	1.5	4.6	3.7	1.9
1.5	1.7	1.4	0.7	2.1	1.7	0.9	3.7	3.0	1.5	4.4	3.6	1.8
1.6	1.7	1.4	0.7	2.1	1.7	0.8	3.5	2.9	1.4	4.3	3.5	1.8
1.7	1.6	1.3	0.7	2.0	1.6	0.8	3.4	2.8	1.4	4.2	3.4	1.7
1.8	1.6	1.3	0.6	1.9	1.6	0.8	3.3	2.7	1.4	4.0	3.3	1.7
1.9	1.5	1.3	0.6	1.9	1.5	0.8	3.3	2.7	1.3	3.9	3.2	1.6
2.0	1.5	1.2	0.6	1.8	1.5	0.7	3.2	2.6	1.3	3.8	3.1	1.6
2.2	1.4	1.2	0.6	1.7	1.4	0.7	3.0	2.5	1.2	3.7	3.0	1.5
2.4	1.4	1.1	0.6	1.7	1.4	0.7	2.9	2.4	1.2	3.5	2.9	1.4
2.6	1.3	1.1	0.5	1.6	1.3	0.7	2.8	2.3	1.1	3.4	2.7	1.4
2.8	1.3	1.0	0.5	1.6	1.3	0.6	2.7	2.2	1.1	3.2	2.6	1.3
3.0	1.2	1.0	0.5	1.5	1.2	0.6	2.6	2.1	1.1	3.1	2.6	1.3
3.2	1.2	1.0	0.5	1.5	1.2	0.6	2.5	2.0	1.0	3.0	2.5	1.2
3.4	1.2	0.9	0.5	1.4	1.1	0.6	2.4	2.0	1.0	2.9	2.4	1.2
3.6	1.1	0.9	0.5	1.4	1.1	0.6	2.4	1.9	1.0	2.9	2.3	1.2
3.8	1.1	0.9	0.4	1.3	1.1	0.5	2.3	1.9	0.9	2.8	2.3	1.1
4.0	1.1	0.9	0.4	1.3	1.1	0.5	2.2	1.8	0.9	2.7	2.2	1.1
4.2	1.0	0.8	0.4	1.3	1.0	0.5	2.2	1.8	0.9	2.6	2.2	1.1
4.4	1.0	0.8	0.4	1.2	1.0	0.5	2.1	1.7	0.9	2.6	2.1	1.1
4.6	1.0	0.8	0.4	1.2	1.0	0.5	2.1	1.7	0.9	2.5	2.1	1.0
4.8	1.0	0.8	0.4	1.2	1.0	0.5	2.0	1.7	0.8	2.5	2.0	1.0
5.0	0.9	0.8	0.4	1.2	0.9	0.5	2.0	1.6	0.8	2.4	2.0	1.0
5.2	0.9	0.8	0.4	1.1	0.9	0.5	2.0	1.6	0.8	2.4	1.9	1.0
5.4	0.9	0.7	0.4	1.1	0.9	0.5	1.9	1.6	0.8	2.3	1.9	1.0
5.6	0.9	0.7	0.4	1.1	0.9	0.4	1.9	1.5	0.8	2.3	1.9	0.9
5.8	0.9	0.7	0.4	1.1	0.9	0.4	1.9	1.5	0.8	2.3	1.8	0.9
6.0	0.9	0.7	0.4	1.1	0.9	0.4	1.8	1.5	0.7	2.2	1.8	0.9

Notes:

1. For method of calculation, refer to Section 5.4.5
2. Mortar composition 1 cement: 1 lime: 6 sand or stronger
3. The end condition refers to the degree of rotational restraint provided at the point of lateral support which affects the horizontal spanning ability of the wall panels. (For details refer to Section 5.4.5.). See Figure 2 for end conditions.

Figure 2. End conditions

End condition type A refers to situations where a wall panel is fully engaged to a pier, buttress or intersecting wall.

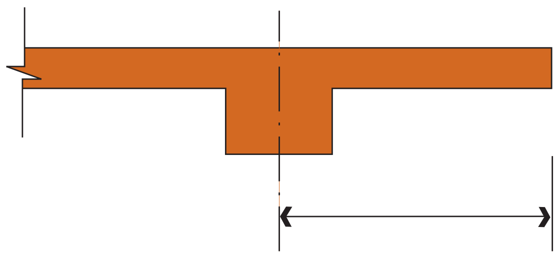


A

End condition type B refers to situations where a wall panel is simply supported against lateral loads but is not provided with rotational restraint.

B

End condition type C refers to situations where a wall panel projects past a fully engaged pier, buttress or intersecting wall as, for example, at a control gap.



C

Table 6. Strengths of reinforced hollow grouted brickwork piers

		Pier type (see Figure 3)															
		A				B				C				D			
Wall thickness (mm)		110	110	110	110	90	90	90	90	110	110	110	110	90	90	90	90
Bar diam. (mm) (Note 1)		10	12	16	20	10	12	16	20	10	12	16	20	10	12	16	20
Shear strength (kN)		33.3	34.1	36.2	39.0	23.4	24.2	26.4	29.2	22.3	23.1	25.2	28.0	15.8	16.6	18.8	21.6
f'_{uc} (Note 2)	f'_m (Note 3)	Bending strength (kN.m)															
5	3.1	9.5	13.4	22.2	28.7	7.7	10.6	16.3	16.0	6.0	8.3	12.0	11.8	4.7	6.4	6.6	6.5
10	4.4	9.7	13.7	23.2	34.0	7.8	11.0	18.2	22.7	6.1	8.6	14.1	16.7	4.9	6.7	9.4	9.2
15	5.4	9.7	13.8	23.6	35.0	7.9	11.1	18.7	27.0	6.2	8.7	14.5	20.5	5.0	6.9	11.1	11.2
20	6.3	9.8	13.9	23.8	35.6	8.0	11.2	19.0	27.7	6.2	8.8	14.8	21.4	5.0	7.0	11.4	13.0
25	7.0	9.8	13.9	24.0	36.0	8.0	11.3	19.2	28.2	6.3	8.8	14.9	21.8	5.0	7.0	11.6	14.5
30	7.7	9.8	14.0	24.1	36.3	8.0	11.3	19.3	28.6	6.3	8.9	15.1	22.1	5.1	7.1	11.8	15.9

Notes:

1. Each pier contains four reinforcing bars of the diameter indicated.
2. Characteristic unconfined compressive strength of bricks (MPa).
3. Characteristic unconfined compressive strength of the masonry when using a 1 cement:1 lime:6 sand mortar.
4. For the method of calculation of pier strengths, refer to Section 5.4.2.

Figure 3. Types of reinforced hollow grouted piers

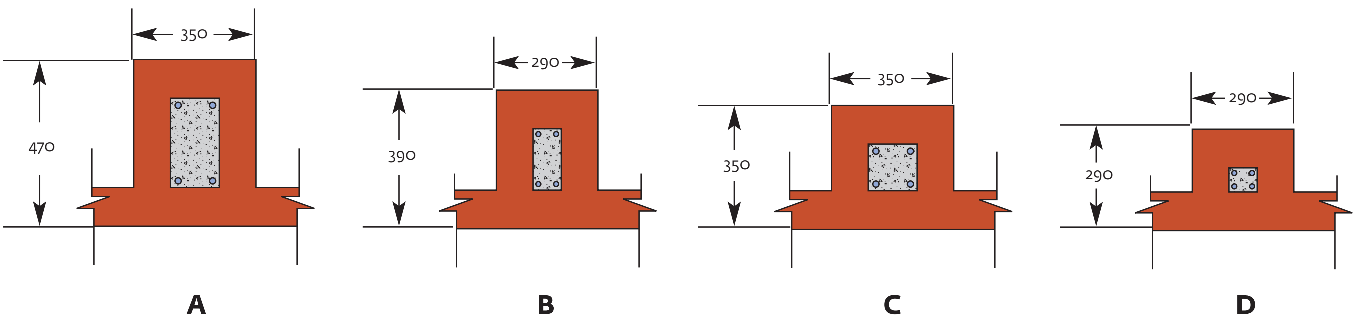


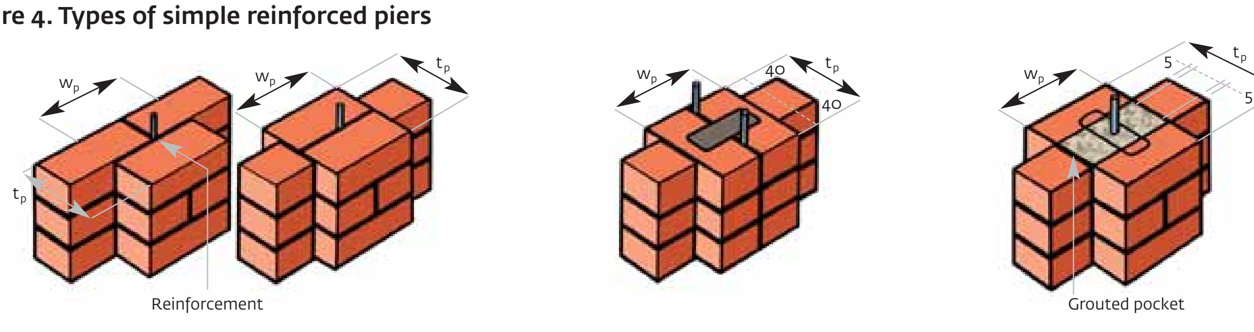
Table 7. Strengths of simple reinforced piers

		Pier type (see Figure 4)															
		E						F				G					
Reinforcement (Note 1)		A	D	A	D	A	D	E	F	E	F	A	B	C	A	B	C
Pier width (mm)		230	230	290	290	190	190	230	230	190	190	230	230	230	290	290	290
Pier depth (mm)		230	230	190	190	290	290	230	230	290	290	280	280	280	210	210	210
Shear strength (kN)		8.0	8.9	8.3	9.2	8.3	9.2	13.2	15.2	14.3	16.3	9.5	9.9	11.4	9.0	9.5	11.0
f'_{uc} (Note 2)	f'_m (Note 3)	Bending strength (kN.m)															
5	3.1	1.5	2.2	1.3	1.9	1.9	2.9	4.7	5.9	6.3	8.5	1.9	2.6	3.3	1.4	1.9	2.3
10	4.4	1.6	2.3	1.3	2.0	2.0	3.0	4.9	5.9	6.6	8.6	1.9	2.7	3.3	1.4	2.0	2.3
15	5.4	1.6	2.4	1.3	2.0	2.0	3.1	5.0	6.1	6.7	8.9	2.0	2.7	3.4	1.5	2.1	2.4
20	6.3	1.6	2.4	1.3	2.1	2.0	3.2	5.1	6.2	6.8	9.1	2.0	2.8	3.5	1.5	2.1	2.4
25	7.0	1.6	2.4	1.3	2.1	2.0	3.2	5.1	6.3	6.8	9.2	2.0	2.8	3.5	1.5	2.1	2.5
30	7.7	1.6	2.5	1.3	2.1	2.0	3.2	5.1	6.4	6.8	9.3	2.0	2.8	3.6	1.5	2.1	2.5

Notes:

1. All steel to be galvanised. Types of steel used are:
   - A. 1 number plain round N10 bar
   - B. 1 number deformed N12 bar
   - C. 2 number deformed N12 bars
   - D. 1 number 25x6 flat bar
   - E. 2 number plain round N10 bars
   - F. 2 number 25x6 flat bars
2. Characteristic unconfined compressive strength of bricks (MPa).
3. Characteristic unconfined compressive strength of the masonry when using a 1 cement:1 lime:6 sand mortar.
4. For the method of calculation of pier strengths, refer to Section 5.4.2.

Figure 4. Types of simple reinforced piers



E **F** **G**

Table 8. Buttressing effect of return walls (stability moment kN.m/m of wall height)

	Single-leaf		Solid or cavity	
Leaf thickness (mm)	90	110	90	110
Return length (brick units)				
1	0.07	0.05	0.14	0.11
2	0.28	0.22	0.55	0.43
3	0.62	0.49	1.25	0.98
4	1.11	0.87	2.22	1.73
5	1.73	1.35	3.46	2.71
6	2.49	1.95	4.99	3.90
7	3.39	2.65	6.79	5.31
8	4.43	3.47	8.86	6.93

Notes:

1. For details and method of design calculation, refer to Section 5.4.3.
2. The length of return used to determine the stability moment should not be greater than the height of the wall.

4. Materials and workmanship

4.1 General

Because most free-standing walls are exposed to the elements on all faces, using high quality workmanship and materials will extend their useful life. Particular attention should be given to the jointing. All head, bed and collar joints should be completely filled, the joints should be tooled to a smooth finish and raked or recessed joints should not be used unless the reduction of wall thickness has been taken into account in the design stage.

4.2 Bricks

The bricks used in free-standing walls should have the appropriate durability for the environment. Durability requirements for various exposure environments can be obtained from AS3700 Table 5.1. Bricks used in reinforced brickwork must have the required compressive strength. Only bricks with a low level of permanent moisture expansion (less than 1.0 mm/m) should be used in the reinforced pier and brick panel fences described in this manual (see Section 5.4.2). Bricks that are to be used in single leaf brickwork should have an acceptable finish on both faces and have low variability in width unless one side of the panels is to be bagged or rendered or an uneven face is acceptable.

4.3 Mortar, grout and concrete

4.3.1 Mortar

The mortar used in free-standing walls must be durable and develop good bond strength. Durability requirements for various exposure environments can be obtained from AS 3700 Table 5.1 and Table 10.1. This manual recommends that the mortar used in reinforced piers and the brickwork panels, should be of 1 cement:1 lime:6 sand composition by volume or better. While mortars stronger than 1:1:6 can be used, they are more prone to shrinkage cracking than those with a higher lime content. Chemical plasticizers or other additives used in the mortar should not be of the air-entraining type and must not be used as a substitute for lime. Mortar for damp-proof courses is discussed in Section 4.5.2.

If good mortar properties are to be achieved it is essential that the correct procedures and materials be used. It is recommended that before construction commences reference be made to CBPI Manual 10, *Construction Guidelines for Clay Masonry* and that if any doubt exists as to whether good bond can be achieved, the simple site test described in AS 3700 Clause D7 be employed.

4.3.2 Grout

The grout used in the reinforced piers illustrated in Table 6 and the Type G pier in Table 7 should be made from 1 cement:2 washed sand:4 10mm aggregate by volume. Sufficient water should be added to ensure that the grout flows into and fills all parts of the grout space. To minimize segregation the grout should be thoroughly remixed before pouring (the use of excess water should be avoided because this may cause segregation of the materials and excessive shrinkage). The grout is usually mixed in small quantities and poured from a bucket in lifts of 300 to 600 mm. Grout should not be poured into brickwork less than 24 hours old otherwise hydrostatic pressure may cause damage. The grout should be thoroughly rodded to eliminate all air pockets. The piers of type E and F shown in Table 7 should be constructed in fresh mortar that completely surrounds and covers the steel reinforcement.

4.3.3 Concrete

The concrete used in footings should have a minimum 28 day characteristic compressive strength of 20 MPa. Concrete made from 1 cement: 2 washed sand: 3 aggregate, usually meets this strength. The slump should not exceed 100 mm.

4.4 Reinforcement

The reinforcement used in hollow grouted piers and in concrete footings may be black steel which is free of grease and rust, but it is desirable that the steel used in mortar bed joints and in piers of the type shown in Table 7 be galvanized.

Design properties of reinforcement are in accordance with Grade 250N as specified in AS/NZS 4671-2001. All hooks, cogs and other construction details must be in accordance with AS 3600-2001.

The steel used in strip footings must have a minimum cover of 50 mm.

4.5 Copings and damp-proof courses (DPCs)

4.5.1 Copings

The primary consideration in coping design is usually appearance, with traditional copings incorporating a sloping top surface to ensure that rainwater ran off before it had a chance to penetrate the brickwork. Products such as bricks, glazed tiles, terracotta tiles, stone, concrete, slate and metal may be used as a coping.

Brick-on-edge copings are simple and convenient and easy to lay. Frequently the core holes at the end of the coping are filled with mortar. If this effect is undesirable a few simple saw cuts can eliminate the effect. Brick-on-edge coping will usually rest upon a damp-proof course (DPC) and overhang by at least 12mm to shed water and prevent stains from water washing dirt down the face of the brickwork. Where the coping itself is flush with the wall the overhang can be achieved by projecting the membrane DPC.

Some other solutions to coping problems are illustrated in Figures 6 and 7.

Differential movement that may occur between the brickwork and copings of dissimilar materials should be taken into account. Where control gaps are required in the wall panels the gap must continue through the coping.

4.5.2 Damp-proof courses

Membrane type DPCs are the most effective water barriers but, except for some that have been especially developed, bond does not develop across them and they remove the wall's vertical bending capacity. The walls in this manual have been designed on the basis of zero vertical bending strength but the structural integrity provided by continuance of bond gives a clearly desirable increased safety margin and the use of properly made mortar DPCs may be desirable.

Beneath a coping, it is best to use a membrane DPC, see CBPI Manual 9, *Detailing of Clay Masonry*. The membrane should be clearly visible on both faces of the wall to ensure that mortar does not act as a bridge across the DPC.

Mortar DPCs must be of composition not weaker than 1 part cement to 3 parts washed sand to which a proprietary waterproofing agent may be added. Two such DPCs are desirable, spaced about two or three courses apart with the lower one at least 150 mm above ground level.

4.6 Control gaps in free-standing walls

Free-standing walls with piers of the types illustrated in Tables 6 and 7 are unlikely to need control gaps when bricks with low permanent moisture expansion "e" values are used (not more than 1.0 mm/m). Where unreinforced piers or buttresses, or bricks with higher "e" values are to be used, control gaps must be used in the walls.

Unless the foundations on which the wall is to stand are completely stable, it is unwise to build the wall without some movement joints to allow stresses resulting from soil swelling and shrinkage to be dissipated harmlessly. The spacing of such movement joints should be based upon the advice of an engineer.

The design of clay brickwork expansion gaps should be in accordance with CBPI Manual 9, *Detailing of Clay Masonry Walls*. The structural effects of control gaps on the horizontal spanning strength of the wall panels must be taken into consideration (see Section 5.4.5).

Control gap spacings for staggered walls are given in Table 1 of the Think Brick Australia publication *Brickwork in Landscape*.

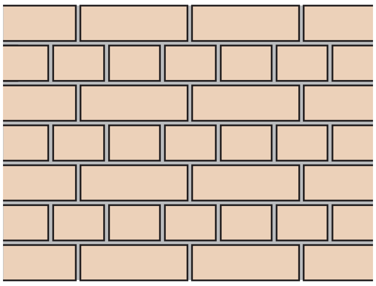
4.7 Bonding details

The appearance of brick walls will be modified to a large extent by the care taken with details and the bonding techniques used. Stretcher bond is almost universally used for single-leaf walls but twin-leaf walls may be enhanced by a number of bonding patterns. Three structurally satisfactory examples are illustrated in Figure 5.

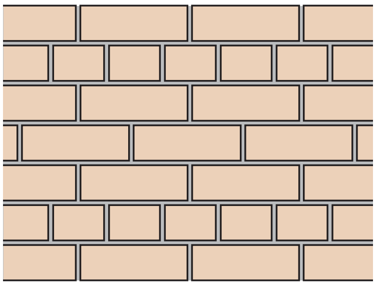
When wall ties are used to bond the two leaves of a twin-leaf wall together, they should be at least medium duty metal ties, spaced at no more than 400 mm horizontally and vertically. The collar joint between the leaves must be filled with mortar as construction proceeds.

Figure 5. Bond patterns for twin leaf walls

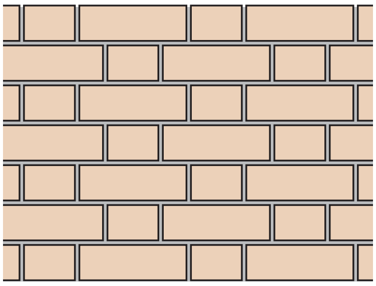
Flemish bond



Colonial bond



English bond



When wall ties are used to bond piers or buttresses to wall panels the number and strength of the ties used should take into account the degree of lateral restraint provided by the member. For single leaf wall panels, sufficient anchorage to piers, buttresses and intersecting walls can normally be provided by using medium duty metal wall ties spaced vertically at 300 mm average and not more than 400 mm between successive ties.

When brick on edge copings are employed, difficulties at corners and wall ends are encountered if perforated bricks are used. The illustrations in Figure 6 give some suggestions as to how perforated bricks may be cut so that the holes are not visible. The use of a masonry saw is necessary for most of the solutions shown. Brick on edge copings should always be used in conjunction with a damp proof course (see Section 4.5).

Figure 6. Coping details for wall panels using extruded bricks

Single-leaf Walls

Twin-leaf Walls

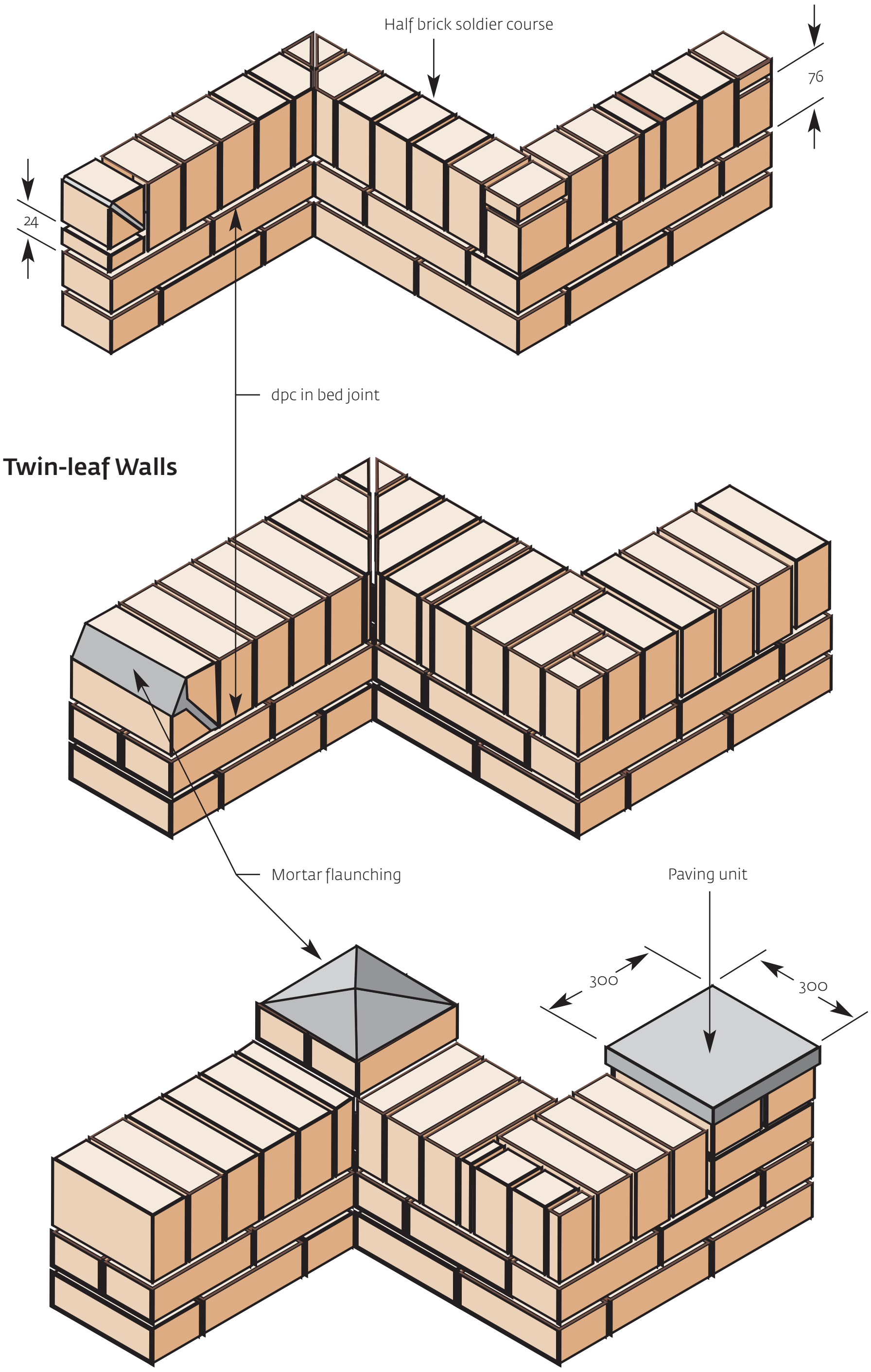


Figure 7. Typical coping details for piers using extruded bricks

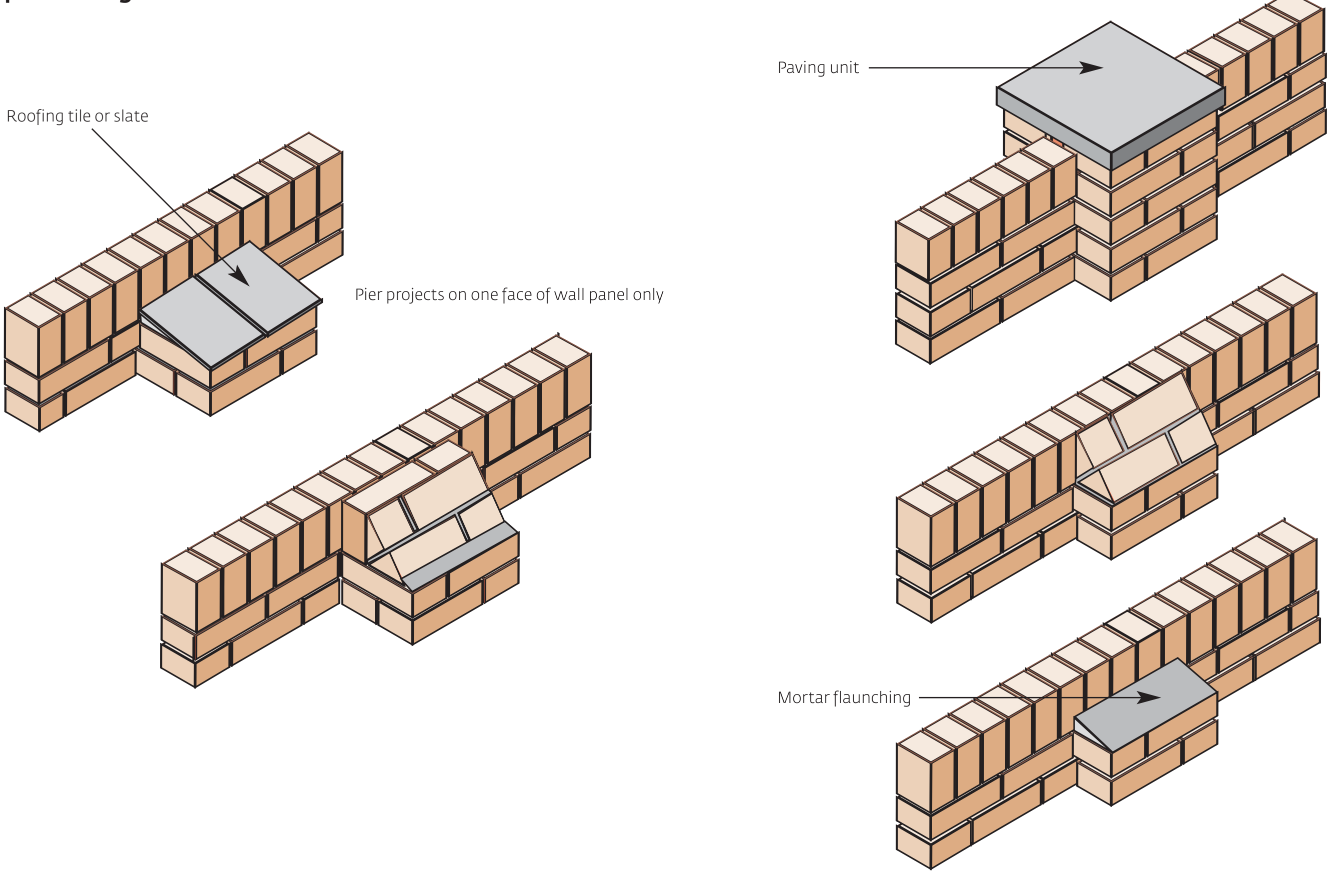
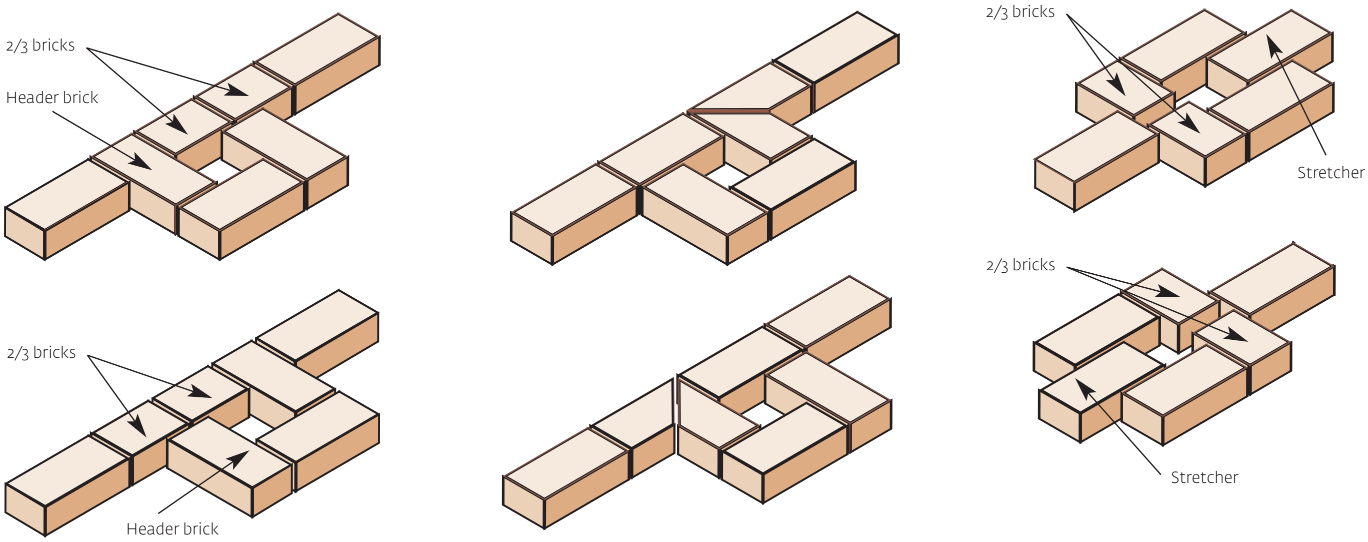


Figure 8. Bonding piers to single leaf wall panels



5. Design theory

5.1 General

This section describes the methods of computation used in the formulation of the tables in Section 3. The limit states method of design has been used throughout. Reference may need to be made to the following standards:

- AS 3700-2001, Masonry Structures
- AS 3600-2001, Concrete Structures
- AS/NZS 1170.1:2002, Structural Design Actions Part 1: Permanent, Imposed and Other Actions and Part 2: Wind Actions
- AS 4055-2006, Wind Loads for Housing
- AS 2870-1996, Residential Slabs and Footings – Construction

5.2 Loads on walls

The only loads that act upon free-standing walls result from the mass of the structure and from wind forces. The wind pressure is dependent upon the geographical location, the shape and size of the wall and the surrounding topography.

In this manual, the wind loads have been related to wind classes from AS 4055, which reflect the effects of geographic location, topographic features, terrain category and shielding. The appropriate wind class will usually be known for new house construction or can be obtained from the local authority or assessed by an engineer if required. The actual load to which a free-standing wall is subjected will also be affected by a drag coefficient, which depends on the length and height of the wall.

Table 1 gives the design wind pressures for free-standing walls based on the wind class determined from AS 4055 and the width/height ratio for the wall.

5.2.1 Overturning moment

Table 2 gives the overturning moments (M) on free-standing walls up to three metres in height, in kN.m per metre length of the wall. For values outside this table or for greater accuracy, the overturning moment can be calculated using the formula:

$$M = \frac{pH^2}{2}$$

5.2.2 Shear force

Table 3 gives the out-of-plane shear forces (V) on free-standing walls up to three metres in height, in kN per metre length of the wall. For values outside this table or for greater accuracy, the shear force can be calculated using the formula:

$$V = pH$$

5.3 Wall stability

5.3.1 Stability of brickwork panels

Table 4 gives the stability moment capacities of free-standing wall panels built in clay brickwork, in kN.m per metre length of the wall. AS 3700 states that in such walls the flexural tensile strength must be taken as zero at the interface with the footing, and therefore the stability moment concept has been used in this manual for unreinforced brickwork panels. AS/NZS 1170.1 gives the weight of clay brickwork as 0.19 kN/m²/10 mm thickness. In the calculation of Table 4, a load factor of 0.9 has been applied.

Table 4 includes single-leaf and solid twin-leaf walls constructed in modular and traditional bricks. The stability moment of cavity walls, with the leaves connected with wall ties in accordance with AS 3700, can be assumed to be equal to the sum of the moments of the individual leaves. For fully bonded diaphragm walls, the stability moment is based on the overall thickness of the wall.

The stability moment of a solid wall in which the centre line is also the centre of gravity can be calculated using the expression:

$$M_r = \frac{0.9mt_w^2 H}{2}$$

Where the wall panel does not have a stability moment capacity greater than the overturning moment due to wind pressure, additional lateral support must be provided in the form of piers or posts or by wall configuration. The economy and efficiency of the wall depends upon the designer balancing the requirements of the wall panels, the lateral support system and the footings design. Thought should be given to the degree of sophistication that can be justified in a given set of circumstances. Single-leaf wall panels with reinforced brickwork piers or steel or timber posts at spacings of 2.1 metres or more, are likely to be more economical than twin-leaf wall panels with lateral support members at much larger spacings. This is because the cost of brickwork is usually proportional to the number of bricks laid, with the degree of complexity as a secondary, although significant, factor.

The choice of methods available to the designer when additional lateral support is required includes:

Walls: Staggered
Chevron
Serpentine
Diaphragm and Hollow

Piers: Reinforced brickwork
Unreinforced brickwork

Posts: Metal sections
Timber posts
Post compression
e.g. Cyclone bolting

5.3.2 Staggered walls

Brickwork walls can be built in a series of returns, usually called a staggered wall, in order to obtain the required stability. Because returns perform the same function as piers the distances between them can be taken from Table 5 (see also Section 5.4.1(b)).

A first term approximation for the stability moment capacity of a staggered wall can be calculated using the expression:

$$M_r = \frac{0.9mt_w T_w H}{2}$$

Where T_w = the overall depth of returns. The free end of a staggered wall must be provided with lateral support equal to half of that required for each panel of brick-work. This can be provided by a reinforced pier, a deep return or by increasing the breadth of the return member. (See also Section 3.1 in the Think Brick Australia manual *Brickwork in Landscape*.)

5.3.3 Chevron and serpentine walls

Zigzag (chevron) and serpentine free-standing walls provide attractive and unusual ways of constructing fences where space is not a major consideration. These walls are usually constructed in single leaf brickwork and the only bonding problems are at the changes of direction in chevron walls. Unless these intersections are adequately bonded the walls cannot be expected to develop their full potential stability. The frequency of the zigzags in chevron walls and the distances crest to crest in serpentine walls should not exceed the allowable spacings of piers given in Table 5 (see also Section 5.4.1 (b)). For serpentine walls and chevron walls with fully bonded panels, end-restraint condition A in Table 5 is applicable but for chevron walls with dogs-tooth squint quoins or wire-tied quoins, the end-restraint condition B is applicable.

The stability moment capacity of chevron walls can be calculated using the formula:

$$M_r = \frac{0.9mt_w T_w H \sqrt{S_p^{\,2} + (T_w - t_w)^2}}{2S_p}$$

Where S_p = horizontal distance between quoins in the major direction of the wall.

Serpentine walls depend upon their curvature for stability against overturning. The Brick Industry Association (USA) Technical Note 29A recommends that for single-leaf serpentine walls the radius of curvature should be no greater than twice the wall height above ground level and the depth crest to crest should be not less than half of the wall height.

The stability moment capacity of a serpentine wall can be estimated using the expression:

$$M_r = 0.9mt_w Hr\left(\frac{Sin^{-1}\left(\frac{S_p}{4r}\right)}{14.3S_p}\right)\left(r - \sqrt{r^2 - \left(\frac{S_p}{4}\right)^2}\right)$$

Where r = radius of curvature of the wall, and
S_p = horizontal distance crest to crest in the major direction of the wall.

When setting out a serpentine wall, having decided upon the radius of curvature r, and S_p, the following expression can be used to determine the overall width of the wall section (T_w):

$$T_w = 2\left(r - \sqrt{r^2 - \left(\frac{S_p}{4}\right)^2}\right) + t_w$$

By transposition, the same expression can be used to determine either S_p or r depending upon which of the dimensions have first been fixed.

5.3.4 Diaphragm walls (hollow walls)

Table 4 includes information on the strengths of two types of diaphragm wall. A diaphragm wall is a cavity wall with the leaves connected at intervals by brickwork webs or diaphragms. The web transfers shear forces, induced by bending, between the two leaves so that they act compositely. Diaphragm walls are therefore similar to twin leaf bonded walls and hollow walls with header ties (e.g. rat-trap bond) except that the overall width of the wall section (T_w) can be increased considerably. The two examples in this note are 290 and 350 mm in overall width being constructed in modular and traditional size bricks respectively. It is usual and convenient to increase the overall width in brick widths, namely 290, 390, 490, etc. in modular bricks and 350, 470, 590, etc. in traditional bricks; the practical limits are imposed by the shear connection between the web and the leaves or the floor space occupied by the wall.

The stability moments of diaphragm walls are proportional to their overall width, but the ability to span between points of lateral support is proportional to the increase in the section modulus. In areas of moderate exposure the diaphragm wall may provide a sufficiently high stability moment not to require additional lateral support, but where this is not so, vertical reinforcement can conveniently be introduced into grouted pockets formed in the centre of the wall.

Diaphragm walls are an economical form of construction with minimal bonding complexity that present two smooth external wall surfaces. The webs are normally located at about 1200 mm centres when the walls span vertically between lateral supports, but for free-standing wall applications this may be increased to 2400 mm or more. The webs can be bonded to the leaves with header units at every fourth course or with medium duty wall ties at not more than 300 mm centres vertically.

A first term approximation of the stability moment of a diaphragm wall can be calculated using the expression:

$$M_r = 0.9 m t_w T_w H$$

5.4 Additional lateral support systems

5.4.1 General

When additional lateral support is required in the form of reinforced piers, buttresses or metal or timber posts, the following design sequence is suggested:

(a) Calculate the additional lateral support required per metre of a given type of wall panel using the expression:

$$M_{required} = M - M_r$$

(b) Using Table 5, determine the maximum allowable spacing of the lateral support members, based upon the design wind pressure and the type of wall selected. Alternatively the maximum allowable spacing of engaged lateral support members used with single-leaf and bonded twin-leaf walls can be calculated using the expressions for horizontal bending moment capacity in AS 3700.

(c) Select a pier spacing corresponding to brickwork dimensions and determine the moment and shear force at the point of lateral support by multiplying the required lateral support per metre by the selected pier spacing.

(d) Select an appropriate system of lateral support.

5.4.2 Reinforced brickwork piers

Table 6 gives the strengths and specifications for reinforced hollow grouted brickwork piers and Table 7 similarly covers three types of reinforced solid piers. The strengths of the piers are expressed in kN.m (for bending moment) and kN (for shear capacity) and both tables stipulate minimum requirements for the following properties:

(i) Pier dimensions

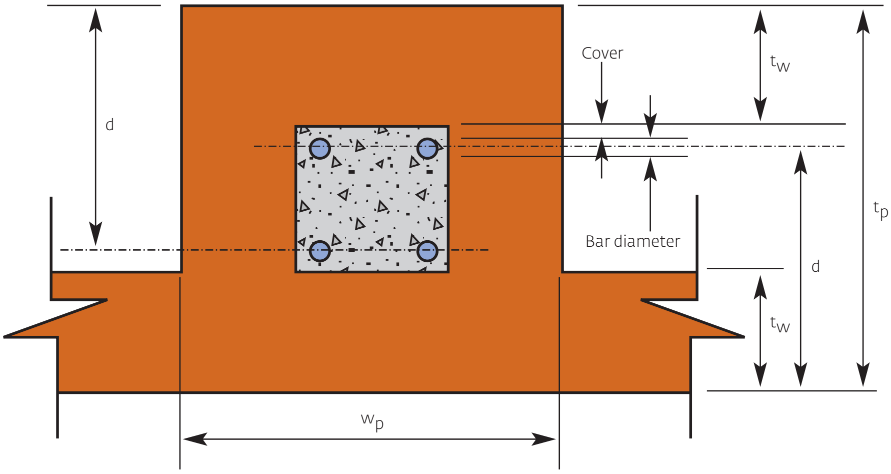
(ii) Steel content (either cross sectional area mm^2 or bar type) and location

(iii) Characteristic unconfined compressive strength of the bricks (f'_{uc})

(iv) Characteristic unconfined compressive strength of the brickwork (f'_m) constructed with 1 cement:1 lime:6 sand mortar.

Should the required compressive strength of the bricks (f'_{uc}) using a 1C:1L:6S mortar be excessive, then it is possible, using Table 3.1 of AS 3700, to design the brickwork in a stronger mortar using the f'_m values given. Reinforced brickwork piers are designed so that they would ultimately fail in tension. They must therefore be checked to ensure the correct relationship between the f'_m and the area of steel (A_s).

The positioning of the steel reinforcement in grout filled piers has been taken in Table 6 as being based upon 15 mm grout cover. This provides adequate protection for marine exposure but not for severe marine exposure (that is, within one kilometre of a surf coast) as defined in AS 3700 Clause 5.2. The corresponding distance from the centre of steel reinforcement in tension to the outside edge of the pier in the direction of bending (d) is therefore:



$$d = t_p - \left(\text{brick width} + 15\text{mm cover} + \frac{\text{bar diameter}}{2} \right)$$

For example:

t_p = 0.350 m

brick width = 0.110 m

bar diameter = 0.010 m

$$d = 0.350 - \left(0.110 + 0.015 + \frac{0.010}{2} \right) = 0.220 \text{ m}$$

5.4.3 Return walls

Most fences incorporate corners and these can provide considerable stability. Table 8 gives the buttressing effect of return walls. The stability moment of a return can also be calculated using the expression:

$$M_r = \frac{0.9 m t_w H L^2}{2}$$

Where L = the length of the return in metres.

For the purposes of calculating the buttressing effect of a return wall, it is recommended the L should not be taken as being greater than H.

Note: All of the piers shown in Table 6 must be provided with pairs of reinforcing bars, divided between each end of the pocket of the pier. It has been assumed that only the reinforcement opposite to the direction of the bending forces is mobilised.

The design capacities of reinforced brickwork piers can be calculated using the formulas given in AS 3700 Section 8. Both the bending capacity and shear capacity should be checked.

5.4.4 Metal and timber posts

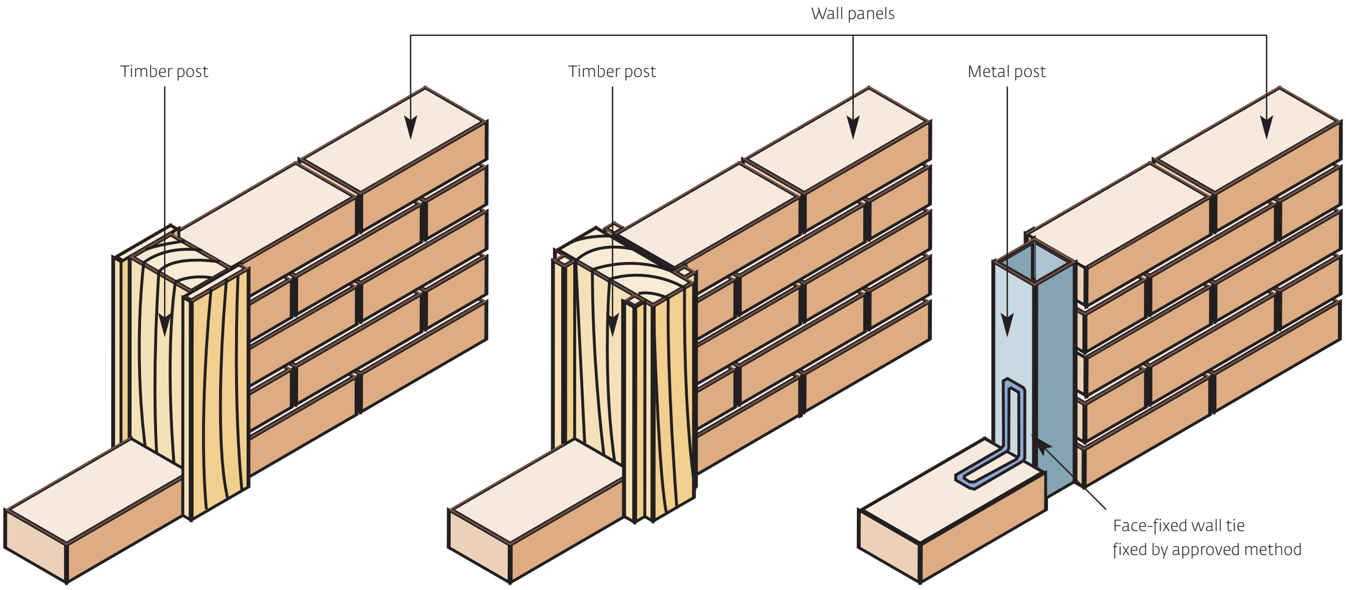
When metal or timber posts are used to provide lateral support for brick walls the manner in which they are connected to the brickwork requires careful attention. The connections cannot provide rotational restraint (a degree of end fixity) to the wall panels, which may therefore be able to span smaller distances than would be the case if engaged brickwork piers or buttresses were used (see Section 5.4.5).

Because steel and timber posts are much more elastic than reinforced brickwork piers of equivalent strength, the deflection of the post must be taken into account. For the purposes of design, either the deflection of the post should be limited or the stability moment of the wall panel should be ignored or reduced because deflection will introduce an eccentricity into the wall panel, which will result in a corresponding reduction in its stability.

Anchorage of the panels to the posts must be made with wall ties that can tolerate long-term differential movement between the two materials. Anchorage may also be achieved by providing a continuous vertical flange into the post in which the panel is located in the same way that a tyre is located by a wheel rim. The connection should be made in a way that gives uniform support. Where ties are used they should be located at every second or third course.

The footings for the posts may be designed in the same manner as for reinforced brickwork piers (see Section 5.5).

Figure 9. Typical brickwork panel to post connections



5.4.5 Structural aspects of control gaps and lateral support connections

In the calculation of Table 5, which gives the maximum allowable spacings of points of lateral support for wall panels, the lateral support for end condition A has been assumed to provide rotational restraint to the wall panels. If the type of lateral support used cannot provide adequate rotational restraint, such as metal or timber posts or at a control gap (see Section 5.4.4) then the ability of the panel to span horizontally will be reduced. The loss will vary according to the degree of lateral support provided. Wall ties can be used to give lateral restraint, but not end fixity between a pier and wall panel at a control gap.

The maximum bending moments induced in wall panels spanning between engaged points of support (end condition A in Table 5) has been assumed to be:

$$M_{max} = \frac{pHS_{p^2}}{12}$$

The maximum bending moment induced in wall panels that are simply supported at one or both ends (end condition B in Table 5) has been assumed to be:

$$M_{max} = \frac{pHS_p^{\ 2}}{8}$$

The maximum bending moment induced in wall panels that project past engaged points of lateral support (end condition C in Table 5) has been assumed to be:

$$M_{max} = \frac{pHS_p^{\ 2}}{2}$$

5.5 Footings

All free-standing walls must be supported on a footing designed in accordance with the standard for Residential Slabs and Footings – Construction AS 2870-1996. This applies also to reinforced piers supporting free-standing walls. The design of footings for specific soil conditions is not covered in this manual.

Where a wall is centrally aligned to a strip footing, the footing width should be not less than 250 mm for a single-leaf wall and 300 mm for a twin-leaf wall. Where the wall is not central to the footing, the width should be increased to 450 and 525 mm respectively.

Pier and beam footings can be integrated very successfully into the design approach for free-standing walls given in this manual, by using deep (reinforced) concrete pier footings and thin wall panels constructed in strong mortar. All that remains is to reinforce the brickwork panels with steel so that they can support their own self weight between the pier footings. The wall panels should be reinforced top and bottom and may be clear of the ground. If they are in contact with the ground, they should incorporate a mortar damp proof course (see Section 4.5.2). The steel reinforcement should be galvanized and preferably be a flat bar.

With pier and beam brick fences, it is usually necessary to employ the services of an engineer to produce individual designs.

6. References

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