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STEEL ROOF MEMBERS

PENETRATION OF CONCRETE FIRE WALLS

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The Issue

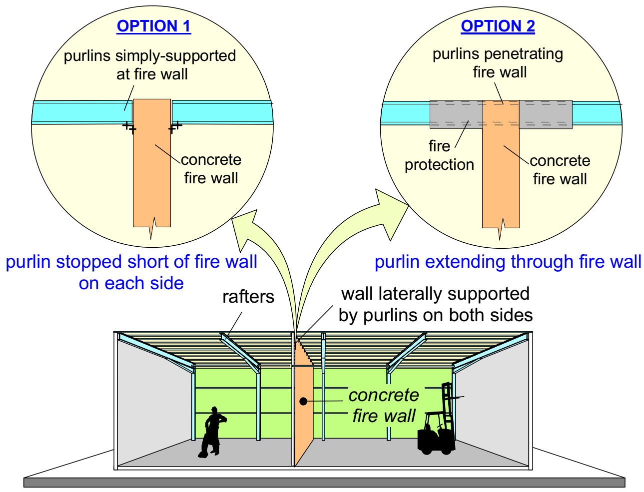
There are many situations where concrete fire walls are used to divide a building into separate fire compartments. The purpose of providing such walls within a building is to prevent the spread of fire from one compartment to another. The ability of the wall to prevent fire spread depends not only on the wall details but also on the presence of penetrating members which have the ability to conduct heat from one space to another.

In many of these situations, it may be practical for structural steel roof members to pass through the concrete wall rather than being curtailed at the wall. However, since steel is a good conductor, it has been traditionally assumed that fire may spread due to excessive temperature rise of the penetrating steel member. In the past such practices have been generally discouraged with steel members being stopped and supported on either side of the wall in order to minimise the flow of heat through the steel member and reduce the likelihood of ignition of combustibles on the non-fire side in the adjacent compartment.

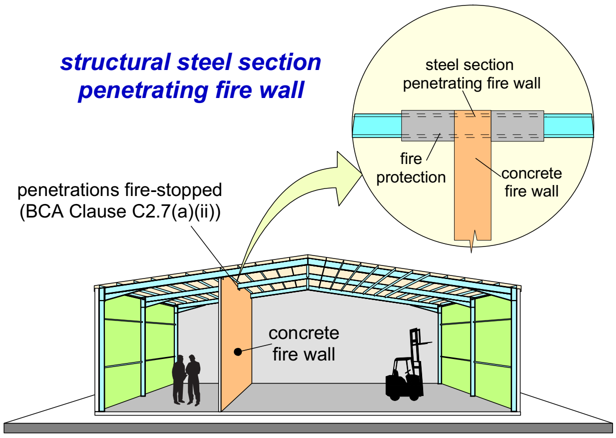
By means of its objectives and performance requirements, the Building Code of Australia (BCA) [1] makes it clear that the role of a wall separating two fire compartments is to prevent the spread of fire from one compartment to another. This is seen as being achieved provided the wall has the required performance with respect to insulation (preventing excessive temperatures on the unexposed face), integrity (preventing the flow of hot gases and flames) and structural adequacy (remaining in place for the required duration. 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.

The presence of a penetrating member through the wall does provide a potential path for heat to be transferred from one side of the wall to the other, and as noted above, this has provided a justification for the practice of stopping the member on each side of the wall.

purlins penetrating fire wall



In other situations where this has not been possible, the steel member has been covered with fire protection material to minimise the flow of heat from one side to the other. This can be costly.

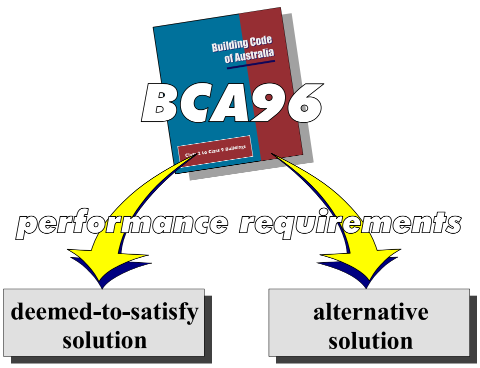


> **The question must be asked: *is it necessary for a steel member to be curtailed at a fire wall, and if it penetrates the wall, is it necessary for it to be fire protected ?***

The purpose of this fire design note is to answer this question.

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.



The penetration of concrete fire walls by bare steel roof members may not strictly comply with the deemed-to-satisfy provisions due to excessive temperature rise.

What temperatures will be reached by steel members on the unexposed side of the wall? Will such temperatures result in fire spread to the other compartment? This design note answers these questions and provides a justification and basis for an alternative solution involving the penetration of concrete fire walls by bare steel roof members.

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 relevant performance requirement is:

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

- (a) to exits; and.
- (b) to sole-occupancy units and public corridors; and
- (c) between buildings; and
- (d) in a building,

appropriate to -

- (i) the function or use of the building; and.
- (ii) the fire load; and
- (iii) the potential fire intensity; and
- (iv) the fire hazard; and
- (v) the height of the building; and
- (vi) its proximity to other property; and
- (vii) any active fire safety systems installed in the building; and
- (viii) the size of any fire compartment; and
- (ix) fire brigade intervention; and
- (x) other elements they support
- (xi) 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?

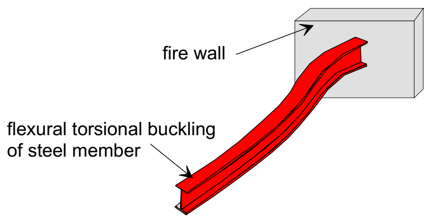
The thermal and structural behaviour of both the wall and the penetrating steel roof member must be sufficient to prevent spread.

Concrete Wall

(a) General

In the case of the wall itself, it will be assumed that it is designed in accordance with AS3600 [3]. The provisions of this standard dictate the wall thickness, height-to-thickness ratio and the level of applied load, to ensure that the wall can achieve the required performance with respect to insulation and structural adequacy. AS3600 presumes that integrity will be achieved provided the thickness requirements of the wall are met. However, since the wall is penetrated it is necessary to ensure that the gaps around the member are sealed with concrete or grout or other fire-stopping material.

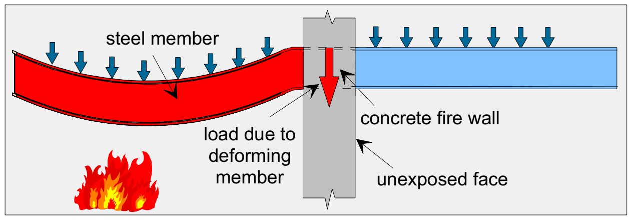
The heating of a steel roof member may result in flexural-torsional buckling of the member as well as vertical deformation, particularly if it is restrained by cooler parts of the roof.



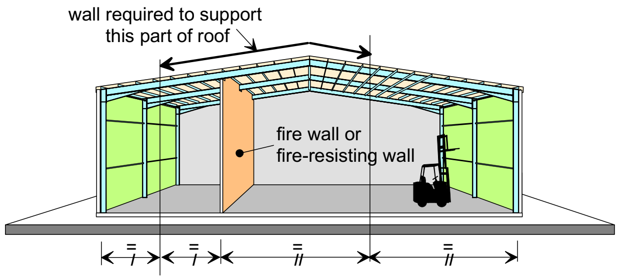
At first sight this might suggest that the integrity of the wall at the penetration may be reduced due to such movements. However this will not be the case due to the fact that the steel temperatures are lowest closest to the wall (due to heat conduction to the cooler side) so that most inelastic deformation will occur away from the penetration. Thus the integrity of the wall will not be affected.

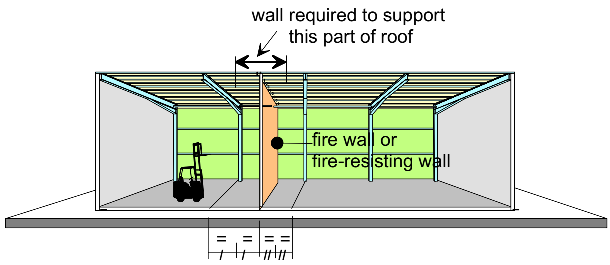
(b) Structural Adequacy

Deformation of a penetrating roof member may impose additional vertical forces at the top of the wall and these need to be considered when designing the wall for structural adequacy in accordance with AS 3600.



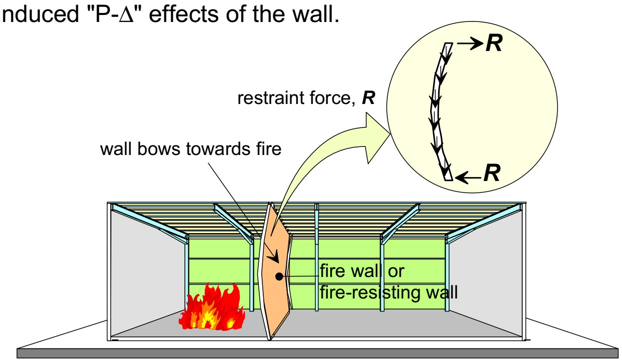
The area of roof that must be supported by a wall is given below for two situations.





The vertical load to be resisted by the wall can be taken as 1.1 times the weight of the area of roof to be supported [4].

The penetrating members may have been designed to provide lateral support to the top of the wall. It is important that such restraint is maintained under fire conditions. In the fire situation the lateral restraining force may be greater than under normal temperarture conditions due to the thermally induced "P-Δ" effects of the wall.



A conservative estimate of this restraining force can be obtained by assuming that the maximum lateral displacement of the wall at midheight will not exceed $H/10$, where H is the height of the wall. The required restraining force can be calculated from

$$\boldsymbol{R = 1.67Ht} \text{ kN per metre width of wall}$$

where H and t are the height (m) and thickness (m), respectively.

These forces are not large. The ability of the roof member on the non-fire side to provide such restraint is a function of the temperature reached by the end of the member and connection. This matter is now considered.

Steel Roof Member

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 raised:

> ***What temperature will be achieved by a penetrating member on the non-fire side?***
>
> ***Will such temperatures reduce significantly the ability of the member to act as an effective restraint?***
>
> ***Will such temperatures lead to spread of fire?***

To address these questions, a test program [5,6] was carried out at the Centre for Environmental Safety and Risk Engineering of Victorian University of Technology.

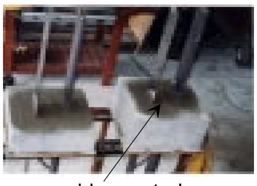
Test Program

A total of eight specimens were tested in a series of four tests. Each test specimen contained two steel plates, one with dimensions of 2 mm thick x 100 mm wide x 1200 mm long and the other having dimensions of 20 mm thick x 100 mm wide x 1200 mm long. A concrete block of dimensions 365 mm x 385 mm x 120 mm (or 200 mm) thick was cast around the middle section of the length of the steel plates. The concrete block was considered to simulate the presence of a concrete wall, and the plates chosen to simulate the web or flange of a rolled section (in the case of the 20 mm plate) and a purlin penetrating the wall (in the case of the 2 mm plate).

Specimen Construction

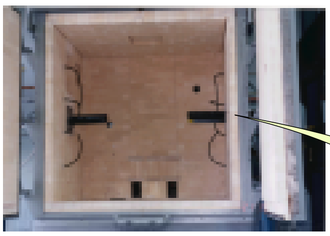
Four specimens were cast in the horizontal position (i.e. with the steel plate vertical) so good compaction of the concrete was obtained. The concrete blocks for the other four specimens were cast with holes to allow grouting of the steel plates once they were located. For two of these specimens, the voids were grouted when the blocks were in the vertical position to simulate a situation that may occur on site. The other two specimens were grouted with the blocks in the horizontal position.


voids around steel plates

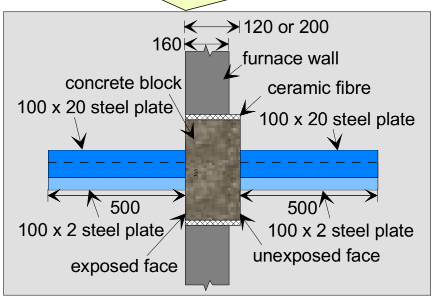

voids grouted

Test Set-up

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.

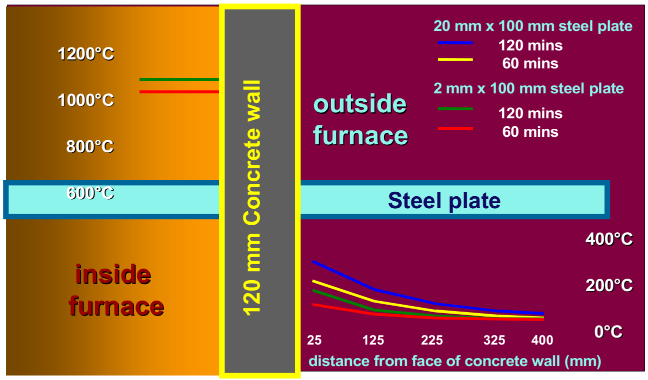

Overall view of test set-up

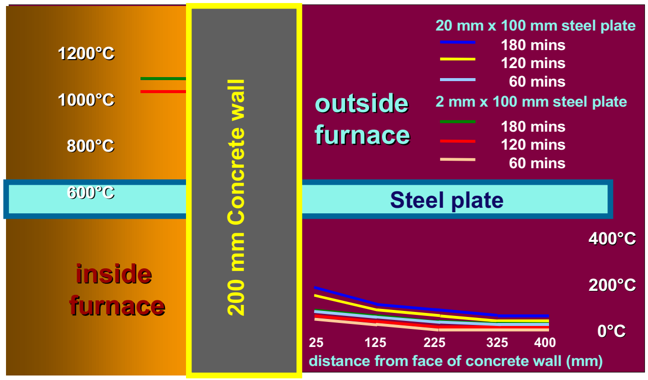
Layout of test set-up



Test Results

Plotted below are the steel temperatures on each side of the wall for wall thicknesses of 120 mm and 200 mm. The plotted temperatures correspond to times of 60 minutes, 120 minutes and 180 minutes (only for 200 mm wall) of standard fire test duration.





The maximum steel temperatures measured at 25 mm from the unexposed face of the walls were:

Maximum steel temperatures (°C)

Exposure duration	120 mm wall	200 mm wall
20 mm steel plate		
180 mins	-	185
120 mins	280	140
60 mins	195	80
2 mm steel plate		
180 mins	-	85
120 mins	155	65
60 mins	95	45

A length of non fire-retarded PVC cable and cardboard were attached to the hottest steel plate directly adjacent to the unexposed face of the wall. The corresponding measured steel temperature 25 mm from the wall was, at this stage, 265°C. After about 12-13 minutes of exposure, no ignition occurred except that the cable melted and the cardboard was lightly scorched.

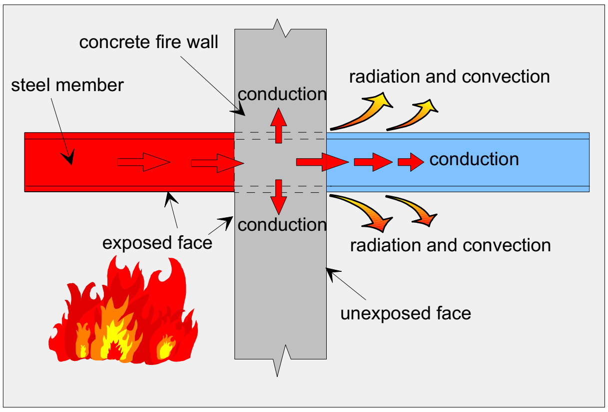

PVC cable


Cardboard


Conditions of PVC and cardboard after 12-13 minutes of exposure

Summary and Discussion

The test results show a dramatic difference in steel temperature from the fire to the non-fire side. This reduction in temperature is due to the mechanisms illustrated below.



At the roof level it is most unlikely that goods and combustibles will be located in close contact with a penetrating member such that the heat loss mechanisms illustrated above will be significantly impaired. It is therefore considered that the test results are directly applicable to the roof situation being addressed in this note.

In all tests, the maximum steel temperatures recorded at the unexposed side of the steel plate were less than 280°C for concrete walls of 120 mm thick (after 120 minutes of fire exposure), and less than 185°C for walls of 200 mm thick (after 180 minutes of fire exposure). The tests also showed that regardless of the voids cast vertically, horizontally or in-situ, the maximum temperatures reached were similar.

On the non-fire side of the wall, the steel members will only be affected locally by the elevated temperature conditions. Furthermore, the temperatures are such that the stiffness of the member will be hardly affected whilst the local strength will be reduced by no more than 15%. The adequacy of the roof members to provide lateral support to the top of wall should be checked given this reduction in strength.

The temperatures at the unexposed side of the steel plates were not sufficient to cause ignition of non-fire-retarded PVC cabling or cardboard. This is not surprising as testing conducted by Lie [7] has demonstrated that the temperatures required for ignition are considerably higher than the insulation failure criteria stated previously and given in AS1530.4. It can therefore be concluded that spread of fire will not occur.

Conclusions

The test results presented in this design note illustrate the dramatic reduction in temperature from the fire to non-fire sides of steel members penetrating concrete walls. The resulting temperatures of the non-fire side of the member are sufficiently low that fire spread will not occur, and in situations where the steel roof member has been designed to resist the lateral forces required to restrain the top of the wall, lateral restraint to the wall will be maintained provided its strength exceeds the applied forces by more than 15%.

The above conclusions are applicable to roof members penetrating concrete walls provided that the walls are designed for the appropriate fire duration in accordance with AS3600, and any additional loads imposed on the top of the wall by deforming roof members, are taken into account. Under these circumstances it is not necessary for the roof members to be fire protected.

REFERENCES

[1] "Building Code of Australia 1996", Volume 1—Class 2 to 9, Australian Building Codes Board, 1996.

[2] Standard Australia, AS 1530.4, "Methods for Fire Tests on Building Materials, Components and Structures, Part 4: Fire-resistance Tests of Building Construction", 1997.

[3] Standard Australia, AS 3600, "Concrete Structures", 1994.

[4] Standard Australia, AS1170.1, "SAA Loading Code - Part 1: Dead and Live Loads and Load Combinations", 1989.

[5] Bennetts, I.D., Culton, M., and Goh, C.C., "Behaviour of Steel Members When Penetrating Fire Walls", VUT-CESARE Report No. VUT/CESARE/BHP/2000/002, March 2000.

[6] Bennetts, I.D., and Goh, C.C., "Fire Behaviour of Steel Members Penetrating Concrete Walls", Electronic Journal of Structural Engineering (EJSE), First Issue: Volume 1 - 2001, pp. 38-51.

[7] Schwatz, K. J. and Lie, T. T., "Investigating the Unexposed Surface Temperature Criteria of Standard ASTM E119", Fire Technology, 21, February 1985, pp. 169-180.

Further information can be obtained from OneSteel on:

Freecall 1800-1-STEEL
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OneSteel Website http://www.onesteel.com

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