Manual 5

THINK BRICK AUSTRALIA

Design of Clay Masonry Walls for Fire Resistance

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When a masonry wall is subjected to fire, which is usually only on one side, a thermal gradient is created through the thickness of the wall and the expansion of the material causes bowing towards the fire source. If this bowing extends far enough it can cause collapse of the wall. Even if the wall does not collapse, it can crack because of internal stresses caused by restraint of the thermal expansion, or it can heat up sufficiently to allow flammable material on the side away from the fire to ignite. Both these consequences can cause the fire to spread.

1 Introduction

A large proportion of the National Construction Code (NCC)' deals with the design of buildings for fire safety. The NCC sets out the requirements, while the means for satisfying these requirements are detailed in the Australian Masonry Structures standard AS 3700[2] . The commentary to AS37003 also contains useful background information on design for fire resistance and guidance on using the standard.

The NCC specifies that walls must be designed to achieve three Fire Resistance Levels (FRLs). These are defined as:

(i) **Structural adequacy**
The ability of a wall to continue to perform its structural function for the fire resistance period.

(ii) **Integrity**
The ability of a wall to maintain its continuity and prevent the passage of flames and hot gases through cracks in the wall for the fire resistance period.

(iii) **Insulation**
The ability of a wall to provide sufficient insulation such that the side of the wall away from the fire does not exceed a pre-defined temperature during the fire resistance period. However, it should be noted that at this temperature – a rise of 140°C over the ambient temperature or a maximum of 180°C – surface finished and furnishings in contact with or near the wall may combust.

The resultant fire resistance level is expressed in minutes for each of these periods and always in the same order. For example, an FRL of 90/90/90 means a fire resistance period of 90 minutes each for structural adequacy, integrity and insulation.

In setting the required levels for FRL, the NCC takes into account many factors including –

(i) The class of building of which the wall forms a part.

(ii) The height and size of the building.

(iii) Whether the wall is loadbearing or non-loadbearing.

(iv) How close it is to a boundary or another building (for external walls).

In order to satisfy these requirements of the NCC, AS 3700 sets out rules for determining a fire resistance period of a masonry wall for each of structural adequacy, integrity and insulation. The fire resistance period (FRP) must be equal to or greater than the FRL for each mode of behaviour.

The FRP may be found by either –

(i) The use of tabulated values,

(ii) The use of test results, or

(iii) A recognised method of calculation.

Tabulated values are conservative and test results will usually give a more cost-effective outcome. However, tabulated values can be used by referring only to AS 3700, whereas the use of test results will usually require precise knowledge of the type of masonry unit to be used. Rules of interpreting the results of fire tests carried out on masonry walls are given in AS 3700. Where two or more results of tests on the same type of masonry unit are available, interpolation and extrapolation from these results can be used. The third alternative, a recognised method of calculation, is difficult not practical given the current state of research.

Structural adequacy and insulation requirements have been determined from an extensive test program conducted since the late 1970s4.5. The results of these tests enable the determination of the relationship (or shape of the curve) for these properties. The structural adequacy charts in this manual were developed based on table 6.1 of AS 3700 and represent the lower bound of the test results.

The FRP for structural adequacy is specific to the wall type and its boundary support conditions. Most common wall types and sizes are covered in this manual; for those not shown, designers should refer to the brick manufacturer for test results.

Note: Some masonry members are not required by the NCC to confine the spread of fire (ie. have an FRL for insulation and/or integrity).

The FRP for structural adequacy is specific to the wall type and its boundary support conditions. Most common wall types and sizes are covered in this manual; for those not shown, designers should refer to the brick manufacturer for test results.

2 Design for Fire Resistance

2.1 Structural Adequacy

The charts in this manual allow the designer to directly determine the fire resistance period for structural adequacy for a given wall type with specific boundary conditions over a range of height and length.

These charts are based on the limits for slenderness ratio given in AS 3700, which are summarised for clay masonry in Table 1. The slenderness ratio Is calculated in accordance with AS 3700 Clause 6.3.2.2.

Table 1: Maximum Slenderness Ratio for Structural Adequacy of Clay Masonry Walls

Fire resistance period for structural adequacy (mins)	30	60	90	120	180	240
Maximum slenderness ratio	25.0	22.5	21.0	20.0	18.0	17.0

The FRP for structural adequacy is specific to the wall type and its boundary support conditions. Most common wall types and sizes are covered in this manual; for those not shown, designers should refer to the brick manufacturer for test results. The use of the charts and design from test results are explained and illustrated with examples in Section 3.1.

2.2 Integrity

Tabulated values for integrity resistance are not provided in AS 3700. A member is deemed to have the required fire resistance for integrity if that level is met for both structural adequacy and insulation. Put simply, the fire resistance for integrity can be taken as the lesser of the values tabulated for structural adequacy and insulation. Design from test results is also an option and this is explained in Section 3.2.

2.3 Insulation

The fire resistance period for insulation is a function of the material thickness of the wall. This manual allows a designer to calculate the fire resistance period for insulation for clay brick walls of any thickness. Design for insulation by tabulated values and test results are explained and illustrated in Section 3.3.

2.4 Specific Test Results Take Precedence

Although clay brick properties are consistent for a particular product, they may vary widely between different products because of differences in raw materials and manufacturing processes.

Recognising that most products will produce a superior performance to the lower bound, some brick manufacturers have submitted specific products for fire testing. Accordingly, specific test results should take precedence over the lower bounds expressed in this manual.

2.5 Brick Veneer Construction

Brick veneer walls consist of an outer lead of brickwork tied to a steel or timber supporting frame. The brickwork provided insulation fire protection to the supporting frame against an external fire source. When required, structural adequacy is provided by the supporting frame.

For housing, where the external walls are closer than 0.9m to the boundary, or closer than 1.8m to another building on the site (that is not a class 10a building) there is a requirement for 60/60/60 FRL (see the NCC). Brick walls in accordance with AS4773.16 are deemed to satisfy this requirement.

2.6 Reinforced Masonry

There are several additional requirements specified by AS 3700 for reinforced masonry:

(i) Minimum reinforcement for member spanning horizontally – such that the member can withstand a design lateral load of 0.5 kPa.

(ii) Minimum reinforcement for a member spanning vertically – such that the member can withstand the greater of:

(a) A flexural moment equivalent to the applied vertical compressive loads times height/36, or

(b) A design lateral load of 0.5 kPa.

(iii) Protection of reinforcement – for structural adequacy, the cover to the face exposed to fire should not be less than the appropriate value summarised in Table 2.

Table 2: Protection for reinforcement for structural adequacy

Fire resistance period for structural adequacy (mins)	30	60	90	120	180	240
Minimum dimension from reinforcement to exposed masonry face	30	30	30	40	50	60

2.7 Walls with Openings

If a wall has an opening greater than one-fifth the height of the wall, the structural adequacy FRP must be calculated by regarding the wall as divided into two sub-panels with a free edge at the centre of the opening.

2.8 Chases

The chasing of masonry members that are subject to fire shall be kept to a minimum. For the purpose of determining structural adequacy, chases in vertically spanning walls may be ignored if:

(i) The chase is vertical; or

(ii) The chase is horizontal and its length is not greater than four times the wall thickness.

Otherwise, the slenderness ratio of the wall is to be based on the overall thickness of the wall less the depth of the chase.

Chases in walls spanning both horizontally and vertically (panel action) can be ignored if:

(i) The chase is horizontal and its length is not greater than half the wall length; or

(ii) The chase is vertical and its length is not greater than half the wall height.

Otherwise, the slenderness ratio of the wall is to be based on the thickness of the wall less the depth of the chase. Alternatively, where a vertical chase is greater than half the height of the wall, the chase may be regarded as an unsupported edge and the wall designed as two sub-panels.

For the purpose of determining integrity and insulation resistance, the effect of chases in walls of solid, cored or grouted hollow units can be ignored if:

(i) The chase depth is less than 30 mm,

(ii) The section of chase is less than 1000 mm2, and

(iii) The total chases face area on both sides of the wall is less than 100,000 mm^2 per five square metres of walling.

Otherwise, determine the integrity and insulation FRPs based on the wall thickness less the chase depth. For ungrouted hollow masonry units, the integrity and insulation FRPs must always be determined based on the wall thickness less the chase depth.

2.9 Recesses

Recesses made in walls for services may be ignored provided:

(i) They penetrate less than half the wall thickness, and

(ii) Their total area (in both faces) within any five square metres of walling is not more than 10,000 mm2.

Otherwise, the wall thickness for fire resistance should be taken as the overall thickness less the depth of the recess.

2.10 Protection of Structural Steelwork

The minimum material thickness of masonry to provide fire protection to structural steelwork, including mullions, is a value obtained from AS41007 or Table 3.

Table 3: Minimum material thickness of clay masonry for the protection of structural steel

Sides of column exposed to fire	Column spaces (3)	Minimum material thickness of clay masonry (mm) (2)				
		Fire Resistance Level (FRL) (1)				
		60/60/60	90/90/90	120/120/120	180/180/180	240/240/240
≤3	Filled	50	50	50	65	90
	Unfilled	50	50	65	-	-
4	Filled	50	50	50	75	100
	Unfilled	50	50	65	-	-

Notes:

(1) Fire Resistance Level (FRL) expressed in terms of minutes for: insulation / integrity / structural adequacy

(2) Maximum 25% coring allowed

(3) Filled column space means that all the area surrounding the column, including re-entrant zones (eg. between flanges of a universal column), is completely filled with grout and masonry.

3 Determining a Fire Resistance Period

3.1 Structural Adequacy

3.1.1 General

The fire resistance period (FRP) for structural adequacy may be calculated from tabulated values or by test results. The charts in this manual have been formulated using the tabulated values in AS 3700. For design using the charts, the FRP for structural adequacy may be read directly from the appropriate chart taking into account the boundary conditions as shown by the icon on the top right of each chart. The FRP is indicated at the point where the wall height and length intersect on the chart.

Design from test results is illustrated by example in Section 3.1.5.

3.1.2 Cavity Walls

Cavity wall charts in this manual are based on the leaves being approximately equally loaded (within 10 per cent of each other). If the leaves are not equally loaded the wall should be designed as a single-leaf wall using the thickness and fixity of the more heavily loaded lead. Note that it is most common for leaves to be not equally loaded.

For cavity walls where both leaves have a superimposed axial force within 10 per cent of each other (including where there is no load on either lead) AS 3700 allows the slenderness ratio to be based on:

(i) A thickness equal to two-thirds of the sum of the thicknesses of the two leaves; and

(ii) The fixity of the leaf not exposed to the fire.

Where cavity walls are constructed with leaves of different masonry unit types, the structural adequacy should be based on the less fire-resistance material.

3.1.3 Slenderness Ratio

For structural adequacy design, using either the charts or test results, the slenderness ratio (S_{rf}) is determined in accordance with Clause 6.3.2.2 of AS 3700 as follows:

For vertically spanning walls (with no support along either vertical edge):

$$S_{rf} = \frac{a_{vf} H}{t} \qquad (1)$$

Where –

a_{vf} = Vertical span coefficient (0.75 where there is lateral support on the top edge, otherwise 2.0)

H = Clear height of the member

t = Overall thickness of the member

For a wall with at least one vertical edge supported (panel action) the slenderness ratio is given by the lesser of:

$$S_{rf} = \frac{a_{vf} H}{t} \qquad (2)$$

$$S_{rf} = \frac{0.7}{t} \sqrt{a_{vf} H a_n L} \qquad (3)$$

$$S_{rf} = \frac{a_n L}{t} \qquad (4)$$

Where –

a_n = Horizontal span coefficient (1.0 where there is lateral support along both vertical edges, or 2.5 where there is lateral support along one vertical edge)

L = The clear length of the member

and the other symbols are as defined before.

3.1.4 Design Loads for Lateral Supports

For structural adequacy design, it is essential that any laterally supporting members and their connections have the capacity to support the wall. Supports and their connections must be designed in accordance with Clauses 2.6.3 and 2.6.4 of AS 3700.

These requirements are summarised as:

(i) Lateral supporting members should be capable of resisting the static reactions for the appropriate load combination, plus 2.5% of the design vertical load.

(ii) Connections should be capable of resisting the load on the member derived from (i) multiplied by 1.25.

3.1.5 Structural Adequacy by Test Results

As discussed in the introduction, structural adequacy charts represent lower bound values and specific test results, where available, can be used to obtain a more favourable result.

Where two or more test results are available, and

(i) the test results are for walls built with the same type of clay masonry units, which AS 3700 defines as having the same mineralogy and geological type, blended in the same proportions and manufactured by similar processes,

(ii) the slenderness ratios of the specimens cover a minimum range of two, and

(iii) the slenderness ratio of the member is not more than two outside the tested range,

then the fire resistance period is obtained by determining a coefficient C_5 as the lowest value from substituting the test results in the following equation.

$$C_5 = \frac{(S_{rf}-13)}{\ln(720/t_f)} \qquad (5)$$

Where –

S_{rf} = The slenderness ratio of the tested specimen, determined according to Section 3.1.3 above.

t_f = The time to failure in structural adequacy for the tested specimen (minutes).

It is necessary to evaluate C_5 from each test result and adopt the minimum value of C_5.

This minimum value can then be used in Equation 5 to determine the FRP for a member with a slenderness ratio not more than two outside the test range.

Example:

Test 1:	S_{rf} = 18	t_f = 180	therefore C_5 = 3.61
Test 2:	S_{rf} = 21	t_f = 90	therefore C_5 = 3.85

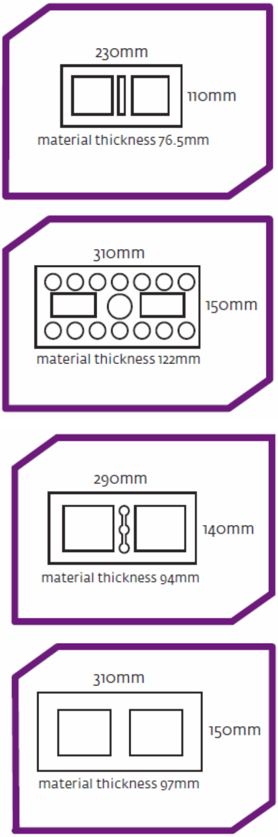
Therefore adopt C_5 = 3.61 as the minimum. This value can then be substituted in Equation 5 for the design of walls having slenderness ratios between 16 and 23.

It could therefore be calculated that a member made from the same type of clay masonry units with S_{rf} = 23 would have a time to failure of 45 minutes for structural adequacy. Therefore, adopt an FRP of 30 minutes for this wall.

It should be noted that the results of tests on non-loadbearing walls must only be applied to design of other non-loadbearing walls, not to the design of loadbearing walls.

As discussed in the introduction, structural adequacy charts represent lower bound values and specific test results, where available, can be used to obtain a more favourable result.

Figure 1.
A Selection of Typical Hollow Clay Units to Illustrate the Concept of Material Thickness for Insulation



3.2 Integrity

3.2.1 Integrity from Tabulated Values

As explained in Section 2.2, a member is deemed to have the required fire resistance for integrity if that level is met for both structural adequacy and insulation. For design from tabulated values, the FRP is determined for structural adequacy and insulation, and the fire resistance for integrity is the lesser of these values.

3.2.2 Integrity by Test Results

When a single test result is available, the FRP of a member can be taken equal to the tested value, provided the thickness is not less than that of the test specimen.

Where two or more test results are available, and

(iv) the test results are for walls built with the same type of clay masonry units, which AS 3700 defines as having the same mineralogy and geological type, blended in the same proportions and manufactured by similar processes, and

(v) the thicknesses of the test specimens cover a minimum range of 20 mm,

then the FRP of the masonry member may be linearly interpolated between the test results. Extrapolation is not permitted.

3.3 Insulation

3.3.1 Material thickness

For a solid wall built from cored or solid units (including those with frogs), or from hollow units fully grouted, the material thickness is the overall thickness of the wall. For these purposes, a cored unit is one with voids not greater than 30 per cent of the total unit volume. For a wall built from hollow unit (with voids greater than 30 per cent) the material thickness is the net volume of the unit divided by the area of the exposed vertical face of the unit where the net volume of the unit equals total volume minus volume of voids. Illustrated in Figure 1 (as examples to illustrate the concept) are four typical hollow clay units.

For cavity walls, the material thickness is equal to the sum of the material thicknesses of the separate leaves.

For a rendered wall, any render up to 20 mm thickness applied to the face of the wall not exposed to fire may be considered part of the material thickness. On a face exposed to fire, render is assumed to be ineffective.

3.3.2 Insulation by Tabulated Values

Material thicknesses for insulation are tabulated in AS 3700, from which Table 3 is a summary applicable to clay masonry.

Table 3: Material Thickness of Clay Masonry for Insulation Resistance

Fire resistance period for insulation (mins)	30	60	90	120	180	240
Material thickness (mm)	60	90	110	130	160	180

3.3.3 Insulation by Test Results

When one test result is available, the thickness of the designed member must not be less than the thickness of the test specimen.

Where two or more test results are available, and

(i) the rest results are for walls built with the same type of clay masonry units, which AS 3700 defines as having the same mineralogy and geological type, blended in the same proportions and manufactured by similar processes, and

(ii) the material thicknesses of the test specimens cover a minimum range of 20mm,

then the fire resistance period is obtained by determining a coefficient Ci as the lowest value from substituting the test results in the following equation.

$$t_c = C_i t_m^{17} \qquad (6)$$

Where –

t_m = The material thickness of the tested specimen, determined according to Section 3.3.1 (millimetres).

t_c = The time to failure in insulation for the tested specimen (minutes).

It is necessary to evaluate C_i from each test result and adopt the minimum value of C_i.

This minimum value can then be used in Equation 6 to determine the FRP for a member with a material thickness not more than 20 mm outside the test range.

Example:

Test 1:	t_m = 110mm	t_c = 90 min	therefore C_i = 0.030
Test 2:	t_m = 180mm	t_c = 240 min	therefore C_i = 0.032

Therefore adopt C_i = 0.030 as the minimum. This value can then be substituted in Equation 6 for the design of walls having material thickness between 90 and 200.

It could therefore be calculated that a member made from the same type of clay masonry units with material thickness of 150 mm would have a time to failure of 150 minutes for insulation. Therefore, adopt an FRP of 120 minutes for this wall.

Chart 1.
Structural Adequacy FRP (minutes) for 90 mm Clay Masonry Walls with Simple Supports on Four Sides.

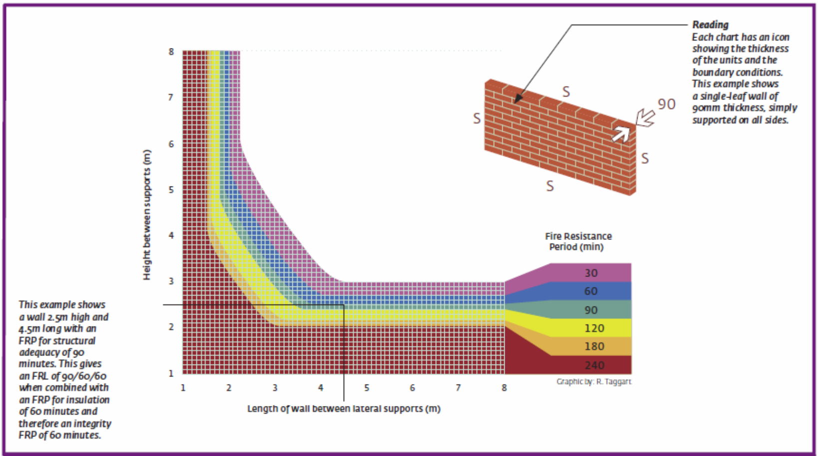


Chart 2.
Structural Adequacy FRP (minutes) for 110 mm Clay Masonry Walls with Simple Supports on Four Sides.

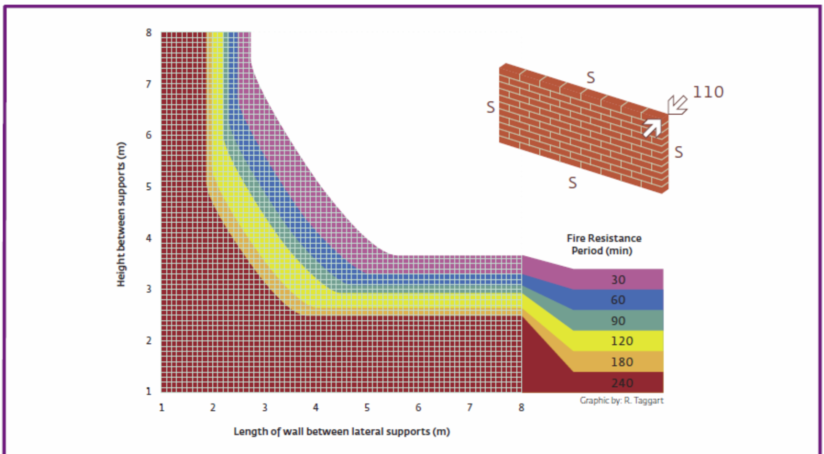


Chart 3.
Structural Adequacy FRP (minutes) for 140 mm Clay Masonry Walls with Simple Supports on Four Sides

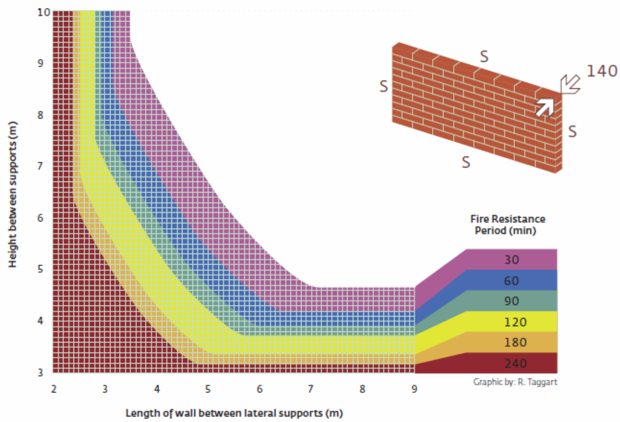


Chart 4.
Structural Adequacy FRP (minutes) for 150 mm Clay Masonry Walls with Simple Supports on Four Sides

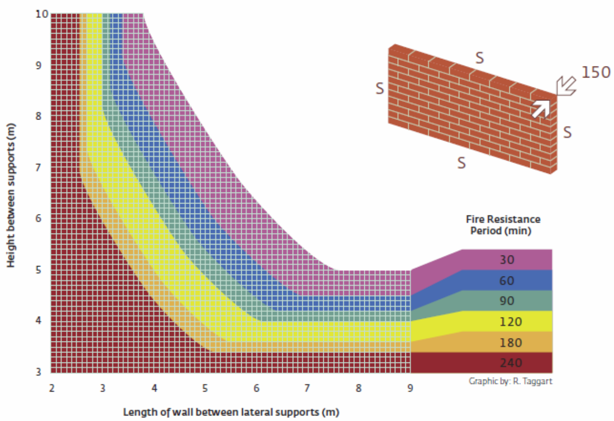


Chart 5.
Structural Adequacy FRP (minutes) for 190 mm Clay Masonry Walls with Simple Supports on Four Sides

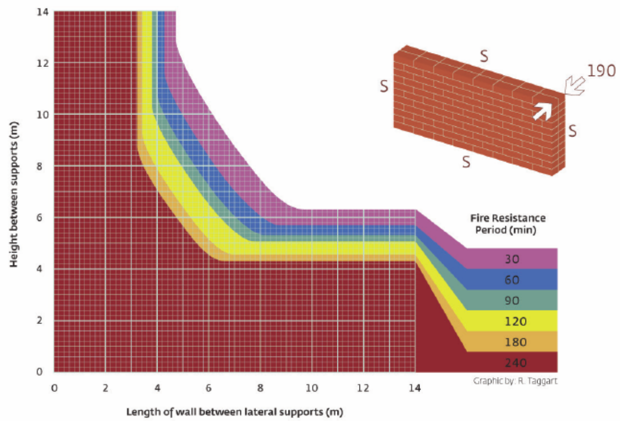


Chart 6.
Structural Adequacy FRP (minutes) for 230 mm Clay Masonry Walls with Simple Supports on Four Sides

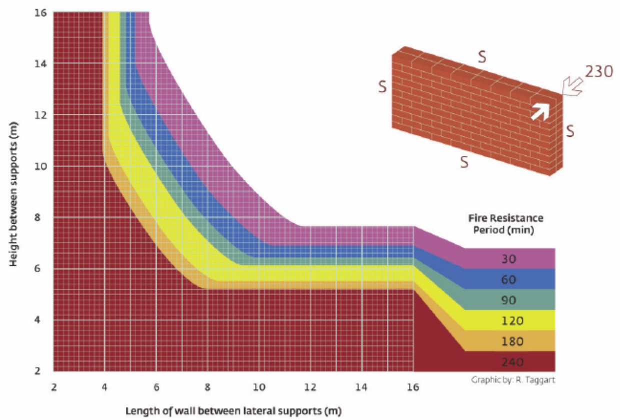
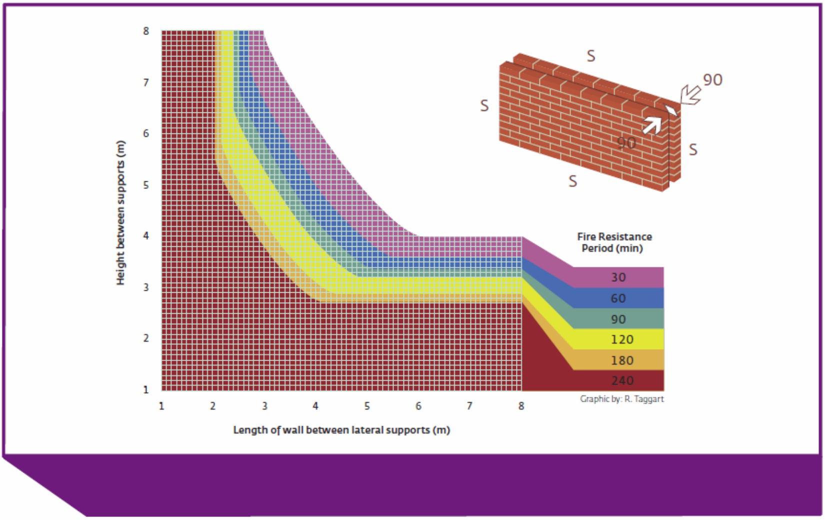
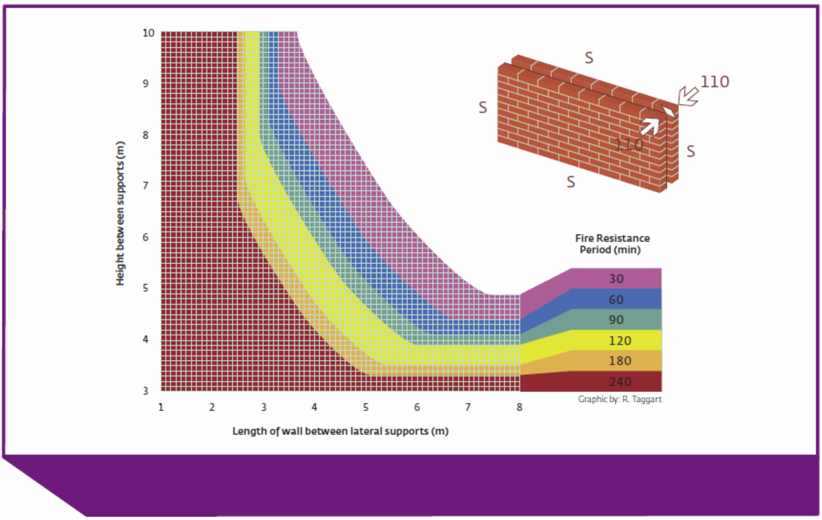


Chart 7.
Structural Adequacy FRP (minutes) for 90-90 mm Cavity Clay Masonry Walls with Simple Supports on Four Sides



Note: It is assumed that both leaves are approximately equally loaded (see Section 3.1.2)

Chart 8.
Structural Adequacy FRP (minutes) for 110-110 mm Cavity Clay Masonry Walls with Simple Supports on Four Sides



Note: It is assumed that both leaves are approximately equally loaded (see Section 3.1.2)

Chart 9.
Structural Adequacy FRP (minutes) for 110 mm Clay Masonry Walls with Simple Supports on Three Sides and One Side Free

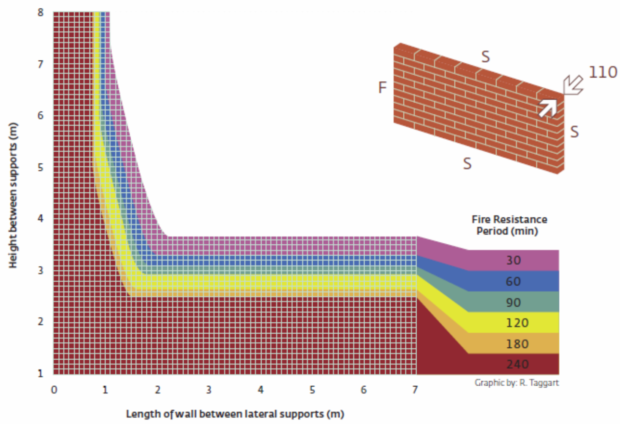


Chart 10.
Structural Adequacy FRP (minutes) for 140 mm Clay Masonry Walls with Simple Supports on Three Sides and One Side Free

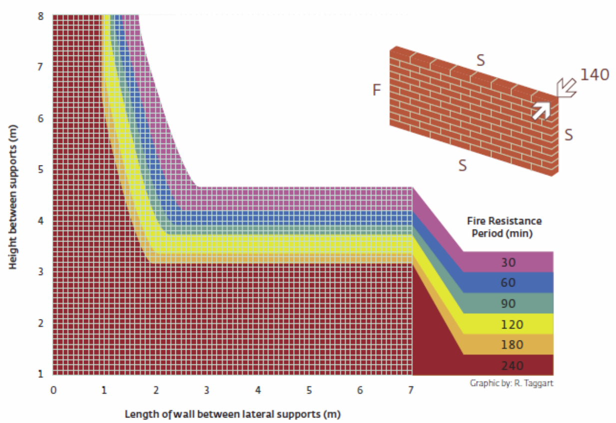


Chart 11.
Structural Adequacy FRP (minutes) for 150 mm Clay Masonry Walls with Simple Supports on Three Sides and One Side Free

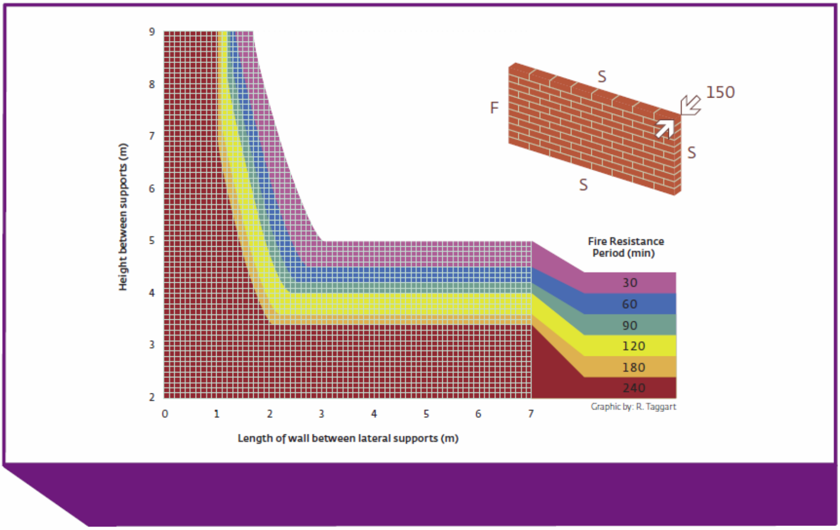


Chart 12.
Structural Adequacy FRP (minutes) for 190 mm Clay Masonry Walls with Simple Supports on Three Sides and One Side Free

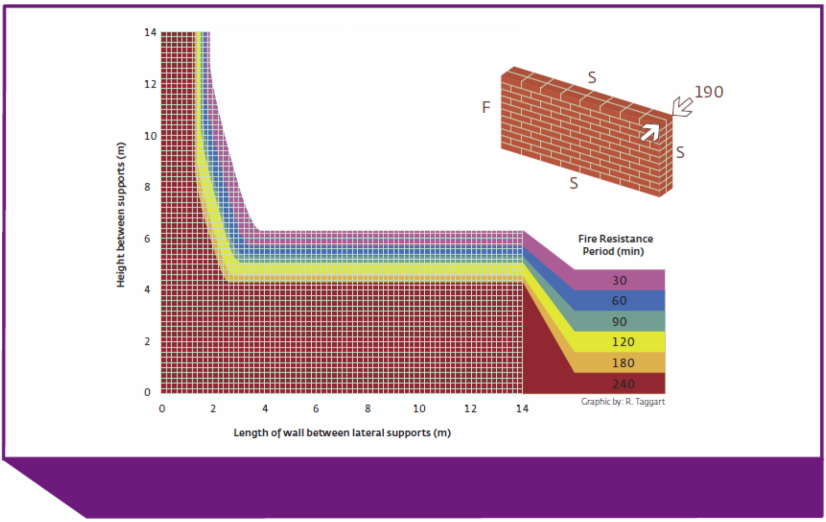


Chart 13.
Structural Adequacy FRP (minutes) for 230 mm Clay Masonry Walls with Simple Supports on Three Sides and One Side Free

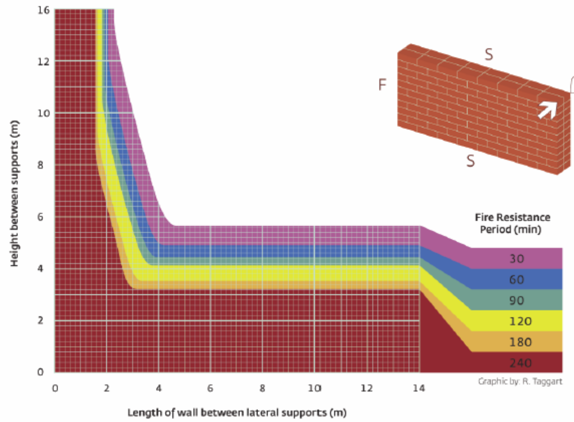
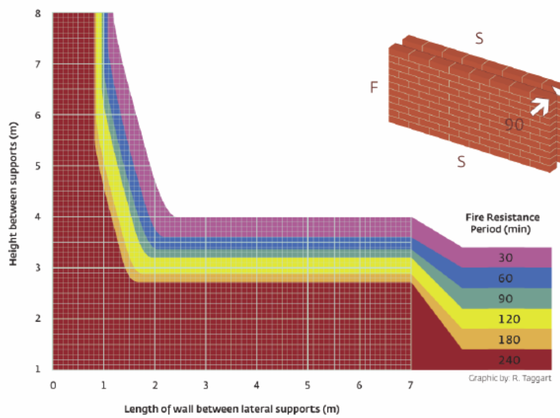
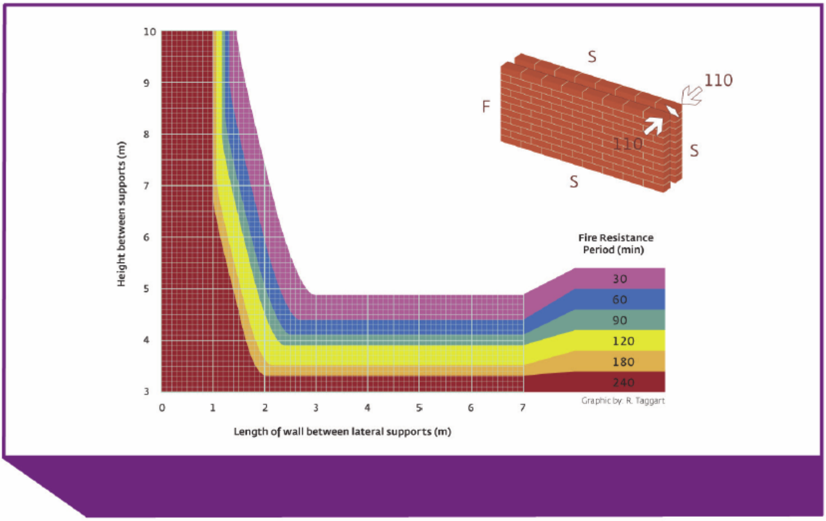


Chart 14.
Structural Adequacy FRP (minutes) for 90-90 mm Cavity Clay Masonry Walls with Simple Supports on Three Sides and One Side Free



Note: It is assumed that both leaves are approximately equally loaded (see Section 3.1.2)

Chart 15.
Structural Adequacy FRP (minutes) for 110-110 mm Cavity Clay Masonry Walls with Simple Supports on Three Sides and One Side Free



Note: It is assumed that both leaves are approximately equally loaded (see Section 3.1.2)

Chart 16.
Structural Adequacy FRP (minutes) for 190mm Clay Masonry Walls with Simple Supports on Three Sides and the Top Free

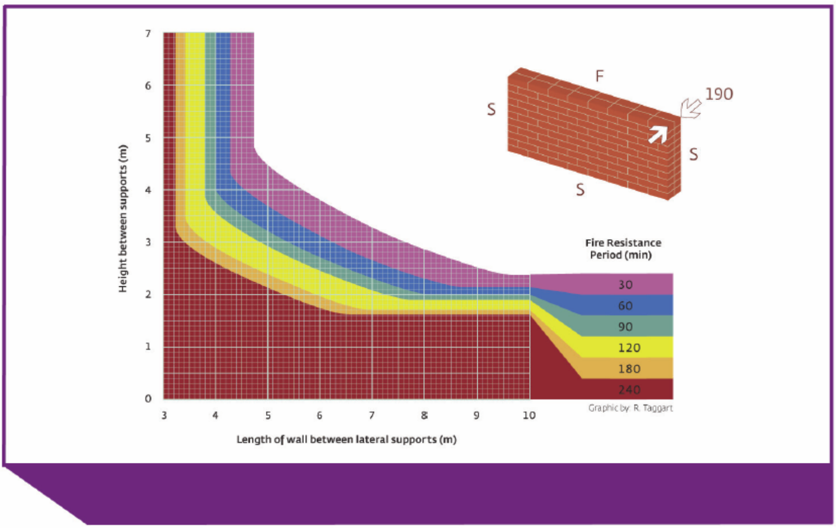


Chart 17.
Structural Adequacy FRP (minutes) for 230 mm Clay Masonry Walls with Simple Supports on Three Sides and the Top Free

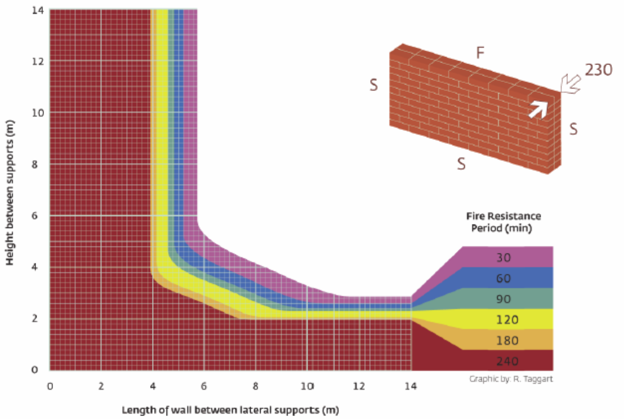
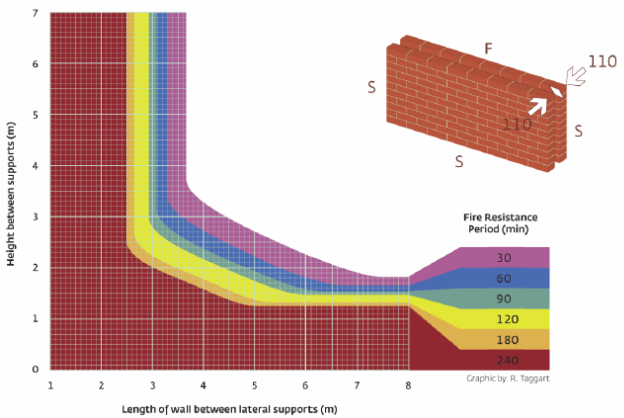


Chart 18.
Structural Adequacy FRP (minutes) for 110-110 mm Cavity Clay Masonry Walls with Simple Supports on Three Sides and the Top Free



Note: It is assumed that both leaves are approximately equally loaded (see Section 3.1.2)

4 References

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Cover image:
Gympie Aquatic Recreation Centre.
Finalist, Horbury Hunt Commercial Awards 2017.
Architect: Liquid Blu
Photographer: Christopher Frederick Jones
Manufacturer: Bowral Bricks
Product: Chillingham White

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