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FDN4 Penetration of Plasterboard Fire Walls

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STRUCTURAL STEEL MEMBERS

PENETRATION OF PLASTERBOARD FIRE WALLS

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The Issue

There are many situations where fire-resistant plasterboard walls are used to divide a building into separate fire compartments. The purpose of providing such walls is to prevent the spread of fire from one compartment to another. This Design Note considers the impact of steel members penetrating such walls on their performance in preventing fire spread.

It is common for structural steel members to penetrate fire-resistant walls. The most common situation is where a steel frame or supporting column is located within a fire-resistant plasterboard wall and other steelwork such as purlins or beams must frame into this supporting steelwork. Inevitably, this results in steel members penetrating the envelope of the wall. Since steel is a good heat conductor, it is traditionally assumed that fire may spread between compartments due to excessive heat flow via the penetrating steel member. In the past measures have been taken to avoid this possibility, with penetrating members being fire-protected on each side of the wall. This can be expensive. Two situations are illustrated below.

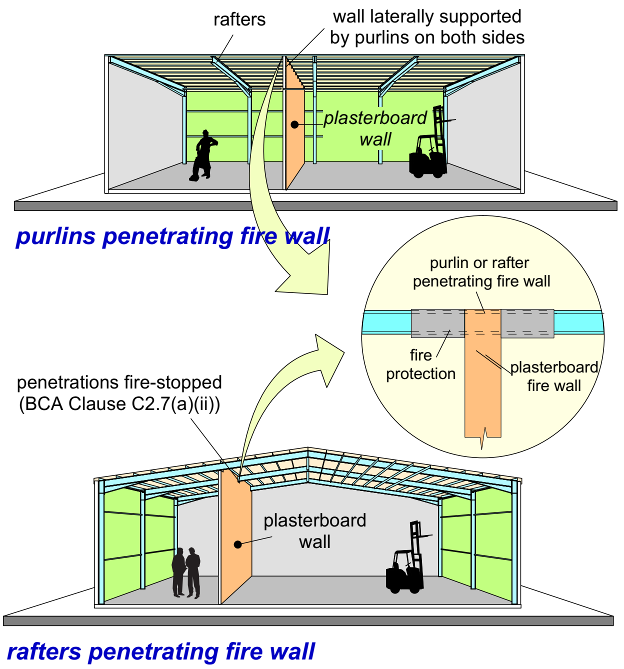

Figure 1

In addition to resisting the transmission of heat via a penetrating member, a plasterboard wall must remain intact despite the deformation of the roof members and the loads that may be applied to the wall. Sufficient wall strength *(structural adequacy)* can be achieved in a variety of ways, to be discussed later in this Design Note.

The purpose of this Fire Design Note is to present a basis for cost-effective solutions where steel members penetrate fire walls.

BCA Requirements

The role of a fire wall is to separate two fire compartments and to assist in achieving the objectives and performance requirements of the Building Code of Australia (BCA) [1]. The behaviour of a fire wall is characterised by its performance with respect to *structural adequacy* (remaining in place for the required duration), *integrity* (preventing transmission of hot gases and flames) and *insulation* (preventing excessive temperatures on the unexposed face, being the face on the side away from the fire).

Deemed-To-Satisfy vs Alternative Solution

The performance requirements of the BCA can be achieved by satisfying the deemed-to-satisfy (DTS) provisions or by demonstrating that an alternative solution satisfies these requirements.

Figure 2

According to AS1530.4 [2], which is referenced by the BCA, failure with respect to insulation occurs when the temperature rise of the unexposed face exceeds an average of 140°C or 180°C maximum at any of the measured locations. Since a penetrating element passes through the wall at one location, it is the maximum temperature rise criterion (180°C) that is relevant. However it is known from fire testing that this temperature limit is lower than necessary. This fact was first noted by Schwartz and Lie [3] who found from a literature survey that the lowest unexposed surface temperature for ignition is at least 300°C. Further testing was carried out at the Centre for Environmental Safety and Risk Engineering (CESARE) at Victoria University [4] which verified a similar minimum ignition temperature. A slightly more conservative value of limiting maximum temperature of 275°C will be adopted in this Design Note. Will this maximum temperature criterion be exceeded for unprotected steel steel members penetrating a plasterboard wall?

This Design Note provides test information on the temperatures that will be attained by unprotected steel elements penetrating fire-resistant plasterboard walls. Furthermore, this Design Note provides a justification and basis for alterative solutions involving the penetration of plasterboard walls by bare steel members.

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What Performance is Required?

An alternative solution must satisfy both the BCA objectives and performance requirements. In the context of the issue being considered, the most relevant performance requirement is:

CP2 - A building must have elements which will, to the degree necessary, avoid the spread of fire -

to exits, to sole-occupancy units and public corridors, between buildings and in a building,

appropriate to -

the function or use of the building, the fire load, the potential fire intensity, the fire hazard, the height of the building, its proximity to other property, any active fire safety systems installed in the building, the size of any fire compartment, fire brigade intervention, other elements they support and the evacuation time.

In summary, the wall construction and any penetrating members between compartments must be designed and detailed so as to prevent the spread of fire.

How Can Adequate Performance Be Achieved?

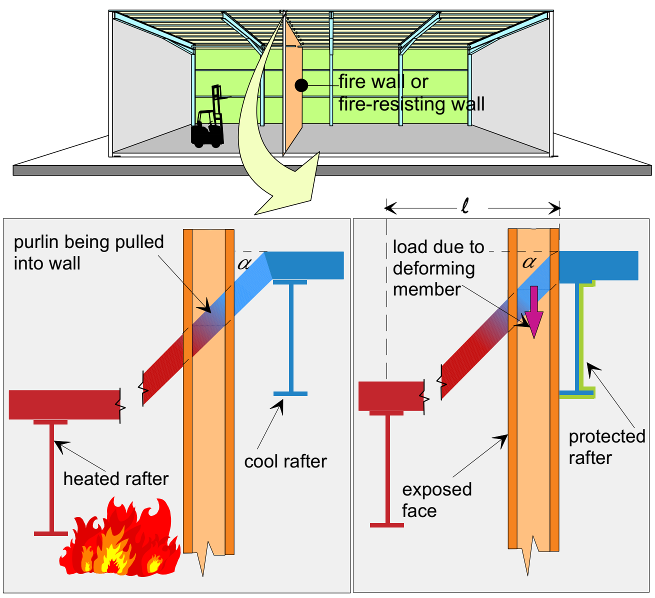
The thermal and structural behaviour of both the wall and the penetrating steel roof member must be sufficient to prevent spread.

Structural Adequacy of Plasterboard Wall

In the event of a fire on one side of a fire-resistant wall, the steel roof structure on the heated side will deform significantly. The structural members both within the wall and forming the roof structure on the non-fire side must maintain their ability to support the wall. These issues are discussed briefly below, and further guidance is given in reference [5].

Wall Intersected by Purlins

If the plane of a wall is perpendicular to the purlins, deformation of the purlins and rafters on the fire side of the wall may be sufficient to drag the purlins downwards into the wall as illustrated below.



(a) (b)

Figure 3

This situation can be avoided as follows:

(i) locate the wall directly adjacent to a protected rafter (see Figure 3(b)) and allow sufficient space below the purlins for some movement (see detail in Figure 4(a)). The rafter adjacent to the fire wall must be protected, since fire may occur either side of the wall, or

(ii) incorporate steelwork within the wall capable of resisting the loads applied to the top of the wall. In this case the rafter does not need to be protected.

Estimates of purlin deflection and purlin reaction loads applied to supporting members will need to be made on a case-by-case basis, but an example will be presented to demonstrate some of the principles involved. Further detail can be obtained from reference [5].

Assume that the purlin is supported by a rafter adjacent to the wall as per Figure 3(b) and that it is discontinuous at all rafter supports, attached to each rafter by two bolts. As the roof on the fire side of the wall is heated, the purlins will tend to heat more rapidly than the rafter due to their thinner steel section. They will thus expand and remain slack until the rafter deflects sufficiently for this slack to be absorbed. At this time the force in the purlin will increase rapidly, with shear failure of the heated bolts occurring shortly thereafter. The vertical component of the axial force in the purlin at this time will be the maximum force applied to the supporting structure. Assuming purlins and bolts to be at a temperature of 800°C, the angle to the horizontal (α) and the vertical component of the reaction force (P) can be calculated as follows:

$$\alpha = \cos^{-1}\left(\frac{1}{1+11.7\times10^{-6}\times800}\right) = 8^{\circ}$$

$$P = \sin\alpha \times 2 \times V_s \times 0.15,$$

where the thermal expansion coefficient of steel is taken to be 11.7e-6°C^{-1}, the residual yield stress of the bolts at 800°C is taken to be 15% of the ambient value, and V_s is the ambient temperature shear strength of one bolt. In addition, an allowance may need to be made for an additional force due to the steel roof sheeting which comes to rest on the structure.

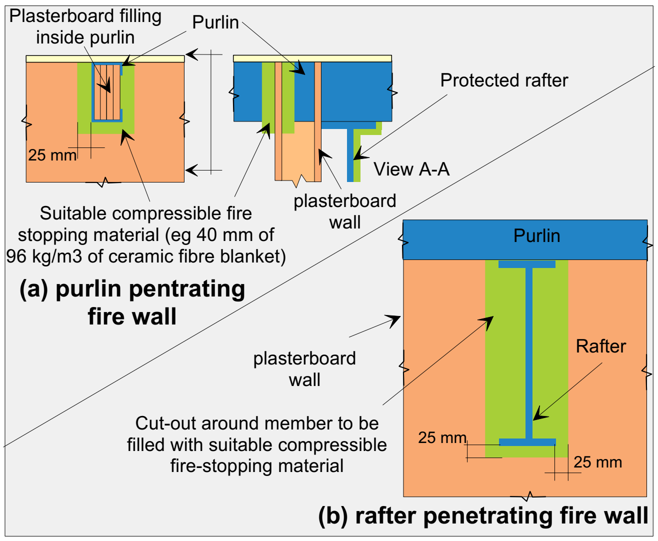


Figure 4

Wall Intersected by Rafters

The second situation is where a unprotected steel rafter penetrates a wall (Figure 5). In this case, the structural adequacy of the wall can be achieved by:

(a) incorporating a steel column (plus beam above column if necessary) within the wall providing direct support to the rafter, or

(b) using a protected column, on one side of the wall directly adjacent to the wall, or
(c) using a unprotected column on each side of the wall.

In cases (b) and (c), the fire stopping of the penetration through the wall must be done in such a way as to allow space for some deformation of the rafter (see Figure 4(b)).

As for the previous case, additional forces may be applied to the column due to failure of the rafter on the fire side of the wall. Further guidance on this subject is given in reference [5].

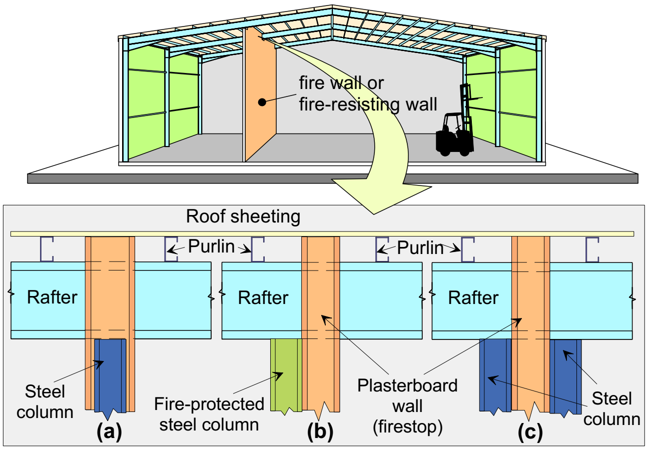


Figure 5

Insulation Performance of Plasterboard Wall

The temperature reached by a steel roof member on the non-fire side of the wall will influence the likelihood of spread of fire and the ability of the member to restrain the wall. Accordingly, the following questions are may be asked:

> ***What temperature will be achieved by a penetrating member on the non-fire side?***
>
> ***Will such temperatures lead to spread of fire?***

To address these questions, a test program [7] was carried out at the CESARE.

Test Method

The tests were conducted in a fire test furnace which internally measures 2.1 m (width) x 1.8 m (depth) x 2.1 m (height). The specimens were subjected to standard fire test durations of up to 180 minutes.

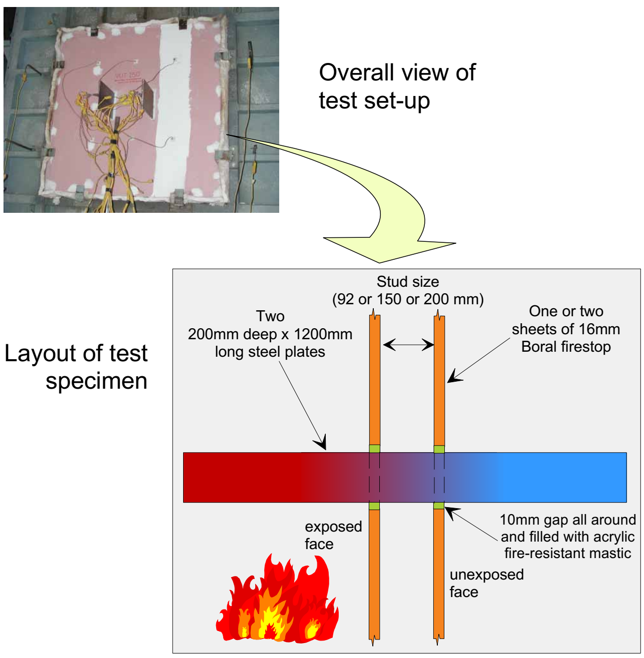


Figure 6

Six specimens were tested, three with a single layer of plasterboard on each side and three with two layers on each side (see Figure 7(a)). In all tests, the plasterboard used was 16mm Boral Firestop. The specimens with a single layer were tested to 120 minutes, while those with two layers were tested to 180 minutes. In practice, the single layer system is typically used to achieve an FRL of -/60/60, while the double layer system is used to achieve an FRL of -/120/120.

Each specimen included two penetrating plates of different sizes, giving 12 curves of unexposed face temperature versus time in total. For each of these curves, three times are of interest, being 60, 90 and 120 minutes for the single layer case and 90, 120 and 180 minutes for the double layer case.

Four plate thickness values were included in the tests, as follows:

- 2mm, representing a typical steel purlin
- 8mm, representing a typical cleat plate
- 12mm, representing the web of a typical hot-rolled beam
- 20mm, representing the flange of a typical hot-rolled beam

In all except one case, the penetrating plates were flat plates, 200 mm wide x 1200 mm long. In the remaining case, a steel purlin with a wall thickness of 2 mm was used.

In addition to the above, one further test was conducted in which a steel member of size 200UC46 was encased within the wall, representing a rafter. A penetrating plate of 12 mm thickness was attached to each side of this member. Two layers of plasterboard were used on each side. This arrangement is illustrated in Figure 7(b).

(a) Two Penetrating Plates **(b) Specimen with rafter**

Figure 7

All test specimens were constructed using standard lipped channel studs. In all cases the penetrations were sealed with a fire-resistant mastic ("Pyropanel" fire-resistant sealant) with the plasterboard sheets being cut around the penetrating plates.

Test Results

The relevant test results are summarised in Figure 8, which shows the measured unexposed face temperature versus thickness of penetrating plate at various times of fire exposure between 60 minutes and 180 minutes. The adopted insulation failure temperature of 275°C is also shown in this figure.

For the smaller stud size and a single layer of plasterboard, it may be seen from Curve 1 in Figure 8 that at 60 minutes all plate thicknesses up to 20 mm gave acceptable performance, with the unexposed face temperature below the adopted insulation failure temperature. Curve 2 shows that acceptable performance can be achieved at 90 minutes for plate thicknesses up to 6 mm.

For two layers of plasterboard, Curve 5 shows that acceptable performance at 120 minutes was achieved for plate thicknesses up to the maximum tested value of 12 mm. Since Curve 5 is below Curve 1 at this point, it seems reasonable to extrapolate these results and conclude that satisfactory performance will be achieved for plate thicknesses up to 20 mm. At 180 minutes, acceptable

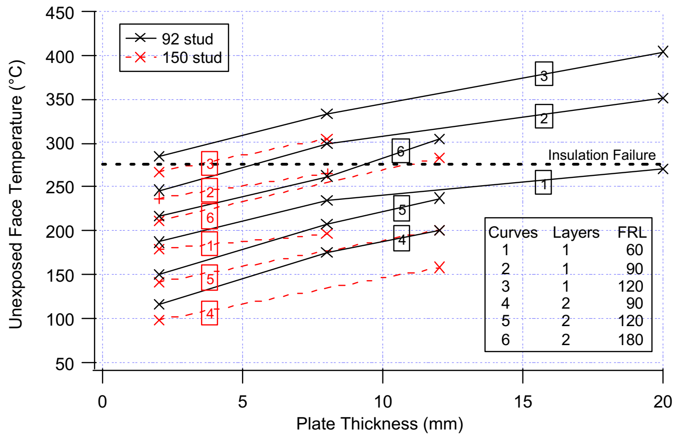


Figure 8

performance was achieved for plate thicknesses up to 9 mm, as shown by Curve 6.

It may be seen from Figure 8 that the larger stud size produced lower unexposed face temperatures in all cases. However, these differences do not provide significant benefit near the limiting insulation temperature, and it is suggested that this effect be ignored.

Temperature attained within the wall cavity are of interest for assessing the structural adequacy of the members within the wall. The maximum temperatures measured on the penetrating plate at the middle of the wall cavity were 480°C and 660°C for the single layer system at 60 and 90 minutes respectively. For the double layer system, the corresponding temperatures were 480°C and 670°C at 120 and 180 minutes respectively. These values may be used for all plate thicknesses between 2 mm and 20 mm.

From the test conducted with the rafter placed within the wall cavity (Figure 7b), the unexposed face temperature was lower than for the corresponding tests described above. This was due partly to some heat being absorbed by the additional steel member and partly to the greater internal wall thickness, which was 200 mm in this case (compared with 92 mm and 150 mm above). The rafter itself reacheda temperature of 280°C at 120 minutes and 410°C at 180 minutes.

Conclusion

It has been demonstrated that an insulation failure criterion of 275°C will provide adequate performance in terms of avoiding ignition of lightweight combustibles on the non-fire side of the wall. This failure criterion has been adopted.

The testing conducted [7] has confirmed that a steel stud wall lined on both sides with a single layer of 16 mm Boral Firestop plasterboard achieves an FRL of -/60/60, while a wall lined with a double layer on both sides achieves an FRL of -/120/120. These walls can be penetrated by bare steel members with a plate thickness of up to 20 mm without producing insulation failure at the unexposed face. This conclusion is based on the stud size (width of internal cavity) being at least 92 mm.

Alternatively, the single layer system may be used where an FRL of -/90/90 is required, provided that the thickness of any steel penetrating plate is limited to 6 mm, while the double layer system may be used for an FRL of -/180/180 with steel plate thickness up to 9 mm.

For steel penetrating members which vary in steel thickness over the profile, their average thickness should be no greater than those stated above. This is equivalent to a requirement that their exposed surface area to mass ratio (k_{sm}) calculated in accordance with AS4100 should be no less than 13 m^2/tonne (20 mm plate), 28 m^2/tonne (9 mm plate) or 42 m^2/tonne (6 mm plate).

Failure of roof members on the fire side of the wall may apply reaction loads to the structural members supporting the wall. Some guidance on calculating these loads has been given.

It is concluded that, using the test data and design guidance presented in this Design Note, compliance with Performance Requirement CP2 [1] can be achieved without requiring the steel members penetrating the wall to be protected.

REFERENCES

[1] "Building Code of Australia 2007", Volume 1—Class 2 to 9, Australian Building Codes Board, 2007.

[2] Standard Australia, AS 1530.4, "Methods for Fire Tests on Building Materials, Components and Structures, Part 4: Fire-resistance Tests of Building Construction", 2005.

[3] Schwartz, K J and Lie, T T, “Investigating the Unexposed Surface Temperature Criteria of Standard ASTM E119”, Fire Technology, Vol. 21, No. 3, August, 1995.

[4] Bennetts, I.D. and Filonov, A., "Investigation of the Behaviour of Composite Slabs in Fire", Australian Structural Engineering Conference, Engineers Australia, Newcastle, 2005.

[5] Bennetts, I.D. and Moinuddin, K. M., "Aspects of the Design of Fire-Resistent Plasterboard Walls in Fire", Electronic Journal of Structural Engineering, 6, pp 39-48, 2006.

[6] Standard Australia, AS 4100, "Steel Structures", 1998.

[7] Moinuddin, K. and Bennetts, I.D., "Temperatures of Steel Members When Penetrating Boral Drywall Construction", VU-CESARE Report No. VU/CESARE/2005/002, August 2005.

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