Safety Design in Buildings

Kuwait Conference

Crown Plaza Kuwait Hotel September 15, 2014

# Optimization of Intumescent Fireproofing Via Structural Analysis

AkzoNobel

**Alex D Tsiolas BEng MSc MiFireE**

Fire Engineer

# Learning Objectives / Overview

- **Structural Fire Protection**
  - Fire Resistance Ratings
  - Fire Testing Standards
  - Specification of Intumescent Fire Protection
- **What is Structural Fire Engineering**
  - Critical Core Temperature
  - Prescriptive vs Performance Based Fireproofing
  - Fireproofing Optimization
- **Benefits of Structural Fire Engineering**
  - Robust and Safe Designs
  - Quantified Structural Fire Performance
  - Cost Optimization

# Structural Fire Protection

Alex D Tsiolas
Fire Engineer

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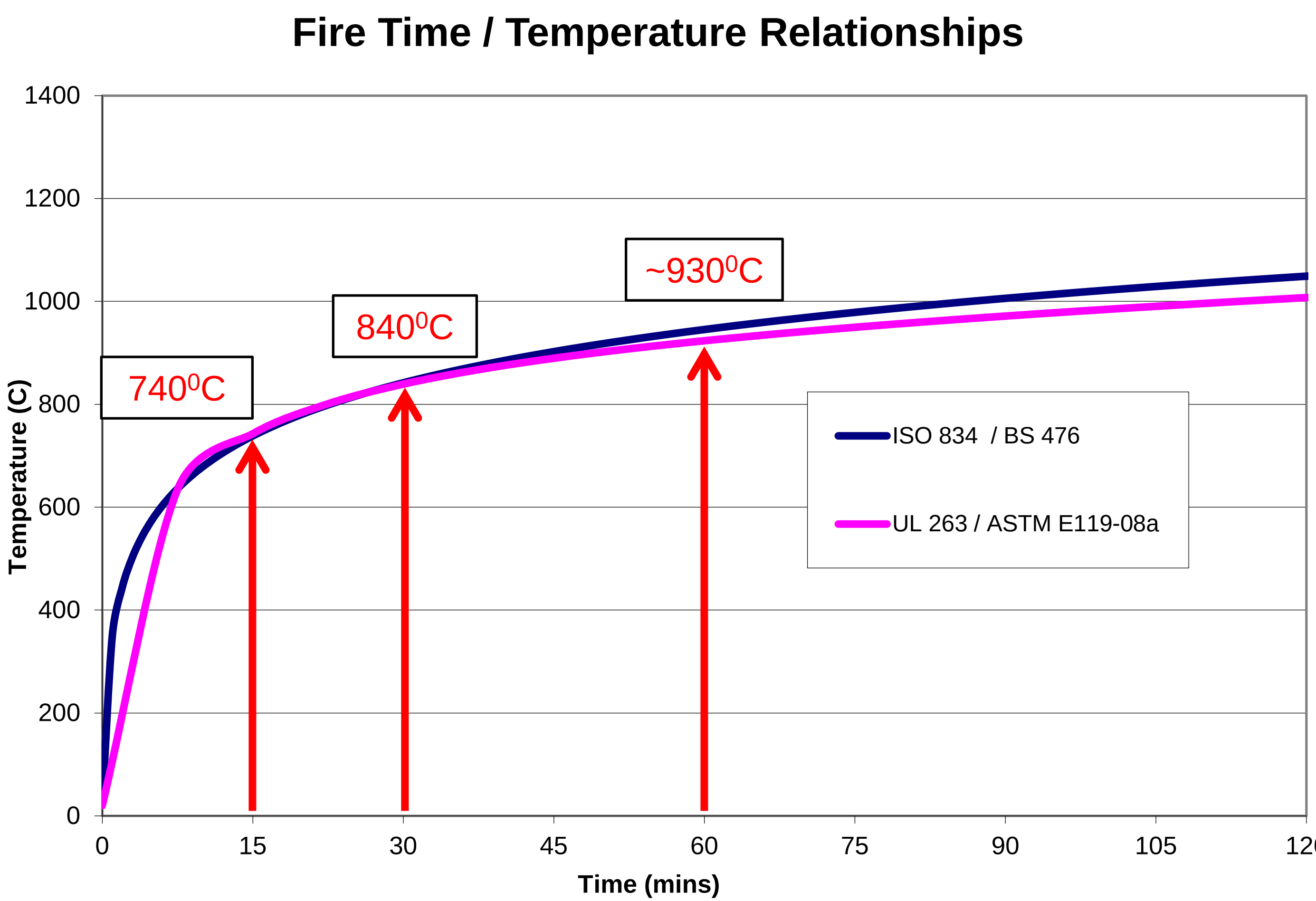
# How is a fire defined in a building?



# Design Codes and Standards

- There is a wide range of International fire safety codes that define all aspects of fire design in a building, including the structural fire resistance rating: -
  - NFPA 101 – *Americas, Canada and Middle East*
  - International Building Code – *Americas, Canada and Middle East*
  - Approved Document B – *England and Wales*
  - British Standards: BS 9999 – *UK*
  - AS 4100– *Australia*

# How are Fire Resistance Ratings Set?

Fire resistance periods for elements of structure (independent of ventilation conditions)

| Use | Sprinklered or unsprinklered [B] | Minimum periods of fire resistance, in minutes | | | | | |
|---|---|---|---|---|---|---|---|
| | | Depth below access level of lowest basement | | Height [C] of top occupied storey above access level | | | |
| | | More than 10 m | Not more than 10 m | Not more than 5 m | Not more than 18 m | Not more than 30 m | More than 30 m |
| Office | Unsprinklered | 90 | 60 | 30 | 60 | 90 | Not allowed |
| | Sprinklered | 60 | 60 | 30 | 30 | 60 | 120 |
| Industrial: high hazard | Unsprinklered | N/A [D] | 120 | 90 | 120 | 150 | Not allowed |
| | Sprinklered | 150 | 90 | 60 | 90 | 90 | 120 |
| Industrial: ordinary hazard | Unsprinklered | N/A [D] | 120 | 60 | 90 | 120 | Not allowed |
| | Sprinklered | 90 | 60 | 30 | 60 | 60 | 90 |
| Industrial: low hazard | Unsprinklered | 90 | 60 | 30 | 60 | 90 | Not allowed |
| | Sprinklered | 60 | 30 | 30 | 30 | 60 | 60 |
| Storage: low hazard | Unsprinklered | 90 | 60 | 30 | 60 | 90 | Not allowed |
| | Sprinklered | 60 | 30 | 30 | 30 | 60 | 60 |
| Car parks: | | | | | | | |
| – open-sided car park | Unsprinklered | — | — | 15 [E] | 15 | 30 | 30 |
| – any other car park | Unsprinklered | 90 | 60 | 30 | 60 | 90 | 120 |
| Shops and commercial | Unsprinklered | 90 | 60 | 60 | 60 | 90 | Not allowed |
| | Sprinklered | 90 | 60 | 30 | 60 | 60 | 120 |

Fire resistance ratings are typically set by an architect or engineer using a simple look-up table.

Ratings are based on: -

- **Occupancy use** (risk of fire)
- **Height of the structure** (for evacuation and access for fire-fighters)
- **Provision of a suppression system** (may act to control a fire)

Example: Office building, 100m high with a sprinkler system

Rating: **120 minutes** for load-bearing elements of structure

*Above example based on BS 9999. Other standards or guidance documents may prescribe a different rating.*

# Fire Resistance Ratings

## Defining a Fire Resistance Rating

- At 120 minutes for example, what is the acceptance criteria..?
  - *"Structural stability shall be maintained for a reasonable period of time…"*

- Limiting steel temperatures
  - Associated closely to the Approval Standard
    - UL 263 / ASTM E-119: 538$^{o}$C [1000$^{o}$F] or 593$^{o}$C [1100$^{o}$F]
    - BS 476: 520$^{o}$C, 550$^{o}$C, 620$^{o}$C (Guidance)

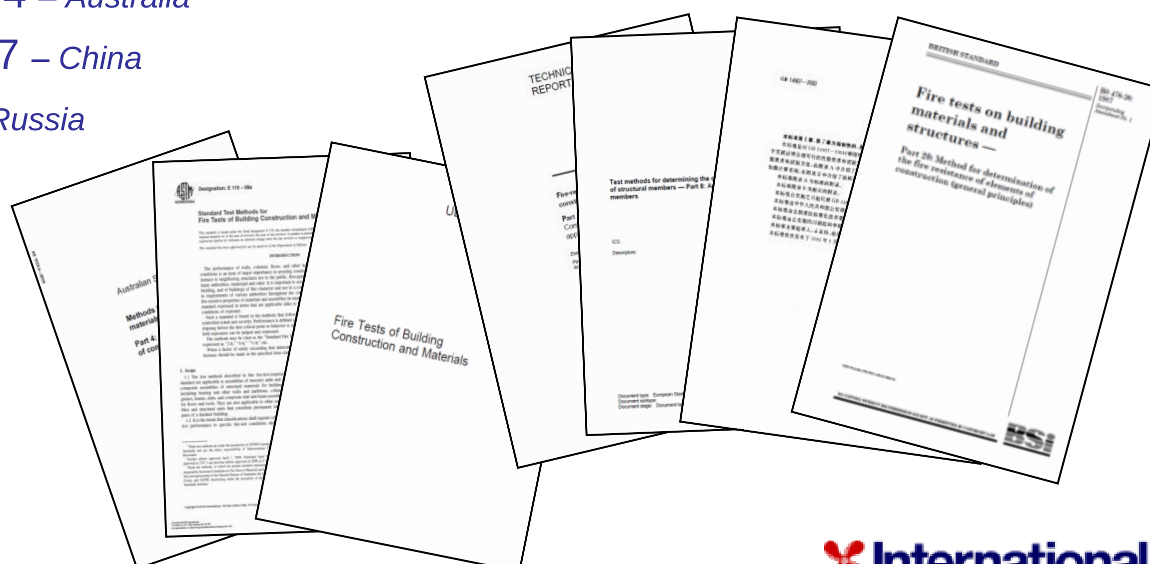
- Typical rating: **620$^{o}$C at 120 minutes** (for a beam)

SCI 4$^{th}$ November 1997: *"The existing temperatures of 550$^{o}$C and 620$^{o}$C are acceptable for most circumstances, but they are not always conservative."*

# Fire Test Codes and Standards

- The design codes call for protection to elements of structures to be tested in accordance with one of a number of fire test standards, including: -

  - UL 263 / ASTM E-119 *– Americas, Canada & Middle East*
  - BS 476: Part 21 *– UK, Brazil, South East Asia, Belgium, New Zealand, Middle East*
  - EN 13381 *– Mainland Europe*
  - AS 1530.4 *– Australia*
  - GB 14907 *– China*
  - GOST *– Russia*



# Fire Protection Concept

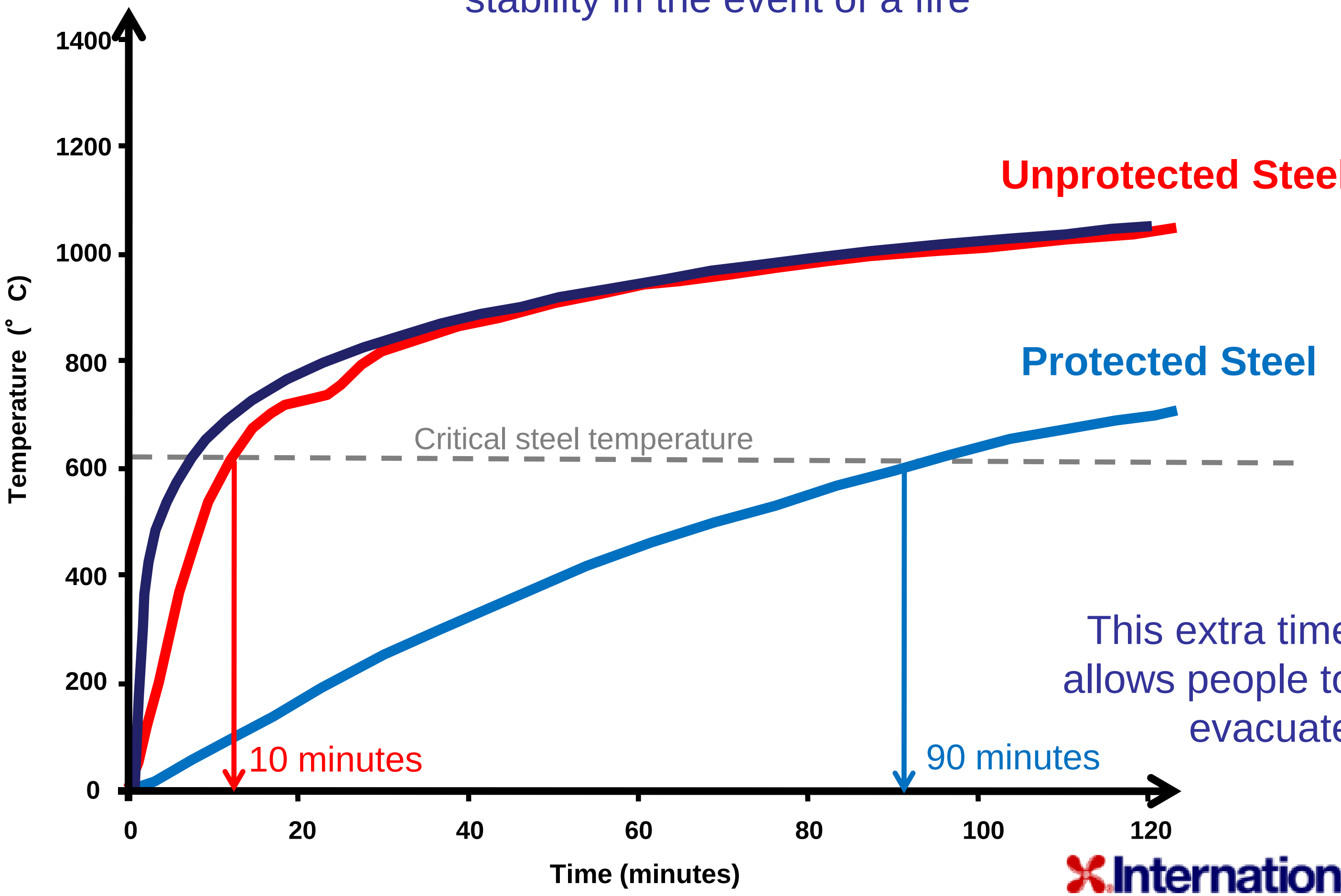
Intumescent coatings

Boards

Cementitious sprays

Insulation blankets

A fireproofing material can extend structural stability in the event of a fire



# Specification of Intumescent Fire Proofing

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Fire Engineer

# Selecting a Thickness of Paint

## How do Suppliers Establish a Thickness of Intumescent?

Typically the following information is required: -

- Standard for approval: *e.g. BS 476: 20-22*
- Fire resistance period: *e.g. 60 minutes*
- Structural section: *e.g. I-beam*
- Degree of exposure: *e.g. 3-sided with a concrete slab on top*
- Limiting steel temperature: *e.g. 620$^{o}$C*
- Steel section: *e.g. UB 406x178x74*

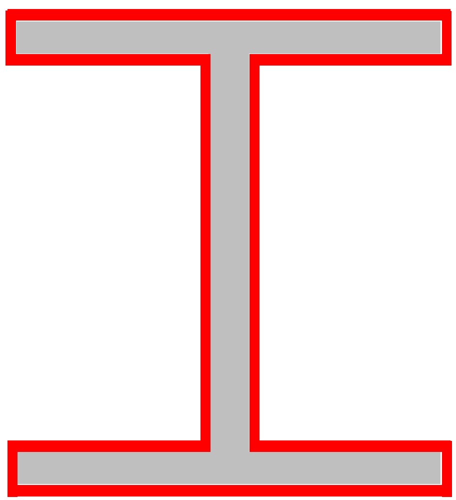
From these a supplier can determine a dry film thickness (DFT) of paint for a range of products that have 3$^{rd}$ party accreditation.

Further information can tailor a specific product for a project

- ○ Environmental exposure – degree of corrosion
- ○ Durability requirements

# Section Factor

- The rate of temperature increase of a steel cross-section can be determined by the ratio of the **heated surface perimeter** to the **area** of the cross section



$A$: Area of steel cross-section ($m^2$)

$H_p$: Length of heated steel perimeter (m)

**Example**

UB 406x178x74: Exposed on 4 sides

Heated perimeter, $H_p = 1.51\text{m}$

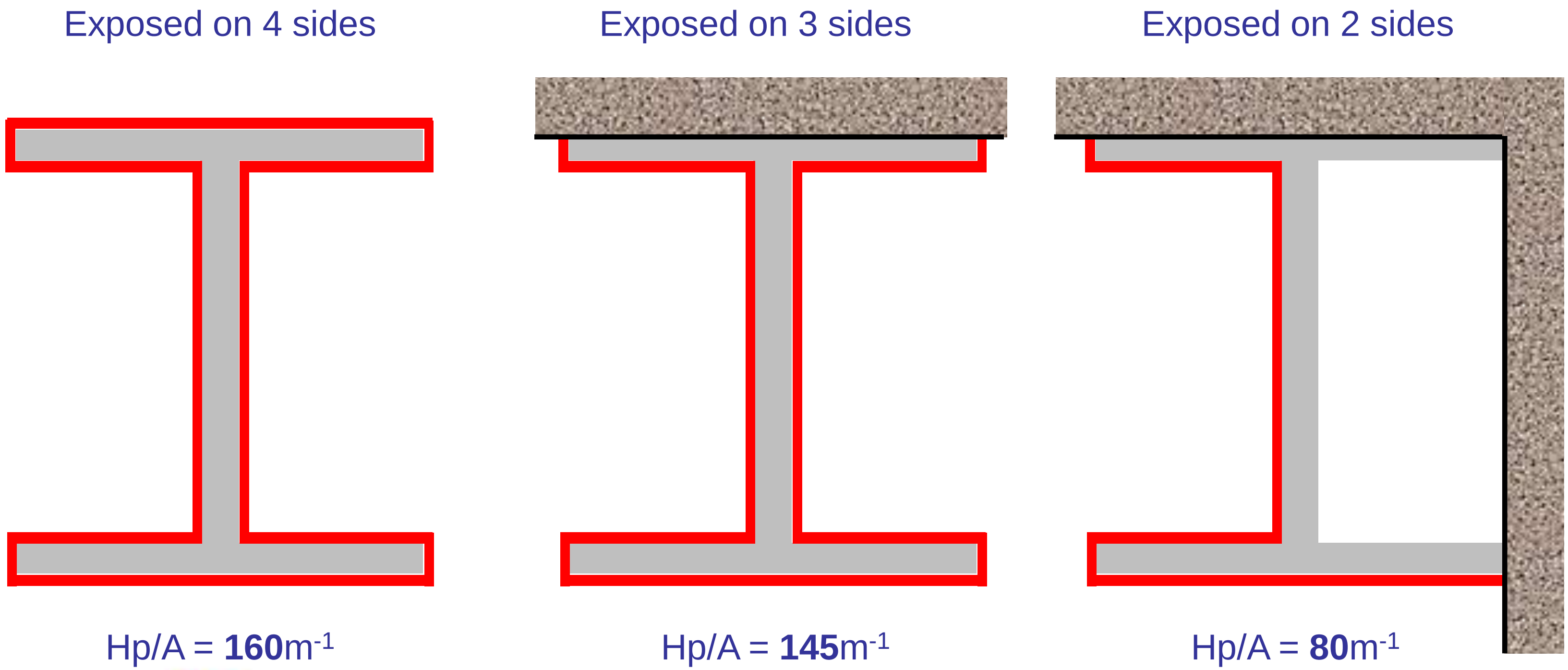
Cross-section area, $A = 0.00945\text{m}^2$

Section Factor, $H_p/A = \dfrac{1.51}{0.00945} = 160\text{m}^{-1}$

# Section Factor

- The section factor for a given structural steel component will change depending upon the heated perimeter value

**UB 406x178x74**



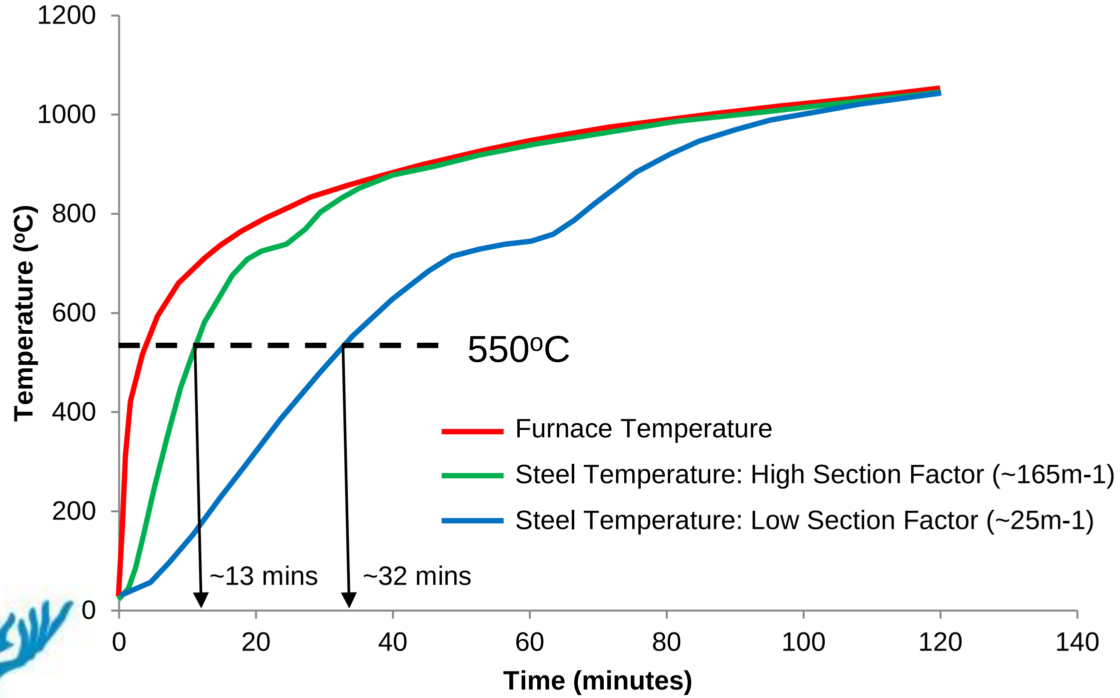
# Section Factor – Hp/A = A/V
# How steel heats up

- Slender Sections: **High** Section Factor

  Heat relatively **quickly** when unprotected

- Stocky Sections: **Low** Section Factor

  Heat relatively **slowly** when unprotected



# Selecting a Thickness of Paint

## How do Suppliers Establish a Thickness of Intumescent?

certifire

1 CERTIFICATE OF APPROVAL
No CF 345

This is to certify that, in accordance with
CERTIFIRE's Rules for Certification
The undermentioned product of

INTERNATIONAL PAINT LIMITED

Stoneygate Lane, Felling, Gateshead, NE10 0JY
Tel: 0191 469 6111 Fax: 0191 438 3711

Have been assessed against the requirements of the Technical Schedule(s) denoted below and are approved for use subject to the conditions appended hereto:

| CERTIFIED PRODUCT | TECHNICAL SCHEDULE |
|---|---|
| Interchar 963 | TS15 Intumescent Coatings for Steelwork |

Signed and sealed for and on behalf of CERTIFIRE

Sir Ken Knight
Chairman - Management Council

Issued: 17th February 2004
Reissued: 12th September 2008
Valid to: 14th November 2012

Page 1 of 20

Only valid when authentic CERTIFIRE seal is in place

Interchar 963

2 Table 6: I-Section Beams 620°C

| 30 minutes | | 60 minutes 3 | | | | 90 minutes | |
|---|---|---|---|---|---|---|---|
| Section factor up to $m^{-1}$ | Thickness mm | Section factor up to $m^{-1}$ | Thickness mm | Section factor up to $m^{-1}$ | Thickness mm | Section factor up to $m^{-1}$ | Thickness mm |
| 290 | 0.275 | 30 | 0.280 | 170 | 0.533 | 60 | 0.582 |
| 295 | 0.281 | 35 | 0.282 | 175 | 0.547 | 65 | 0.627 |
| 300 | 0.286 | 40 | 0.284 | 180 | 0.561 | 70 | 0.671 |
| 305 | 0.291 | 45 | 0.285 | 185 | 0.575 | 75 | 0.716 |
| 310 | 0.297 | 50 | 0.287 | 190 | 0.589 | 80 | 0.760 |
| 315 | 0.302 | 55 | 0.289 | 195 | 0.603 | 85 | 0.805 |
| 320 | 0.308 | 60 | 0.290 | 200 | 0.618 | 90 | 0.849 |
| | | 65 | 0.292 | 205 | 0.632 | 95 | 0.894 |
| | | 70 | 0.294 | 210 | 0.646 | 100 | 0.938 |
| | | 75 | 0.296 | 215 | 0.660 | 105 | 0.983 |
| | | 80 | 0.297 | 220 | 0.674 | 110 | 1.027 |
| | | 85 | 0.299 | 225 | 0.707 | 115 | 1.072 |
| | | 90 | 0.306 | 230 | 0.751 | 120 | 1.116 |
| | | 95 | 0.320 | 235 | 0.796 | 125 | 1.161 |
| | | 100 | 0.334 | 240 | 0.840 | 130 | 1.205 |
| | | 105 | 0.348 | 245 | 0.885 | 135 | 1.250 |
| | | 110 | 0.362 | 250 | 0.929 | 140 | 1.295 |
| | | 115 | 0.377 | 255 | 0.974 | 145 | 1.339 |
| | | 120 | 0.391 | 260 | 1.018 | 150 | 1.384 |
| | | 125 | 0.405 | 265 | 1.063 | | |
| | | 130 | 0.419 | 270 | 1.108 | | |
| | | 135 | 0.433 | 275 | 1.152 | | |
| | | 140 | 0.447 | 280 | 1.197 | | |
| | | 145 | 0.462 | 285 | 1.241 | | |
| | | 150 | 0.476 | 290 | 1.286 | | |
| | | 155 | 0.490 | 295 | 1.330 | | |
| 4 | | 160 | 0.504 | 300 | 1.375 | | |
| | | 165 | 0.518 | | | | |

Thickness is intumescent only. Three sided beams with a concrete slab.

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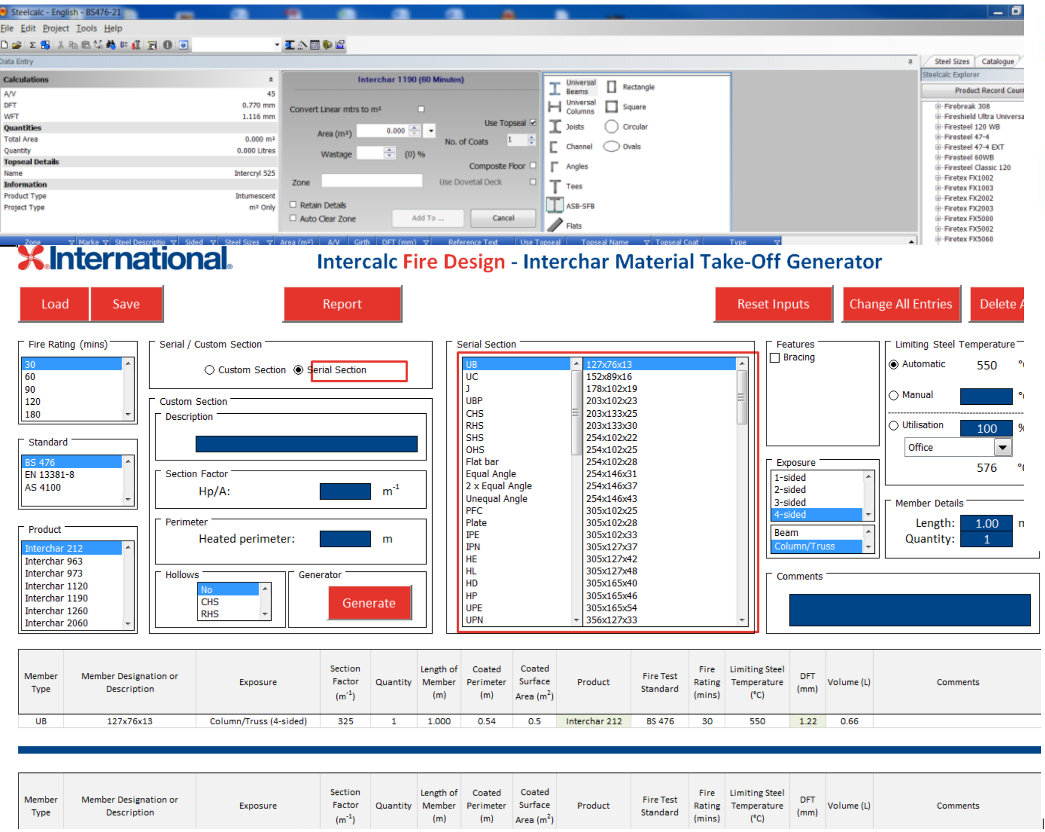
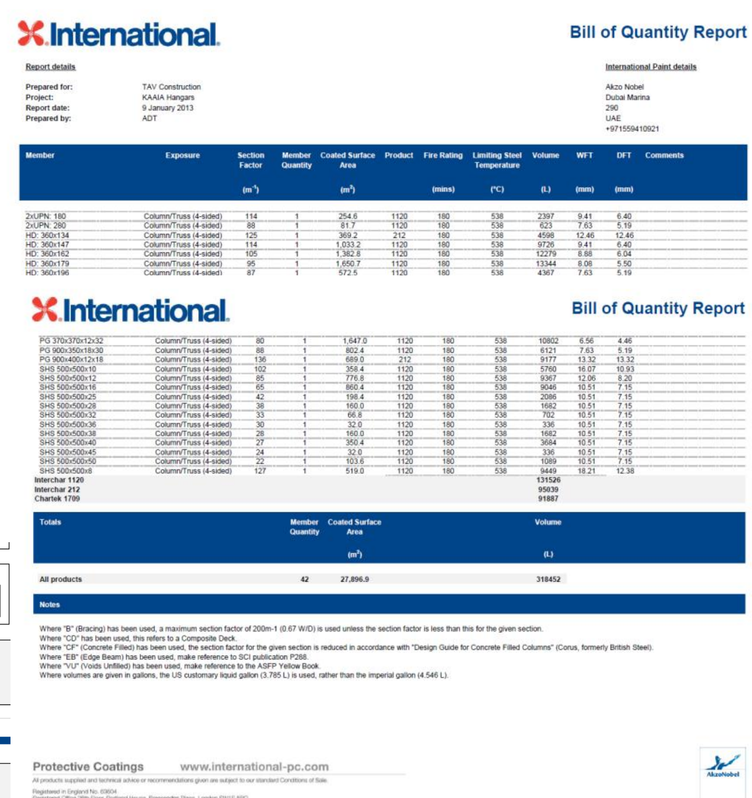
# Selecting a Thickness of Paint

## Steel BOQ → MTO



International

**Bill of Quantity Report**

Report details

| | |
|---|---|
| Prepared for: | TAV Construction |
| Project: | KAAIA Hangars |
| Report date: | 9 January 2013 |
| Prepared by: | ADT |

International Paint details

Akzo Nobel
Dubai Marina
290
UAE
+971559410921

| Member | Exposure | Section Factor (m-1) | Member Quantity | Coated Surface Area (m²) | Product | Fire Rating (mins) | Limiting Steel Temperature (°C) | Volume (L) | WFT (mm) | DFT (mm) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2xUPN: 180 | Column/Truss (4-sided) | 114 | 1 | 254.6 | 1120 | 180 | 538 | 2397 | 9.41 | 6.40 | |
| 2xUPN: 280 | Column/Truss (4-sided) | 88 | 1 | 81.7 | 1120 | 180 | 538 | 623 | 7.63 | 5.19 | |
| HD: 360x134 | Column/Truss (4-sided) | 125 | 1 | 369.2 | 212 | 180 | 538 | 4598 | 12.46 | 12.46 | |
| HD: 360x147 | Column/Truss (4-sided) | 114 | 1 | 1,033.2 | 1120 | 180 | 538 | 9726 | 9.41 | 6.40 | |
| HD: 360x162 | Column/Truss (4-sided) | 105 | 1 | 1,382.8 | 1120 | 180 | 538 | 12279 | 8.88 | 6.04 | |
| HD: 360x179 | Column/Truss (4-sided) | 95 | 1 | 1,650.7 | 1120 | 180 | 538 | 13344 | 8.08 | 5.50 | |
| HD: 360x196 | Column/Truss (4-sided) | 87 | 1 | 572.5 | 1120 | 180 | 538 | 4367 | 7.63 | 5.19 | |

International

**Bill of Quantity Report**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PG 370x370x12x32 | Column/Truss (4-sided) | 80 | 1 | 1,647.0 | 1120 | 180 | 538 | 10802 | 6.56 | 4.46 |
| PG 900x350x18x30 | Column/Truss (4-sided) | 88 | 1 | 802.4 | 1120 | 180 | 538 | 6121 | 7.63 | 5.19 |
| PG 900x400x12x18 | Column/Truss (4-sided) | 136 | 1 | 689.0 | 212 | 180 | 538 | 9177 | 13.32 | 13.32 |
| SHS 500x500x10 | Column/Truss (4-sided) | 102 | 1 | 358.4 | 1120 | 180 | 538 | 5760 | 16.07 | 10.93 |
| SHS 500x500x12 | Column/Truss (4-sided) | 85 | 1 | 776.8 | 1120 | 180 | 538 | 9367 | 12.06 | 8.20 |
| SHS 500x500x16 | Column/Truss (4-sided) | 65 | 1 | 860.4 | 1120 | 180 | 538 | 9046 | 10.51 | 7.15 |
| SHS 500x500x25 | Column/Truss (4-sided) | 42 | 1 | 198.4 | 1120 | 180 | 538 | 2086 | 10.51 | 7.15 |
| SHS 500x500x28 | Column/Truss (4-sided) | 38 | 1 | 160.0 | 1120 | 180 | 538 | 1682 | 10.51 | 7.15 |
| SHS 500x500x32 | Column/Truss (4-sided) | 33 | 1 | 66.8 | 1120 | 180 | 538 | 702 | 10.51 | 7.15 |
| SHS 500x500x36 | Column/Truss (4-sided) | 30 | 1 | 32.0 | 1120 | 180 | 538 | 336 | 10.51 | 7.15 |
| SHS 500x500x38 | Column/Truss (4-sided) | 28 | 1 | 160.0 | 1120 | 180 | 538 | 1682 | 10.51 | 7.15 |
| SHS 500x500x40 | Column/Truss (4-sided) | 27 | 1 | 350.4 | 1120 | 180 | 538 | 3684 | 10.51 | 7.15 |
| SHS 500x500x45 | Column/Truss (4-sided) | 24 | 1 | 32.0 | 1120 | 180 | 538 | 336 | 10.51 | 7.15 |
| SHS 500x500x50 | Column/Truss (4-sided) | 22 | 1 | 103.6 | 1120 | 180 | 538 | 1089 | 10.51 | 7.15 |
| SHS 500x500x8 | Column/Truss (4-sided) | 127 | 1 | 519.0 | 1120 | 180 | 538 | 9449 | 18.21 | 12.38 |
| **Interchar 1120** | | | | | | | | **131526** | | |
| **Interchar 212** | | | | | | | | **95039** | | |
| **Chartek 1709** | | | | | | | | **91887** | | |

| Totals | Member Quantity | Coated Surface Area (m²) | Volume (L) |
|---|---|---|---|
| All products | 42 | 27,896.9 | 318452 |

**Notes**

Where "B" (Bracing) has been used, a maximum section factor of 200m-1 (0.67 W/D) is used unless the section factor is less than this for the given section.
Where "CD" has been used, this refers to a Composite Deck.
Where "CF" (Concrete Filled) has been used, the section factor for the given section is reduced in accordance with "Design Guide for Concrete Filled Columns" (Corus, formerly British Steel).
Where "EB" (Edge Beam) has been used, make reference to SCI publication P288.
Where "VU" (Voids Unfilled) has been used, make reference to the ASFP Yellow Book.
Where volumes are given in gallons, the US customary liquid gallon (3.785 L) is used, rather than the imperial gallon (4.546 L).

Protective Coatings www.international-pc.com

# Structural Fire Design

Safety Design in Buildings
17th June 2014

Alex D Tsiolas
Fire Engineer

# Selecting a Thickness of Paint

## How do Suppliers Establish a Thickness of Intumescent?

Typically the following information is required: -

- Standard for approval: *e.g. BS 476: 20-22*
- Fire resistance period: *e.g. 60 minutes*
- Structural section: *e.g. I-beam*
- Degree of exposure: *e.g. 3-sided with a concrete slab on top*
- Limiting steel temperature: *e.g. $620^{o}C$*
- Steel section: *e.g. UB 406x178x74*

From these a supplier can determine a dry film thickness (DFT) of paint for a range of products that have 3rd party accreditation.

Further information can tailor a specific product for a project

- Environmental exposure – degree of corrosion
- Durability requirements

# Structural Fire Engineering

The critical core temperature can be defined as the temperature that the steel will reach whilst still maintaining enough strength to carry an amount of load and thus prevent collapse.

This is not the temperature at which the structure will actually collapse.

Fireproofing manufacturers expect this to be provided in tenders, but it never is...

# Prescriptive Design Approach

Prescriptive design does not consider the amount of actual load on a structural element, but assumes a fixed reduction factor approach sometimes known as fixed load ratio approach..

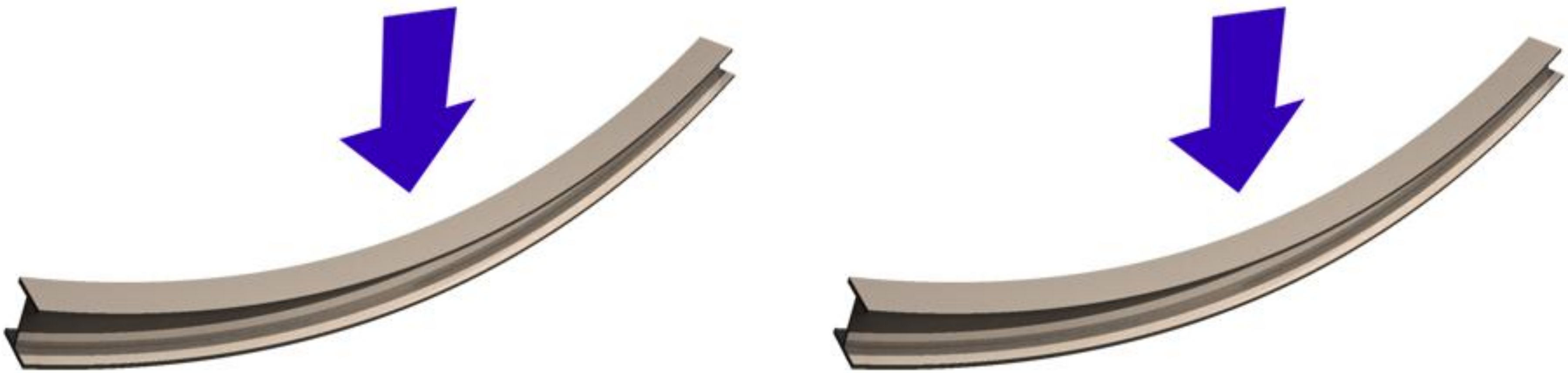
$$\text{Load ratio} \ \frac{\text{Load or moment at time of fire}}{\text{Member strength at } 20^{\circ}\text{C}}$$

In the UK prescribed design assumes that an unprotected steel column will fail when its temperature reaches 550˚C (1022˚F) equating to a reduction factor of 0.6.

Similarly a temperature of 620˚C will cause the failure of an unprotected steel beam supporting a concrete floor.

# Prescriptive Fire Protection

Steel Utilization (e.g. 60%) vs Steel Utilization (e.g. 80%)



Limiting Steel Temperature == Limiting Steel Temperature

Fire Protection Thickness == Fire Protection Thickness

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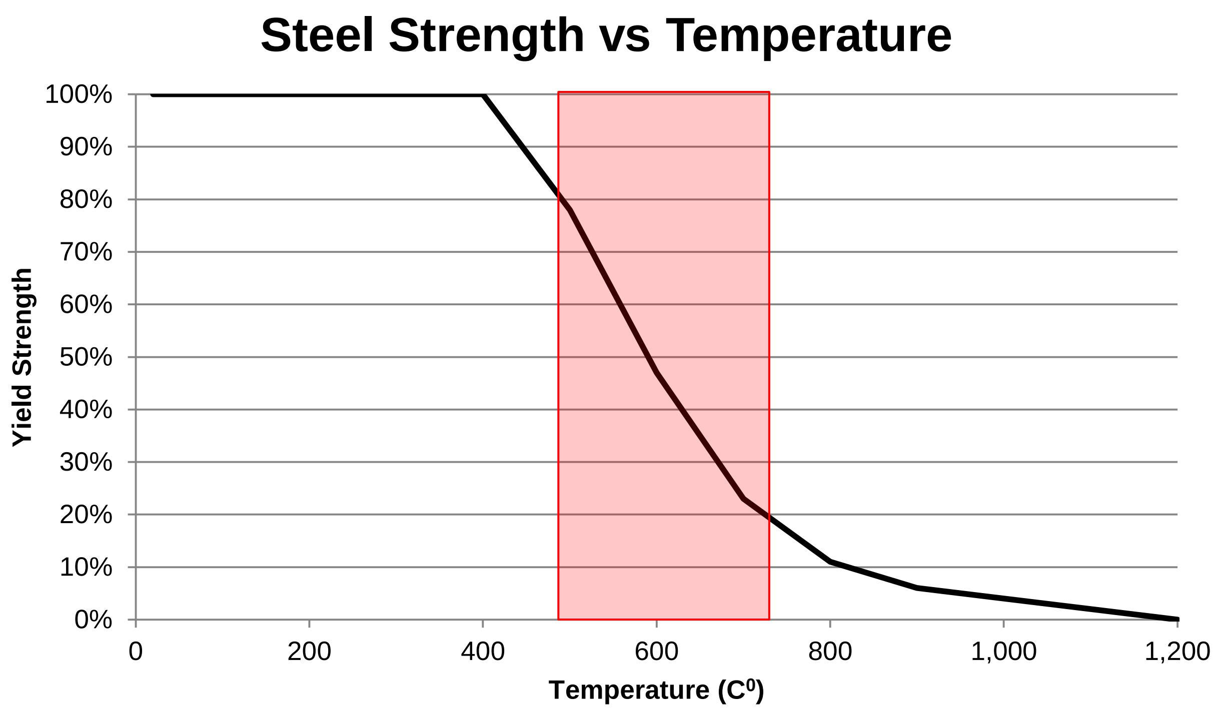
# Structural Fire Engineering

## Understanding Structural Engineering & Steel




Assumes that the steel is loaded to a certain stress

Is this always the case?

Analysis at the Fire Limit State

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# Performance Based Fire Design

Steel Utilization (e.g. 60%) vs Steel Utilization (e.g. 80%)

Limiting Steel Temperature >> Limiting Steel Temperature

Fire Protection Thickness << Fire Protection Thickness

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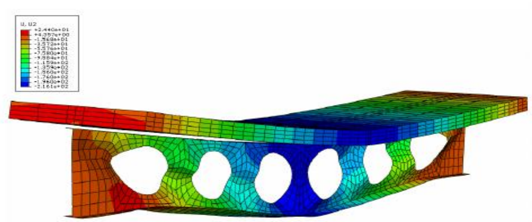
# Structural Fire Engineering

- A limiting steel temperature for each member can be determined by a number of different calculations
  - Tensile or buckling resistance for tension or compression members
  - Moment and shear resistance for beams
  - Lateral torsional buckling resistance moment for beams
- Beams with web openings have even more modes of failure to consider...



# Structural Fire Engineering and Fireproofing Solutions

## Multi-Temperature Assessment Data (MTA)

- UK and European fire testing methods (BS 476: 20-22 and EN 13381) make allowance for varying limiting steel temperatures
- US test methods work to a single 538ºC [1000ºF] or 593ºC [1100ºF] limiting temperature

| Table 1: I-Section Beams 400°C | | | | | |
|---|---|---|---|---|---|
| 30 minutes | | | | 60 minutes | |
| Section factor up to $m^{-1}$ | Thickness mm | Section factor up to $m^{-1}$ | Thickness mm | Section factor up to $m^{-1}$ | Thickness mm |
| 120 | 0.275 | 225 | 0.475 | 30 | 0.478 |
| 125 | 0.285 | 230 | 0.484 | 35 | 0.513 |
| 130 | 0.294 | 235 | 0.494 | 40 | 0.548 |
| 135 | 0.304 | 240 | 0.503 | 45 | 0.583 |
| 140 | 0.313 | 245 | 0.513 | 50 | 0.617 |
| 145 | 0.323 | 250 | 0.522 | 55 | 0.652 |
| 150 | 0.332 | 255 | 0.532 | 60 | 0.687 |
| 155 | 0.342 | 260 | 0.541 | 65 | 0.722 |

Table 2: I-Section Beams 450°C

Table 3: I-Section Beams 500°C

Table 4: I-Section Beams 550°C

Table 5: I-Section Beams 600°C

Table 6: I-Section Beams 620°C

Table 7: I-Section Beams 650°C

Table 8: I-Section Beams 700°C

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# Structural Fire Engineering - Example

| Member Analysis | | Section Factor Hp/A | Steel Temperature θ | Dry Film Thickness | No of Coats | Fire protection material saving |
|---|---|---|---|---|---|---|
| 1 | **UKC 202x203x46** Industry standard temperature | 200 /m | $550^0$C | 3.129mm | 5 | **0%** |
| 2 | **UKC 202x203x46** Limiting temperature for a given applied loading | 200 /m | $576^0$C | 2.816mm | 4 | **10%** |
| 3 | **UKC 202x203x86** Limiting temperature as in 2 but with serial weight increased from 46 kg/m to 86 kg/m | 110 /m | $673^0$C | 1.27 mm | 2 | **59%** |
| 4 | **UKC 202x203x46** Limiting temperature as in 2 but steel yield strength increased from 235 $N/mm^2$ to 355 $N/mm^2$ | 200 /m | $639^0$C | 2.213 mm | 3 | **29%** |

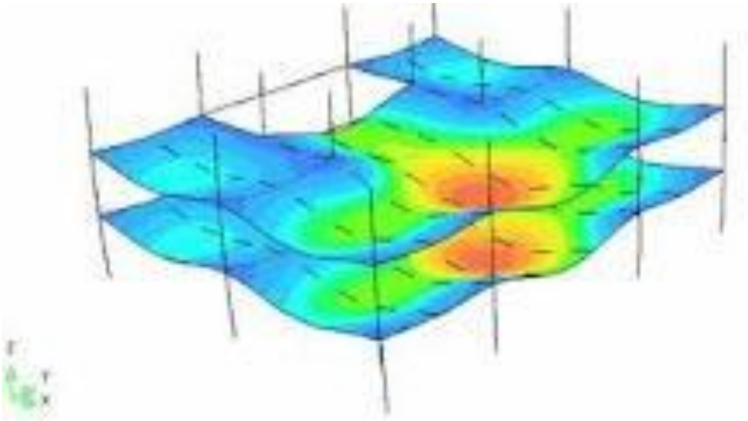
International.

Marine & Protective Coatings

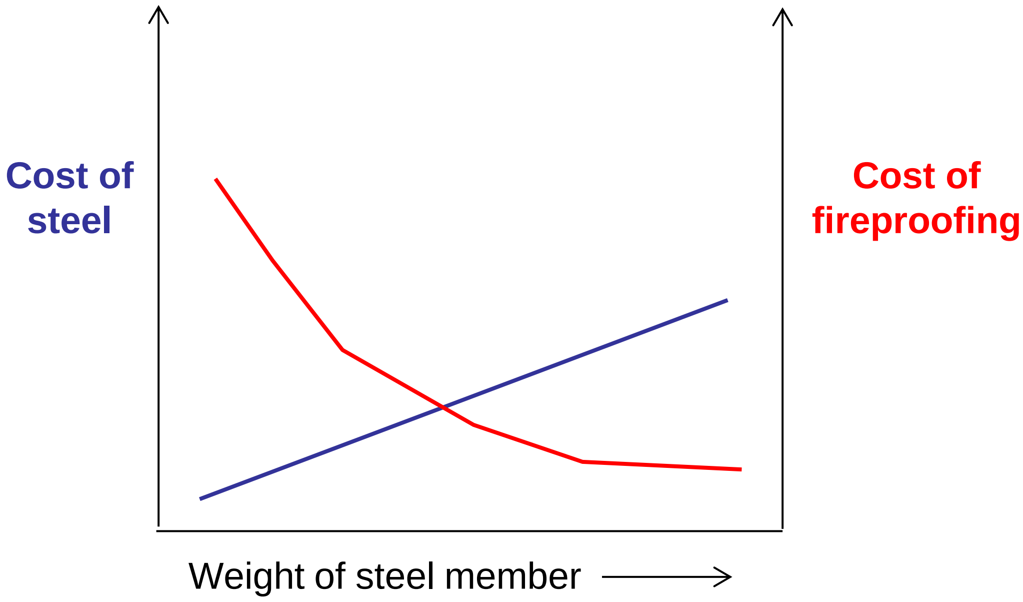
# Structural Fire Engineering Optimisation

## Optimisation

- Optimisation of steelwork and fire protection combined
- Large opportunities for designers to show up-front savings to their client – provided costs are accurately quantified



**In some instances, steel can be cheaper than fireproofing materials**



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# Structural Fire Engineering DO's & DON'Ts

## DO

- Optimize fire proofing based on project requirements
- Question basis of temperature selections
- Question product limitations – Hp/A & Temperatures

## DON'T

- Don't accept material thicknesses without certifications
- Don't accept increased limiting temperatures without a report
- Don't accept anything that is not understood!!!

# Benefits of Performance Based FP Design

## Safe and Robust Designs in Buildings

- Demonstrate building integrity in a fire
- Identify potentially weak areas

## Quantified Structural Performance

- Understand the limitations of steel at elevated temperatures
- Enable performance based design
- Add value in design

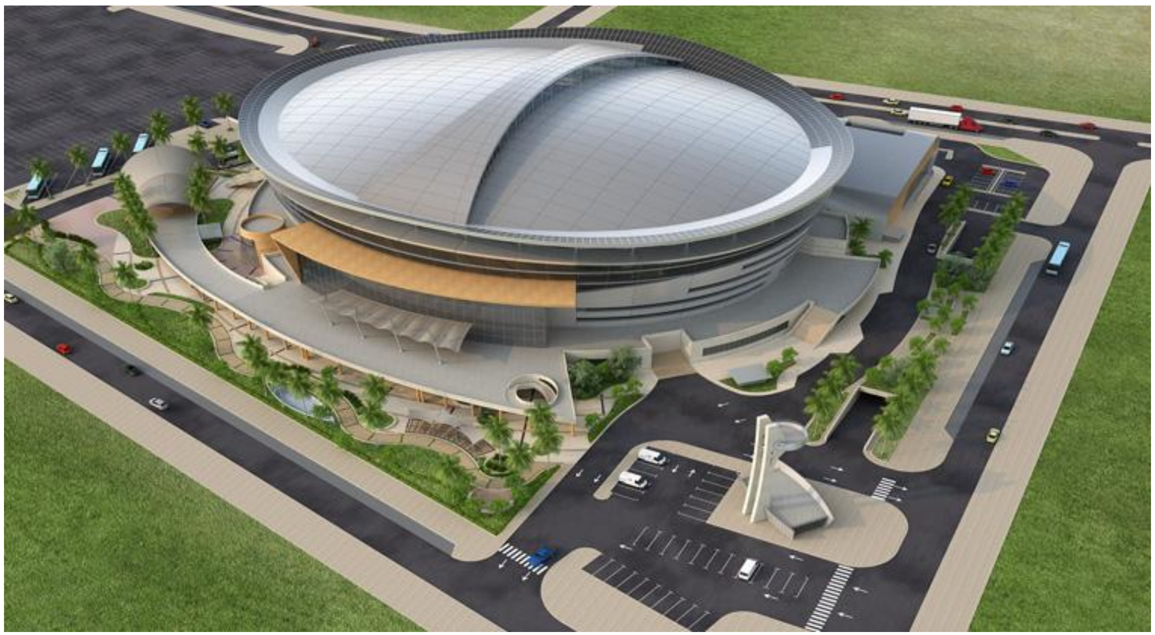
# Benefits of Performance Based FP Design

## Cost Optimization

- Enable performance based design of fire protection materials
    - Optimized construction material usage
    - Steel optimized on par with PFP to ensure max value
- Reduced number of coats resulting in faster preparation times
- Reduced scaffolding times
- Reduced erection times
- Reduced manhours on site

# Structural Fire Design

## Al-Sadd Sports Club - Qatar



| | |
|---|---|
| Value | $5 Billion |
| Client | Fosters |
| Contractor | Nurol |
| Product | Interchar 1190 |
| Scenario | R120 |
| Volume | 90,000 L |
| Status | Won |

# Structural Fire Design

## Emirates Sky Cargo - Dubai World Central

| | |
|---|---|
| Value | $100+m |
| Client | Emirates |
| Contractor | Amana Steel Buildings |
| Product | Interchar 1190 |
| Scenario | R90 – FM Approval |
| Volume | 300,000 L |
| Status | Specified and won |

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# Summary

## Intumescent Coatings

- Structural Fire Proofing
- Data Required for system design
- Process to establish material thicknesses/volumes

## Structural Fire Design

- Critical core temperatures
- Steel behaviour at elevated temperatures
- Calculation of optimum steel temperatures

## Benefits of Fire Design

- Promoting safe design in buildings
- Fire limit state should be treated as an important load case
- By addressing fire protection in early stages of design significant costs savings can be demonstrated

# Thank you for your attention

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