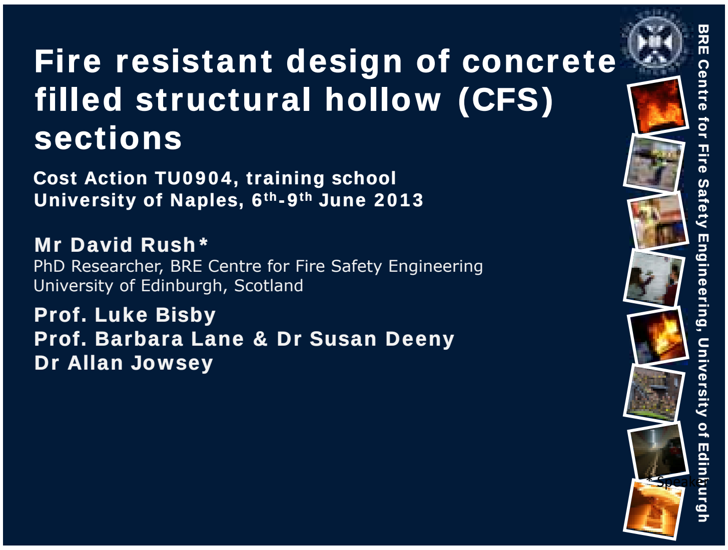

Fire resistant design of concrete filled structural hollow (CFS) sections

Cost Action TU0904, training school
University of Naples, 6th-9th June 2013

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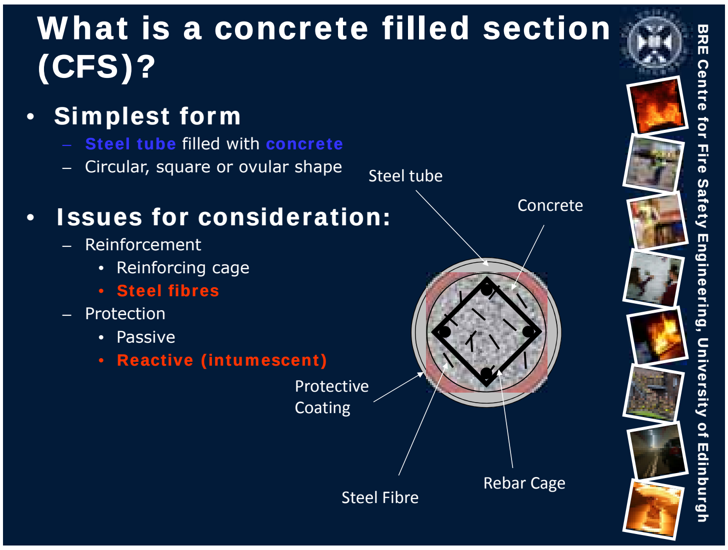
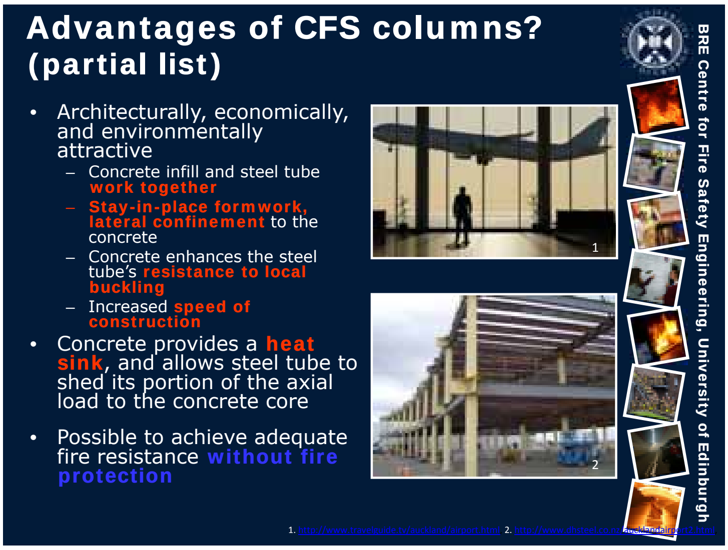


What is a concrete filled section (CFS)?

- **Simplest form**
  - Steel tube filled with concrete
  - Circular, square or ovular shape
- **Issues for consideration:**
  - Reinforcement
    - Reinforcing cage
    - Steel fibres
  - Protection
    - Passive
    - Reactive (intumescent)



Advantages of CFS columns? (partial list)

- Architecturally, economically, and environmentally attractive
  - Concrete infill and steel tube work together
  - Stay-in-place formwork, lateral confinement to the concrete
  - Concrete enhances the steel tube's resistance to local buckling
  - Increased speed of construction
- Concrete provides a heat sink, and allows steel tube to shed its portion of the axial load to the concrete core
- Possible to achieve adequate fire resistance without fire protection

1. http://www.travelguide.tv/auckland/airport.html, 2. http://www.dhsteel.co.nz/aucklandairport2.html,

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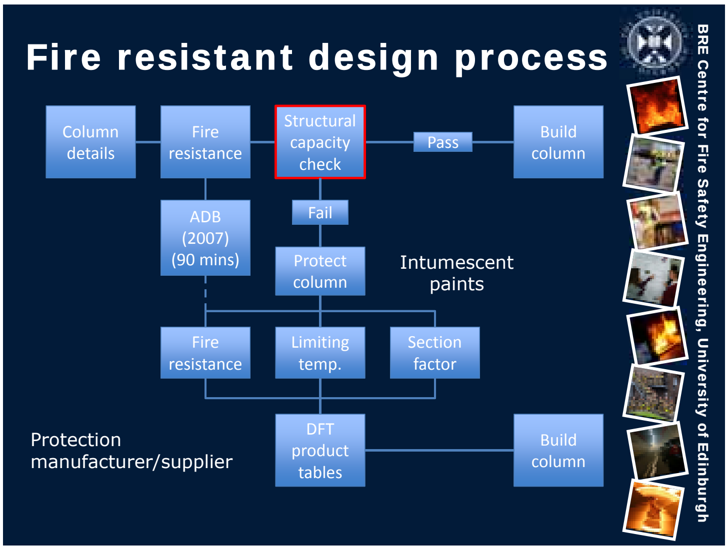
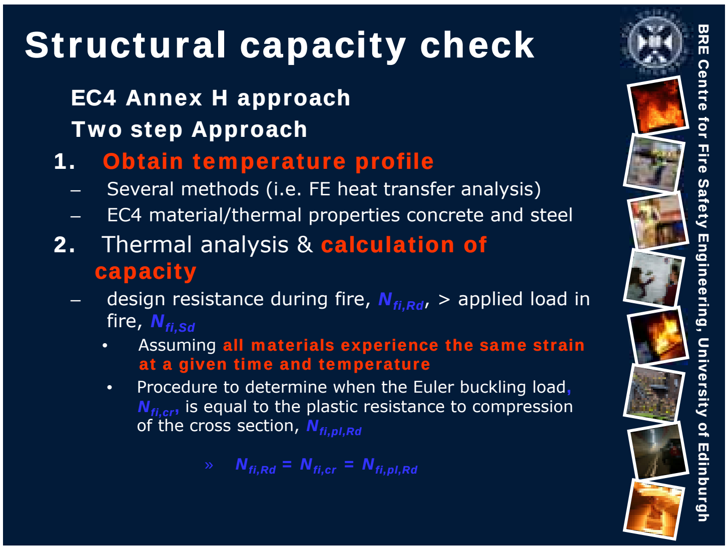


Fire resistant design process

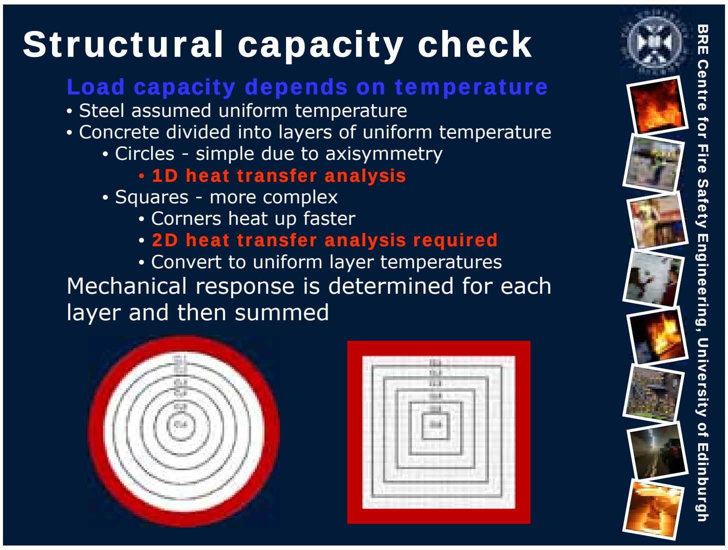


Structural capacity check

EC4 Annex H approach

Two step Approach

1. **Obtain temperature profile**
   - Several methods (i.e. FE heat transfer analysis)
   - EC4 material/thermal properties concrete and steel
2. Thermal analysis & **calculation of capacity**
   - design resistance during fire, $N_{fi,Rd}$, > applied load in fire, $N_{fi,Sd}$
     - Assuming **all materials experience the same strain at a given time and temperature**
     - Procedure to determine when the Euler buckling load, $N_{fi,cr}$, is equal to the plastic resistance to compression of the cross section, $N_{fi,pl,Rd}$
       - » $N_{fi,Rd} = N_{fi,cr} = N_{fi,pl,Rd}$

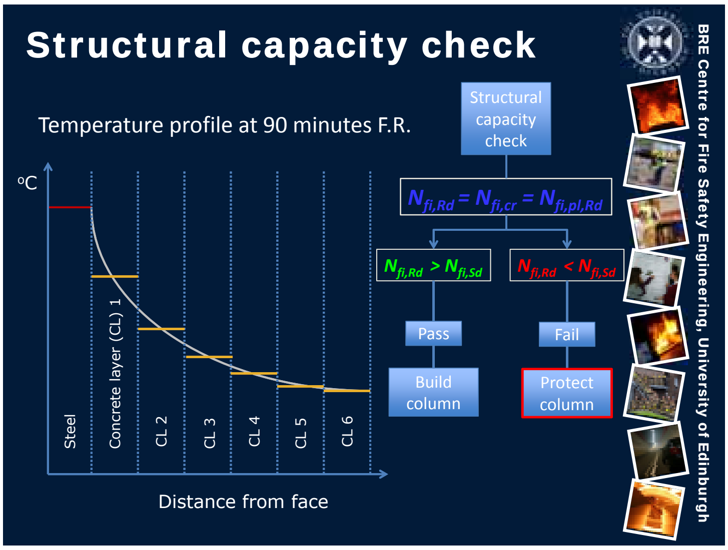


Structural capacity check

Load capacity depends on temperature

- Steel assumed uniform temperature
- Concrete divided into layers of uniform temperature
  - Circles - simple due to axisymmetry
    - **1D heat transfer analysis**
  - Squares - more complex
    - Corners heat up faster
    - **2D heat transfer analysis required**
    - Convert to uniform layer temperatures

Mechanical response is determined for each layer and then summed



Structural capacity check

Temperature profile at 90 minutes F.R.

Structural capacity check

$N_{fi,Rd} = N_{fi,cr} = N_{fi,pl,Rd}$

$N_{fi,Rd} > N_{fi,Sd}$

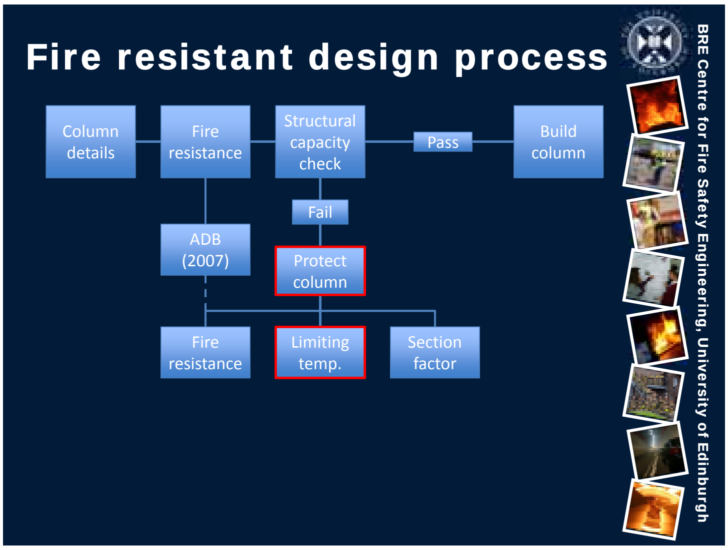
Pass

Build column

$N_{fi,Rd} < N_{fi,Sd}$

Fail

Protect column



Fire resistant design process

Column details

Fire resistance

Structural capacity check

Pass

Build column

Fail

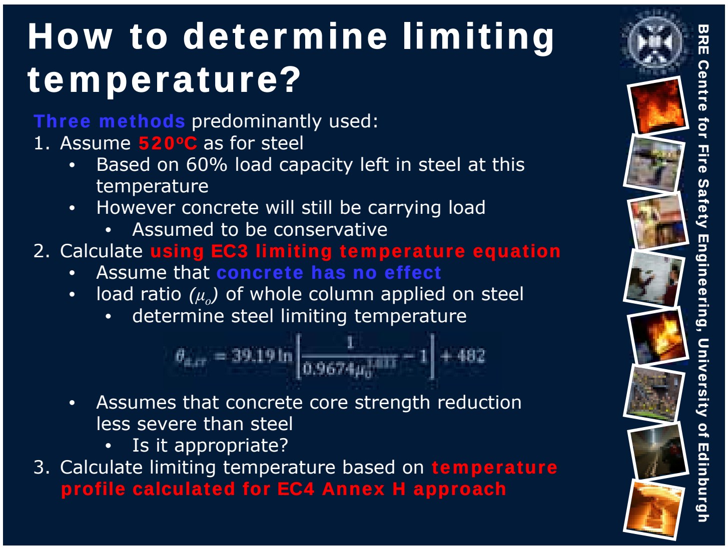
ADB (2007)

Protect column

Fire resistance

Limiting temp.

Section factor



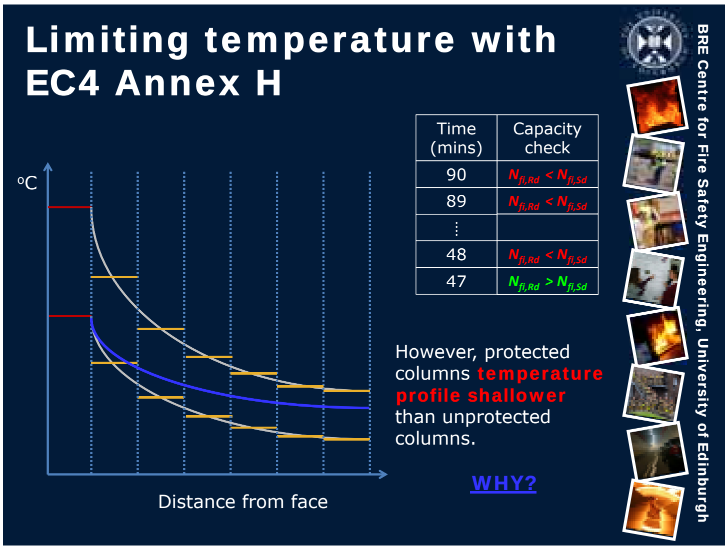
How to determine limiting temperature?

Three methods predominantly used:

1. Assume **520°C** as for steel
   - Based on 60% load capacity left in steel at this temperature
   - However concrete will still be carrying load
     - Assumed to be conservative
2. Calculate **using EC3 limiting temperature equation**
   - Assume that **concrete has no effect**
   - load ratio (μ_o) of whole column applied on steel
     - determine steel limiting temperature

$$\theta_{a,cr} = 39.19 \ln\left[\frac{1}{0.9674\mu_0^{3.833}} - 1\right] + 482$$

   - Assumes that concrete core strength reduction less severe than steel
     - Is it appropriate?
3. Calculate limiting temperature based on **temperature profile calculated for EC4 Annex H approach**

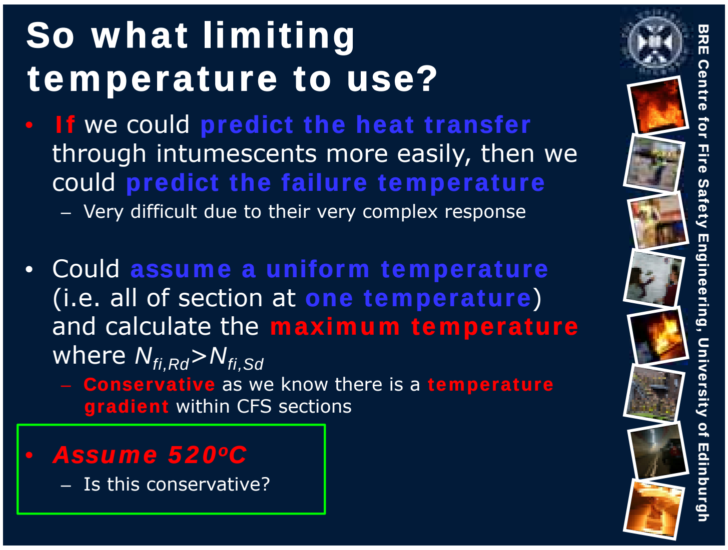


Limiting temperature with EC4 Annex H

Time (mins)	Capacity check
90	$N_{fi,Rd} < N_{fi,Sd}$
89	$N_{fi,Rd} < N_{fi,Sd}$
⋮	
48	$N_{fi,Rd} < N_{fi,Sd}$
47	$N_{fi,Rd} > N_{fi,Sd}$

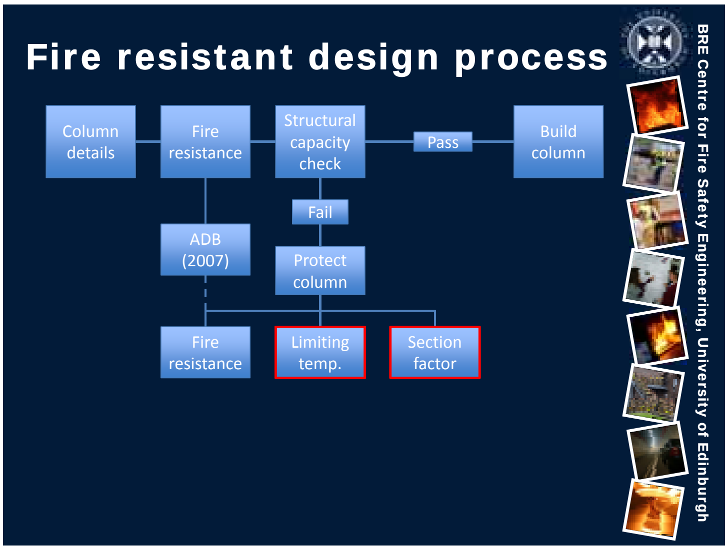
However, protected columns **temperature profile shallower** than unprotected columns.

WHY?



So what limiting temperature to use?

- **If** we could **predict the heat transfer** through intumescents more easily, then we could **predict the failure temperature**
  - Very difficult due to their very complex response
- Could **assume a uniform temperature** (i.e. all of section at **one temperature**) and calculate the **maximum temperature** where $N_{fi,Rd} > N_{fi,Sd}$
  - **Conservative** as we know there is a **temperature gradient** within CFS sections
- ***Assume 520°C***
  - Is this conservative?



Fire resistant design process

Column details

Fire resistance

Structural capacity check

Pass

Build column

Fail

ADB (2007)

Protect column

Fire resistance

Limiting temp.

Section factor

What is a section factor?

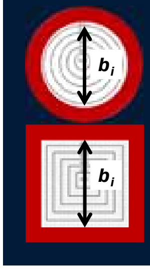
- Plain steel section
  - Surface area (A_m) / Volume (V) (m^{-1})
- Uniform cross section
  - Heated perimeter (H_p) / Cross-sectional area (A)
- Uniform hollow tube
  - 1 / thickness of the steel tube (t_a)
- What does it mean?
  - Used in **calculation of temperature increase in unprotected steel members**
  - assumes **uniform cross-section temperature**

$$\Delta\theta_{a,t} = \frac{\dot{h}_{net}}{c_a \cdot \rho_a} \cdot \frac{H_p}{A} \cdot \Delta t$$

HOWEVER, temperature profiles in concrete are not uniform

What is a section factor for CFS sections?

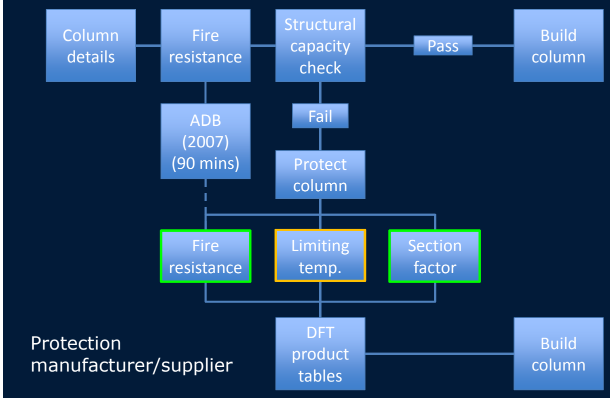
- Current guidance
  - Developed from tests conducted in 1990's
  - Observed that as fire exposure time increased the effective section factor decreased
    - Unlike steel where the section factor is constant
  - Assumed that CFS can be modelled as a steel tube where concrete gives an equivalent thickness of steel



$$\boxed{\frac{H_p}{A_{eff}} = \frac{1000}{t_{se}} = \frac{1000}{t_s + t_{ce}}}$$

$$t_{ce}(mm) = \begin{cases} 0.15 b_i, & b_i < 12\sqrt{t_{FR}} \\ 1.8\sqrt{t_{FR}}, & b_i \geq 12\sqrt{t_{FR}} \end{cases} \rightarrow \text{Fire resistance}$$

Fire resistant design process



Is it right? Is it safe?

- Conducted 18 thermal tests on protected CFS sections
  - F.R. = 90 mins
  - Limiting temperature 520ºC
  - Section Factor – based on available guidance
    - H_p/A_{eff}
- Results
  - Temperatures of steel at 90 minutes
    - 260ºC (average)
  - Temperatures of steelat 120 minutes
    - 320ºC (average)

WHY?

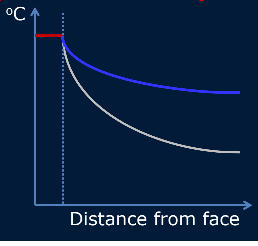
- Safe = yes, Right = no

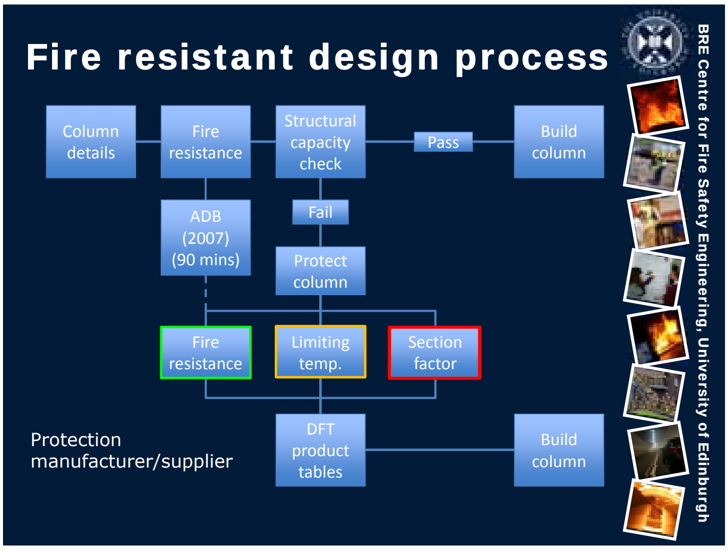
Source of the conservatism?

- Was it the **design tables**?
  - **No**
  - Highly optimised to be competitive
- Was there a **fundamental change in coating reaction** due to concrete fill?
  - i.e. does increasing the substrate mass with the adding of the concrete mean that the coatings perform better?
  - **No**
  - Variable thermal conductivity of coatings are same on **filled** and **unfilled** hollow tubes
- Was it the **calculation of the section factor**?
  - **YES!!!**

What's wrong with the section factor?

- Guidance was developed on unprotected columns
- 14 **unprotected** tests conducted
  - same process used for developing guidance followed
  - **Similar results found**
  - Guidance to calculate the section factor for an **unprotected** CFS column is correct
- But **wrong to use it to prescribe coatings**
  - Why?
  - **Thermal gradient** within protected column are **shallower**
  - Concrete more effective at **"acting" like steel**
  - H_p/A_{eff} should be lower!





Fire resistant design process

Column details

Fire resistance

Structural capacity check

Pass

Build column

ADB (2007) (90 mins)

Fail

Protect column

Fire resistance

Limiting temp.

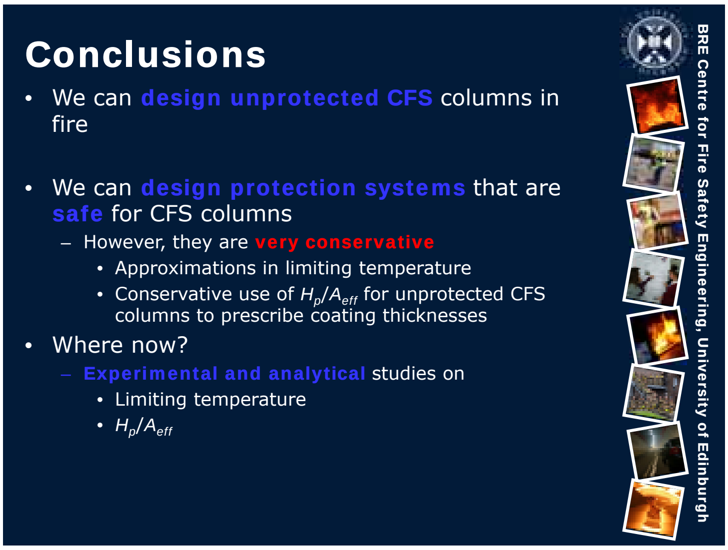
Section factor

Protection manufacturer/supplier

DFT product tables

Build column

BRE Centre for Fire Safety Engineering, University of Edinburgh



Conclusions

- We can **design unprotected CFS** columns in fire
- We can **design protection systems** that are **safe** for CFS columns
  - However, they are **very conservative**
    - Approximations in limiting temperature
    - Conservative use of H_p/A_{eff} for unprotected CFS columns to prescribe coating thicknesses
- Where now?
  - **Experimental and analytical** studies on
    - Limiting temperature
    - H_p/A_{eff}

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