Safety Design in Buildings

Doha Conference Renaissance Doha City Center Hotel June 17, 2014

Optimization of Intumescent Fireproofing Via Structural Analysis

AkzoNobel

Alex D Tsiolas
Fire Engineer

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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

Presenter Bio – Alex D Tsiolas

- **Structural Fire Engineering Expertise**
  - BEng in Civil & Structural Engineering
  - MSc in Structural Dynamic
  - MSc in Fire and Blast Engineering

- **Expertise in:**
  - Intumescent Fire Protection
  - Fire Protection System Design
  - Fire Safety Codes
  - Fire Testing and Product Certification
  - Heat Transfer Modelling
  - Structural Fire Design

Structural Fire Protection

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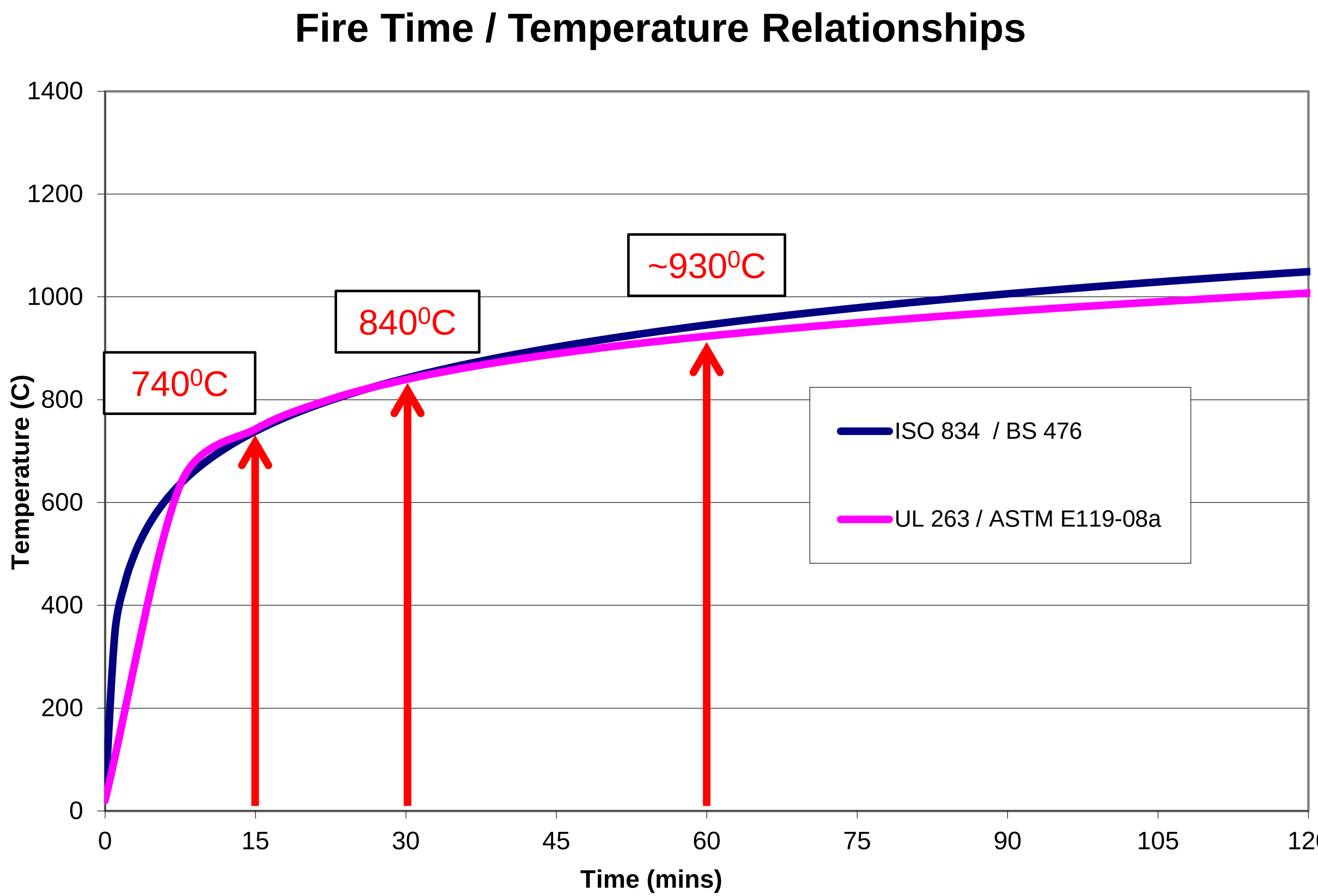
How is a fire defined in a building?



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: More than 10 m	Depth below access level of lowest basement: Not more than 10 m	Height [C)] of top occupied storey above access level: Not more than 5 m	Height [C)] of top occupied storey above access level: Not more than 18 m	Height [C)] of top occupied storey above access level: Not more than 30 m	Height [C)] of top occupied storey above access level: 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)

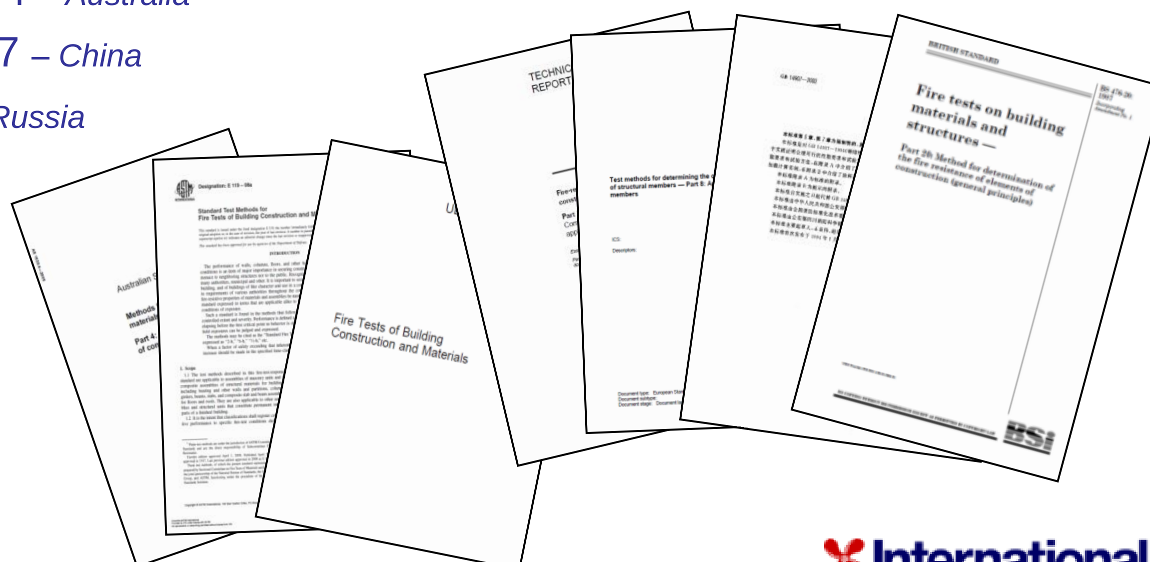
- Typical rating: **620^{o}C at 120 minutes** (for a beam)

SCI 4th 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

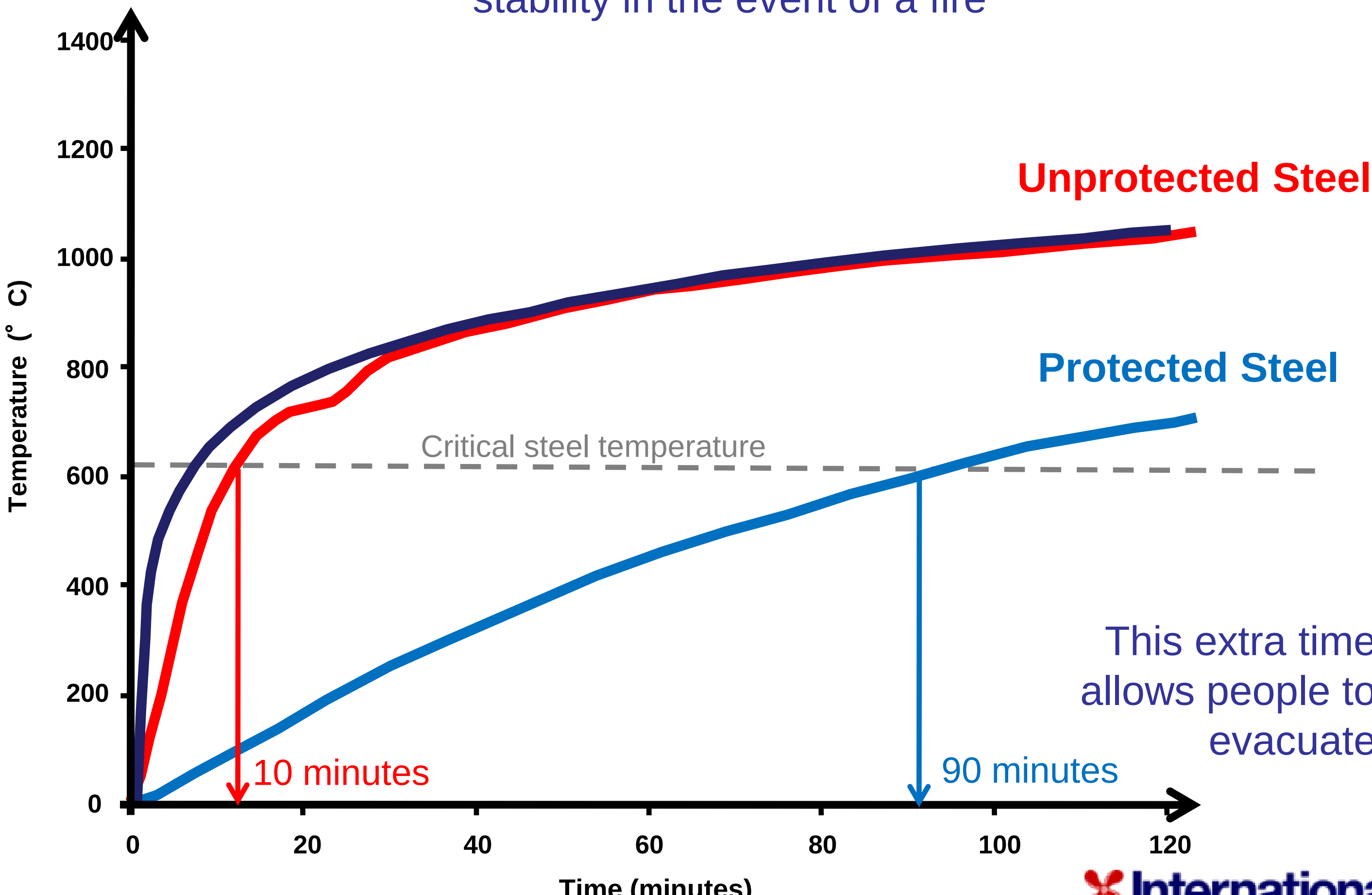
Intumescent coatings

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

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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*

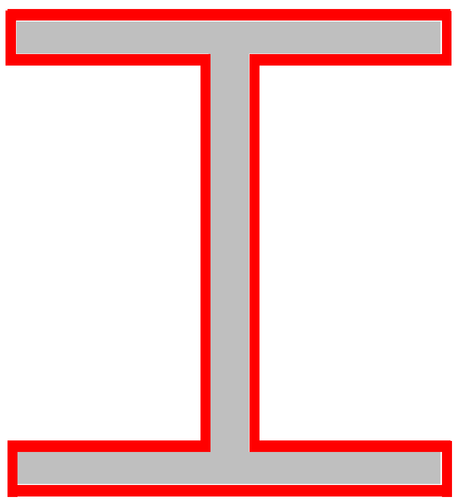
From these a supplier can determine a dry film thickness (DFT) of paint for a range of products that have 3rd party accreditation.

Further information can tailor a specific product for a project

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

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, $H_p = 1.51m$

Cross-section area, $A = 0.00945m^2$

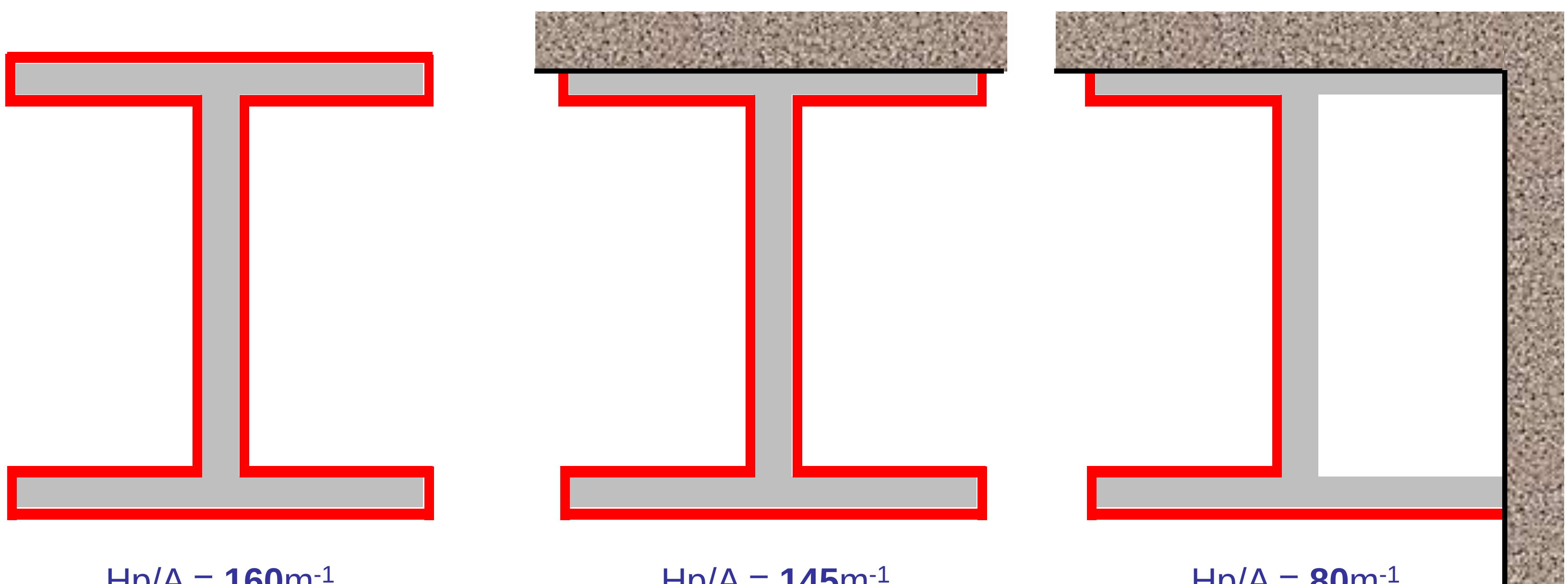
$$\text{Section Factor, } H_p/A = \frac{\mathbf{1.51}}{\mathbf{0.00945}} = \mathbf{160m^{-1}}$$

Section Factor

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

UB 406x178x74

Exposed on 4 sides | Exposed on 3 sides | Exposed on 2 sides



Hp/A = **160**m^{-1} | Hp/A = **145**m^{-1} | Hp/A = **80**m^{-1}

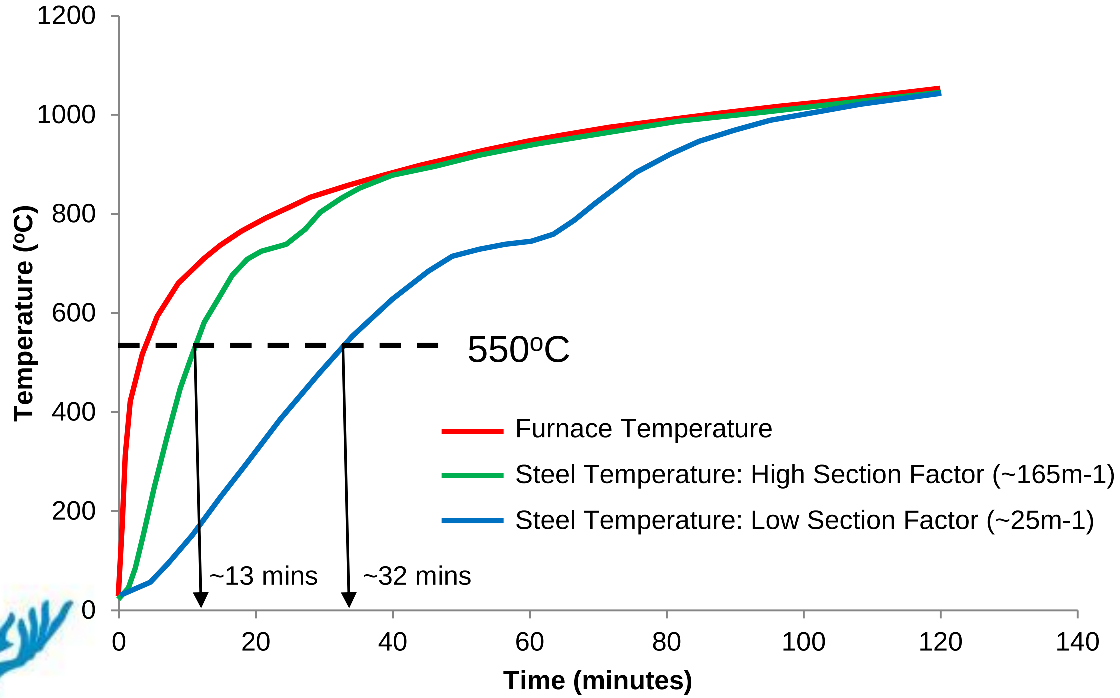
Section Factor – Hp/A = A/V
How steel heats up

- Slender Sections: **High** Section Factor

  Heat relatively **quickly** when unprotected

- Stocky Sections: **Low** Section Factor

  Heat relatively **slowly** when unprotected



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Selecting a Thickness of Paint

How do Suppliers Establish a Thickness of Intumescent?

certifire

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

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Interchar 963

Table 6: I-Section Beams 620°C

30 minutes		60 minutes				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		
		160	0.504	300	1.375		
		165	0.518				

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

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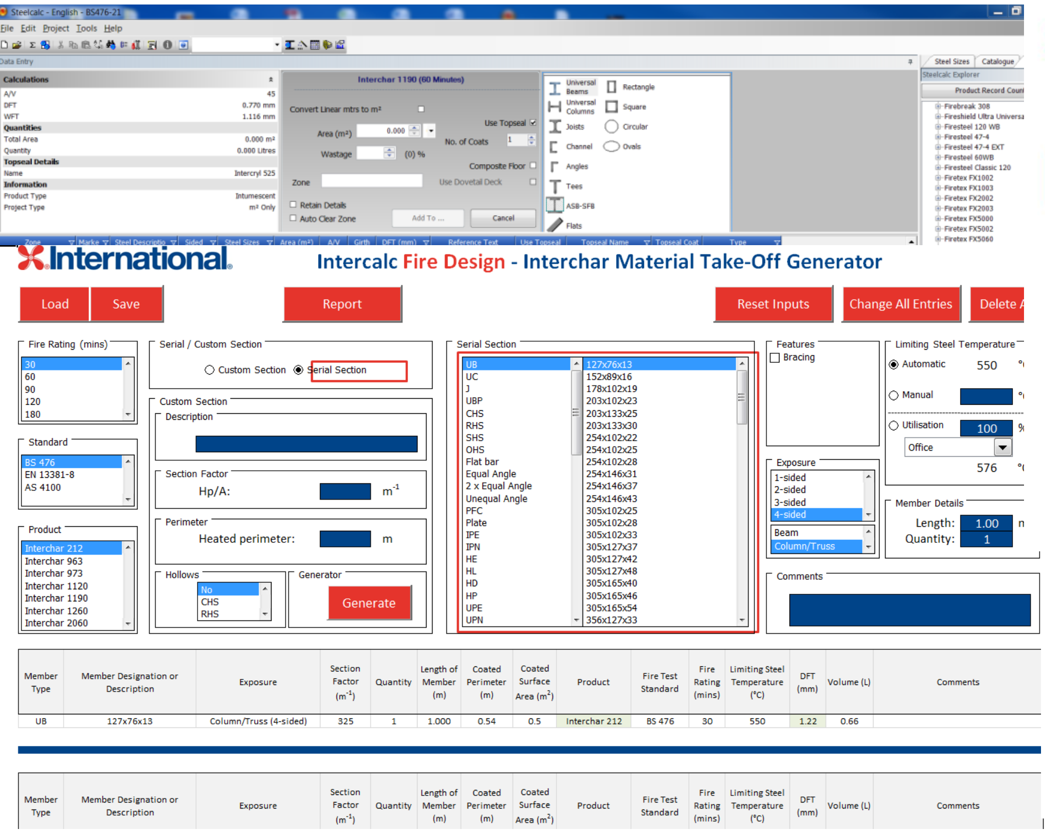
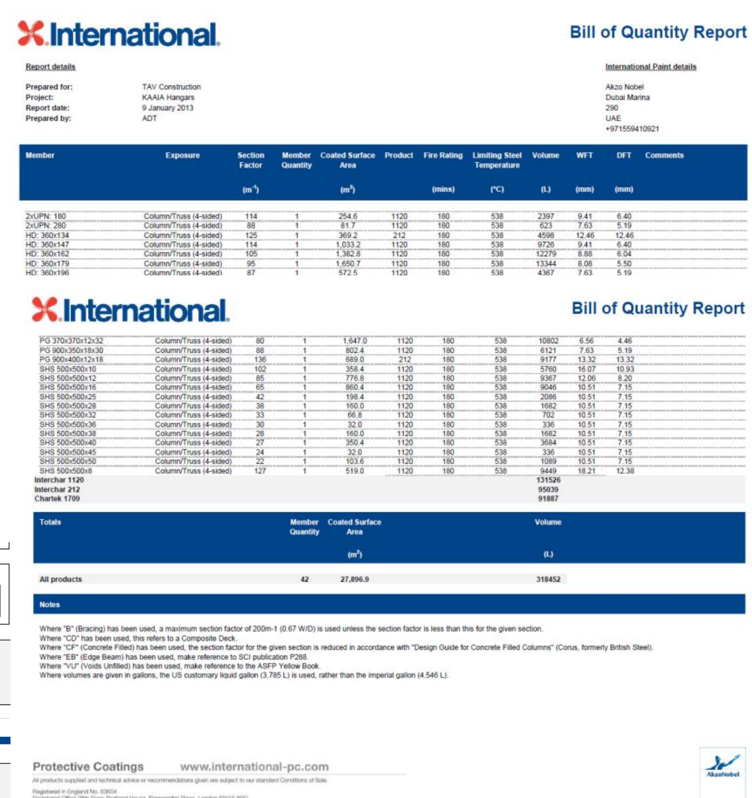
Selecting a Thickness of Paint

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

AkzoNobel

International

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..

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

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

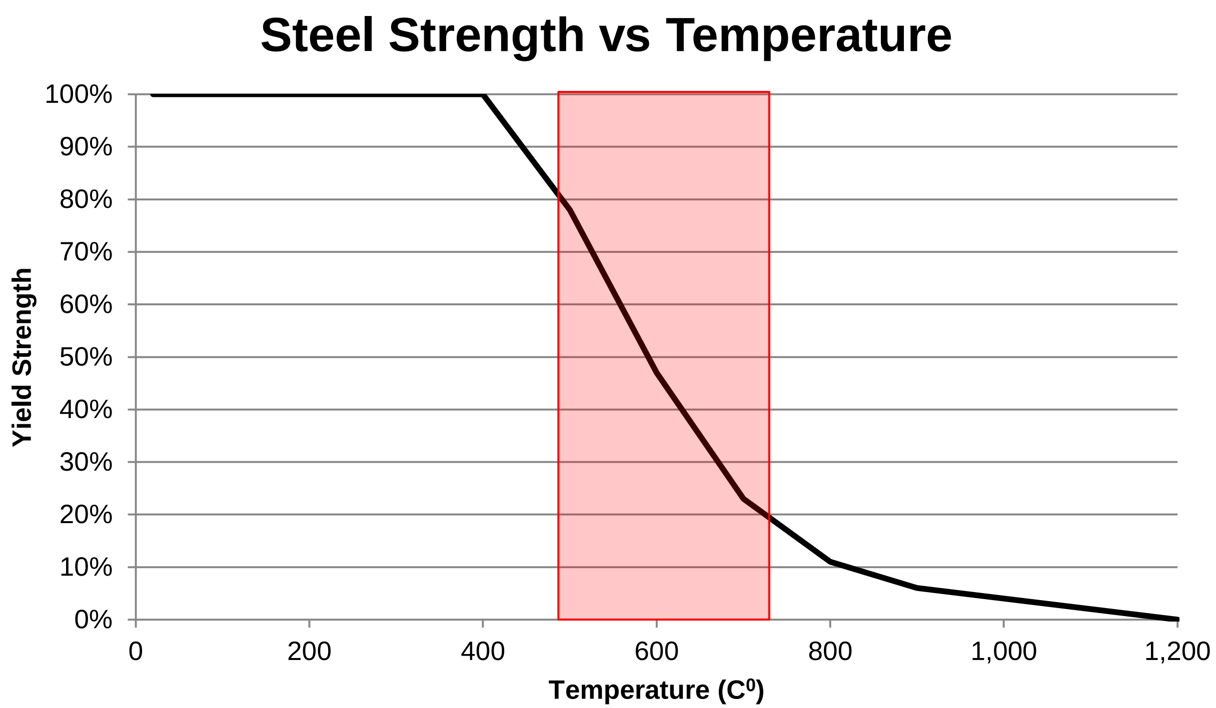
Steel Utilization (e.g. 60%) >> Steel Utilization (e.g. 80%)

Limiting Steel Temperature == Limiting Steel Temperature

Fire Protection Thickness == Fire Protection Thickness

Structural Fire Engineering

Understanding Structural Engineering & Steel



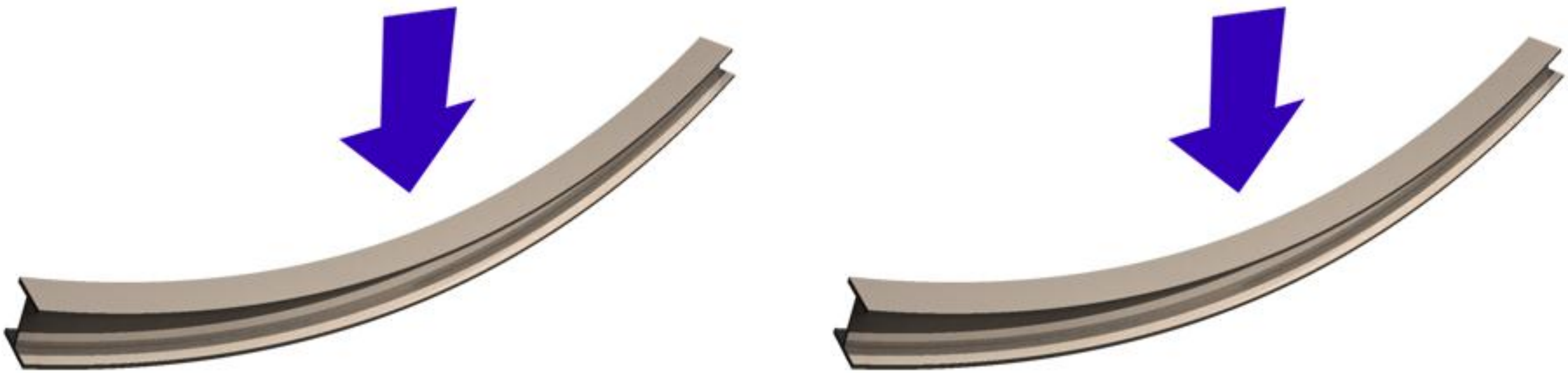
Assumes that the steel is loaded to a certain stress

Is this always the case?

Analysis at the Fire Limit State

Performance Based Fire Design

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

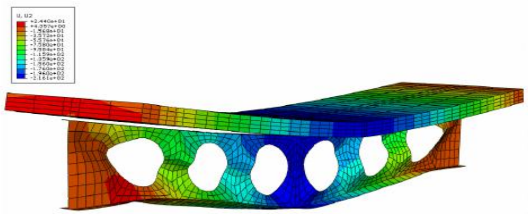


Limiting Steel Temperature >> Limiting Steel Temperature

Fire Protection Thickness << Fire Protection Thickness

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...



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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	550^0C	3.129mm	5	**0%**
2	**UKC 202x203x46** Limiting temperature for a given applied loading	200 /m	576^0C	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	673^0C	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	639^0C	2.213 mm	3	**29%**

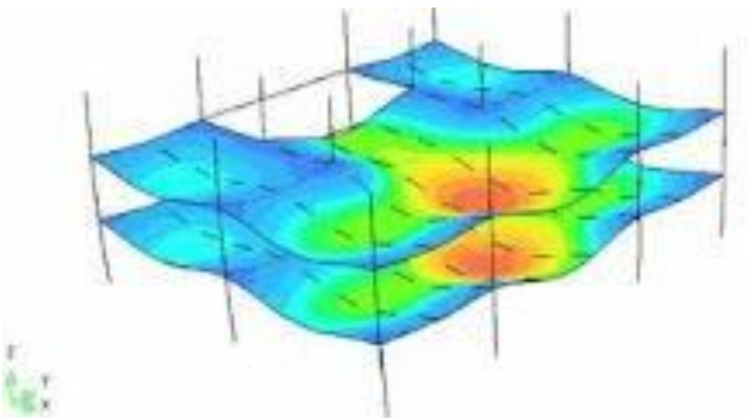
International.

Marine & Protective Coatings

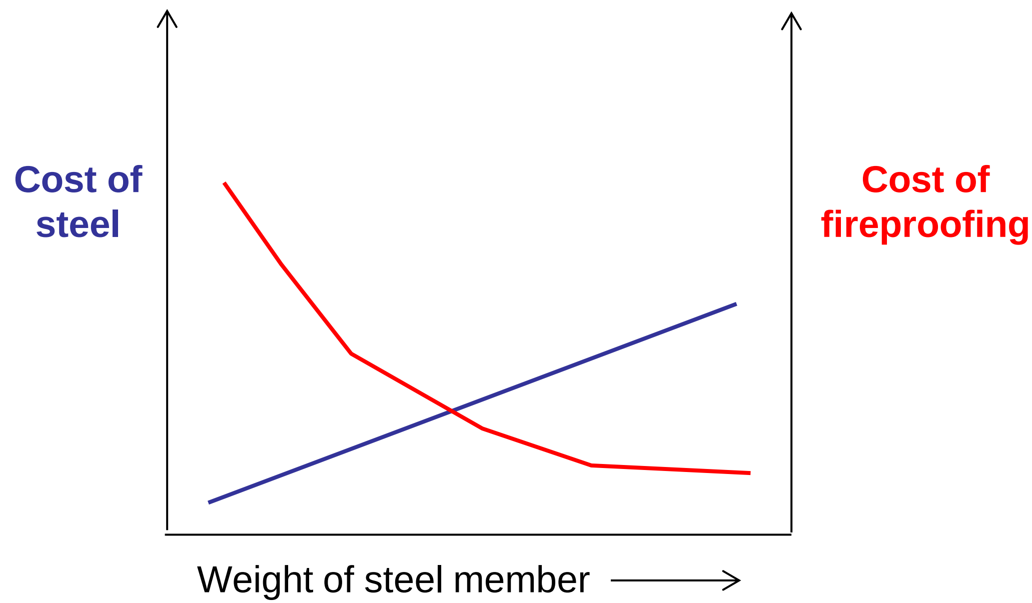
Structural Fire Engineering Optimisation

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

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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

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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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