Dry film thickness of intumescent coatings for structural steel bracing members

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Project Overview

Overview - Steel in Fire

One way to insulate steel from fire is by applying an intumescent coating which reacts to heat to form a thick char that insulates the steel.

Overview - Braced Frames

- Common form of steel construction used around the world.
- Economic and relatively simple to design.
- Bracing systems carry all lateral load so columns and beams only need to be designed against gravity loads.
- Bracing members can be crucial in maintaining the stability of a steel structure in the event of a fire

Overview – Current Guidance

"The apparent cost of fire protecting bracing members is often expected to be high because the members are comparatively light and therefore have high section factors and correspondingly require high thicknesses of fire protection.

fire protection thickness should be based on the section factor of the steel member, or a value of 200m-1, whichever is the smaller value."

Technical Issue:

- British standards have now been withdrawn (including BS5950-8).
- No technical justification has ever been given to show that 200 m^{-1} is safe for Eurocode design.

Objectives:

- Determine whether the guidance for bracing members provided in BS5950-8 is safe for a Eurocode design.
- Present a solid technical justification for bracing members in the event of a fire based on Eurocode approaches.

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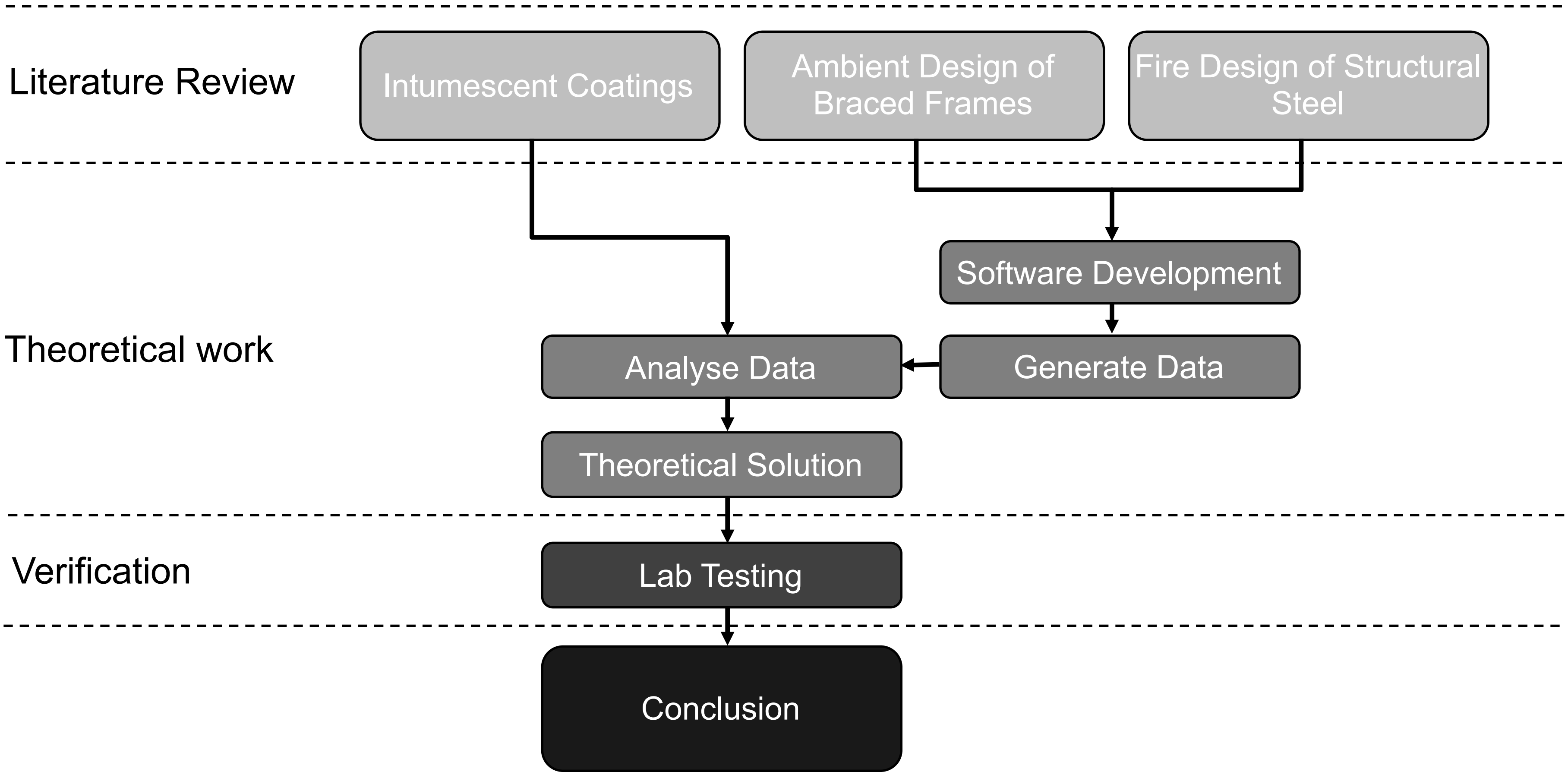
Project Overview



International

Literature Review

Intumescent Coatings

Intumescent Coatings

Loading tables (derived by testing) are used to calculate required thicknesses of intumescent

Fire Duration (R): **120 mins**

Section Factor: **100 m-1 (A/V)**

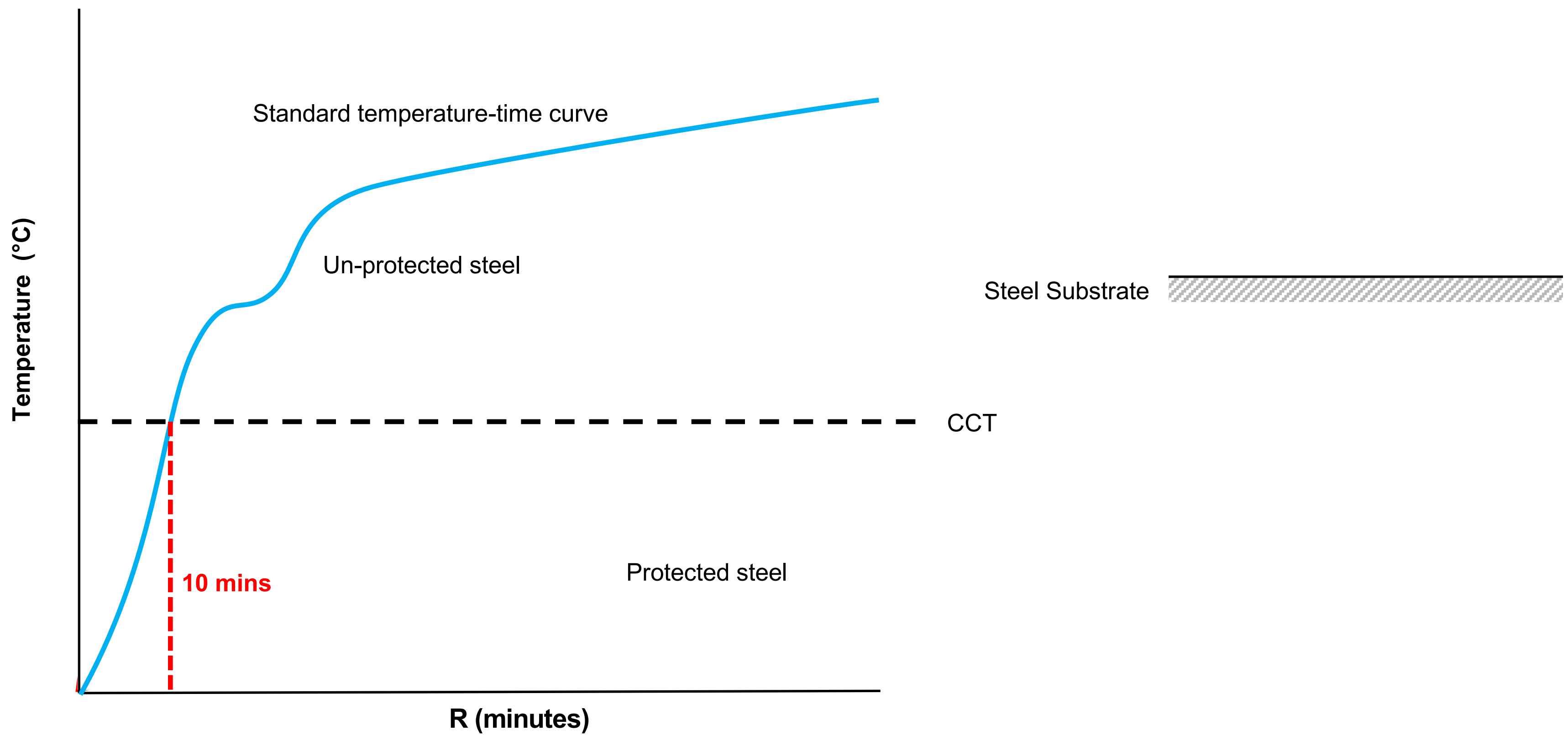
Limiting temperature (CCT): **550°C**

A/V	350°	400°	450°	500°	550°	600°	650°	700°
25	2.277	1.662	1.530	1.305	1.178	0.977	0.750	0.586
30	2.277	1.662	1.530	1.305	1.178	0.977	0.750	0.586
35	2.411	1.833	1.645	1.396	1.234	1.022	0.791	0.586
40	2.545	2.004	1.760	1.486	1.289	1.068	0.831	0.597
45	2.679	2.175	1.874	1.576	1.345	1.113	0.872	0.635
50	2.812	2.346	1.989	1.666	1.401	1.159	0.912	0.672
55	3.003	2.517	2.104	1.756	1.456	1.205	0.952	0.709
60	3.217	2.688	2.219	1.847	1.512	1.250	0.993	0.747
65	3.430	2.856	2.333	1.937	1.568	1.296	1.033	0.784
70	3.643	2.959	2.448	2.027	1.623	1.342	1.074	0.821
75	3.857	3.062	2.563	2.117	1.679	1.387	1.114	0.858
80	4.070	3.165	2.677	2.208	1.735	1.433	1.154	0.896
85	4.284	3.268	2.792	2.298	1.790	1.479	1.195	0.933
90	4.497	3.371	2.889	2.388	1.846	1.524	1.235	0.970
95	4.711	3.474	2.968	2.478	1.902	1.570	1.276	1.008
100	4.995	3.577	3.046	2.568	1.957	1.615	1.316	1.045
105	5.296	3.681	3.125	2.659	2.013	1.661	1.356	1.082
110	5.597	3.784	3.203	2.749	2.069	1.707	1.397	1.120
115	5.897	3.887	3.282	2.839	2.124	1.752	1.437	1.157
120	6.198	3.990	3.361	2.905	2.180	1.798	1.478	1.194
125	6.499	4.093	3.439	2.967	2.236	1.844	1.518	1.232
130	6.800	4.196	3.518	3.029	2.291	1.889	1.558	1.269
135	7.100	4.299	3.597	3.091	2.347	1.935	1.599	1.306
140	7.401	4.402	3.675	3.153	2.403	1.980	1.639	1.344
145		4.505	3.754	3.215	2.458	2.026	1.680	1.381
150		4.608	3.833	3.278	2.514	2.072	1.720	1.418
155		4.712	3.911	3.340	2.570	2.117	1.760	1.455
160		4.847	3.990	3.402	2.625	2.163	1.801	1.493
165		5.001	4.068	3.464	2.681	2.209	1.841	1.530
170		5.155	4.147	3.526	2.737	2.254	1.882	1.567
175		5.309	4.226	3.588	2.792	2.300	1.922	1.605
180		5.463	4.304	3.650	2.848	2.345	1.962	1.642
185		5.617	4.383	3.713	2.918	2.391	2.003	1.679
190		5.771	4.462	3.775	2.988	2.437	2.043	1.717
195		5.925	4.540	3.837	3.059	2.482	2.084	1.754
200		6.079	4.619	3.899	3.129	2.528	2.124	1.791
205		6.233	4.698	3.961	3.200	2.574	2.164	1.829
210		6.387	4.803	4.023	3.270	2.619	2.205	1.866
215		6.541	4.960	4.086	3.341	2.665	2.245	1.903
220		6.695	5.118	4.148	3.411	2.710	2.286	1.940

Prescriptive limiting temperatures (CCT) for bracing members range from 500ºC to 550°C globally

Intumescent Coatings

Section Factor - Limiting temperature (CCT) – Fire Duration (R)



Literature Review

Ambient Design of Braced Frames

Structures in Fire

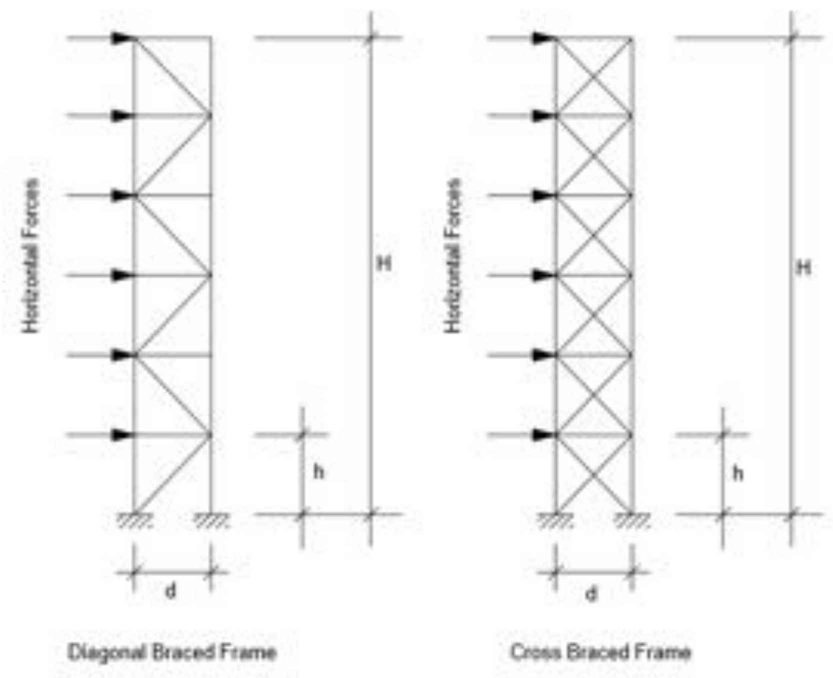
Ambient Design of Braced Frames

Braced frames resist horizontal forces by having bracing systems added vertically between columns which transfers horizontal loads to the foundations

Diagonal and cross braced configurations are very common forms of vertical bracing

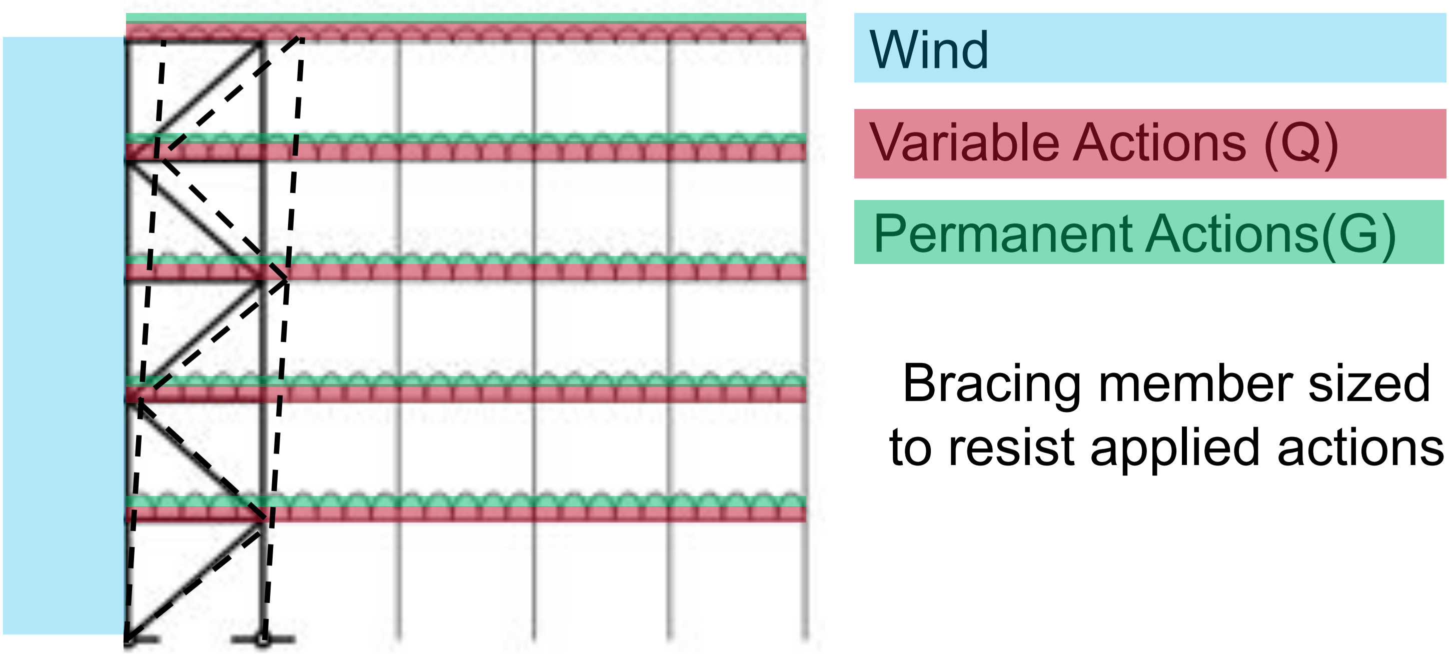
Cross braced frame will only be subjected to tension

Diagonal braced frame can have both tension and compression forces.



Ambient Design of Braced Frames

- **Wind loads**
- **Equivalent horizontal forces (EHF) due to imperfections**



Bracing member sized to resist applied actions

Literature Review

Fire Design of Structural Steel

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Fire Design of Structural Steel

Temperature domain

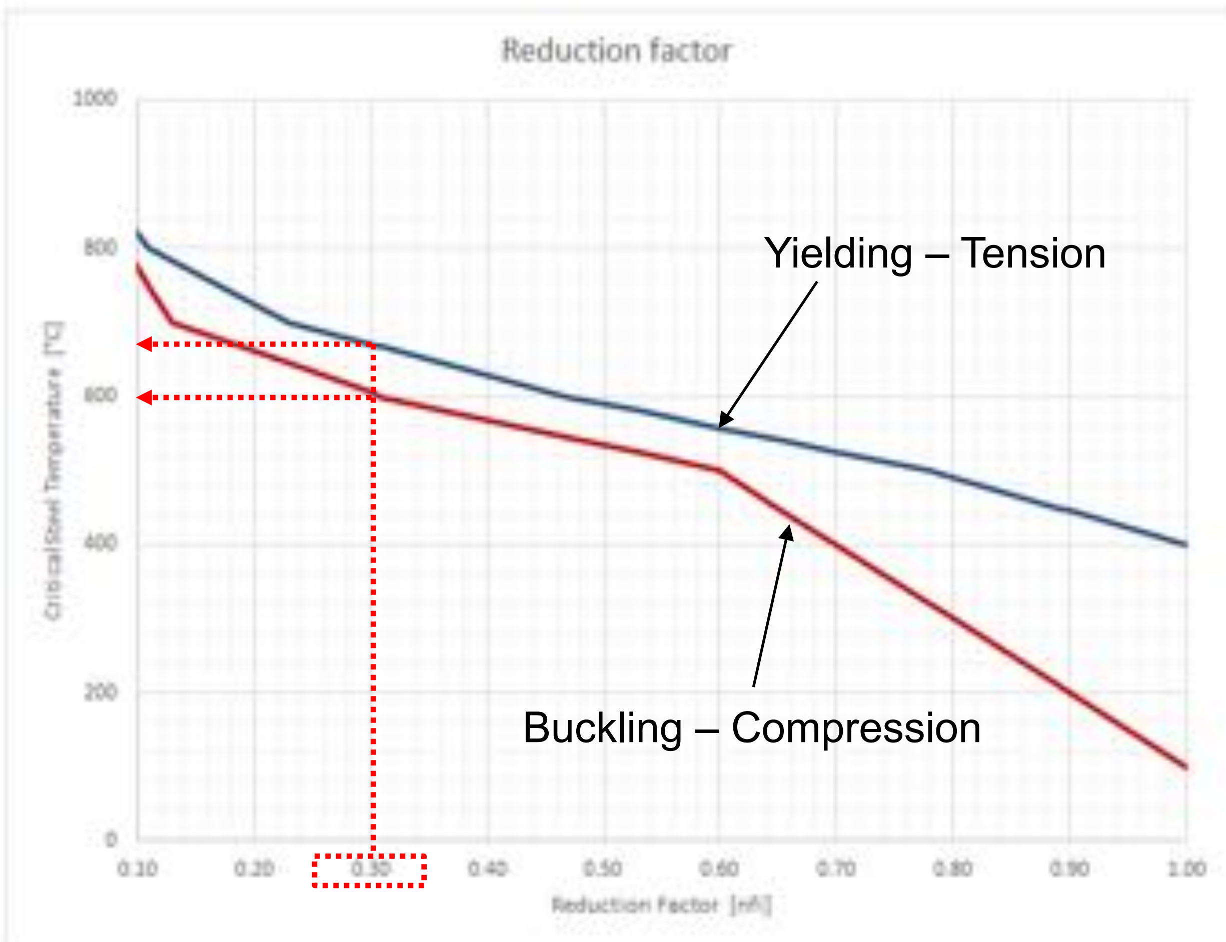
$$\theta_d \leq \theta_{cr.d}$$

where

θ_d design value of material temperature

$\theta_{cr.d}$ design value of the critical material temperature

Fire Design of Structural Steel

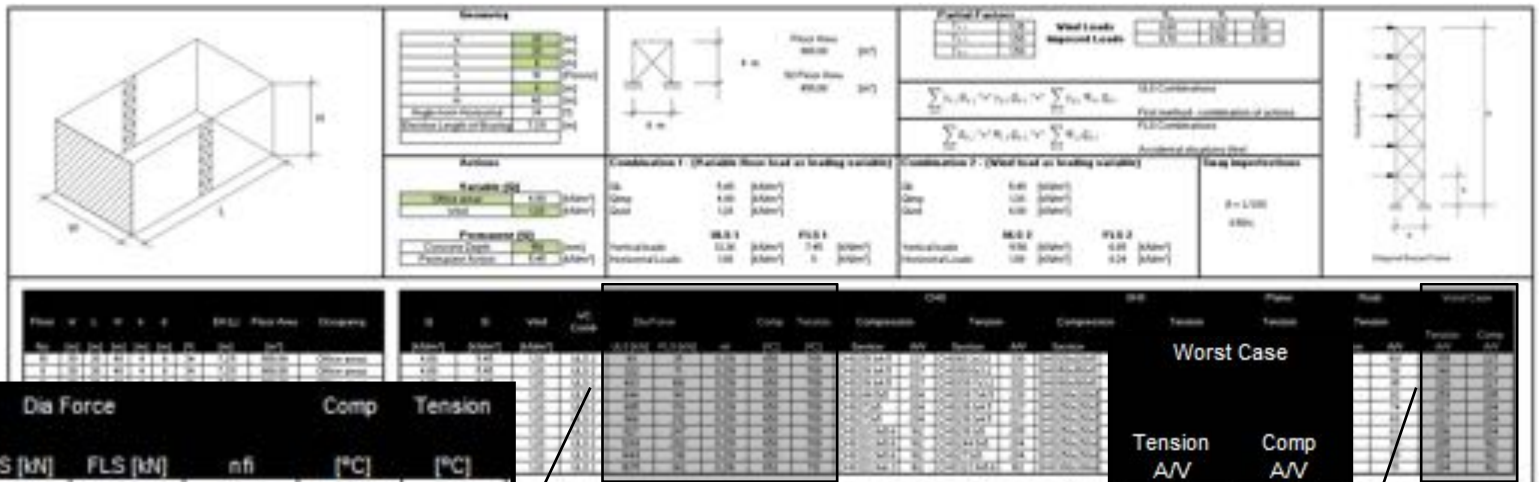


Yielding -Tension
680ºC

Buckling – Compression
600ºC

Theoretical work

Software Development



Dia Force			Comp	Tension
ULS [kN]	FLS [kN]	nfi	[°C]	[°C]
161	35	0.219	650	709
322	71	0.219	650	709
483	106	0.219	650	709
644	141	0.219	650	709
805	176	0.219	650	709
966	212	0.219	650	709
1127	247	0.219	650	709
1288	282	0.219	650	709
1449	318	0.219	650	709
1675	362	0.216	652	712

CHS - Compression / Tension
SHS - Compression / Tension

Plates - Tension
Rods - Tension

Worst Case	
Tension A/V	Comp A/V
355	227
346	227
320	227
259	205
227	204
227	204
206	204
205	182
204	182
204	162

Software Development

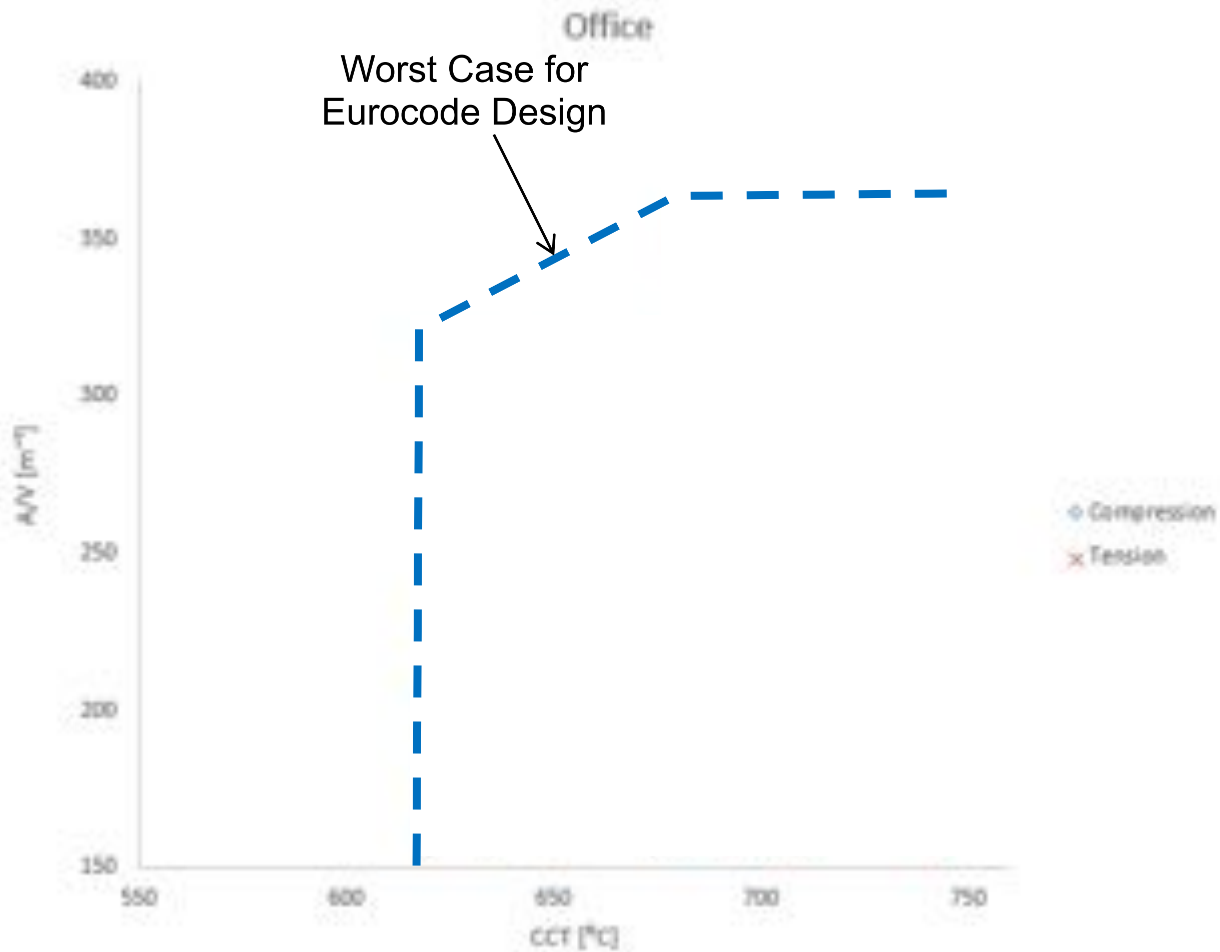
Design:

- Different floor geometries
- Different load cases

Generated data:

- Section factors - A/V
- Tension and compression member - CCTs

CCT vs A/V



Office
Worst Case for
Eurocode Design
400
350
300
250
200
150
550
600
650
700
750
CCT [°C]
Compression
Tension

Constant Thermal Conductivity

Thermal properties of materials can be used in numerical heat transfer calculations to predict temperature increases.

Heat source: Standard temperature-time curve

Material heat transfer properties:

- Thermal conductivity: λ (W/m.K)
- Density: ρ (kg/m3)
- Specific heat: c_p (J/kg.K)

RTC Calculations

A/V: 300 m-1

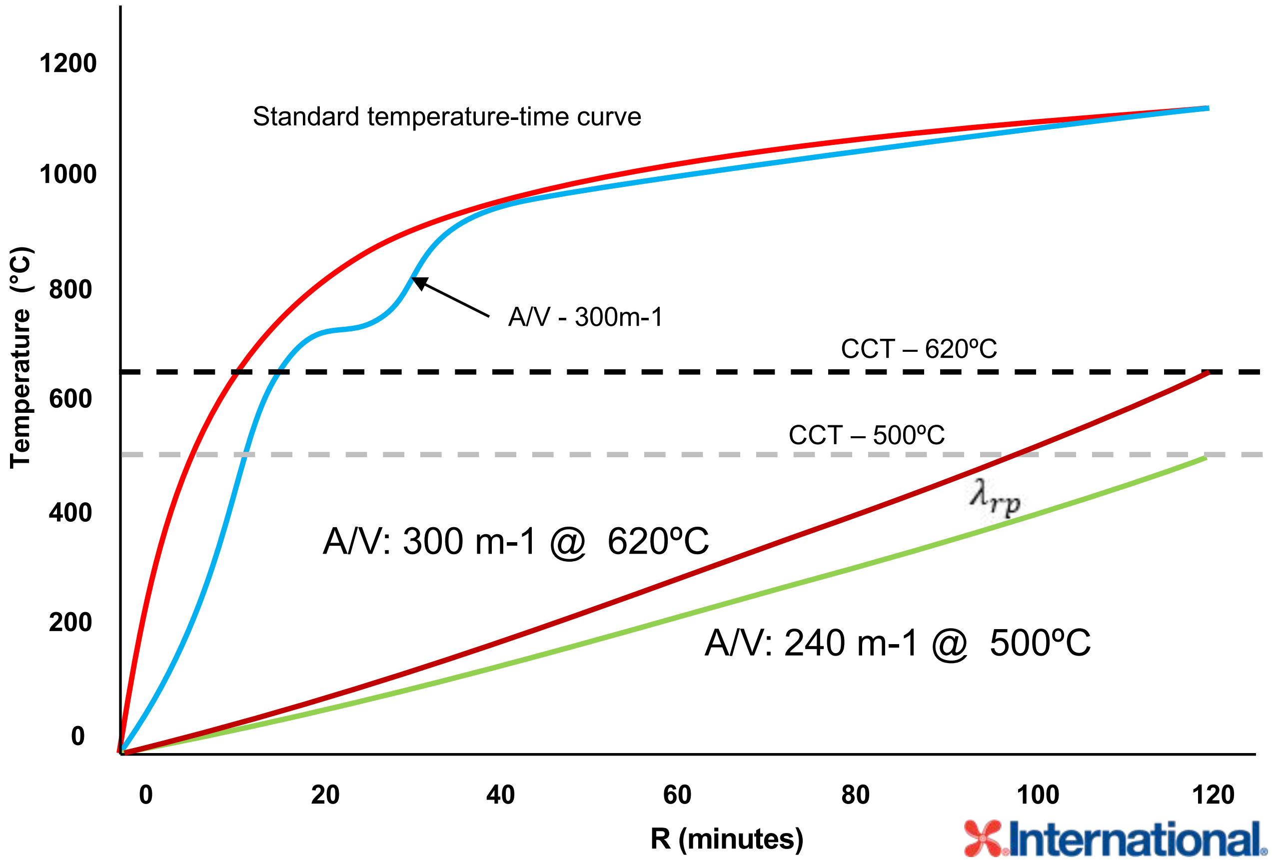
CCT: 620ºC

$$\Delta\theta_{a,t} = \lambda_{rp} \times \frac{A_p/V}{c_a \rho_a}(\theta_{g,t} - \theta_{a,t})\Delta t$$

λ_{rp}

CCT: 500ºC

A/V: 240m-1



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RTC Results

Modified A/V for Bracing Members [m⁻¹]		
Actual A/V [m⁻¹]	550°C	500°C
350	285	255
300	265	240
250	220	200
200	175	160

Verification

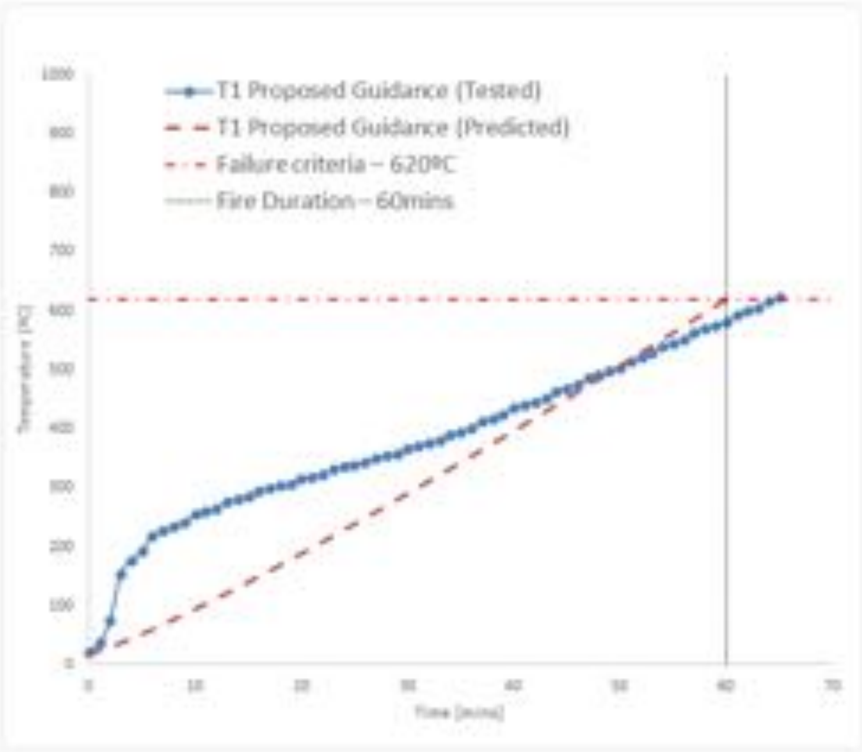
Lab Test

Product Type:	Solvent borne, Single pack acrylic Intumescent
Fire Duration:	60 mins
Failure Criteria:	Steel Temperature 620°C

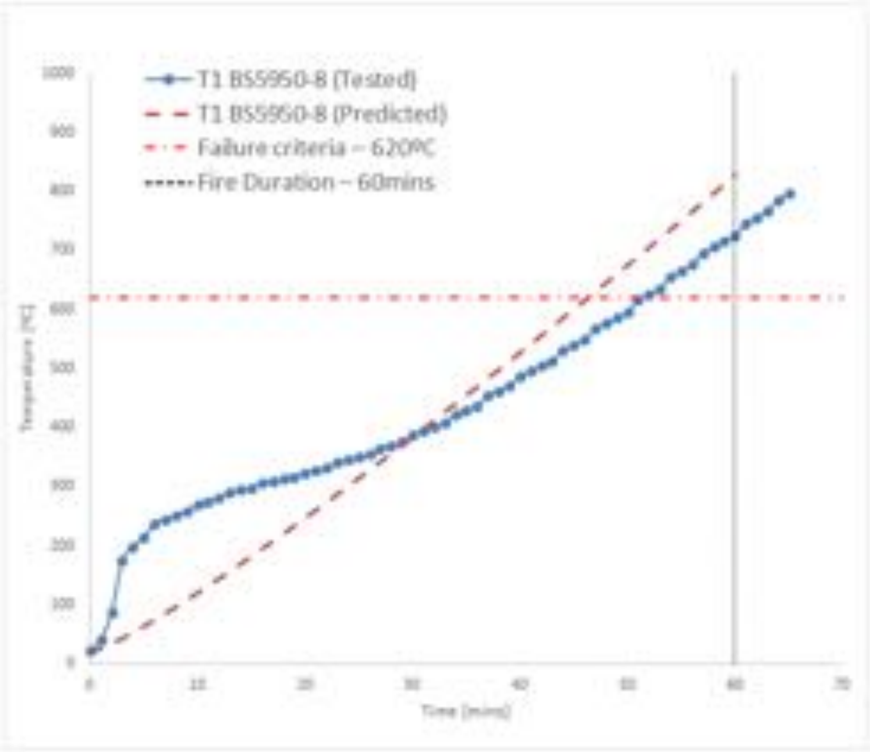
		Proposed Guidance		BS5950-8	
Test Reference	Actual A/V [m^{-1}]	DFT @ 550°C	Modified A/V [m^{-1}]	DFT @ 550°C	Modified A/V [m^{-1}]
T1	305	2.33	267	1.49	200
T2	235	1.56	207	1.49	200
T3	180	1.09	157	1.29	180

TEST 1 – 305 m-1

Proposed Guidance

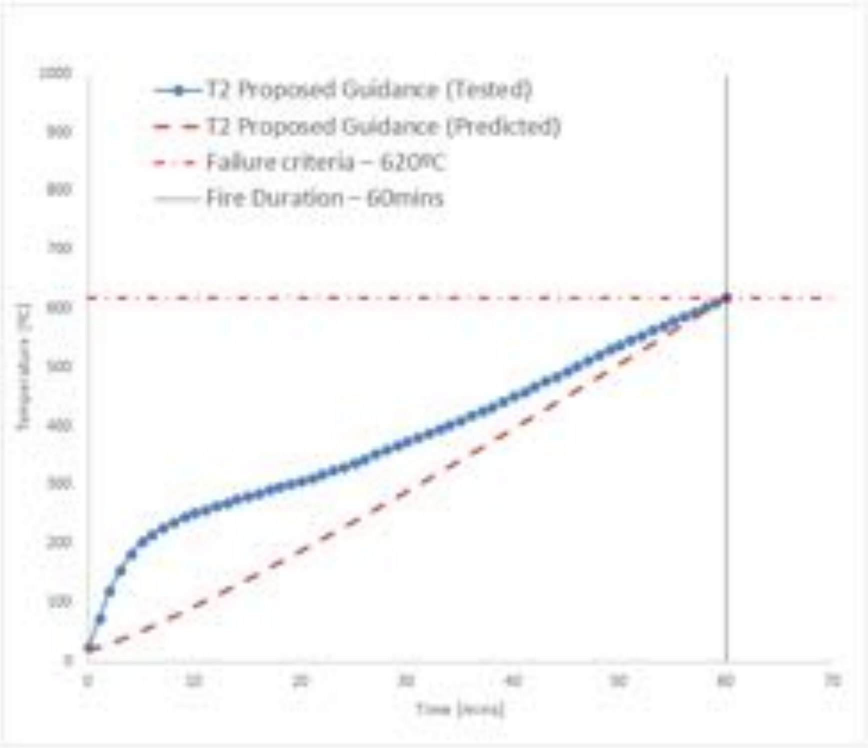


BS5950-8

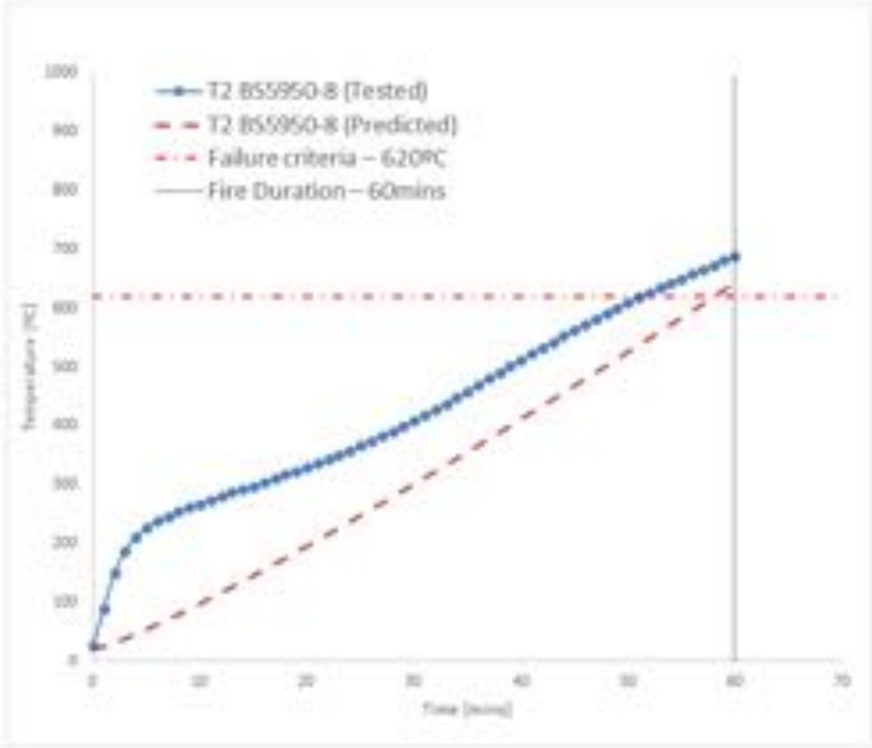


TEST 2 – 235 m-1

Proposed Guidance

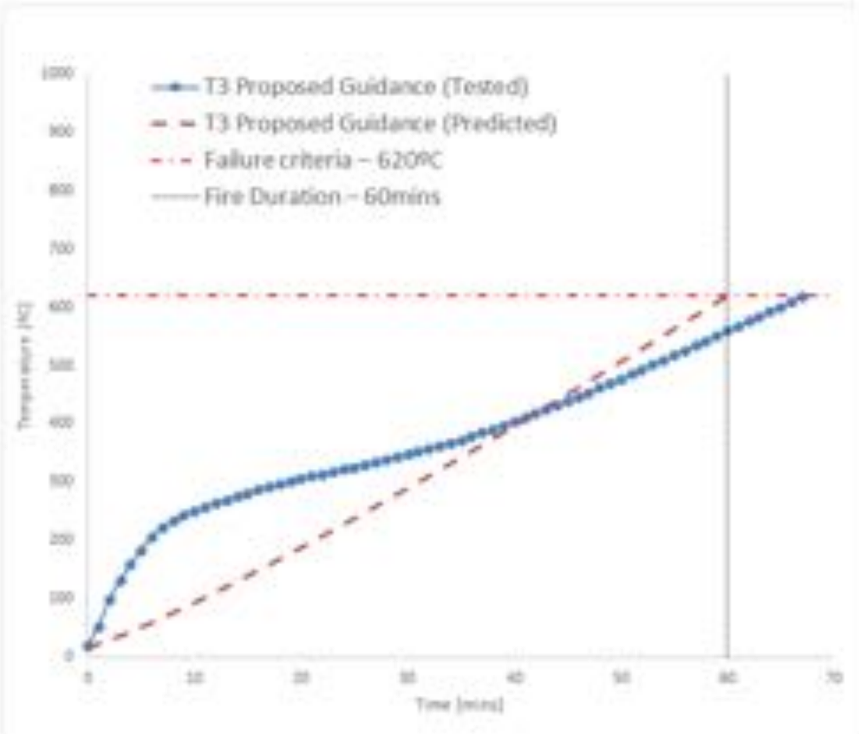


BS5950-8

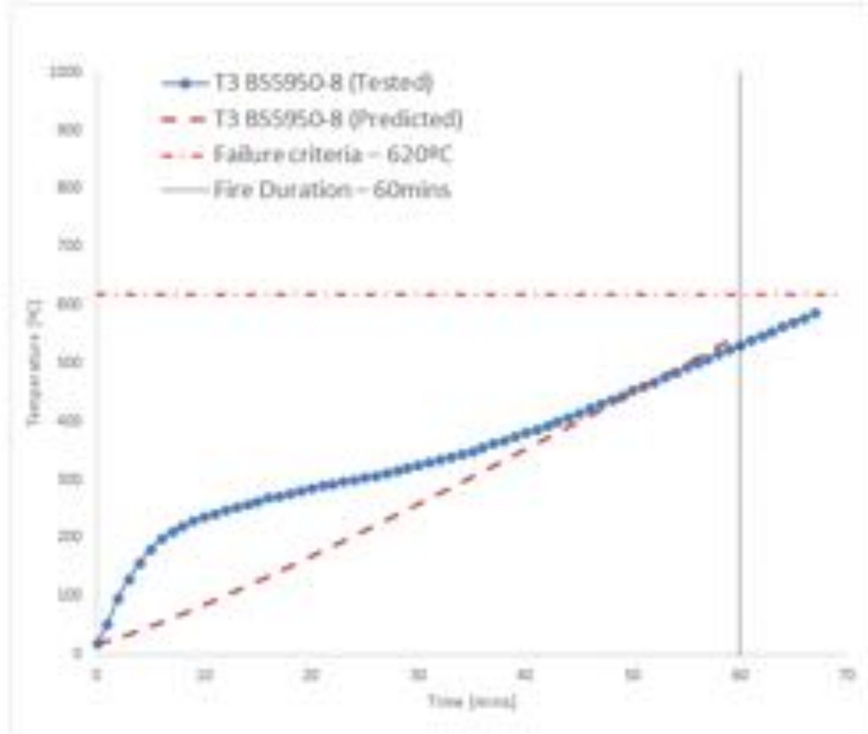


TEST 3 – 180 m-1

Proposed Guidance



BS5950-8



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Lab Results

The proposed guidance insulated the steel to the failure criteria of 620ºC for the given fire duration as predicted by RTC calculations

The guidance of BS5950-8 under insulated in tests T1 and T2 and over insulated T3 as predicted by RTC calculations

Temperatures predicted using relative thermal conductivities were only a maximum of 10% out from the observed results

Relative thermal conductivities can be used as a method to correlate the performance of intumescent coatings for a given set of conditions against existing certified data.

Conclusions

Conclusions

The guidance of BS5950-8 appears only safe (based on Eurocode design) for a small range of section factors

The proposed method shows that equivalent protection can be achieved using modified section factors at prescriptive temperatures

Thank you for your attention