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Limiting Steel Temperatures and Structural Steel Fire Protection in Australia

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Passive fire protection is considered the last line of defence when a fire cannot be contained and active fire suppression systems are depleted, or do not operate as expected.

Maintaining structural adequacy on load bearing members in a fire event is critical to the safety of building occupants, fire fighters and the surrounding built environment.

Structural adequacy, integrity and insulation are the three components of a Fire Resistance Level (FRL).

The National Construction Code Volume 1, otherwise known as the BCA, demonstrates the fire protection requirement for different buildings. Depending on the type of construction, in some cases where the structural elements function as compartment separating elements, integrity and insulation may be critical also. However, it is important to note that most structural steel fire protection can only achieve the structural adequacy component of an FRL (e.g. 60/--/-- or 120/--/--), as structural components are designed to withstand the building loads, rather than separate compartments.

Fundamentally structural adequacy of a building when exposed to fire, requires structural engineers to ensure the loads acting on a structure in a fire event can be resisted by the capacity of the structural members and their connections at elevated temperatures. This involves understanding the effects of thermal expansion on the structure, thereby ensuring the structure has enough capacity and robustness to allow occupants to evacuate, fire fighters to supress the fire and safeguard fire spread to surrounding buildings.

Load bearing structural elements can be made of many different building materials. Common material types include reinforced concrete, timber and the material most commonly requiring passive fire protection, structural steel. These materials all behave differently in a fire event, depending on their inherent thermophysical and material properties. Steel begins to lose its strength at 215˚C. Timber chars when the surface reaches 300˚C, resulting in a reduced effective cross-section. Concrete has a low thermal conductivity which is critical in providing insulation to steel reinforcement thereby limiting the loss of strength in the composite member.

Without fail structural engineers document the required concrete cover to insulate reinforcement in a fire event or oversize timber members to allow for char loss within their design process.

Why is it not common practice in Australia, for structural engineers to document the same design detail when it comes to structural steel fire resistance?

The importance of Limiting Steel Temperature on structural steel fire protection

Limiting steel temperature (LST) is critical as it specifies the temperature which the steel must maintain for the duration of the FRL in order to continue to support the design actions on the structure.

Standard assumptions of 550˚C for columns and 620˚C for beams are commonly used throughout industry in the absence of documented advice from structural engineers.

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Unfortunately, at times this can lead to an un-conservative or over-conservative design, which could lead to structural failure or additional material cost.

In the Australian structural steel passive fire protection market, product manufacturers and applicators face a difficult battle to ascertain the required LSTs on structural elements for every project. Some structural engineers are fully aware of the LST calculations and are able to provide this information easily.

On the other hand, some structural engineers become irritated at the request to re-visit a design in the construction phase. At times builders also hesitate to request the additional information from structural engineers, in anticipation of a variation for their time spent. It is important to notice each passive fire protection product has its own unique characteristics. Therefore, it is essential to ensure the building design team provide the correct information so that a suitable system can be selected.

Why is the limiting steel temperature important to me?

Architect	LST determines the ability for a steel section to achieve the required FRL member. If the steel section is checked against the required LST by the product manufacturer, it can be ensured no last-minute upgrades to steel sizes is required.
Structural engineer	Specifying the LSTs in structural steel documentation communicates the level of fire protection required so that structural adequacy can be maintained.
Fire engineer	Obtaining the LSTs from structural engineers ensures that the structural adequacy component of the FRL has been considered in the design.
Certifier	The LST supplied by the structural engineer needs to be checked against the material thickness calculated by the product manufacturer to ensure the structural steel has been adequately fire rated.
Builder	Passive fire protection to structural steel can be a costly task. If the correct steel sizes and LSTs are specified, it can save cost on fire rating product and eliminate the stress of last-minute changes.
Applicator and product supplier	In order to ensure the correct thickness of passive fire protection material can be applied it is essential that the LST is provided.

Requirements of the BCA

Structural fire design is not commonly included in the training of young structural engineers which in turn creates a gap within the industry from the very beginning. This includes the lack of understanding on passive fire protection and building compliance in regards to the BCA.

The deemed to satisfy and performance requirements of the BCA, Part B1 Structural Provisions require the following:

- B1.1 requires the resistance of a building or structure to be greater than the most critical action effect on a structure in accordance with B1.2, B1.4 and general design procedures of AS1170.0
- As per B1.2, the magnitude of individual actions must be determined in accordance to AS1170.1 including actions not limited to thermal effects imposed on the structure
- While B1.4 specifies the structural resistance of materials for steel construction need to be designed in accordance with AS4100.

These BCA provisions are directly linked to the Australian Standards.

AS4100 Steel Structures Standard

Section 12 of the structural steel standard, AS4100, focuses on steel design under fire conditions. It details the calculation process required to determine the LSTs of structural elements.

Specifically, Clause 12.5 explains the relationship of limiting steel temperature T_l, to the load ratio acting on the member r_f.

Equation 1 below describes the method to calculate r_f, while Equation 2 shows the relationship between T_l and r_f.

Equation 1

$$r_f = \frac{\text{Design load under a fire load case as per AS1170.0}}{\text{Design member capacity at ambient conditions}}$$

Equation 2

$$T_l = 905 - 690\, r_f$$

In the design phase of a building, structural engineers ensure structural members are appropriately sized to withstand the most critical combination of design actions on a building, which includes the behaviour of the structural elements during a fire event.

Documenting the design load under the fire load case against the capacity of the member (r_f) can be a simpler process during the design phase of a project compared to revising at later stage.

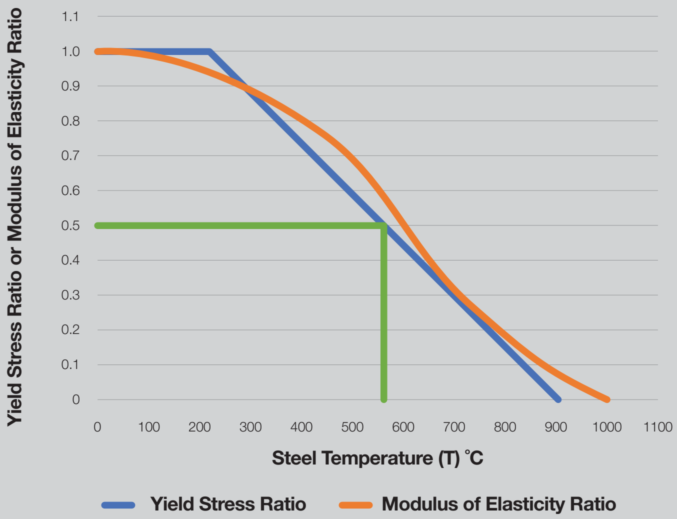
With the correct LST specified, each product manufacturer can accurately calculate the sufficient fire protection thickness required as per the relevant fire assessment reports.

The risks of an unconservative design

If a steel column is fire-protected based on an assumed LST of 550˚C the column is expected to retain approximately 50% of its strength capacity as per Figure 1.

In some cases where the actual fire load on the structural element is greater than 50% of the member capacity it can lead to an unconservative design eventually resulting in structural failure.

Figure 1 Variation of mechanical properties of steel with temperature



The disadvantages of an over-conservative design

An over-conservative design on the other hand can significantly increase the cost of passive fire protection on the project and require unnecessary steel member upgrades. The thickness of a fire protection material required to fire protect a steel element to 700˚C can be 60% lower of that required to achieve 550˚C on the same member.

Often it can be seen that steel members require lower LSTs at the bottom of a structure as it is supporting more load compared to the upper levels.

Therefore, in order to achieve the most cost effective and safe building structure, it is critical that a multi-temperature analysis is carried out throughout a structure.

Industry passive fire protection guidance

In the absence of specific passive fire protection guidance in Australia often the guidelines produced by the Association for Specialist Fire Protection (ASFP) in the UK, are the only reference point.

As an industry striving for compliance, similar guidelines and advisory notes for structural steel fire protection should really be produced in Australia. In particular for intumescent fire protection to structural steel.

ASFP Advisory Note 12, recently published by the ASFP, has been developed by intumescent manufacturers and installers to assure that intumescent coatings are specified in the correct way to ensure a structure is treated with the required level of fire protection.

It highlights the responsibilities placed on the designers and specifiers to ensure the chosen fire protection system is fit for purpose.

The structural engineer needs to be involved in the passive fire protection specification process, as the ability for the fire protection system to achieve the desired FRL is directly linked to the structural behaviour.

Applicators and product suppliers/manufacturers are continuously encouraging, educating and requesting structural engineers, to specify required limiting steel temperatures in their steelwork specification.