

# Developments and Future Direction of Structural Fire Engineering



Colin Bailey



‘Structural Fire Engineering is the science and art of designing and constructing with economy and elegance, buildings, frameworks and other similar structures to protect people, property and the environment from the destructive effects of fire’



# Fire Safety in Building

Occupants, Fire-Fighters,  
Public in the proximity of  
the building

Aims:

*To limit, to acceptable levels, the probability of death and injury to people, property loss, and damage to the environment.*

Loss of business

Limit emissions of gaseous pollutants

## Minimum levels of safety covered by legislation

Given in the Building Regulations and seeks to ensure reasonable levels of health and safety for people in and around buildings

The Regulations relating to fire cover:

- Means of escape
- Internal fire spread (linings and structure)
- External fire spread
- Access and facilities for the fire service.

***Covers life safety only !!!!***

**Fire Safety in Buildings**

**Prescriptive Approach:**

*States how a building is to be constructed*

*Used with care to solve a particular problem*

**Performance Approach:**

*States how a building is to perform under stated criteria*

# Prescriptive Approach – *Set of rules*

For Example :

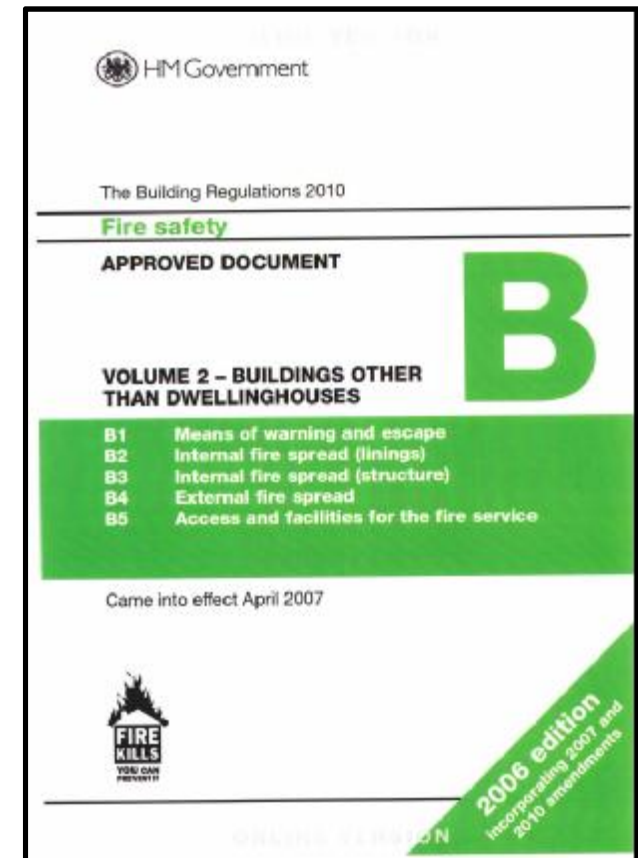
Minimum fire resistance for members

Maximum fire compartment size

Maximum travel distances

Minimum number of exits

Etc..

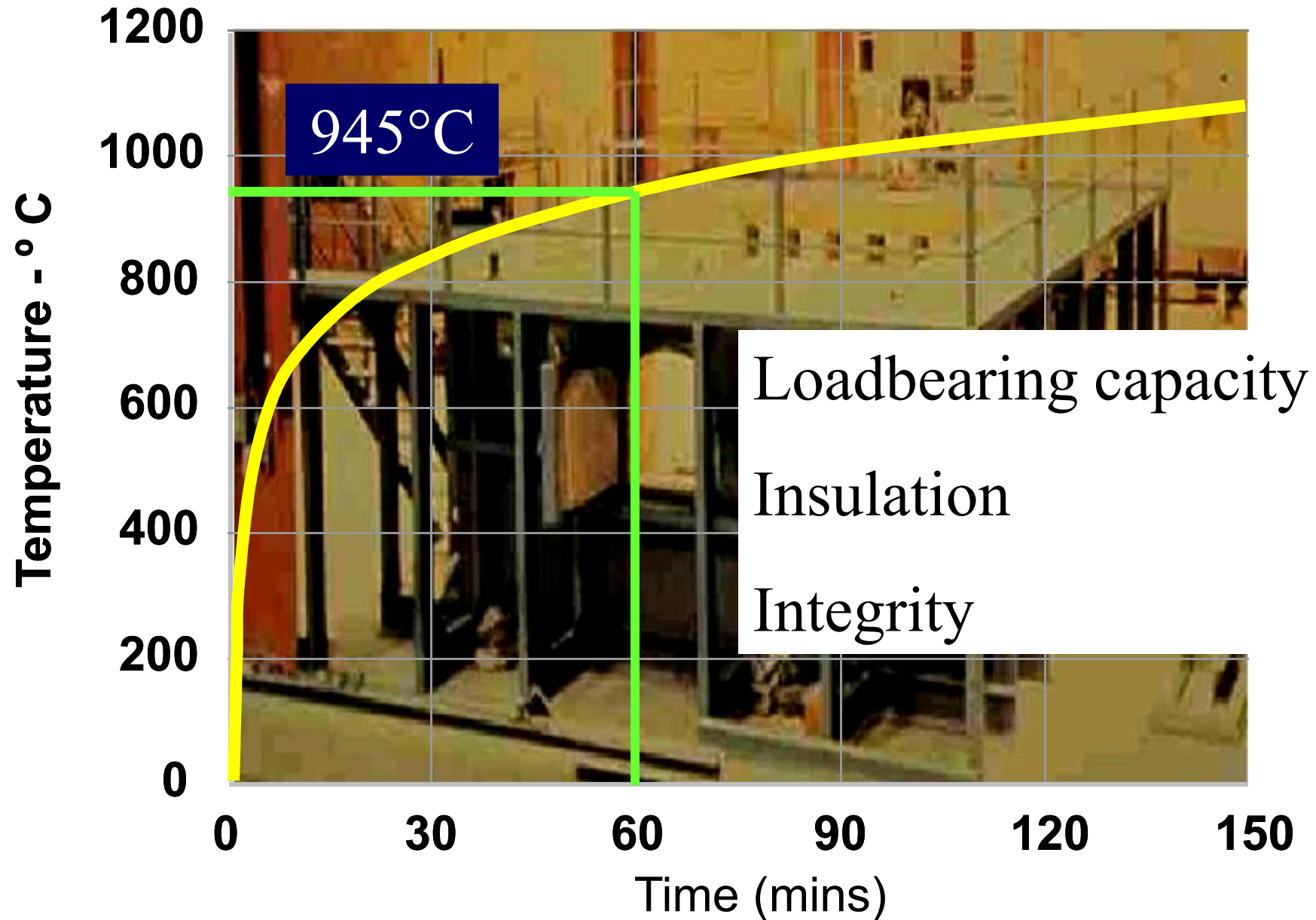


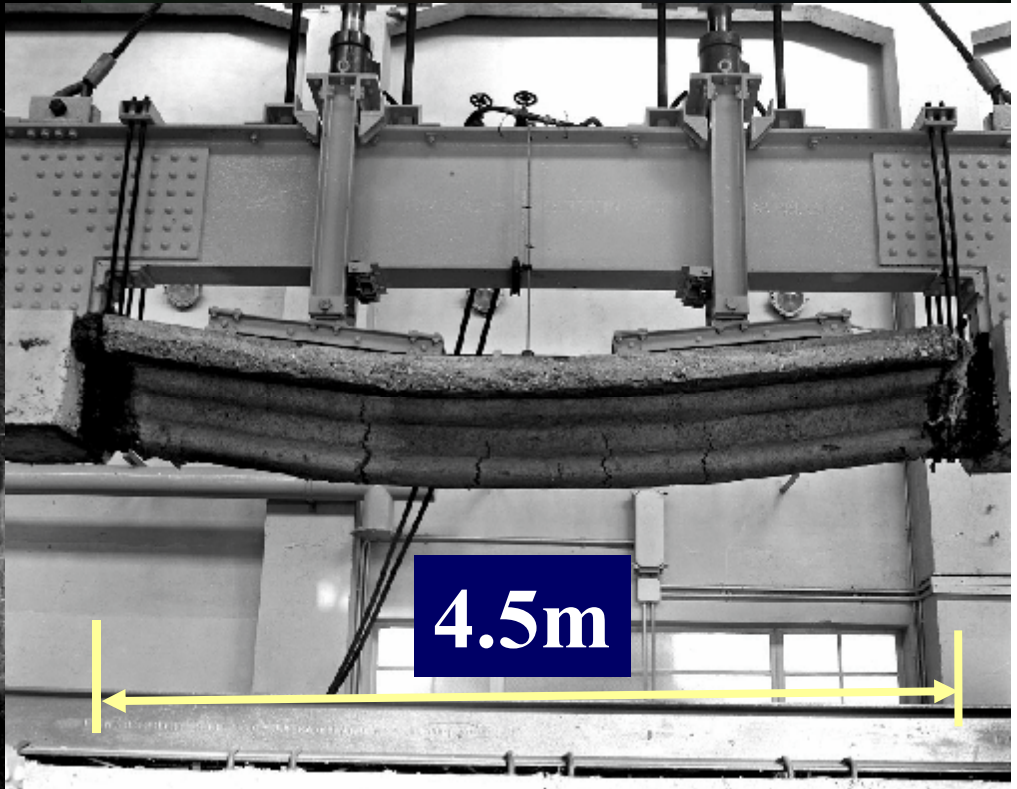
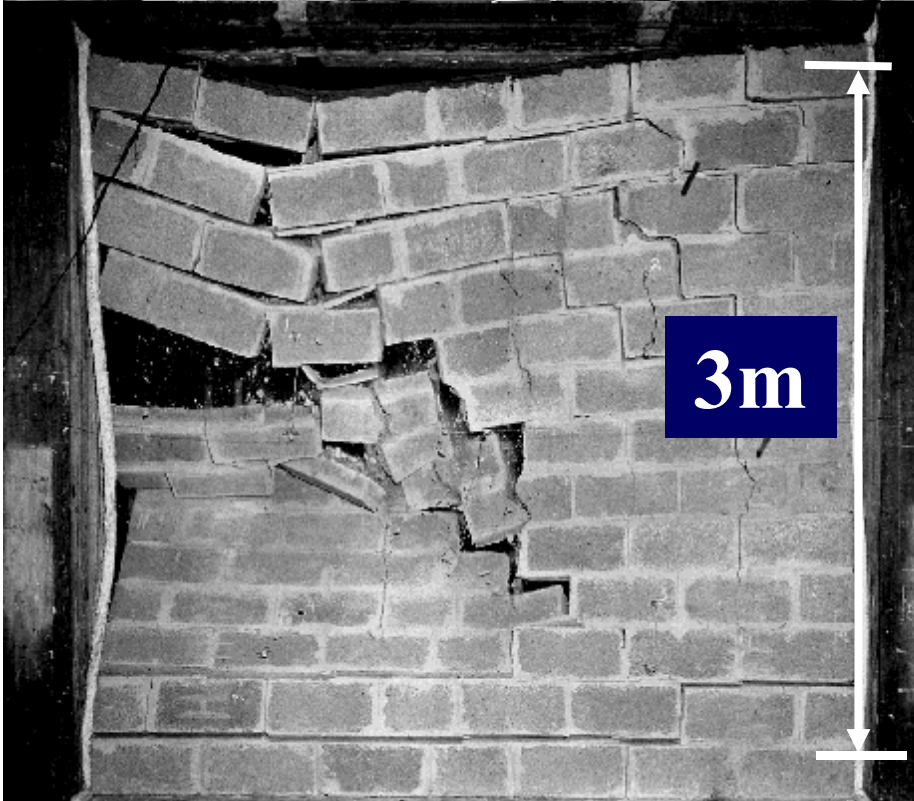
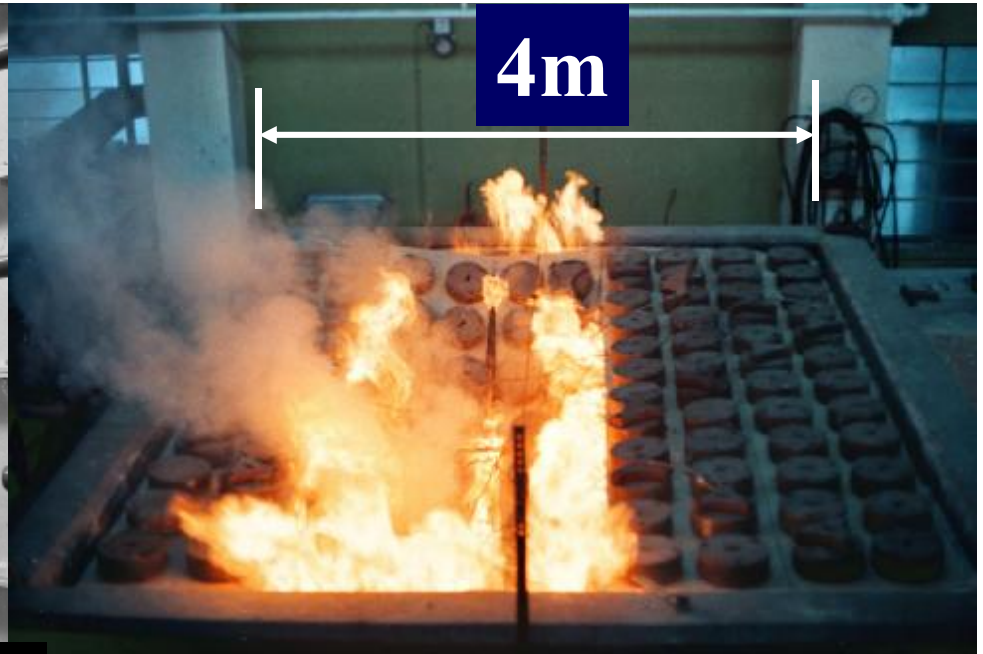
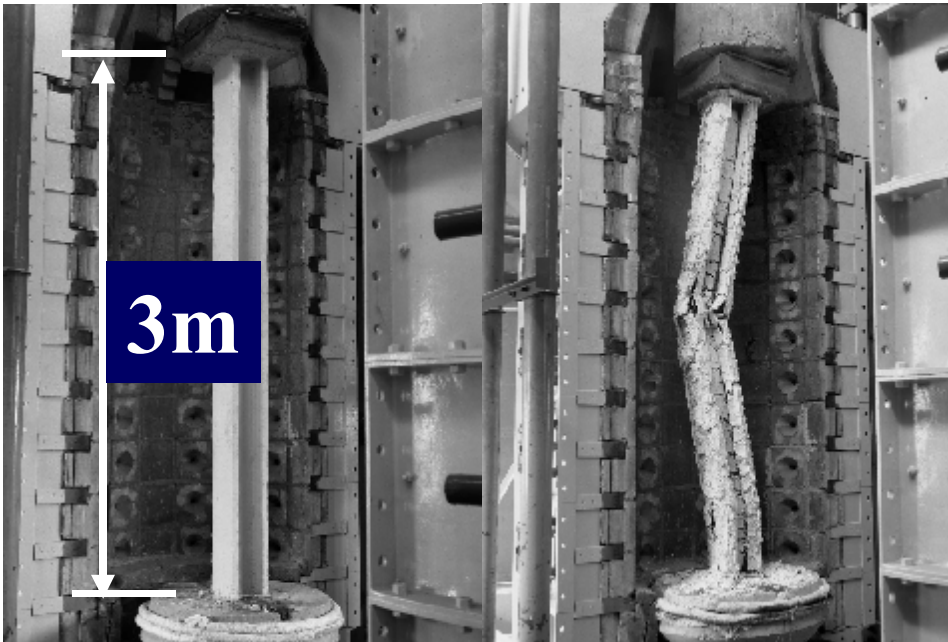
## Example of fire resistance periods (Approved Document B Vol. 2 )

	Height of Building (m)			
	<5	<18	<30	>30
<b>Residential (Non Domestic)</b>	30	60	90	120
<b>Offices</b>	30	60	90	<b>+ Sprinklers</b>
<b>Shops, Commercial, Assembly</b>	60	60	90	
<b>Industrial &amp; Storage</b>	60	90	120	
<b>Car Parks - Open</b>	15	15	15	15

60 minutes fire resistance means that the elements in the building will survive 60 minutes in a standard fire test

# Standard Fire Resistance





# History of the Standard Fire Test



- 1890's where early attempts at establishing structural fire behaviour were made at the behest of insurance companies
- 1917 First US Standard produced.
- 1932 First Edition of BS476 (UK)
- 1933 E119 (US) produced.
- 1985 ISO 834
- BSEN 1363-1

124 years of testing ! & still going

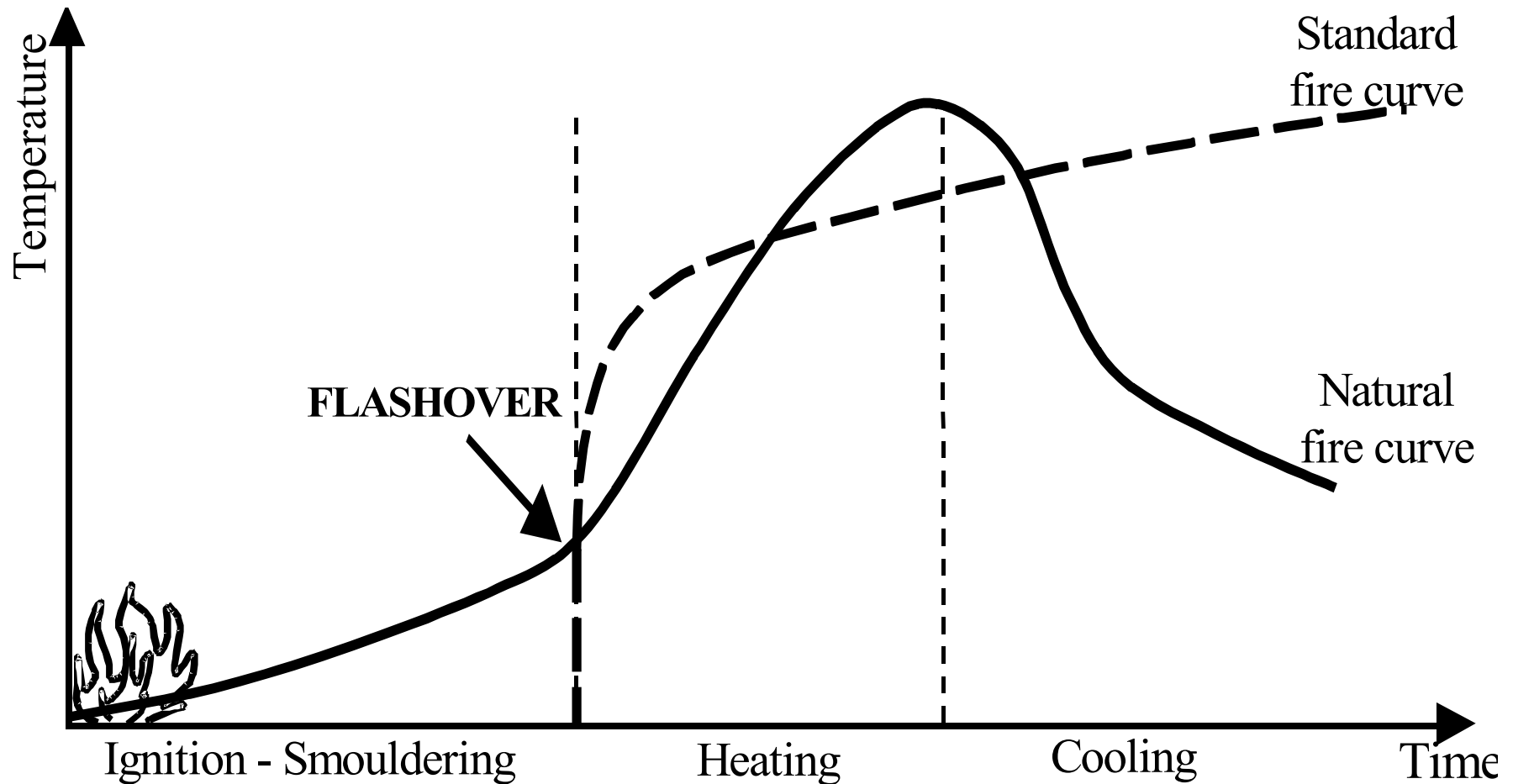


Minimum fire resistance for members  
(Deemed to satisfy rules)

# Quality of test v Quality on site



# Limitations of the prescriptive approach

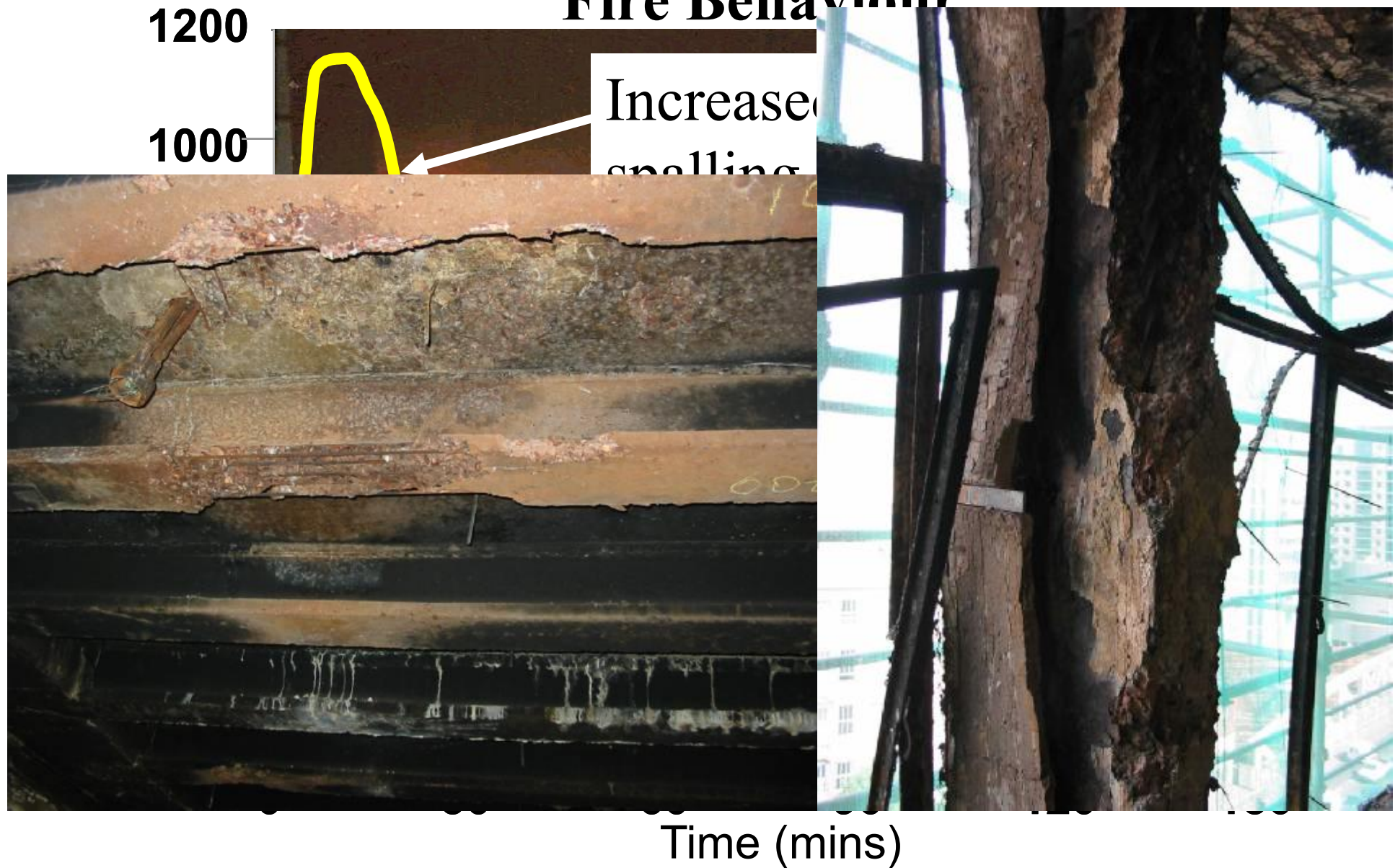


Life safety

Structural damage – risk of collapse – structural fire engineering only concerned with this phase of the fire

# Limitations of the prescriptive approach

## Fire Behaviour



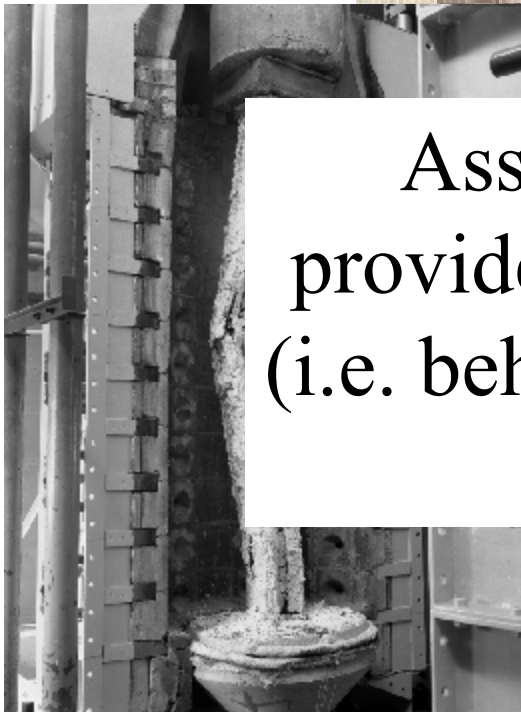
Real buildings;  
spans up to  
15m



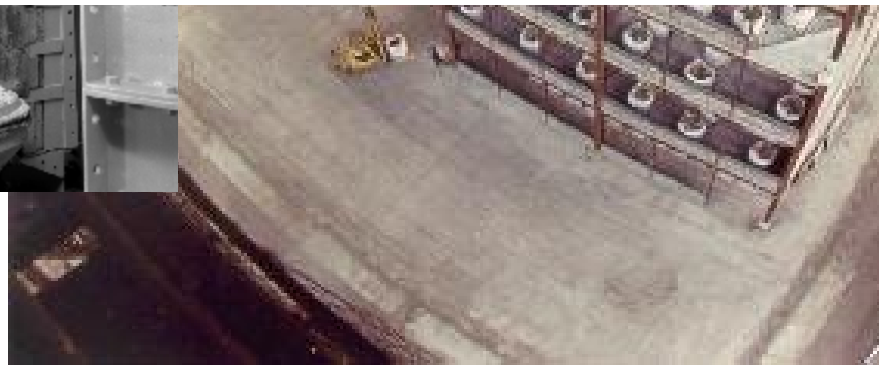
Standard fire tests;  
span = 4.5m

# Limitations of the prescriptive approach

Members within buildings ?

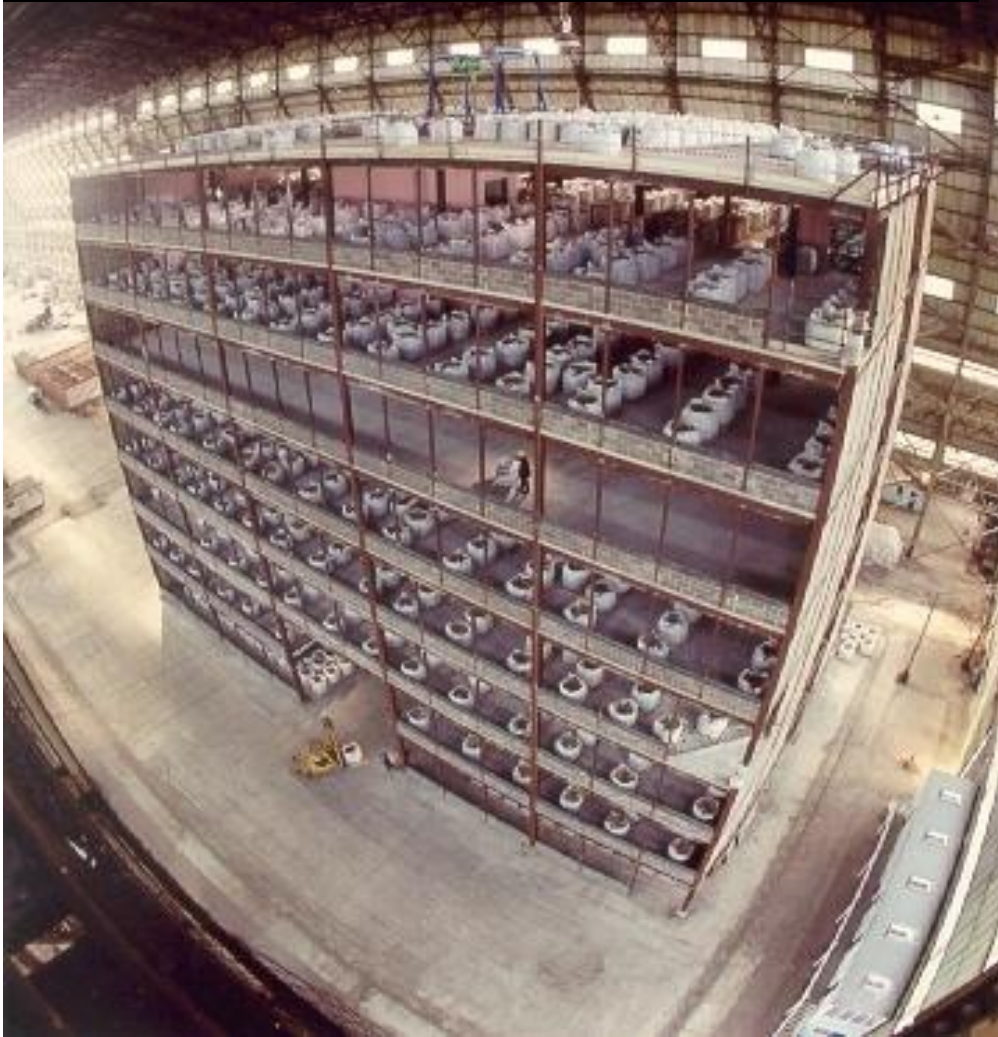


Assumption: The members will provide the same level of performance (i.e. behave in a similar way) when they form part of a building.



- 8 Storey steel-framed building.
- 7 compartment fire tests of varying size.
- All steel beams left unprotected.
- Max. steel temp 1150°C.

- 7 storey concrete-framed building.
- 1 compartment fire test.
- Max atmospheric temp 950°C



Cardington Fire Tests :  
Steel-framed building  
Max. steel temperature  
1150°C



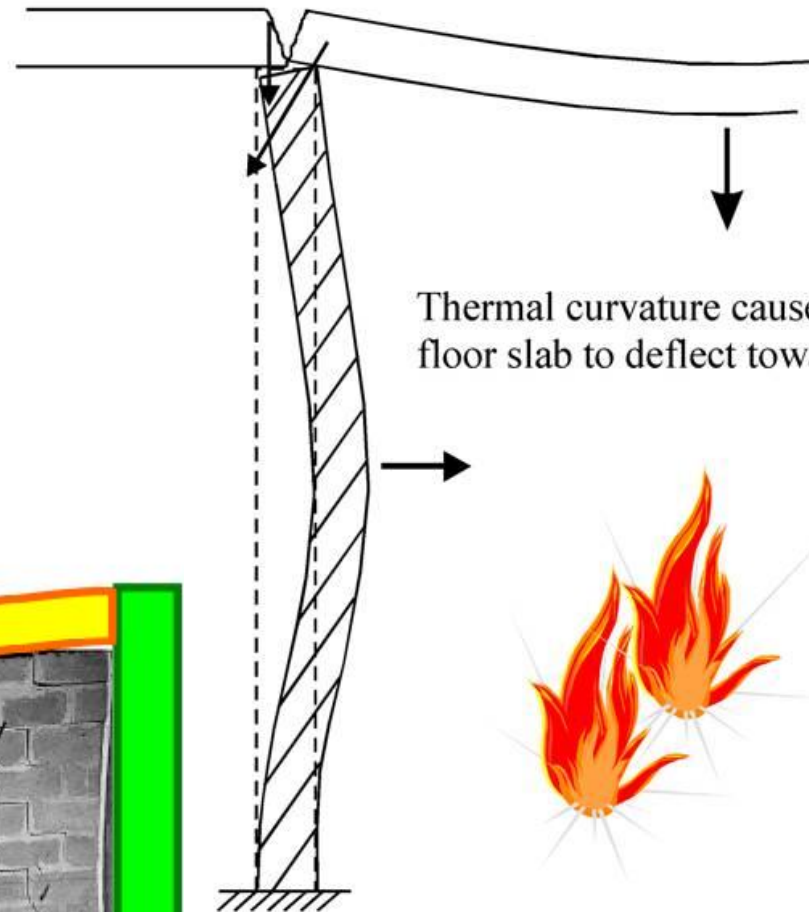
Maximum Atmosphere temperature = 950°C



# Detrimental Behaviour



Rotation of floor slab causes detrimental load on supporting wall which is not considered in the standard fire test

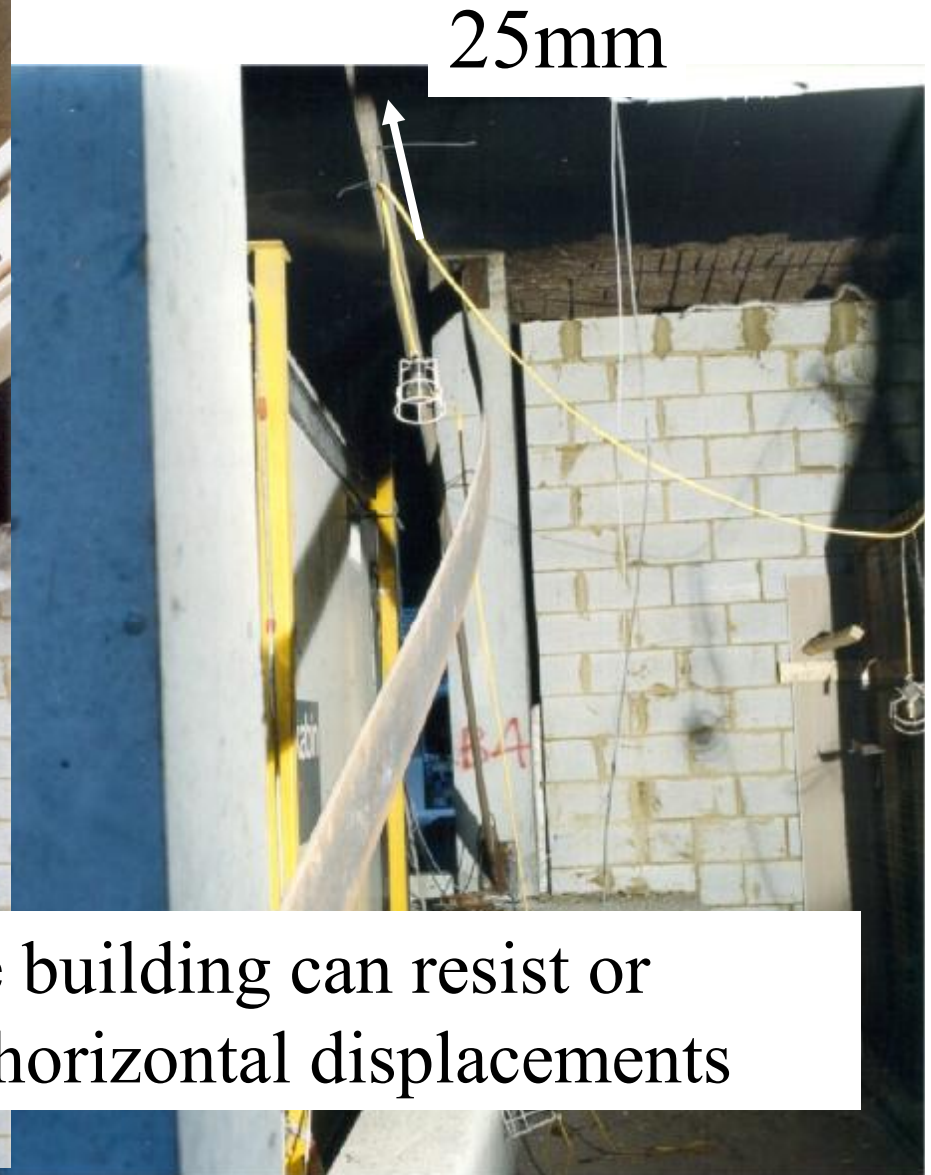
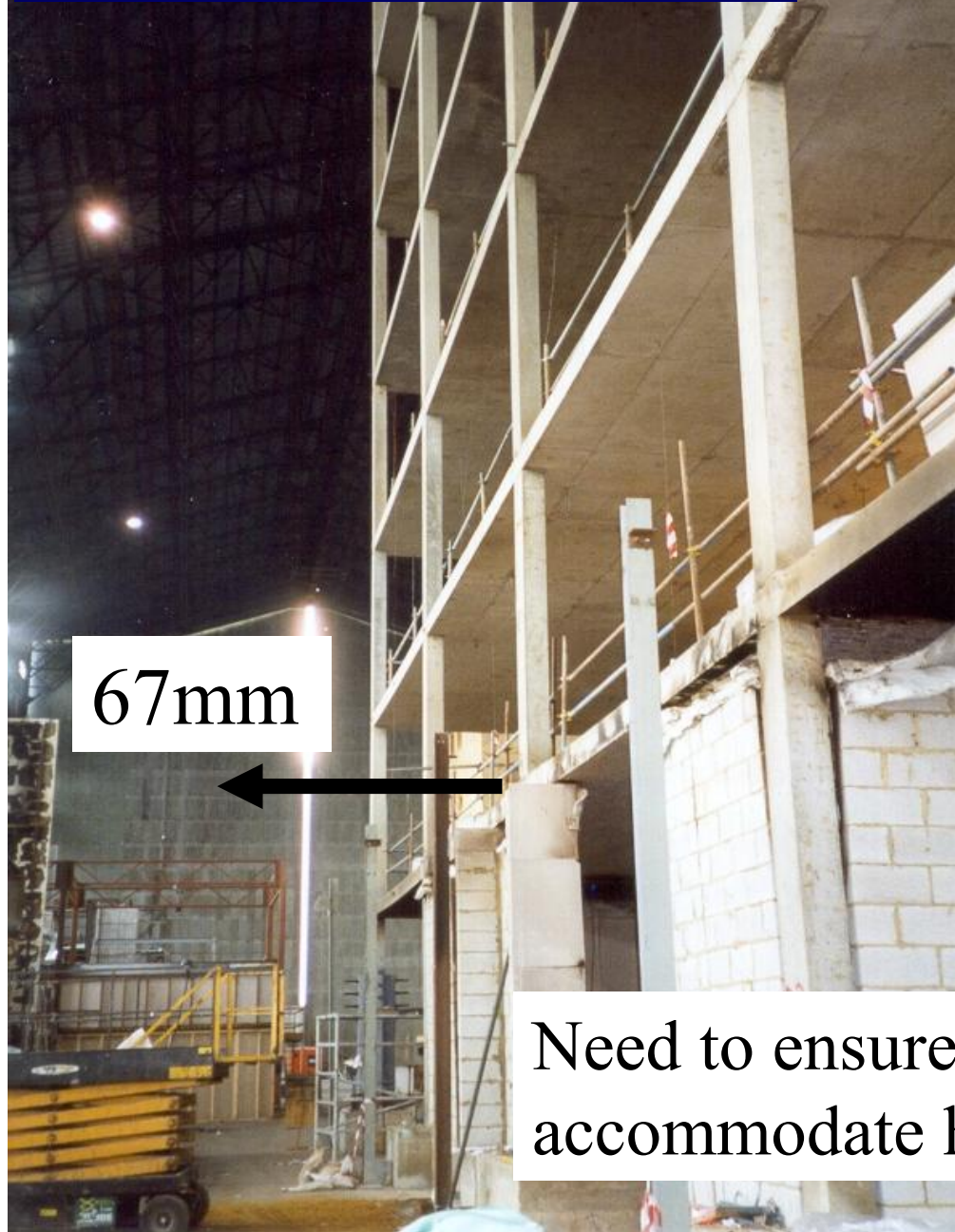


Thermal curvature causes wall and floor slab to deflect towards the fire





# Detrimental Behaviour



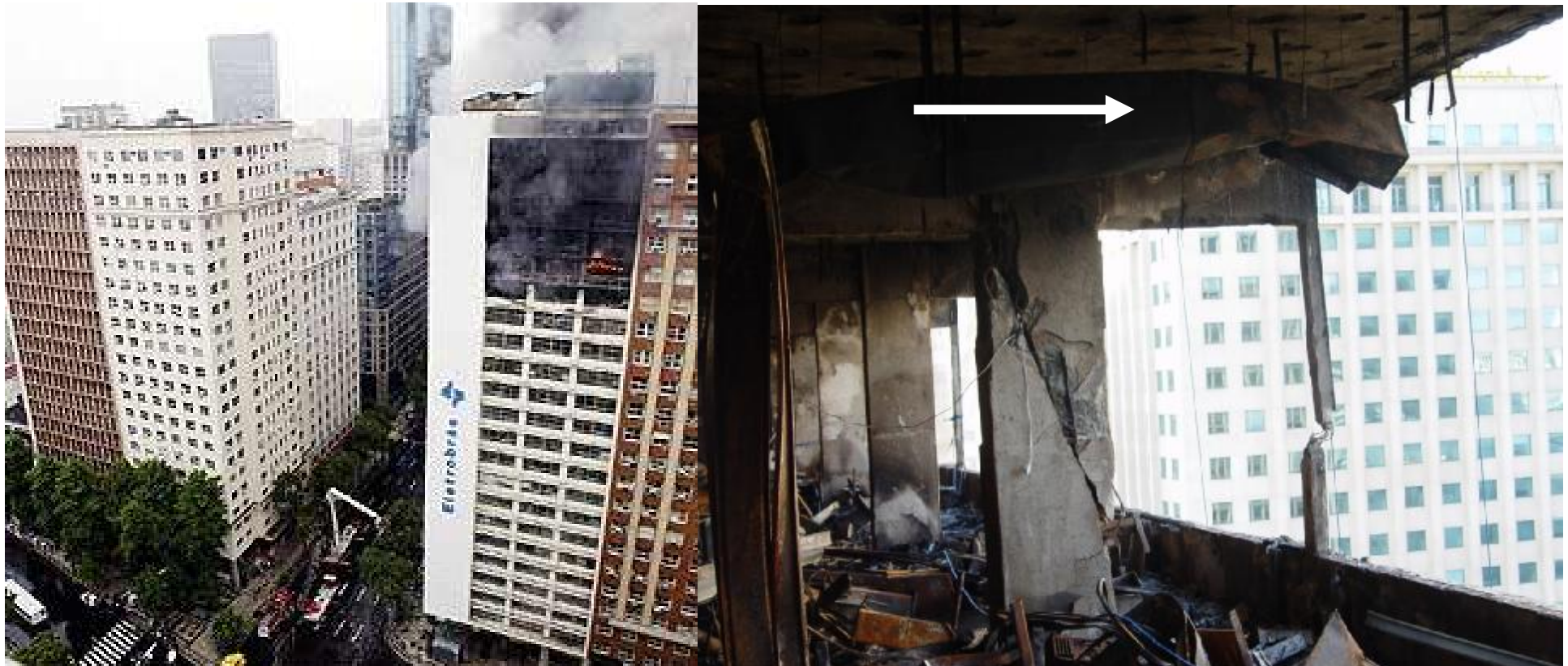
Need to ensure building can resist or accommodate horizontal displacements

Fire in a concrete building with 22 stories

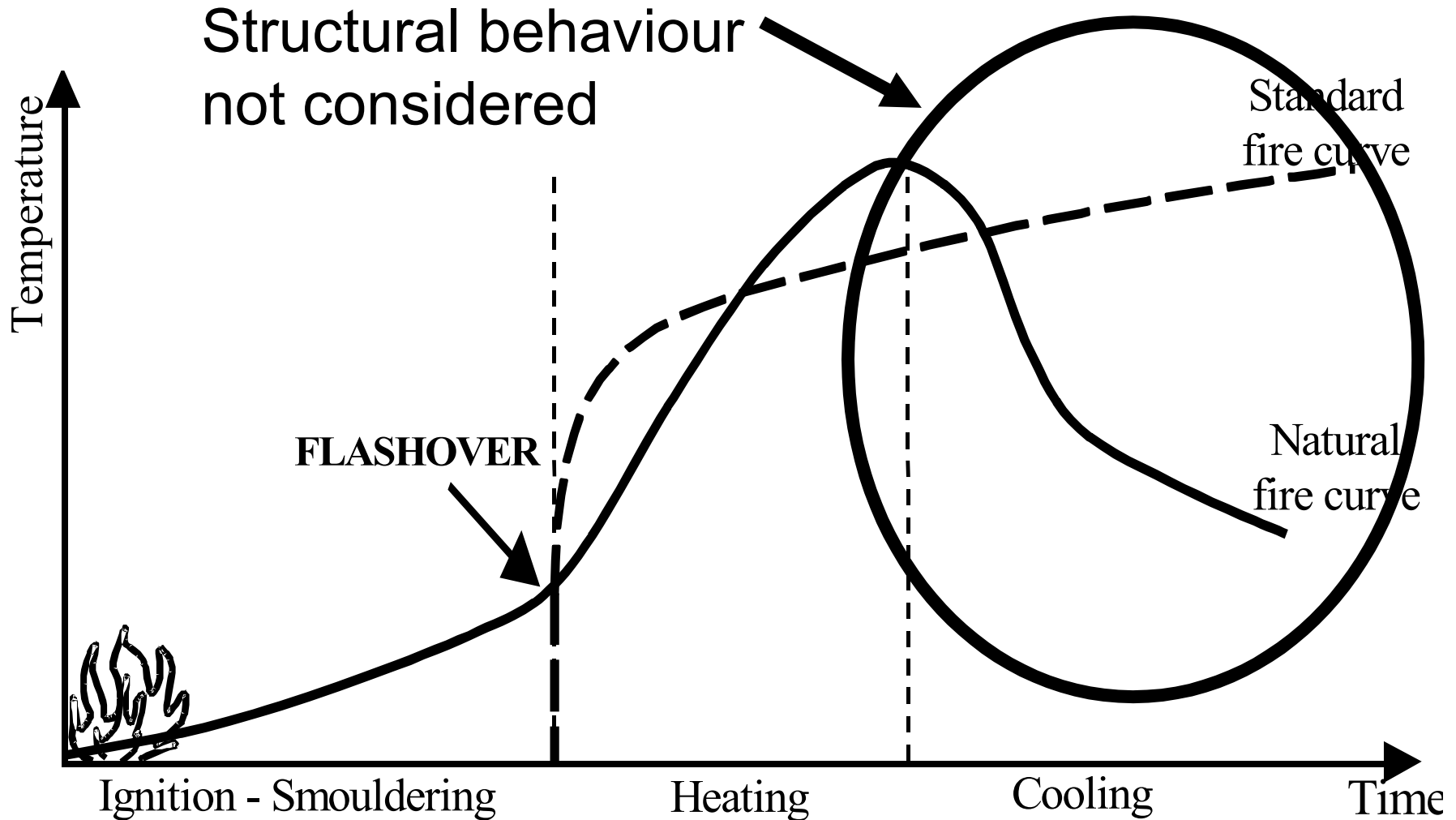
Date: 26-Feb-2004

Helm Stoltz Building– Rio de Janeiro (downtown) – Brazil

Year of construction: 1960



# Limitations of the prescriptive approach



Structural behaviour  
not considered

Standard  
fire curve

Natural  
fire curve

**FLASHOVER**

Ignition - Smouldering

Heating

Cooling

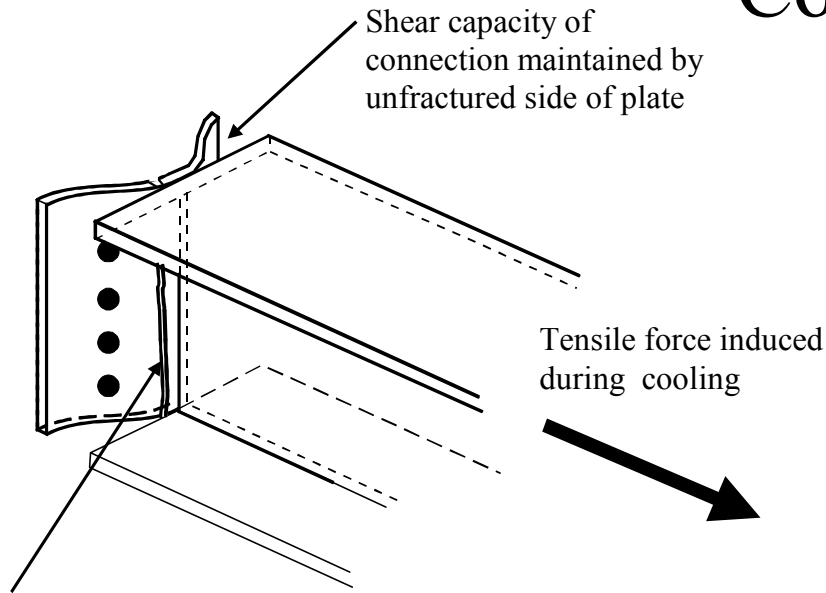
Time

Life safety

Structural damage – risk of collapse – structural fire  
engineering only concerned with this phase of the fire

# Limitations of the prescriptive approach

## Cooling



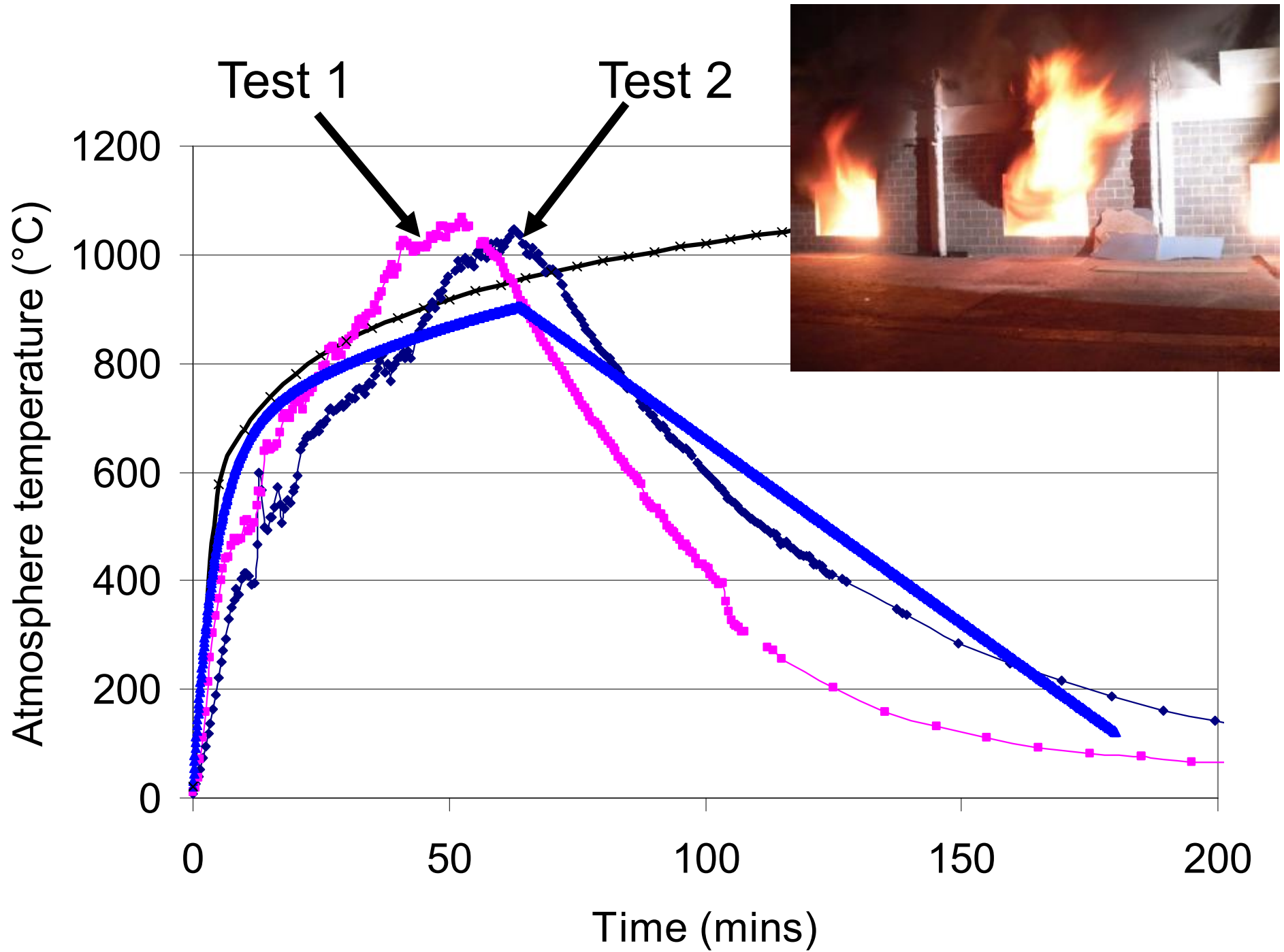
Typical fracture in end-plate occurring during cooling



# Full-scale testing on hollowcore slabs

Limitations of the prescriptive approach



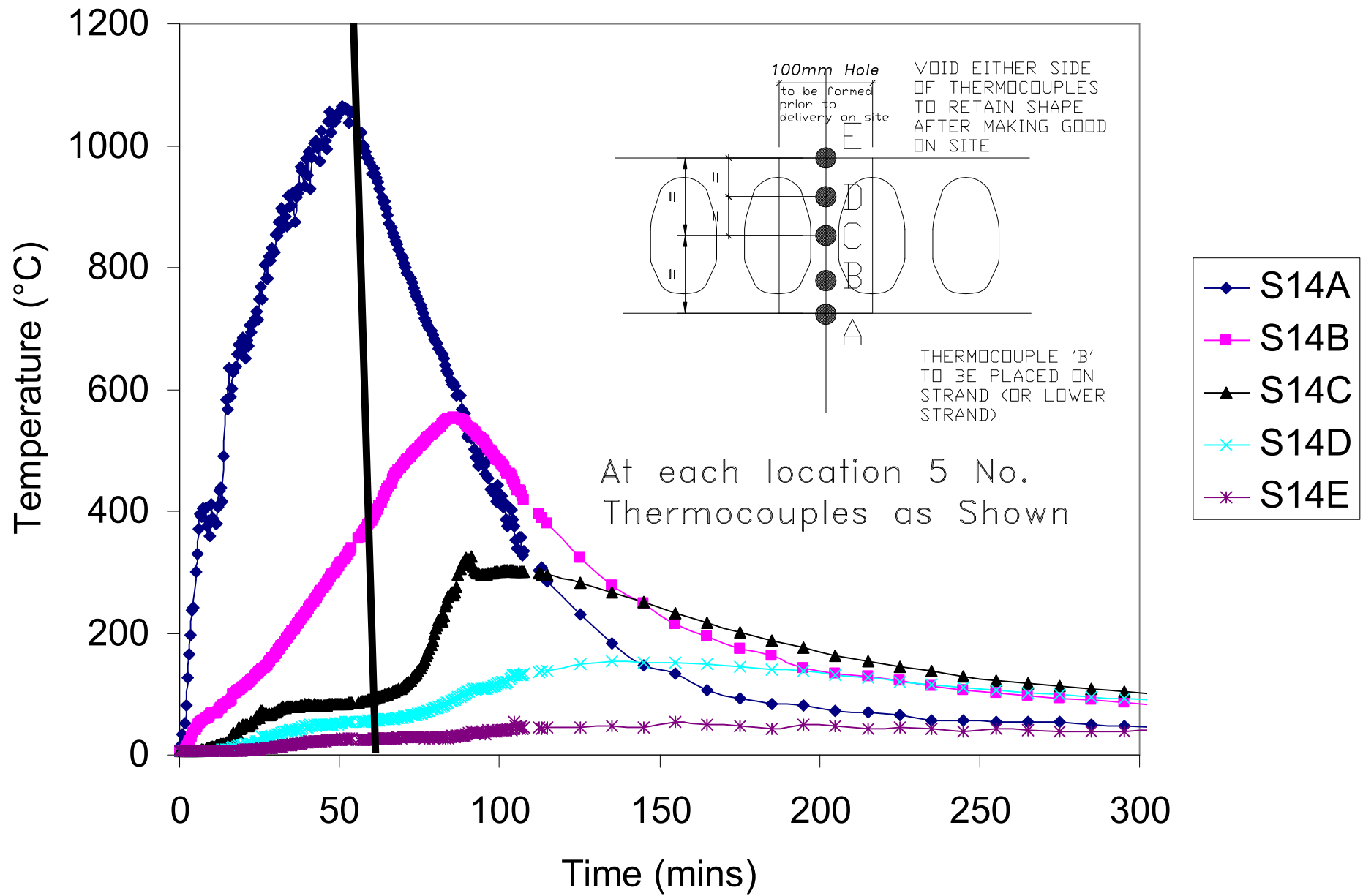


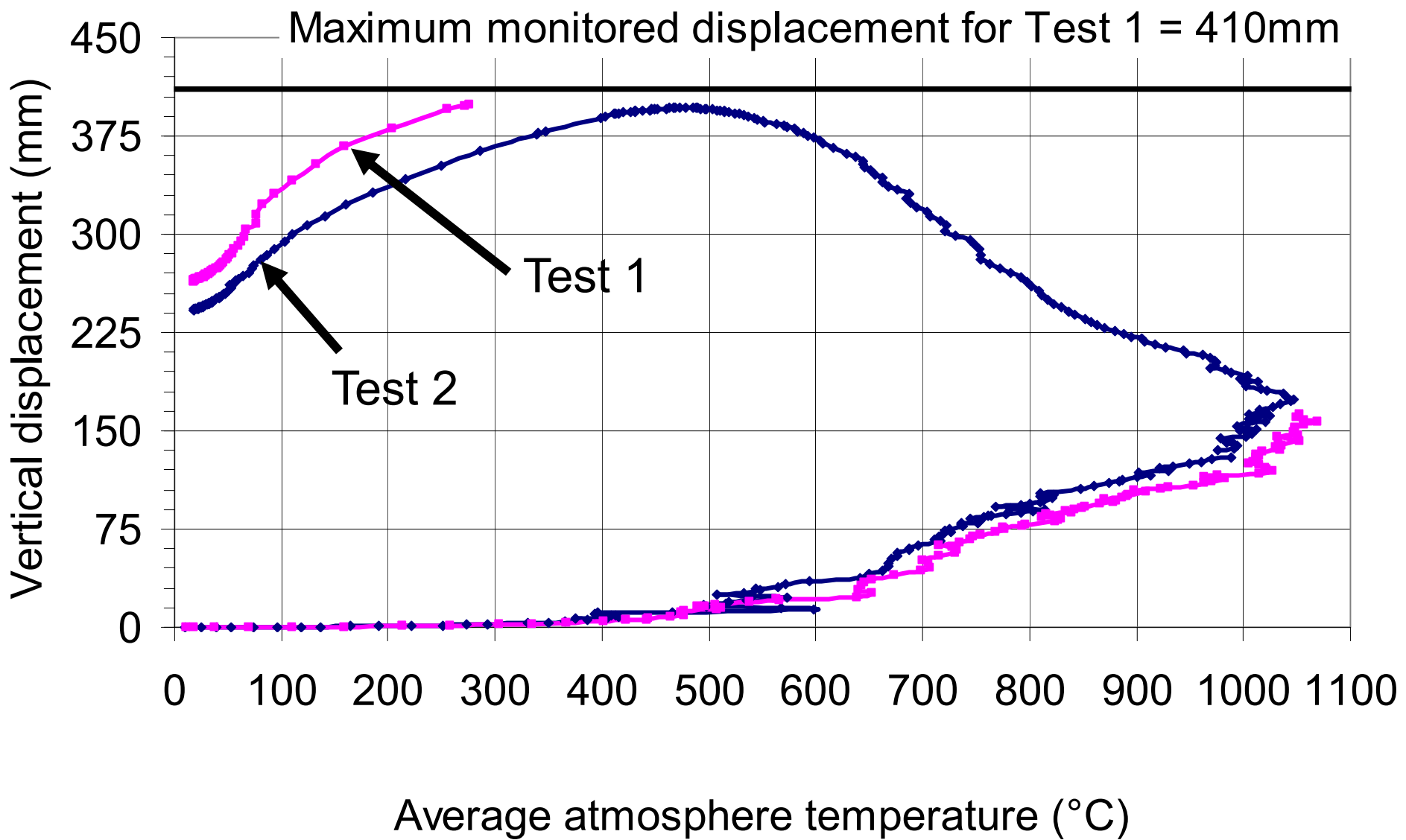




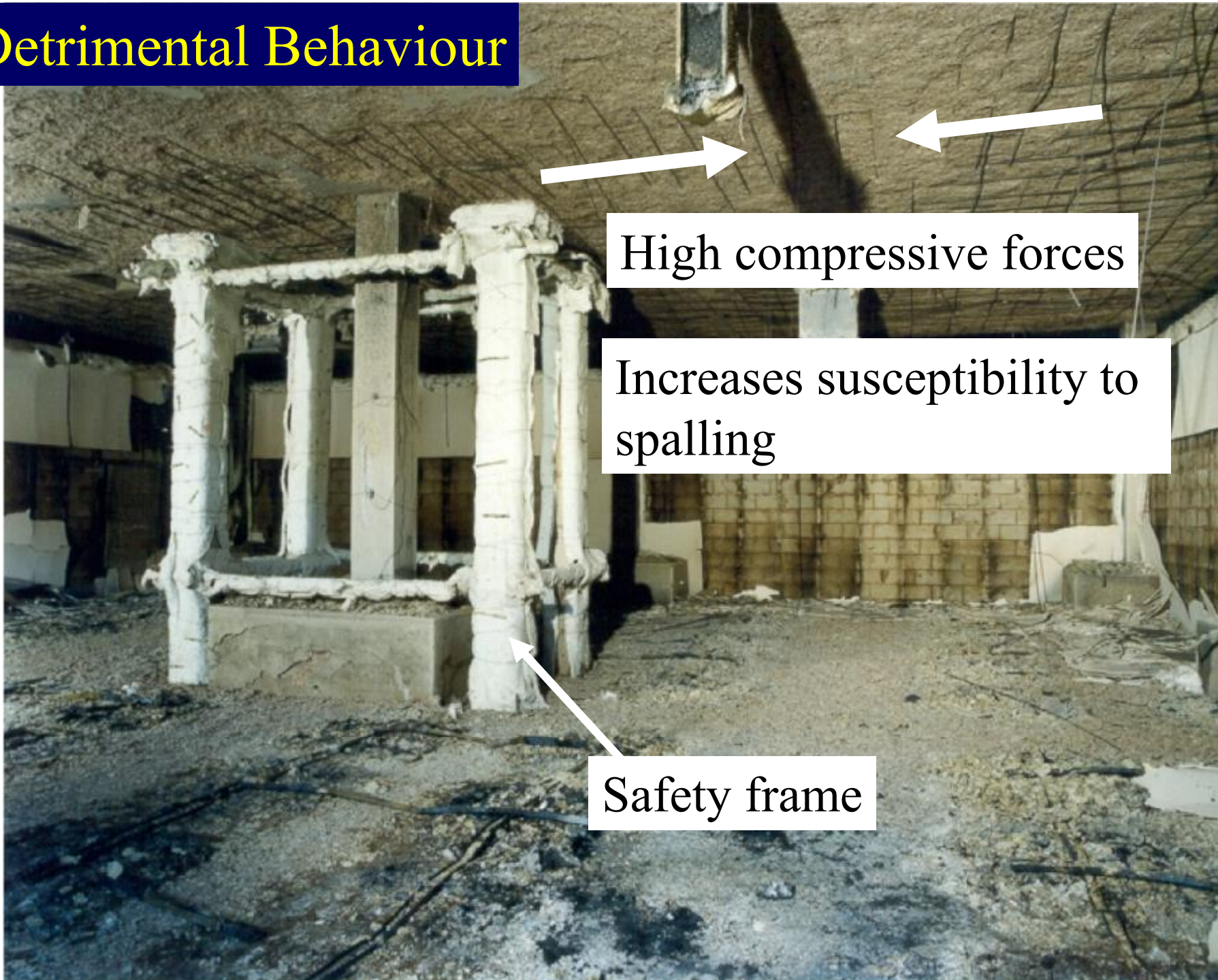


Fire protection fell off at 60 mins !





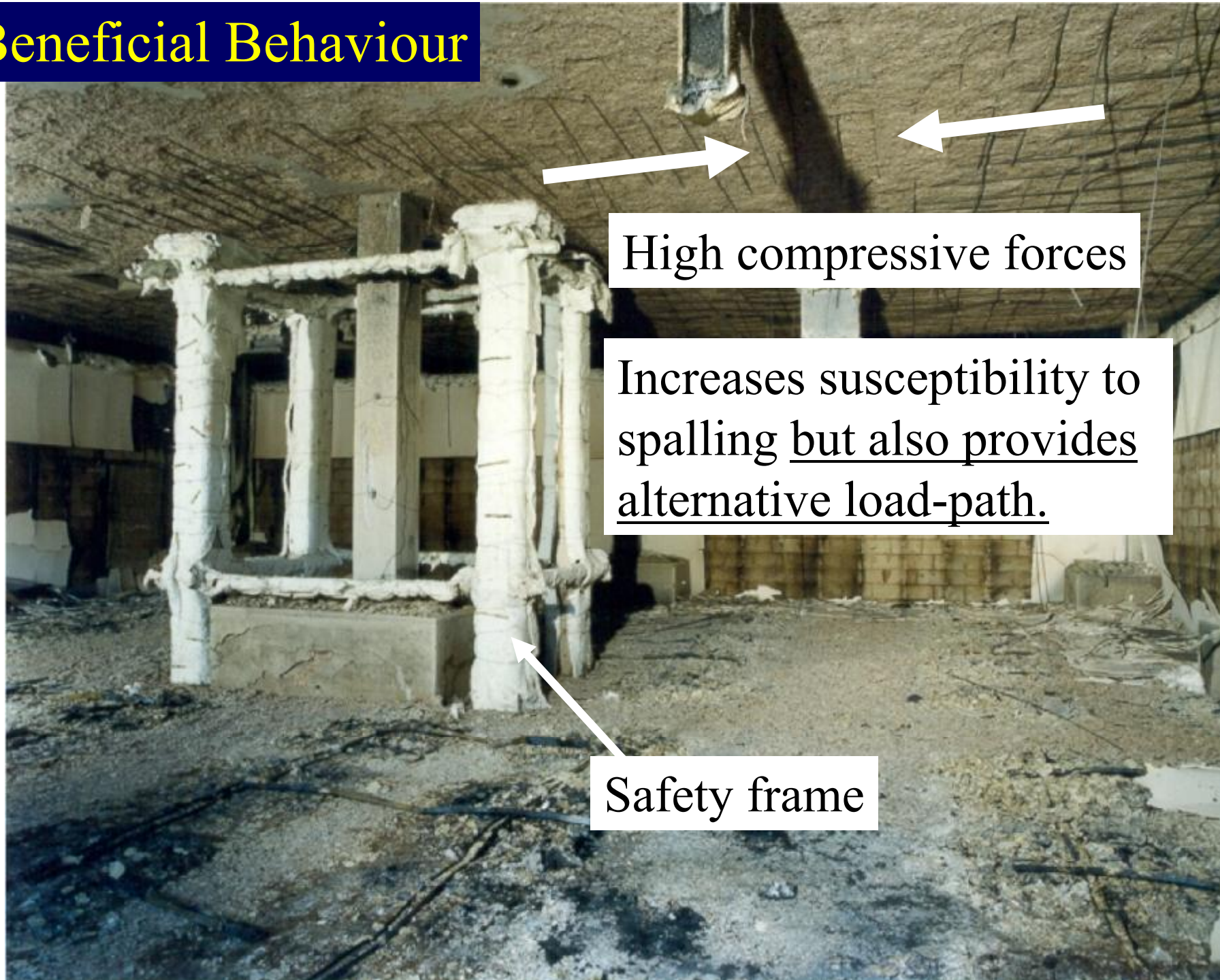
# Detrimental Behaviour



# Beneficial Behaviour



# Beneficial Behaviour



High compressive forces

Increases susceptibility to spalling but also provides alternative load-path.

Safety frame



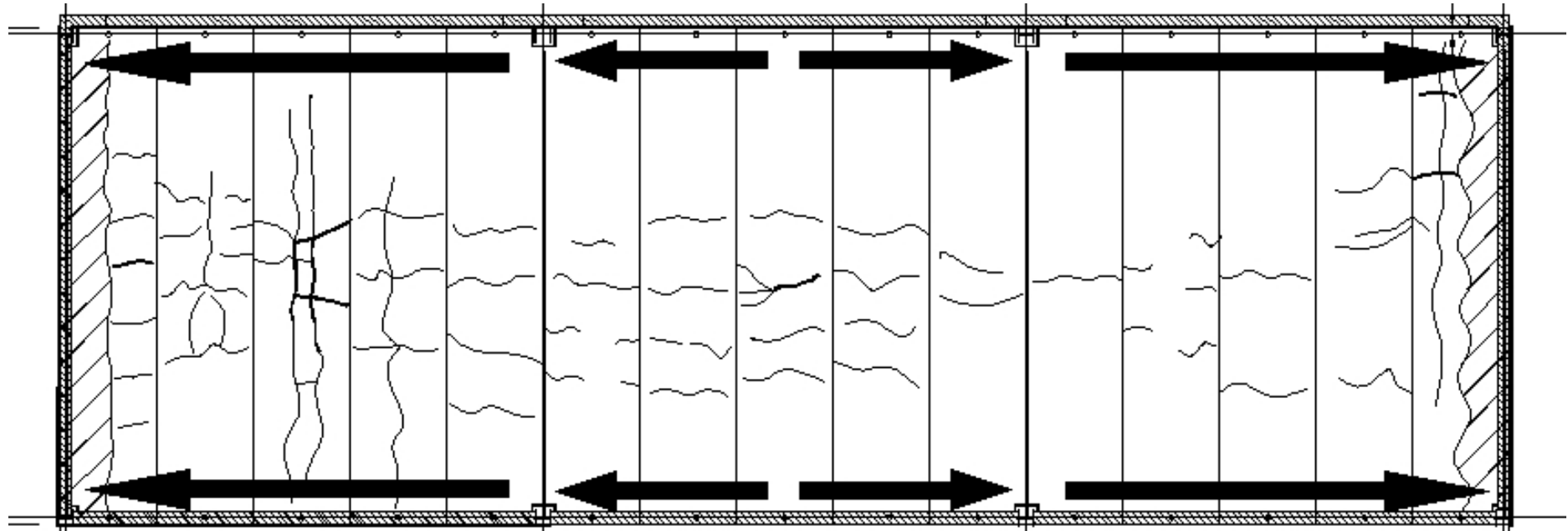
Design to BSEN1992-1-2

Maximum strand temp =  $553^{\circ}\text{C}$

Flexural capacity =  $39.7\text{kNm}$

Applied load =  $54.8\text{kNm}$





Evidence of a lateral compressive strip forming enhancing flexural and shear capacity

# Prescriptive approach

(Based on Standard Fire Tests)

## Advantages:

- Limited design effort
- Experience has shown that approach works (to date!)
- Approach is easily understood by all parties



# Prescriptive approach



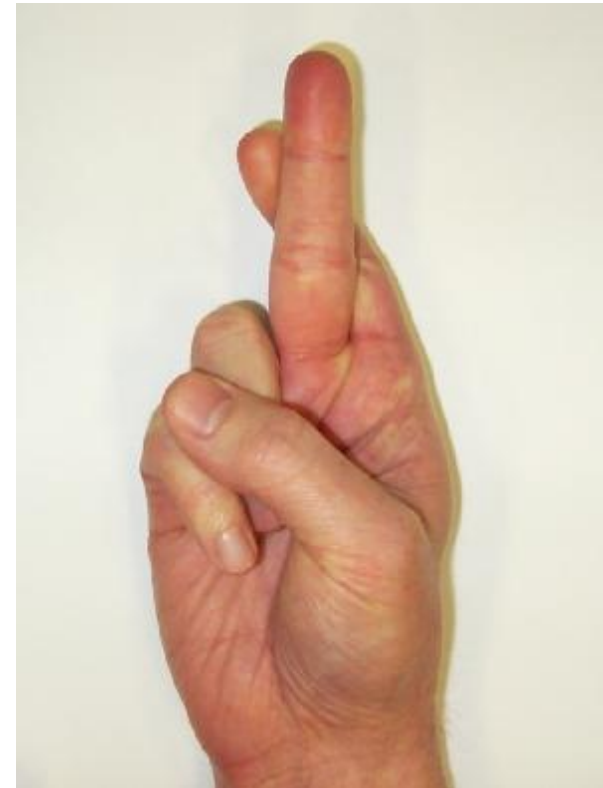
## Disadvantages:

- Actual structural behaviour is ignored
- Effect of real fires ignored.
- Levels-of-safety and robustness are unknown.
- Optimum solution in terms of life safety, economical impact and environmental damage is unknown.

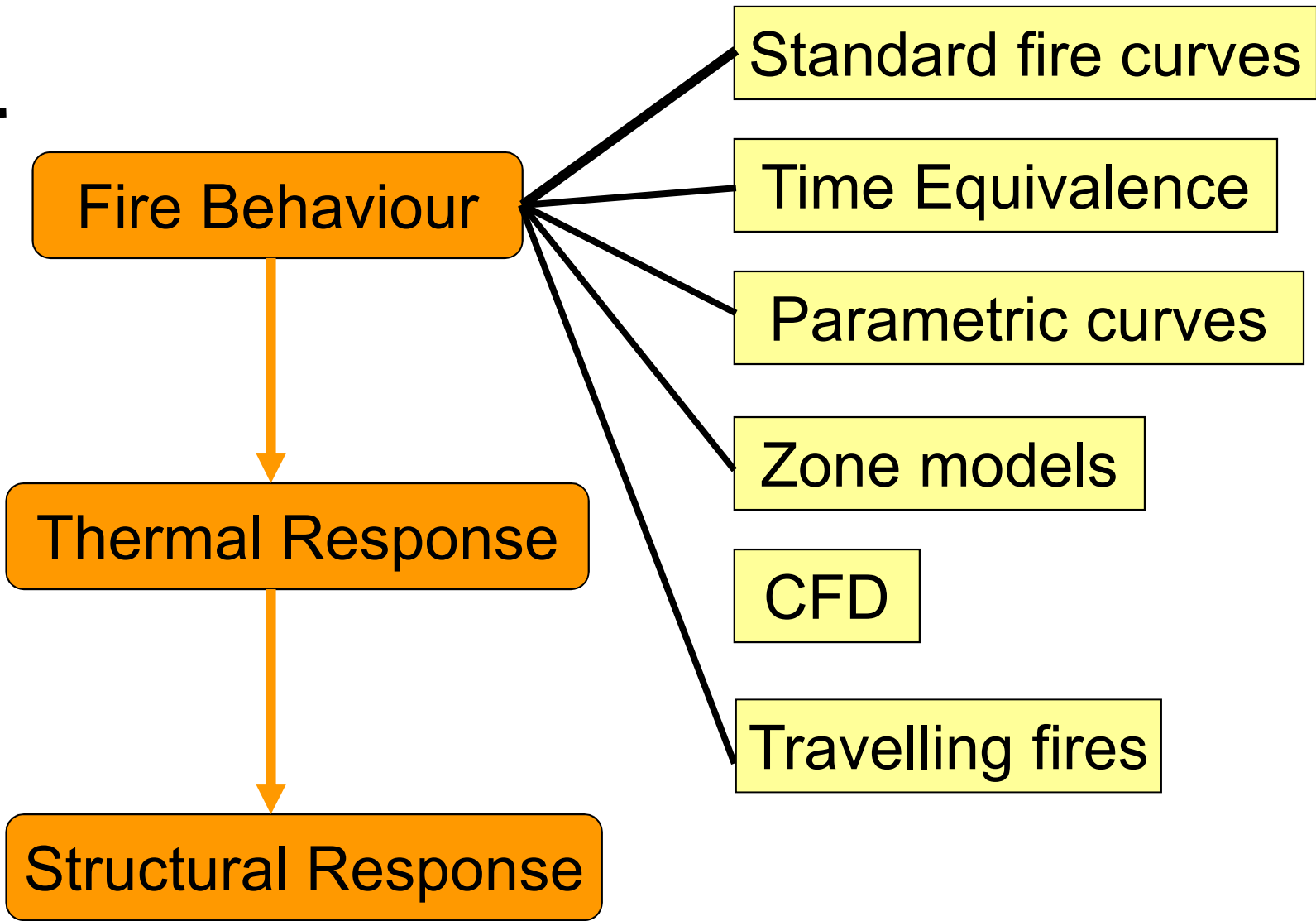
## Structural fire engineering – prescriptive approach

- Actual structural behaviour is ignored
- Effect of real fires ignored.

Compensating errors ???



Structural fire engineering



Structural fire engineering

Fire Behaviour

Test Data (Generally based on Standard Fire Curve)

Thermal Response

Simple heat transfer models

Structural Response

Advanced heat transfer models



Structural fire engineering

Fire Behaviour

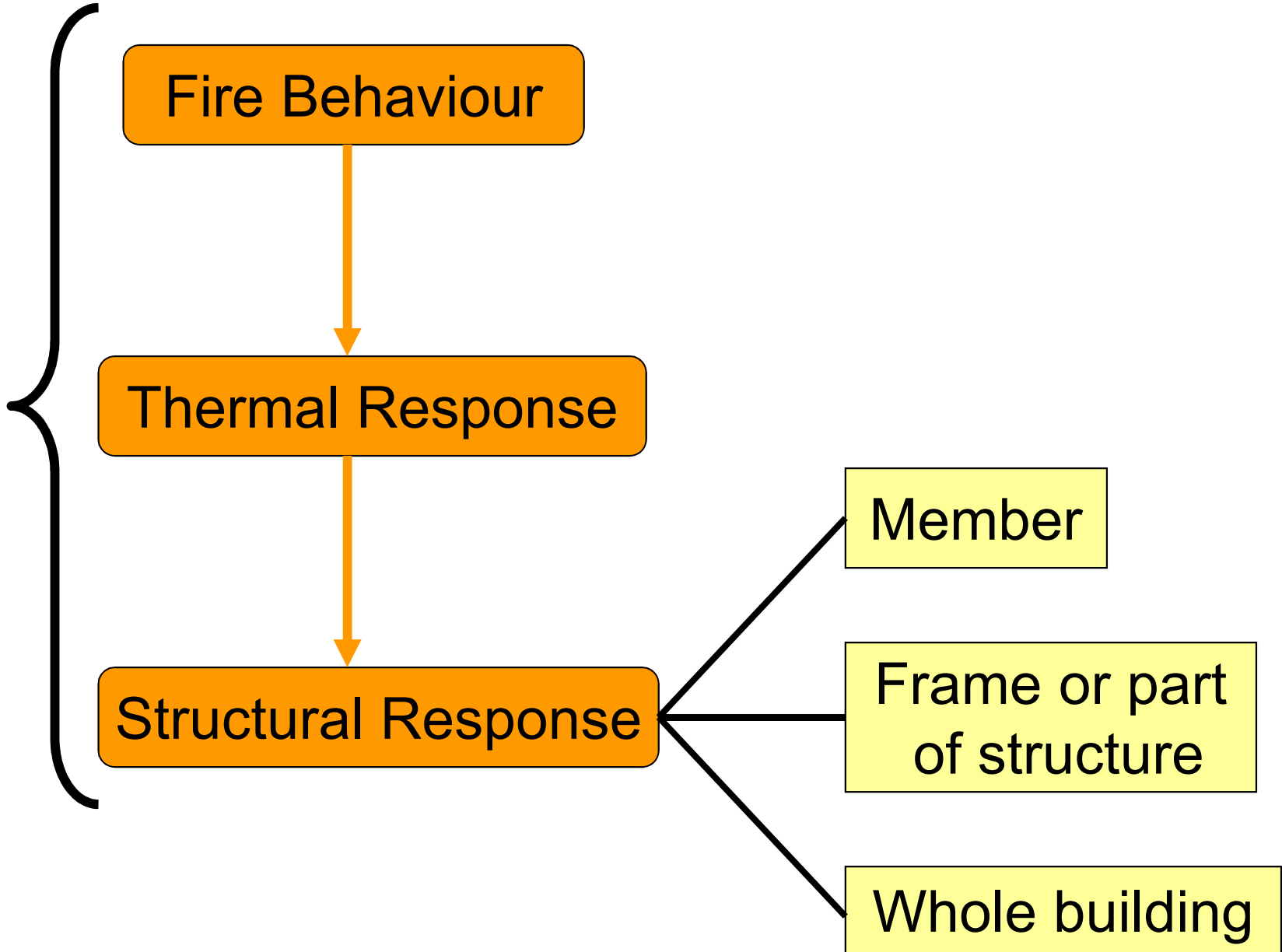
Thermal Response

Structural Response

Member

Frame or part  
of structure

Whole building



# Performance-based structural fire engineering

## Advantages

- Allows actual behaviour and robustness of the building to be assessed.
- Allows optimum design to be determined taking into account life safety, financial impact and environmental issues.
- Can be used as part of an assessment of multiple risks (e.g. explosions followed by a fire)

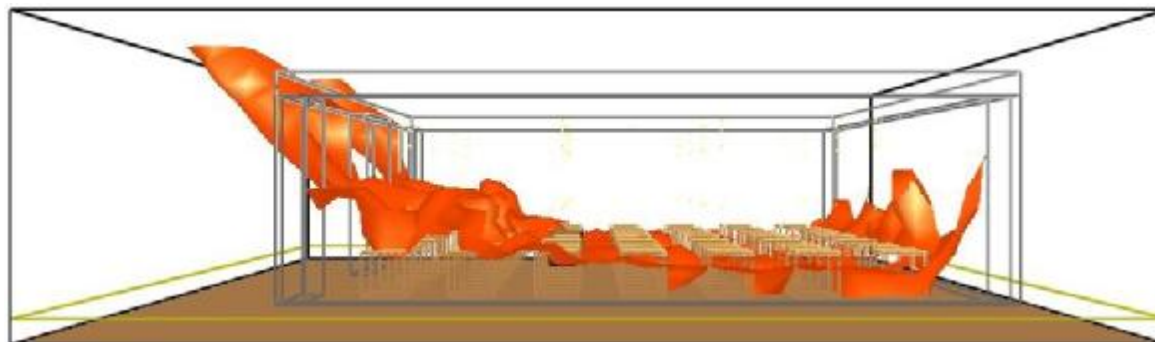
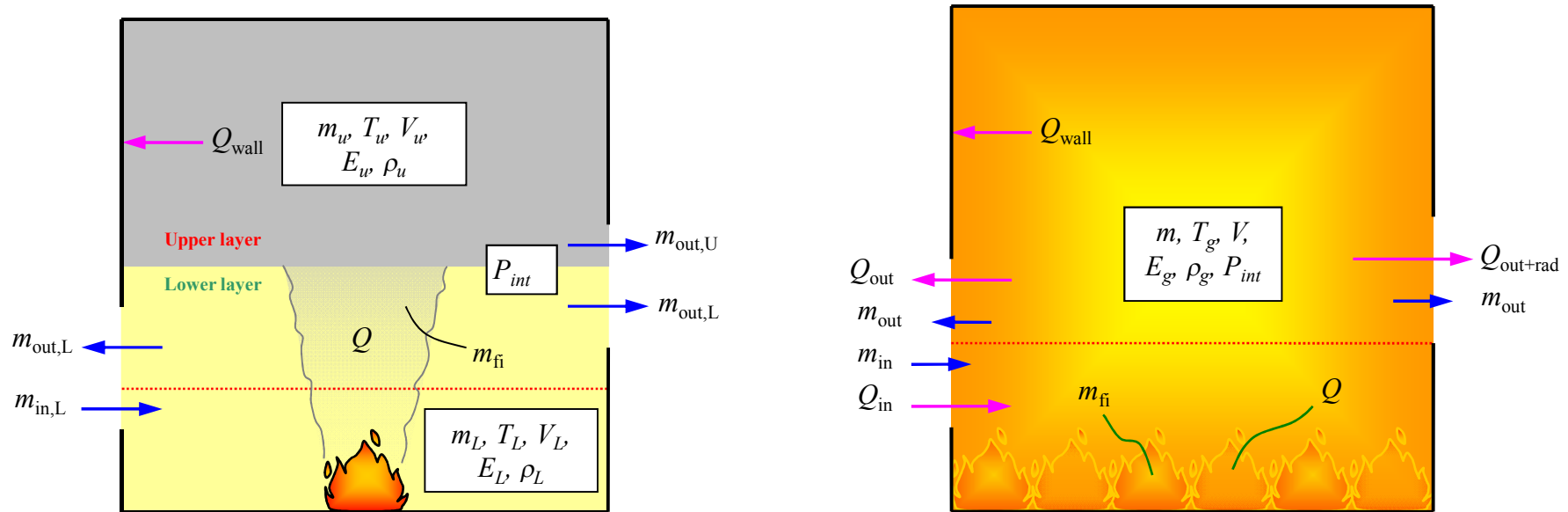
# Performance-based structural fire engineering

## Disadvantages

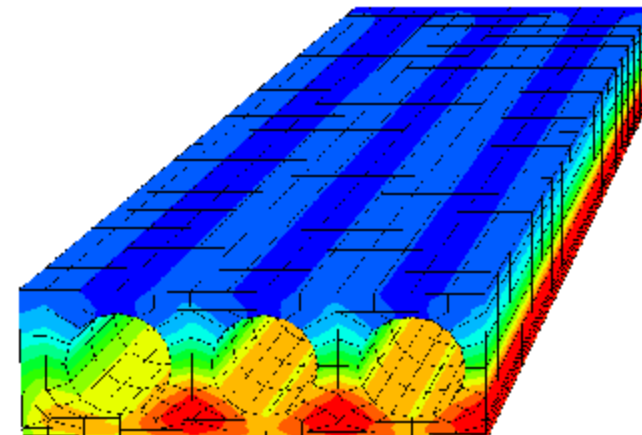
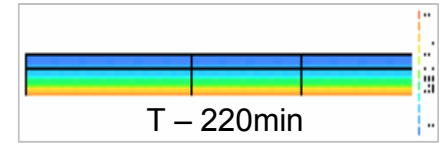
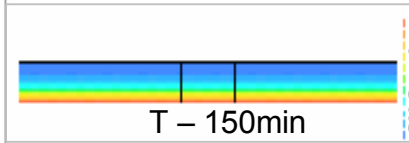
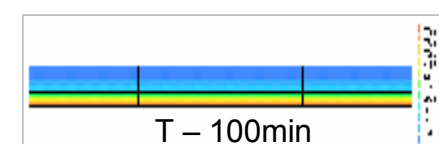
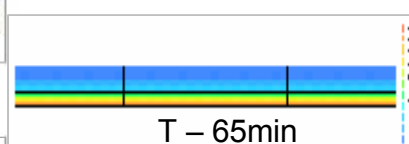
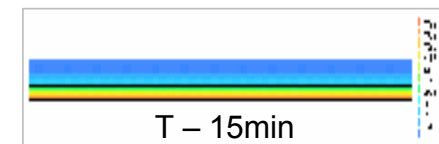
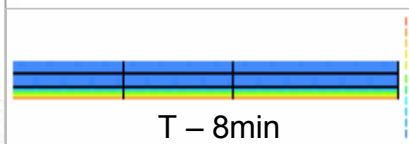
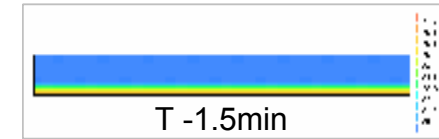
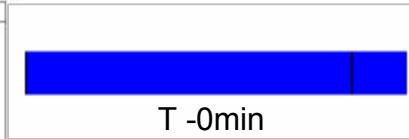
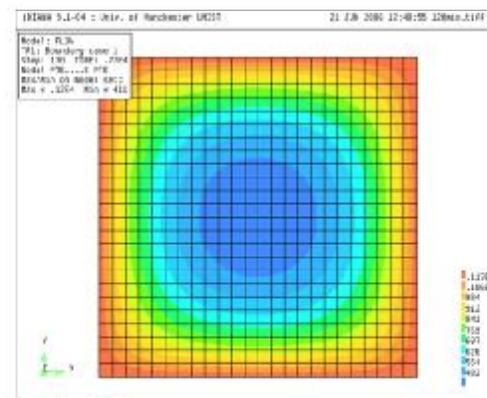
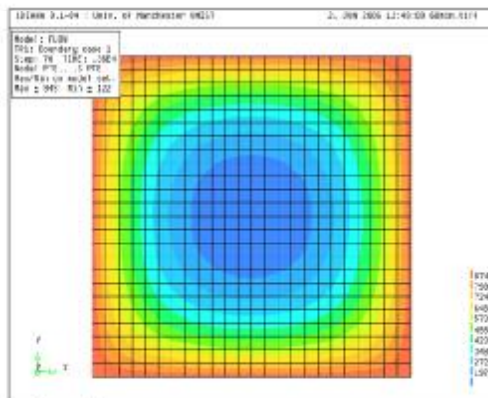
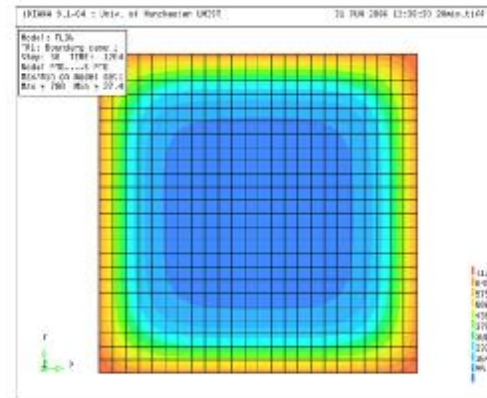
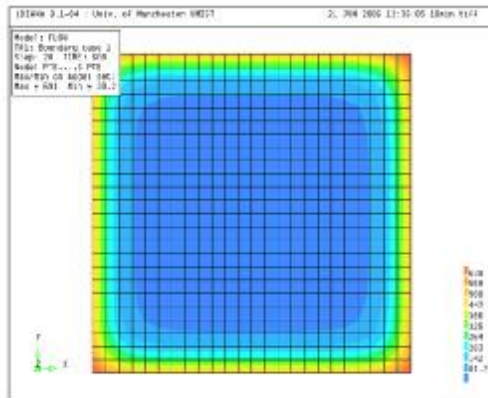
- Design effort increased compared to other methods (client may not understand added-value).
- Requires multi-discipline skills.
- Design can be complicated.
- Change of building use may make the fire design invalid.

# Use of Advanced Models

To predict fire, thermal and structural behaviour.



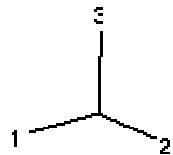
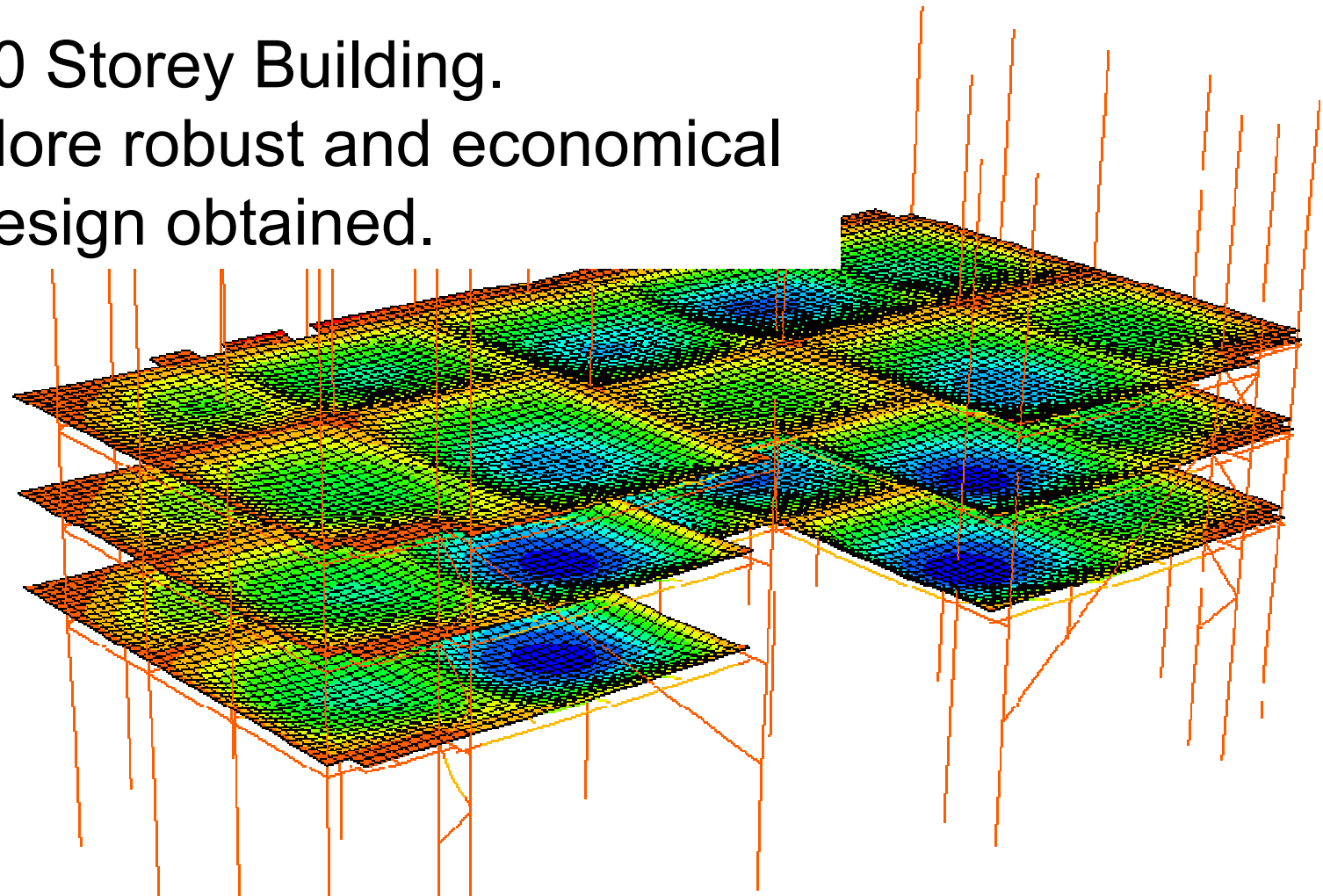
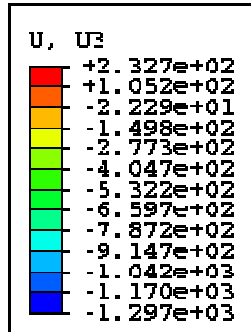
# Use of Advanced Models



# Use of Advanced Models

40 Storey Building.

More robust and economical design obtained.



Step: Fire4  
Increment 308388: Step Time = 3.100  
Primary Var: U, U3  
Deformed Var: U Deformation Scale Factor: +1.000e+00

(images courtesy Arup Fire)







Guide to the advanced  
fire safety engineering  
of structures

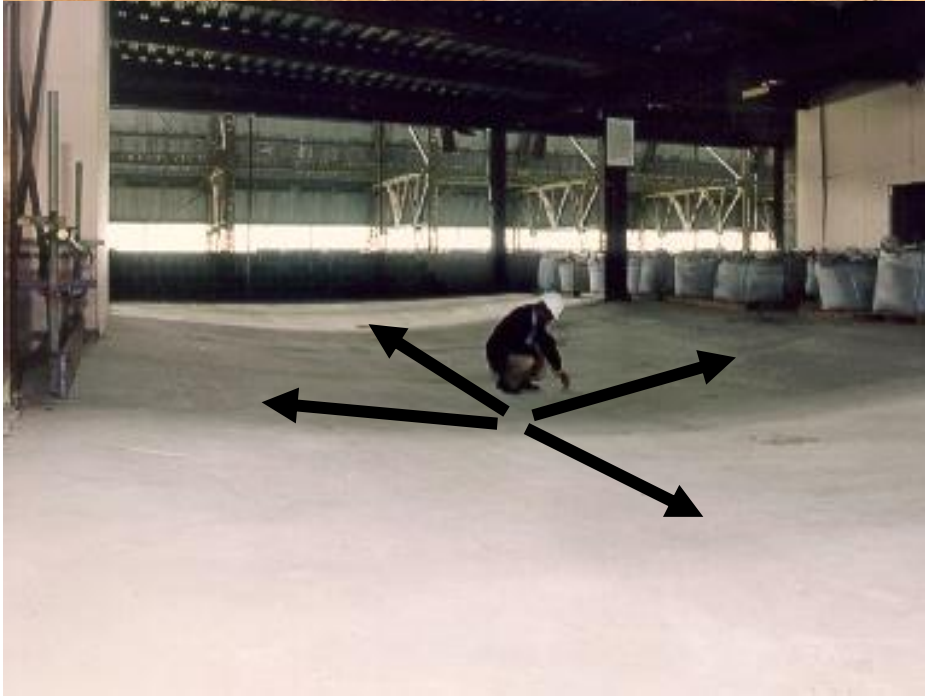


August 2007

Presents a framework  
for carrying out  
advanced Structural  
Fire Engineering.

Guidance on  
Validation, Verification  
& Review

# Membrane Action





Unprotected beams

*40 to 55% of beams can be left unprotected.*



**DETR**  
Department of the Environment, Transport and the Regions

**The Steel Construction Institute**

**Fire Safe Design**  
A new approach to multi-storey steel framed buildings

Fire and Steel Construction

ONLINE 2007

**Steel structures supporting composite floor slabs: design for fire**

**Digest 462**

Sabri Bahay  
BRE Laboratory Specialist Designer

Test results and observations from real fires in real buildings have consistently shown that steel framed structures comprising composite floor slabs and concrete/metal decks perform far better than current fire design methods suggest.

This Digest shows how the true structural behaviour of these types of buildings can be calculated in fire, allowing a reduction in the amount of passive fire protection currently used.

Designers can now provide that steel structures will perform badly in a fire, result up to the greatest portion of protecting or partially protecting exposed parts of a steel frame, beam, or wall or column, based strength and stiffness, as its temperature rises and the building structure is considered as an element of a fire. The perception of the performance of these steel structures as far as reasonable. However, more (Figure 1) and observations from real fires in real steel structures, which have made a significant contribution to the design of steel structures with composite floor slabs, have shown that these types of composite perform far better than current design methods suggest. It is possible, by considering the actual behaviour and performance of these structures, that a significant amount of passive fire protection that is currently specified for the steel frame is unnecessary. Analysis of test results<sup>1,2</sup> has shown that the load path mechanism of a steel structure supporting a composite slab during a fire are different from those assumed during the normal use of the building. In particular, the failure action of the composite slab at large displacements is far more ductile than is a fire (fire-then-steel). This Digest shows how the mechanical action of the composite slab can be incorporated into the structural fire design and how greater fire resistance is required only in specific supporting downward roof spans.

Figure 3 Fire test on a steel framed structure with a composite floor.

**BRE**  
constructing the future

European Union  
Education and Culture DG

Living Learning Programme  
LEONARDO DA VINCI

1&4  
ANEFORÉ

**FRACOF**  
Fire Resistance Assessment of Partially Protected Composite Floors

**Design Guide**

O. Vassart  
B. Zhao

ArchieWills ctkm

Simple design guides



Fire Load =  $587\text{MJ/m}^2$   
45 No.  $1\text{m} \times 1\text{m} \times 0.5\text{m}$   
wooden cribs

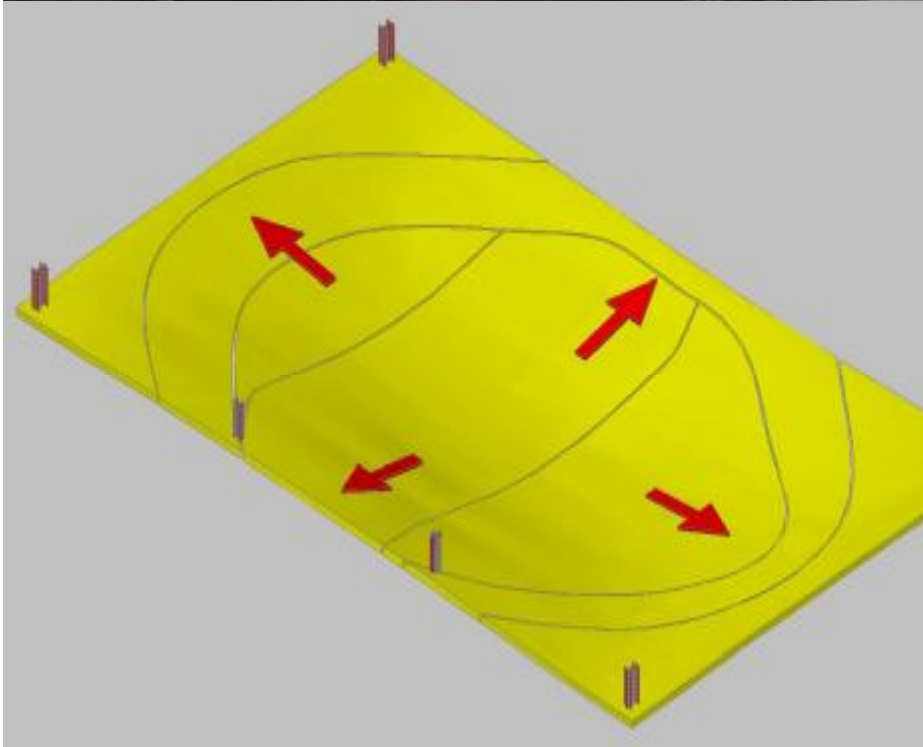


Applied load =  $3.25\text{kN/m}^2$

Total load =  $6.15\text{kN/m}^2$







# Limited testing on PT slabs



# Post-tensioned Slabs in Fire



Unbonded System

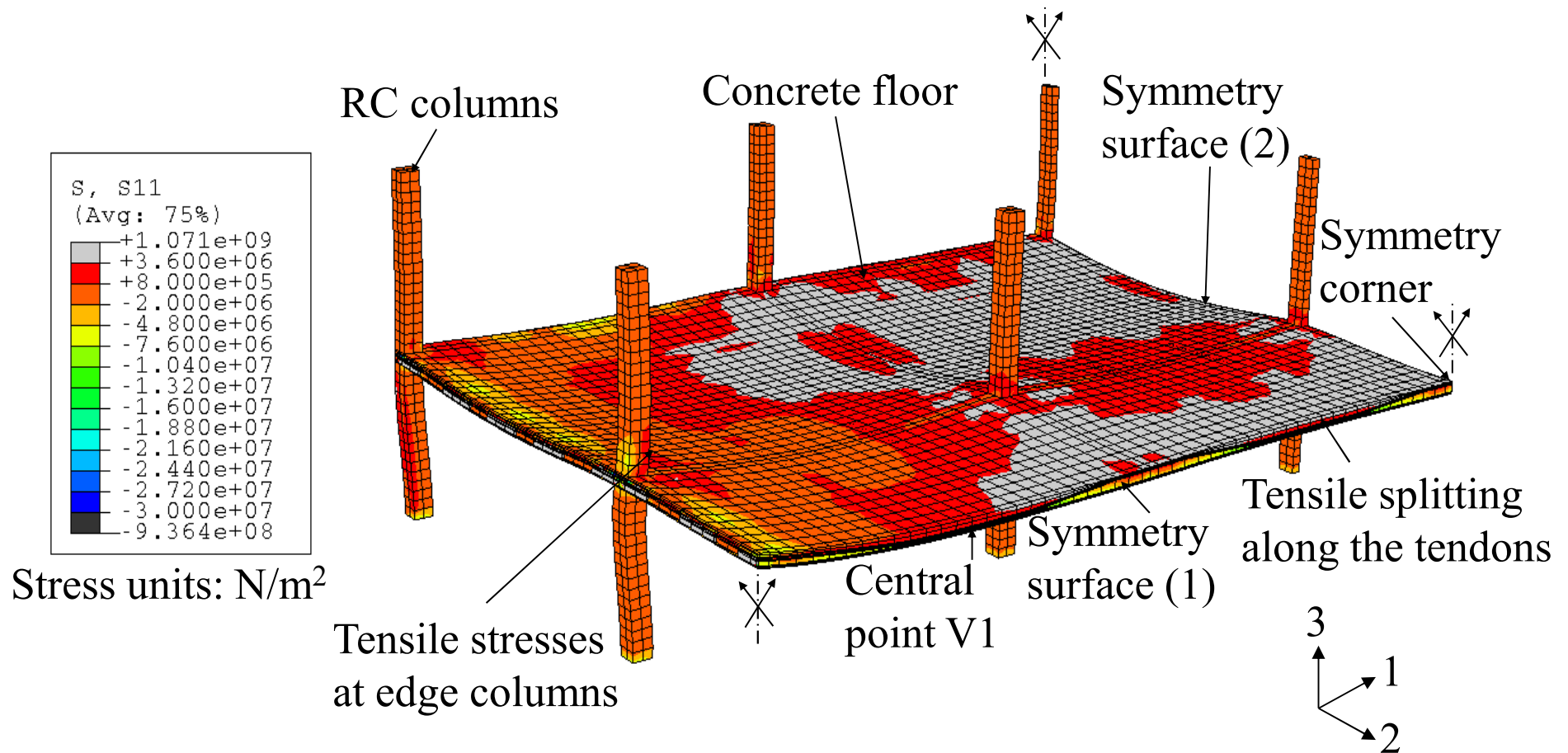


Bonded System

Main post-tensioning systems investigated



# Whole building behaviour



Maximum principal stresses in F4 (scale 5:1)

# Structural Fire Engineering

## Prescriptive Approach:



## Performance Based Approach:

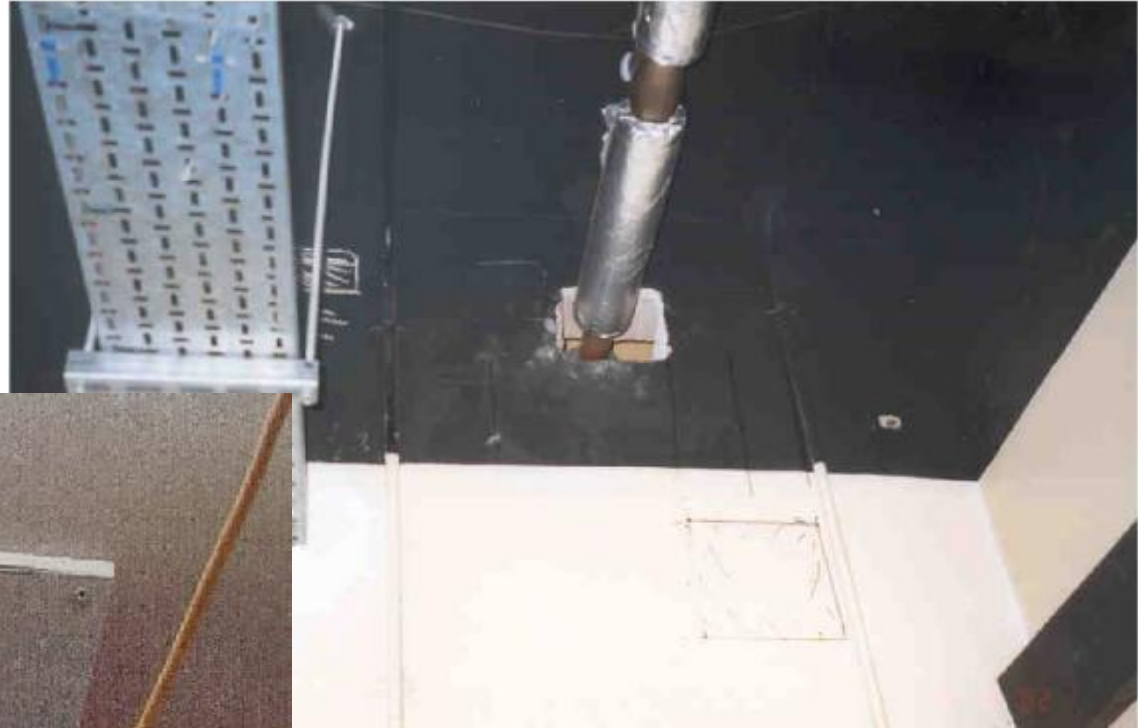
Greater understanding of how buildings behave in fire.

More robust designs


More economical designs



Whatever Design Approach is Followed  
- if the simple things **MUST** be done correctly !!!







We must continue to promote a performance-based approach – otherwise rely on luck.

Education, Research, New Materials

The End

Thank you

