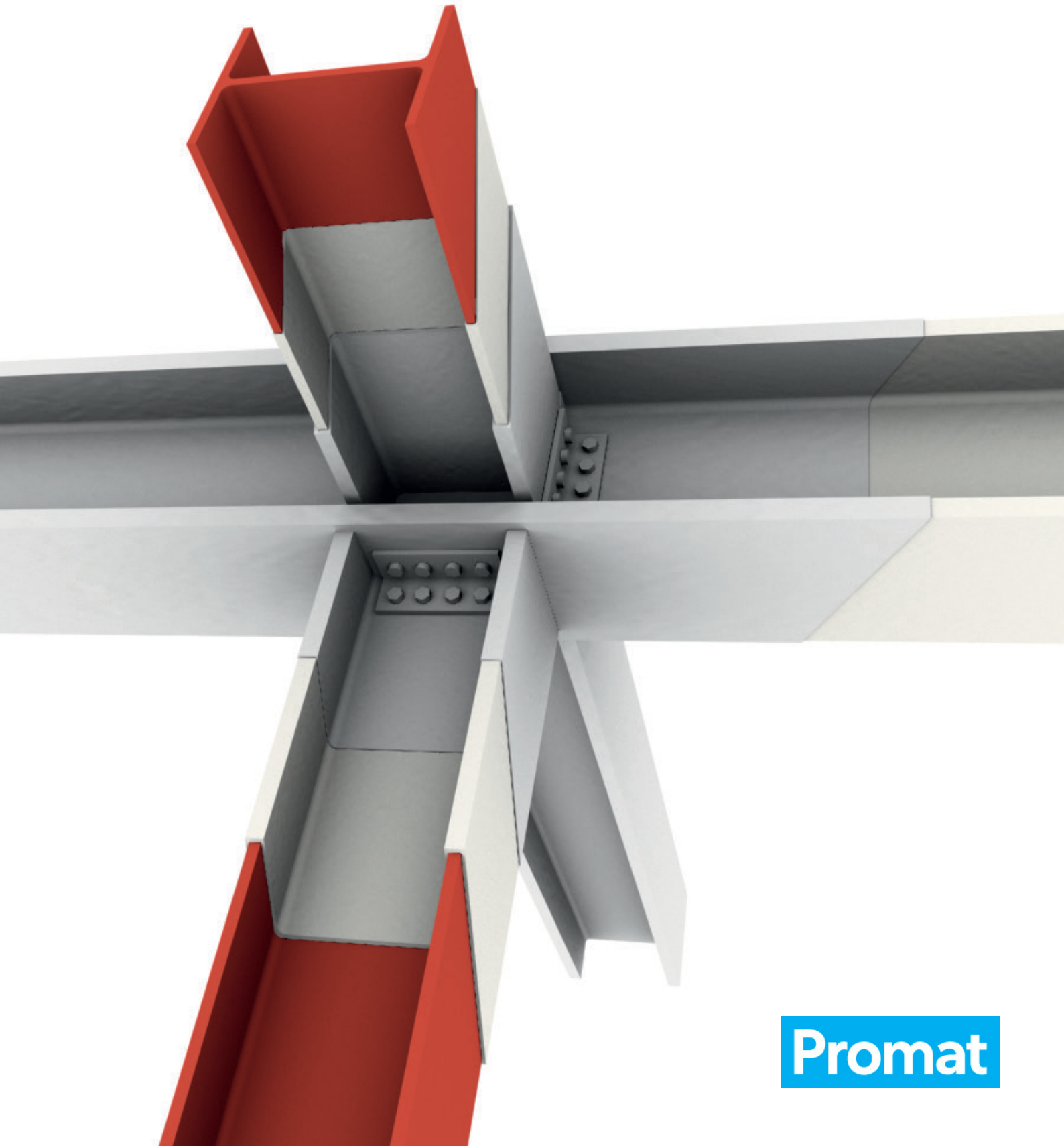


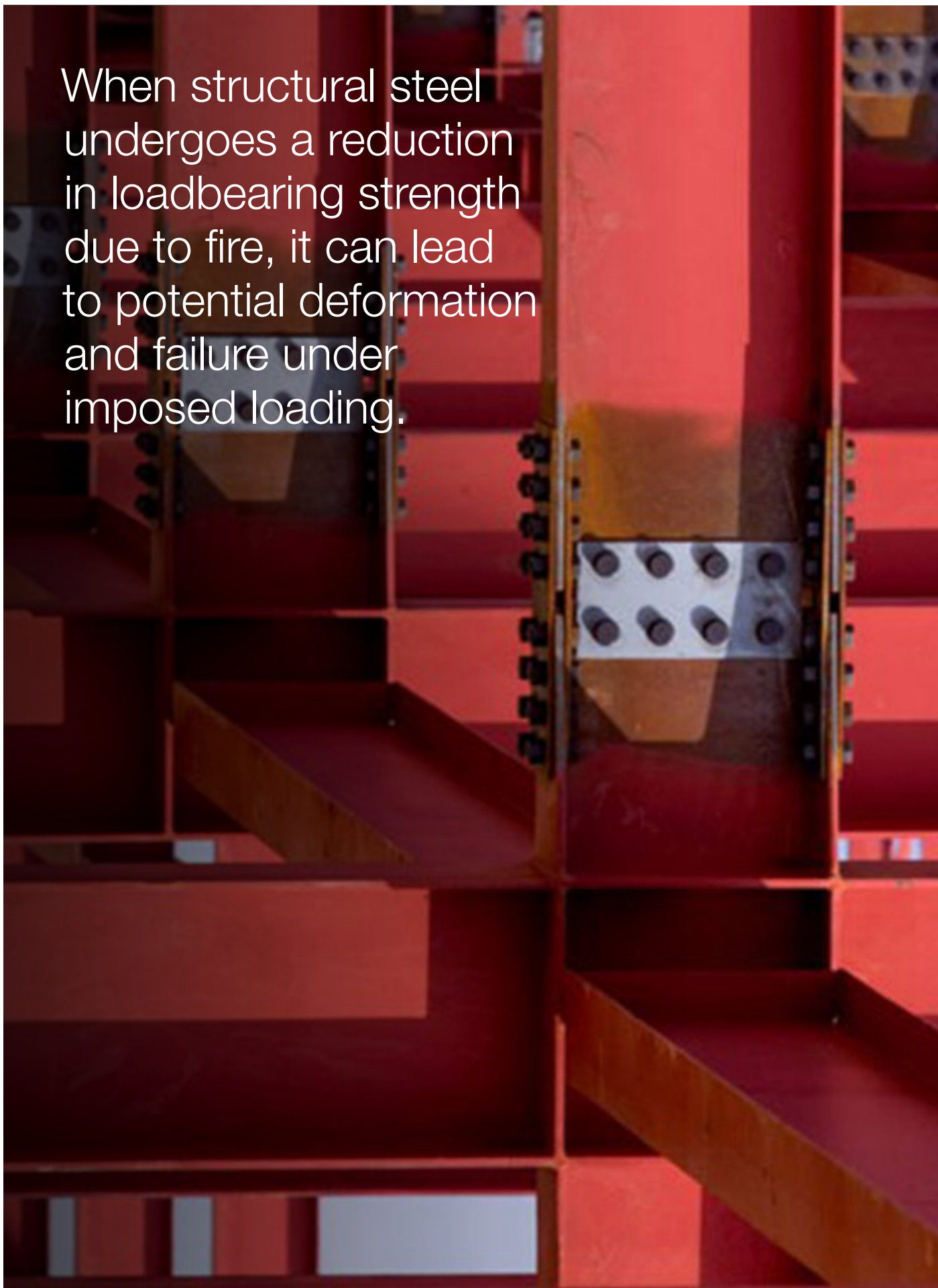
Fire Protection of Structural Steel

Design Considerations for Steel Members, Joints and Connections



Promat

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INTRODUCTION

It is critical to the success of a project that design and construction professionals understand how fire affects the behaviour of steel structures. Structural steel is among the most commonly-used materials in building construction, primarily due to its high strength and ductility. There are numerous examples of large-scale, multi-storey projects employing steel-framed construction throughout the country, with more on the way as planning and development works increase to keep up with our growing population.

While steel is non-combustible, it loses its loadbearing capacity when heated above certain temperatures. Structural steel can withstand approximately 425°C before it begins to soften. Between 600°C and 650°C, steel loses half its strength and poses a risk of failing. For reference, a simple candle can burn at 600°C or more, whereas a fully-developed building fire can reach temperatures of around 1000°C¹.

Given these scenarios, the stakes are high when it comes to steel-framed buildings. When structural steel undergoes a reduction in loadbearing strength due to fire, it can lead to potential deformation and failure under imposed loading. In the worst case scenario, a steel building can collapse causing significant property damage and loss of life.

A careful and informed approach is needed when designing steel structures – especially when it comes to protecting steel from the effects of fire exposure. This means knowing how and when to incorporate fire protection systems – including vermiculite sprays, board encasement systems, and intumescent coatings – to ensure structural integrity and safety.

In this whitepaper, we deep dive into the regulations, standards and design considerations impacting the choice of fire protection for structural steel, and answer some key questions a specifier might have when putting together a plan or specification for a project.

NATIONAL CONSTRUCTION CODE: FIRE-RESISTING CONSTRUCTION

Structural steel protection is required under the National Construction Code (NCC) to preserve the structural adequacy of the building in the event of fire. Under Performance Requirement CP1 in NCC Vol. 1, a building must have elements which will, to the degree necessary, maintain structural stability during a fire.

To achieve this, structural steel must meet the Fire Resistance Level (FRL) corresponding with the relevant building type and class of construction. The FRL is a measure obtained by a fire-rated system when it is tested to AS1530.4:2014 "Methods for fire tests on building materials, components and structures: Fire-resistance tests for elements of construction", and equivalent or more severe test regimes.

Requirements for FRLs vary between buildings of different classes and types. The NCC divides construction between Class 1 through to Class 10 (depending on

use) and Types A, B and C, (depending on height). Specification C1.1 establishes the requirements for the fire-resisting construction of building elements in Class 2 to 9 buildings.

The FRL is given in minutes for three criteria – structural adequacy, integrity and insulation (e.g. 60/90/90). 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.

To meet the requirement for structural adequacy, the load-bearing elements of the structure of the building must be capable of withstanding the effects of fire for a specific period without loss of stability. To achieve the required FRL, fire protection systems are used to insulate the steel to avoid a temperature rise above unsafe levels during a fire.

WHAT IS THE RELEVANCE OF AS 4100?

The design of steel structures subjected to fire are governed by the steel-related design standards including AS 4100:2020 "Steel structures". This Standard sets out the minimum requirements for the design, fabrication, erection, and modification of steelwork in structures in accordance with the limit states design method. The structural resistance of materials for steel construction must be designed in accordance with this Standard.

Section 12 of AS 4100:2020 applies to steel building elements required to have a FRL. This provision details the calculation process required to determine the Limiting Steel Temperature (LST) of structural elements. The LST refers to 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. Clause 12.5 describes the relationship of the LST to the load ratio acting on the member.

Under Section 12, the assessed period of structural adequacy (PSA) for steel members and connections must be equal to or greater than the required FRL. The PSA is the time (in minutes) for each steel member to reach the limit state of structural adequacy in the standard fire test.

For this application, "structural adequacy" is defined as the ability of the member to carry the required test load when exposed to the standard fire test defined in AS 1530.4.

The PSA is assessed in accordance with Clause 12.3 using the variation of the mechanical properties of steel with temperature as specified in Clause 12.4. Rules are provided for determining the PSA for both protected and unprotected steel members and connections.

Clause 12.6 covers the determination of time at which limiting temperature is attained for protected members. As per Clause 12.6.1, the time at which the limiting temperature is attained shall be determined by calculation on the basis of a suitable series of fire tests in accordance with Clause 12.6.2 or from the results of a single test in accordance with Clause 12.6.3. Clause 12.6.2.1 provides that the calculation of the variation of steel temperature with time shall be by interpolation of the results of a series of fire tests using the regression analysis equation in Clause 12.6.2.2 subject to the limitations and conditions of Clause 12.6.2.3.

WHICH FIRE PROTECTION SYSTEM IS BEST FOR MY PROJECT?

Determining the suitable fire protection system for a steel structure is dependent on the specifics of the project, including the required level of fire protection, environmental and site conditions, and practical considerations such as time and budget.

It is necessary to understand the environmental conditions to which the steel structure is exposed as it can impact the longevity and effectiveness of the fire protection system. Different considerations will apply if the steel structure is internal, semi-exposed or fully-exposed to the external environment. Special care must be taken in more demanding conditions, such as high humidity and corrosive environments.

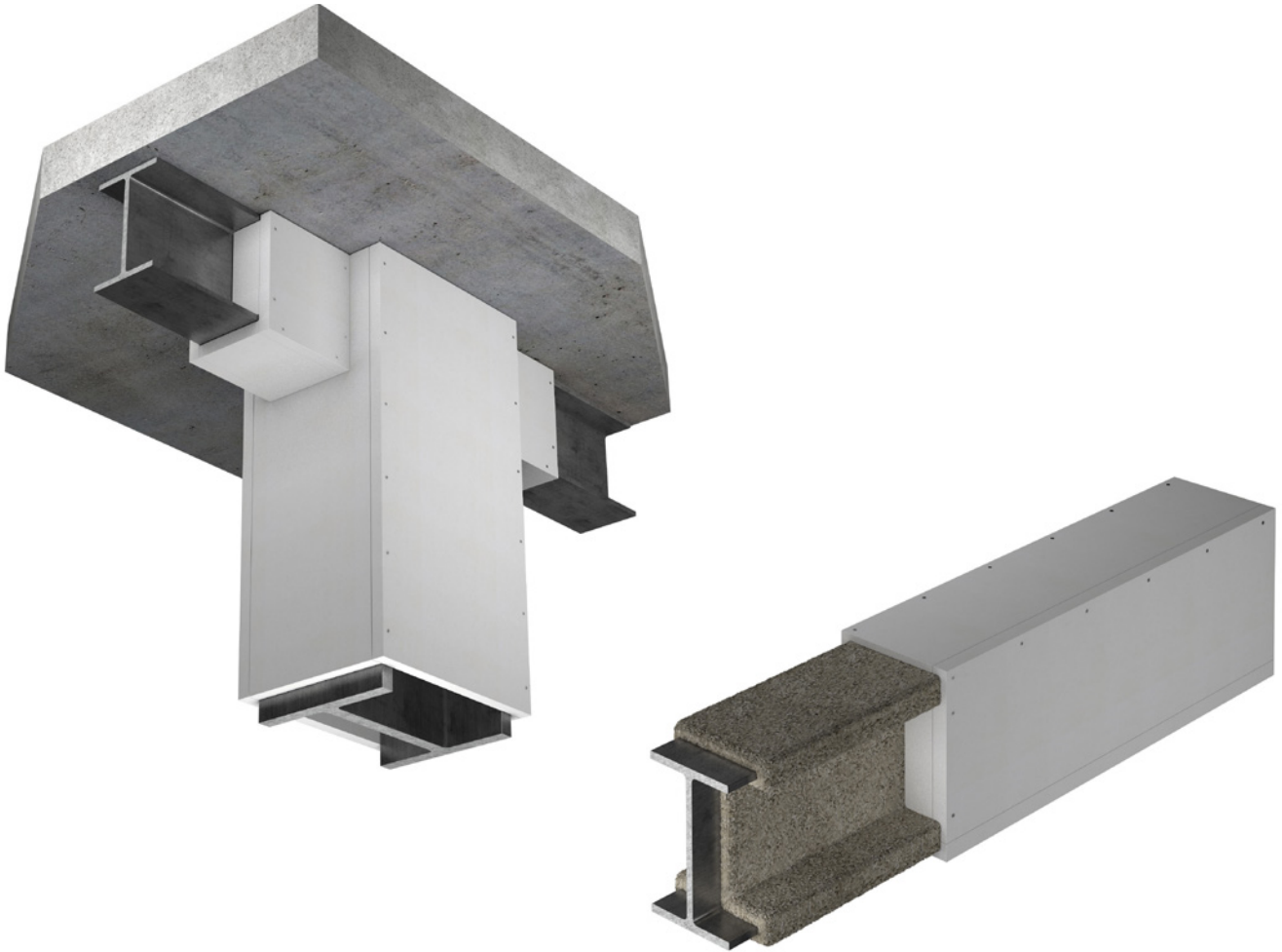
Designers and specifiers need to know the FRL and the critical temperature for the entire structure, and ideally for each individual element of the structure. Such requirements will determine the thickness of the fire protective material required to achieve the required fire resistance level.

Section factor (also known as H_p/A or k_{sm}) is the ratio of perimeter to cross-sectional area of structural steel members and gives an indication of heating rate. Smaller, thinner steel members will generally have a higher section factor value and therefore require more fire protection (greater thickness) than larger, thicker steel members. A lower section factor value means relatively less protection is required to achieve the required fire resistance.

The building design, project timescales and site constraints are also influential factors in the selection of fire protection systems. The building may impose design limitations on the types of systems that may be used, for example in relation to weight, dimensions and mechanical resistance. Some fire protection systems take longer to install than others and require specialist installers and equipment. Aesthetics may be a concern for steelwork that is visible from the outside of the building.

Main types of fire protection for steel structures

Fire protection system	How do they work?	Advantages	Disadvantages
Board and casing systems (eg PROMATECT 250, 100, L or XS)	Fire protection boards are typically mineral boards (e.g. made of calcium silicate or calcium sulphate) reinforced with fibers and fillers. They are used to encase a steel member to provide an insulative layer of fire protection.	<ul style="list-style-type: none"> Boards are factory manufactured and thicknesses can be guaranteed. High durability and low maintenance. Architectural appearance. 'Dry' installation has minimal impact on other site activities. 	<ul style="list-style-type: none"> Thicker boards add significant weight. Longer timeframe for installation. Difficult to install around details and connections.
Intumescent coatings (eg Cafco SPRAYFILM WB3)	Intumescent coatings are paints that are primarily designed for the protection of structural steel from fire. The products work by expanding when heated to form an insulating char around the substrate being protected.	<ul style="list-style-type: none"> Very thin (0.23 -6.24mm DFT (Dry Film Thickness)). Low FRLs may require only a single coat. Clean and fast application (up to 500m²/day excluding primers and top coats). Variety of colours and finishes. Low maintenance. Allows greater freedom when designing with steel. 	<ul style="list-style-type: none"> Exterior applications or aggressive environments require multiple coatings. Requires the area around the member to be clear for paint to expand into. High FRLs require greater thickness which may compromise aesthetic finish. Specialist installers and equipment. Time for curing may impact project timescales.
Spray systems (eg CAFCO300, Cafco MANDOLITE Cp2 or Cafco FENDOLITE MII)	Fire sprays are supplied as a powder, which is then mixed with water to produce a pumpable mixture. This is then pumped through a hose, mixed with compressed air at the nozzle so that it can be applied or sprayed on to the substrate that is being protected.	<ul style="list-style-type: none"> Simple and cost-effective. Lightweight. Ideal for hidden steel work. 	<ul style="list-style-type: none"> Vulnerable to water damage. Suitable for internal protected environments. 'Wet' installation meaning other trades cannot work in areas during application until solution is fully cured. Tarping or ventilation around construction areas required. Large equipment footprint (water and power). Poor aesthetics.



DESIGN CONSIDERATIONS FOR JOINTS AND CONNECTIONS

Testing of fire protection for structural steel often focuses on individual members. In real life, however, this approach does not reflect how buildings are put together. Some of the most critical components of a steel structure are its joints and connections and they must be properly protected from fire to prevent premature collapse. Below we discuss some common design scenarios:

What happens when different-sized steel members with the same fire protection meet?

Section 12.10 of AS 4100 stipulates that where there are two different-sized members, the thickness of protection for the connected points shall be the same as the thicker of the two members. This means that the bolts, bolt heads, and plates that are used for connecting the steel members shall have the same thickness of protection applied as the smaller of the two members.

What happens if two different types of fire protection meet?

This scenario occurs when you have different types of protective material that are being used together, for example board and a spray, or a spray and an

intumescent coating. You need to ensure that the products can be used together such that, for example, they do not adversely impact each other's performance or they remain stuck together in different environmental conditions.

What happens when a protected member meets an unprotected one?

This is a common occurrence in steel buildings when elements such as the framing for windows and doors have to connect back to the building structure. In such circumstances, the protected member will heat up at a greater rate due to the unprotected member connected into it.

This effect can be overcome by applying a 'coatback'. Using the same protective material as the protected member, a small section of material is added to the unprotected member to slow the transfer of heat from the unprotected member to the protected member. The addition of coatbacks has a huge impact on the design and construction of building structures (e.g. the sizing of window and door frames), so it must be considered in the early design phases of the project.

PROMAT INTERNATIONAL

The Experts in Passive Fire Protection for Structural Steel

For more than 60 years, Promat has led the global industry in sophisticated fire science and passive fire protection strategies. In Australia, Promat has earned a reputation for reliable, unrivalled fire performance across a breadth of sectors and project types.

Promat's drive toward innovation is bolstered by an innovative, experienced research and development team that marries design skills with the latest technology. Their successes have led to the development of industry leading solutions for protection against fire, smoke, fumes and heat. Promat's range of products includes a suite of passive fire protection products for structural steel, including PROMATECT® boards, CAFCO® sprays and intumescent coating systems.

All Promat products and systems have been tested at nationally accredited laboratories around the world to a variety of standards, for example AS 1530: Part 4, AS 4100, DIN 4102, ASTM E119, EN 13381-4 and BS 476: Part 21.

Determining the suitable fire protection system for a steel structure is dependent on the specifics of the project, including the required level of fire protection, environmental and site conditions, and practical considerations such as time and budget.

REFERENCES

- 1 National Institute of Standards and Technology. "Fire Dynamics." NIST.
<https://www.nist.gov/el/fire-research-division-73300/firegov-fire-service/fire-dynamics> (accessed 25 March 2022).