



The Ove Arup  
Foundation



The Royal  
Academy of  
Engineering

Structural Fire Testing:

# Where are we, how did we get here, where are we going?

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Cost Action TU0904 – Training School for Young Researchers  
Sliema, Malta, 11-14 April 2012

**BRE Centre for Fire Safety Engineering**



**“I am an academic/researcher.  
I seek the truth...  
the consequences be damned!”**

Structural Fire Engineering Researcher  
Concrete in Fire Forum, London 2011

**BRE Centre for Fire Safety Engineering**

# Prof Malcolm Bolton's 2012 Rankine Lecture

“ When a company advertises that they'll design something to Eurocodes, they are essentially stating in bold faced font:

**"No improvements since 1960!"**

I am vehemently anti-code for Geotechnical Engineering, as it doesn't mesh well with the levels of uncertainty in our craft, and therefore **stifles innovation, drags everyone to the lowest common denominator, and makes our infrastructure needlessly cost more...**

”

# Fire Safety Engineering

“To limit the probability of (1) death, (2) injury, and (3) property loss in an unwanted fire”

**Note:** All modern codes emphasize ‘life safety’.

Was this always the case, and was it always the intent?



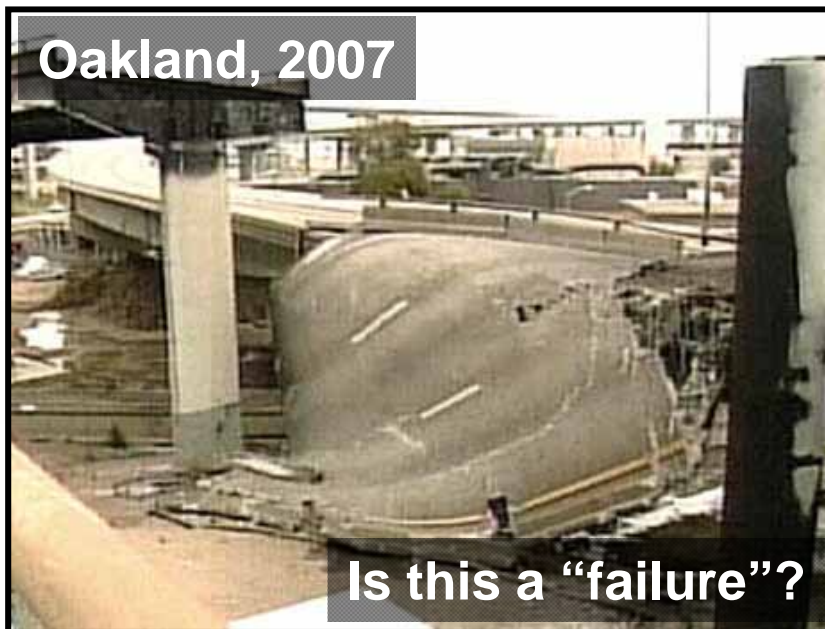
# Structural Fire Engineering

**“Any building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period”**

**Questions:** What do we mean by ‘stability’?

What is a ‘reasonable period’?

Are we Engineers, or just playing games?





**Were these always the goals?  
How did we get here?**

# Origins of Structural Fire Testing

- Initial purpose:
  - a **comparison of different building materials and systems** to assess claims of ‘fireproof’ construction in late 1800s
- Was **not intended to be a ‘solution’** for structural fire testing or regulation
  - Was a practice correction in the wake of various conflagrations (e.g. Baltimore, San Francisco)
  - Construction industry was being flooded by ‘fireproof’ building system patents which had either
    - Never been proven, or
    - Shown to fail to provide appropriate protection in real fires
- The standard fire test emerged as a test for **comparative performance** in the **most severe possible fire**

# Birth of Structural Fire Testing

- Thermal scenario **intended** to be **more severe than a real fire** (based on **qualitative** experience)
  - “no ordinary room would have enough inflammable material in it to maintain a **1700°F fire for more than 30 minutes**”.
  - “When fearful consequences may result from a failure of a structure due to fire, **no test is too severe** which **reasonable care and expense in construction** can resist”



Ira Woolson's early 'furnace'



# Fire Resistance Ratings

- Over time, the temperature-time curves were formalized and became ASTM E119, ISO 834, etc.
- Assumed:
  - No real fire could heat faster
  - No real fire could reach the temperatures obtained in the furnace
  - No real fire could last longer (thus, burnout)
  - Structural restraint and continuity are always helpful

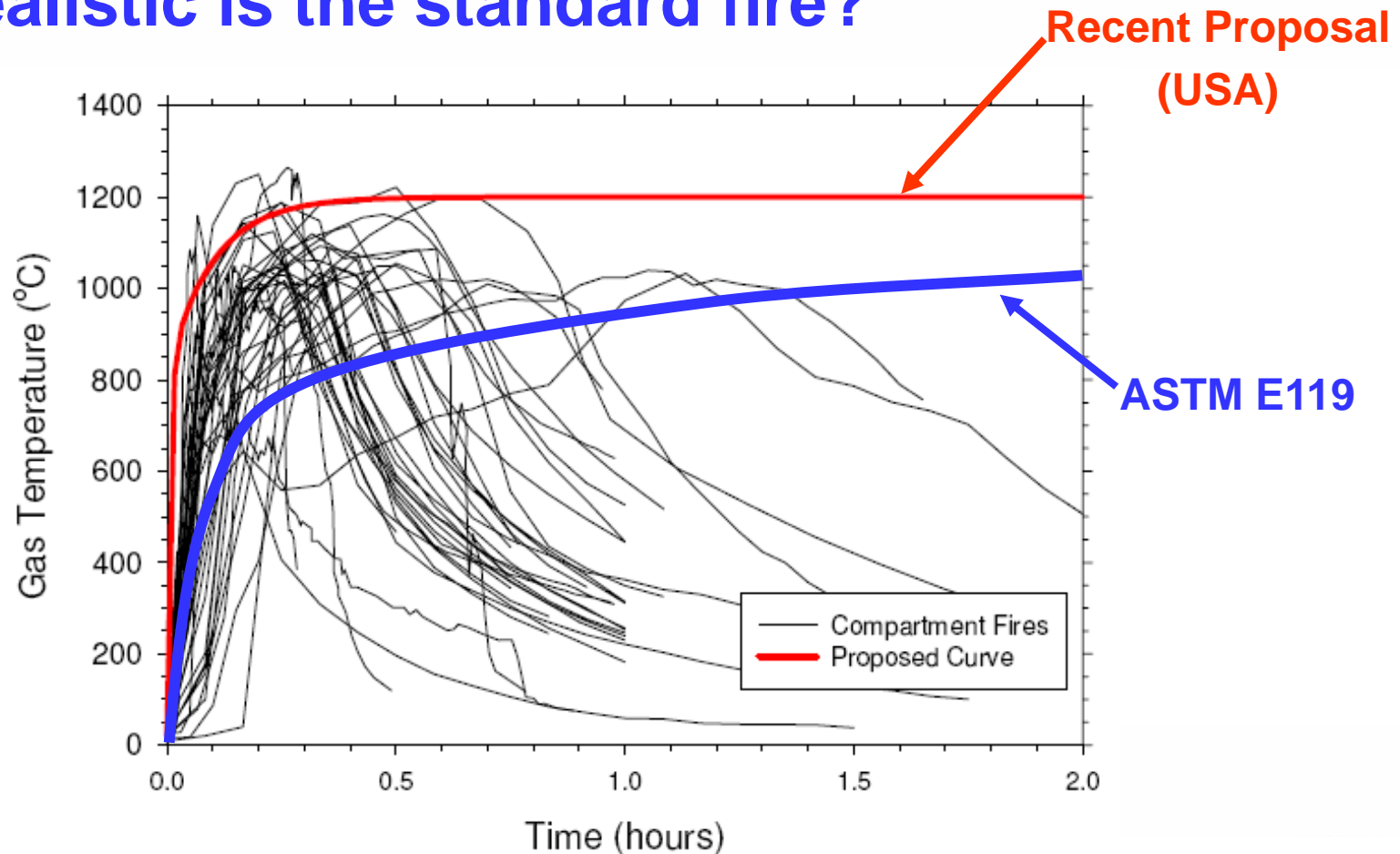
But what is the relationship to *reality??*

AND

On what basis do we say '*REI 120 minutes*'??

# “Standard” versus “Real” Fire?

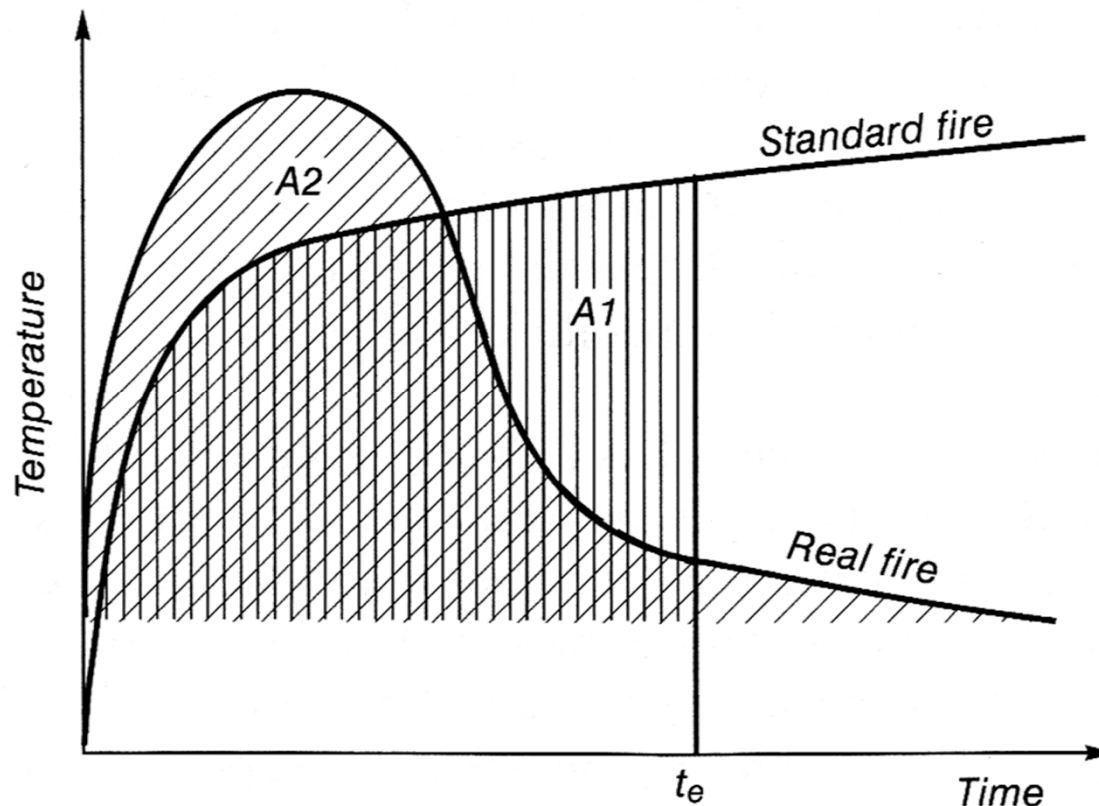
## How realistic is the standard fire?



**Average gas temperature in compartment fires as function of time, compared with a proposed 1200°C ‘maximum’ time-temperature curve**

# Ingberg & Quantification of REI Times

Around **1928**, Ingberg introduced the concept of **'fire severity'**



**Note:** The intent was therefore **'design for burnout'**

**Note:** 120 minutes and then collapse was **NOT** the intent

# Ingberg's Fuel Load vs. Fire Resistance

Fire Load Of Occupancy <sup>(1)</sup>		Fuel Load <sup>(2)</sup>		Fire Resistance <sup>(3)</sup>
<u>kg/m<sup>2</sup></u>	<u>lb/ft<sup>2</sup></u>	<u>MJ/m<sup>2</sup></u>	<u>BTU/ft<sup>2</sup></u>	<u>minutes</u>
24.4	5	456	40,000	30
48.8	10	912	80,000	60
73.2	15	1,368	120,000	90
97.6	20	1,824	160,000	120
146.5	30	2,736	240,000	180
195	40	3,590	320,000	270

Note: (1) ratio of combustible fuel load per unit floor area.  
 (2) ratio of energy content of combustibles per unit area.  
 (3) FRR required for structures exposed to fire in room with fire load shown.

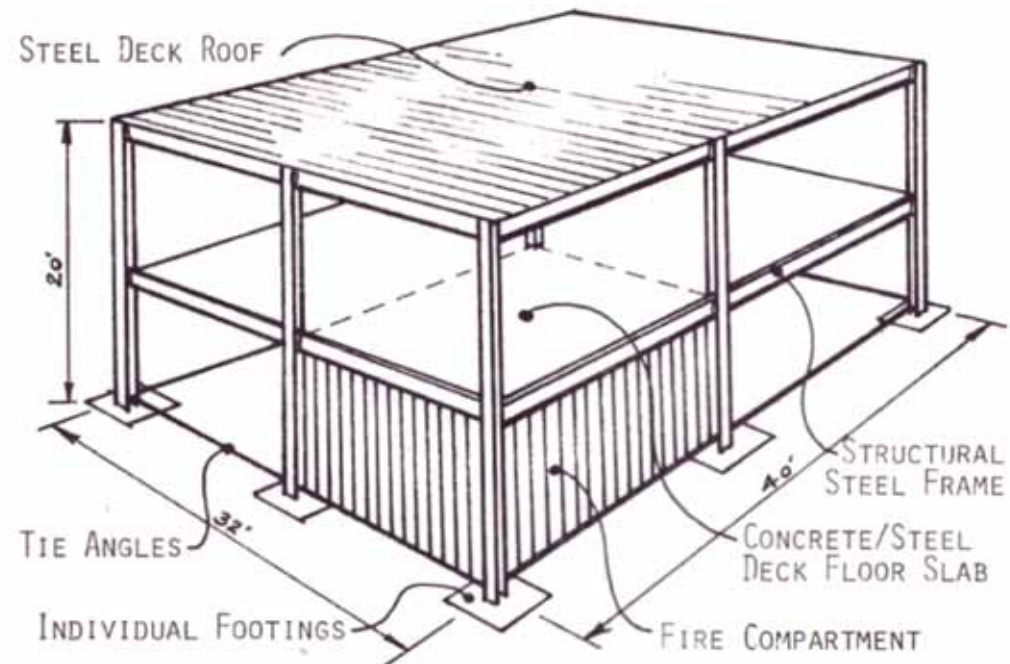


# The SFE Renaissance

**BRE Centre for Fire Safety Engineering**

# The “Renaissance”

- Large-scale **non-standard fire resistance testing** started (again) in the 1980s
  - *Important: Why?*
- First contemporary test?
  - **1982**, NIST, USA
  - Steel-concrete composite
  - FASBUS model validation



- Now **25+ large-scale, non-standard fire tests** in literature
  - Steel-concrete composite ( $\approx 20$ )
  - Concrete ( $\approx 5$ )
  - Timber (1?)

# Example: Cardington Steel Building

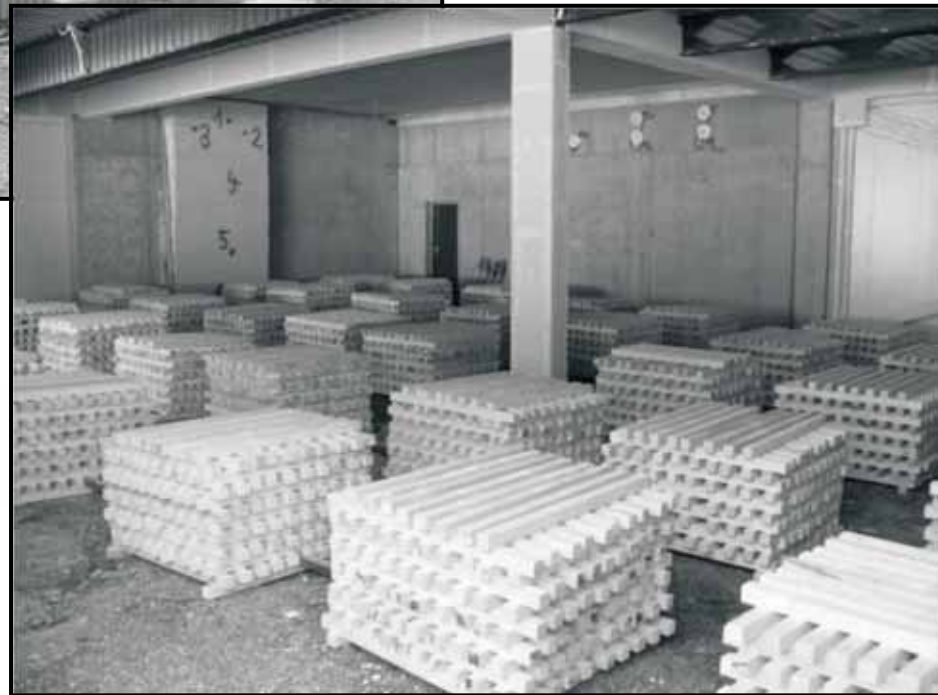


# Example: Cardington Concrete Building





# Example: Mokrsko Fire Test





**Where are we now?**

The current state of practice

Structural Model Fire Model		Materials & Partial Elements	Single Elements	Sub-Frame Assemblies	Transiently Simulated Restrained Assemblies	Full-Scale Structures
Elevated Temperature Exposures (transient or steady-state)		Generate design/model input data	O/R [T]	M/C	M/C	M/C [E.1-2]
Standard Fires		Generate design input data	<b>Obtain fire resistance ratings (STANDARD)</b> [T]	O/R [O]	M/C [W]	M/C [A]
Equivalent Fire Severity to a Standard Fire		Validation of fire severity concept	Obtain fire resistance ratings (using alternative metric for fire severity) [Q]	O/R	O/R	M/C [B];[G];[N]
Parametrically Defined Model Fires		Generate design input data (highly dependant time-temperature phenomenon)	O/R	O/R [K];[M];[R];[S]	O/R	O/R [E.3-5]; [H];[J];[L];[U];[V]
Localised Model Fires		Generate design input data (highly dependant time-temperature phenomenon)	O/R	O/R	O/R	O/R
Zone Model Fires		Research (highly dependant time-temperature phenomenon)	M/C	O/R	O/R	O/R [I]
Field Model Fires		Research (highly dependant time-temperature phenomenon)	M/C	M/C	O/R	O/R
Real Fires		Research (highly dependant time-temperature phenomenon) [P]	M/C	M/C [C];[D];[F]	O/R	<b>Research REAL behaviour in a REAL fire</b> [E.6]



# Where are we now?

## 'Standard' Furnace Testing

***“No progress since the 1930s”***

# Standard Fire Testing



Wall Furnace



Column Furnace



Floor Furnace

# 'Standard' Testing Procedure

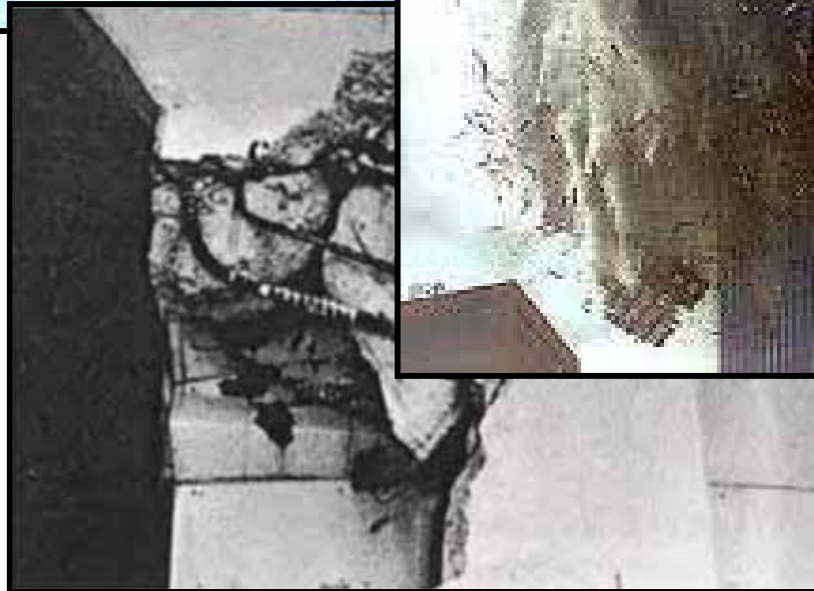
1. Construct test specimen to accurately represent “**as-built**” construction
2. Place specimen in “**rigid**” loading frame
3. Position **inside, next to, or over** a standard testing furnace (depending on member type)
4. Apply “**likely service load**” to the specimen
5. Maintain constant load and apply the “**standard**” time-temperature curve
6. Continue test until a **failure criterion** is reached
7. Test is normally **stopped once rating is obtained**

# Issues for consideration...



- **Standard of Construction:**
  - Typically much **better for the test** than in reality
  - Only the **successful tests are reported**
- **Applied Loads:**
  - Choose loads which produce stresses in the tested element **“similar” to those expected in the actual building** at the time of the fire
- **Restraint & Continuity:**
  - Both have significant effects on fire resistance
  - Should use support conditions **“similar” to those expected in the actual building**
- **Size effects:**
  - Furnaces are severely **limited in size**
- **Connections & Critical Failure Modes:**
  - **Connection details are completely overlooked but often govern** in reality
  - When structures **fail in fires** it is rarely for the reasons we would expect
- **Size effects:**
  - Furnaces are severely **limited in size**

# Element vs. Structure Response







## Note: All furnaces are not created equal

- **Standard furnace exposures are *NOT* the same, even if they are intended to be:**
  - **Type of control thermocouples**
    - Results in **higher (or lower) gas temperatures** in some cases
  - **Type of fuel and burner**
    - Affect the flame luminosity → emissivity → **heat transfer to structure**
  - **Furnace lining materials**
    - Bricks and ceramic fibre blankets have different thermal properties → **different heat transfer to the test element**
  - **Furnace geometry**
  - **Control by Temperature**
    - Gas **temperature is fundamentally misleading** as a comparative test method



# Where are we now?

## Non-Standard Fire Testing

*“Using Frankenstein to repeatedly demonstrate things we essentially already know”*

# Cardington vs. Ulster

Cardington Steel Frame



Lack of investment in research necessitates “**Frankenstein**” testing

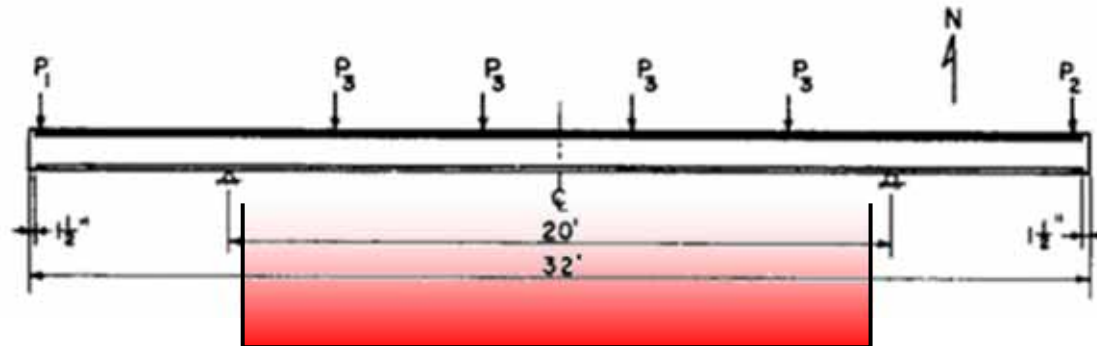
VS.



FireSERT Panel Test, 2010

# Element Testing

- **Non-Standard** use of **Standard** Furnaces
  - Ramp up structural complexity (defensibly?)
  - Don't really address the thermal boundary condition



- **Standard** use of **Non-Standard** Furnaces
  - Attempt to simulate a standard fire without using a standard furnace
  - **Why!?** *The tail is wagging the dog!*

# Furnaces with “Brains”

- Based on active feedback from the computational models that we are trying to calibrate/validate!?



**CERIB's Promethee Testing Facility, Paris**

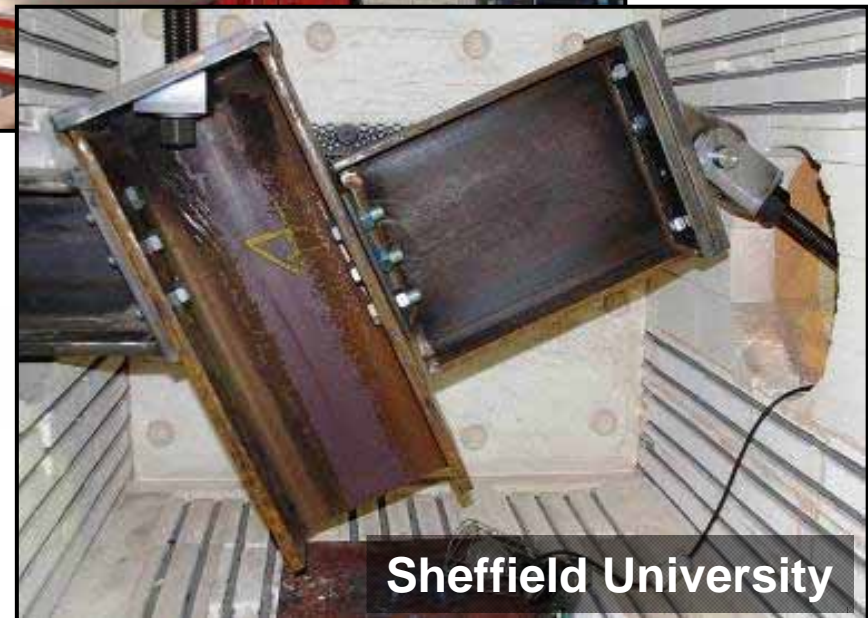
# Material & Component Testing



University of Edinburgh



Sheffield University



Sheffield University

# Where are we now?: Knowledge Gaps

- **Fire Exposure**
- Structural Interactions & Asymmetry
- Failure Localizations
- **Compartmentation & Fire Spread**
- Detailing & Construction Errors/Omissions
- Cooling Phase Response & Residual Behaviour
- Instrumentation & Measurement
- Data for Model Input, Calibration, Validation & Verification
- **New materials (FRPs, Aluminium, CrossLam, etc)**
- Structural optimization
- Connections & Resilience
- **Spalling**

***Test  
methods?***

**\*What is the *quantifiable benefit* of new knowledge?**





**The Future:  
Where are we going?**

# Drivers for Structural Fire Engineering?

## 1. Economic

- Client saves money (e.g. reduced applied fire protection)

## 2. Architecture

- Enable interesting and unusual buildings

## 3. Innovation

- Ensure/demonstrate that new methods, materials, or innovative designs are safe

## 4. Sustainability

- Structural optimization removes inherent redundancies

## 5. Safety?

- Ensure methods provide “equivalent” safety



Courtesy Arup Fire

Heron Tower, London, 2010

# Lack of Investment: Is this Justified?

- The 1900s “**birth**” was about safety (and perhaps \$)
- The 1980s “**renaissance**” was (is) essentially about \$\$\$

**Where is the next significant gain?**



# Possible Gains: Safety?

**Safety:** Is there a problem?

Year	Reported Fires	Civilian Deaths	Civilian Injuries	Firefighter Deaths	Firefighter Injuries	Core Cost of Fire (\$ B In 2008 dollars)
1980	3,000,000	6,505	30,200	138	98,070	\$74
1990	2,250,000	5,195	28,600	108	100,300	\$86
2000	1,750,000	4,045	22,350	103	84,550	\$102
2008	1,349,000	3,320	16,705	105	79,700	\$138

- Statistics say? ***no, not really.***
- **But is this because we know what we're doing?**

# Possible Gains: Money?

- **Money:** Is there a ***quantifiable*** gain?
  - **Steel (\$)**
    - The significant gains to be made are now largely **regulatory/sociological**, rather than technical
  - **Concrete (\$\$)**
    - **Regaining market share** from steel, but again only if the **regulatory environment** changes and the concrete industry invests
  - **Timber (\$\$\$)**
    - My view is that there are clear gains here for the **“sustainable design”** movement

# Possible Gains: Regulatory?

- **Regulatory:** Let me do things you say I can't
  - Testing for '**compliance**' rather than research for knowledge/innovation (wrong-minded)
  - **What types of buildings are people being prevented from building... and why?**



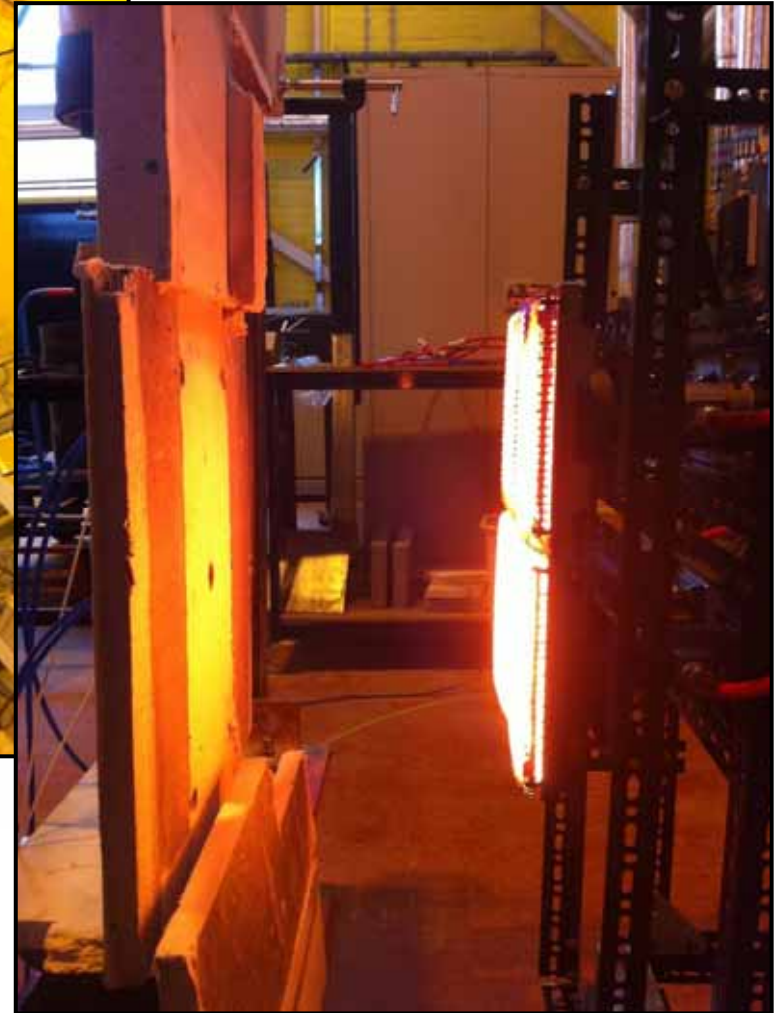
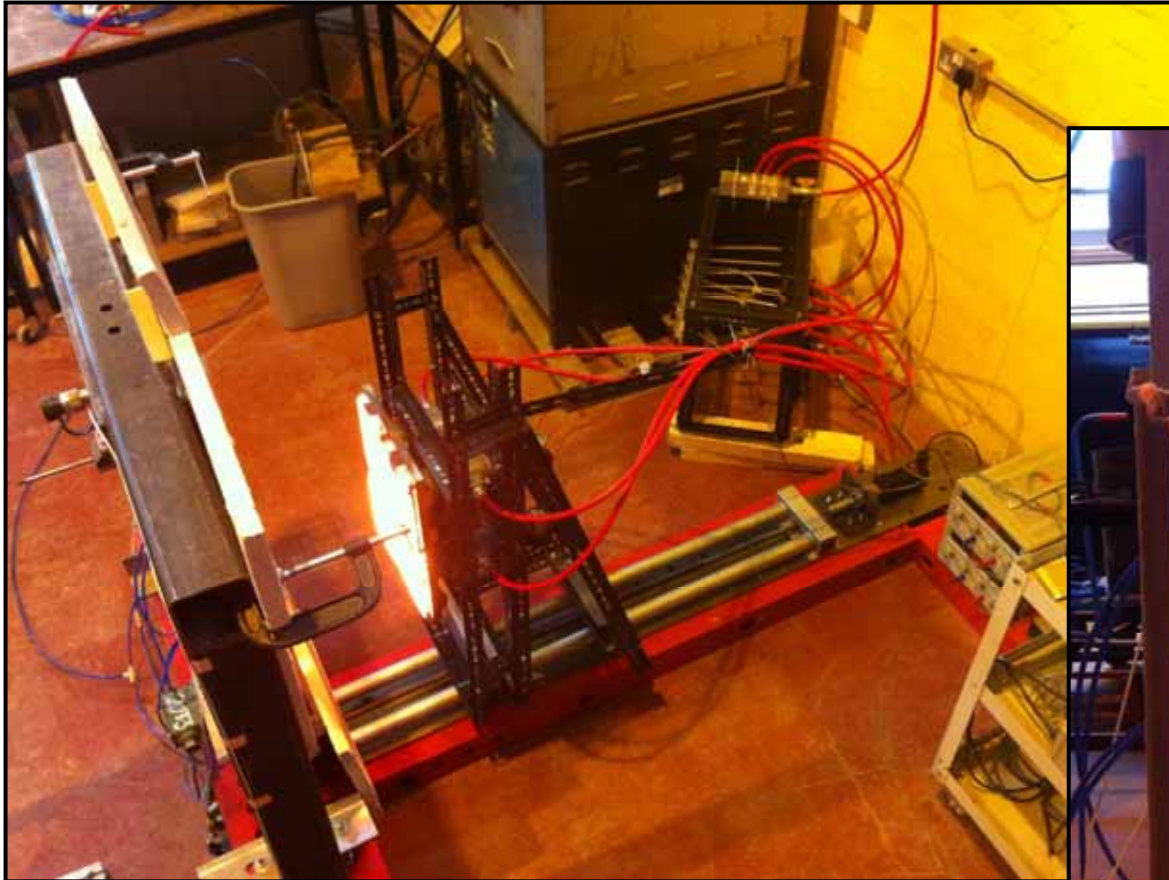
# A New Hope? The New NIST Facility

J-M Franssen: “**Make it simple... or not!**”



- 18 m × 27 m × 9 m high “real” structures
- 20 MW “real” fires
- Oxygen combustion calorimetry
- Active loading using servo-hydraulics
- On-line sometime 2014

# Getting the Thermal Boundary Condition Right



**H-TRIS @ Edinburgh**



# Final Thoughts

- If fire structural fire safety is to be addressed in isolation, as it is currently, then few people will (or should) care about further advancements and we should not bother to improve SFE design methods.
- SFE has therefore already delivered all that it could deliver.
- Further gains will only be achieved by streamlining existing methods and expanding into an increasingly wide sector of construction.
- Streamlining requires simplification, standardization, cost reduction, and training of all parties involved in the approvals process.
- Deep education is expensive, so methods need to be simplified so low cost training is sufficient to practice and recognize the quality of a solution.
- The last two decades have thus seen the transition of SFE from knowledge-based innovation toward mainstream commodity engineering practice.

**The alternative? Fire as a design load...  
performed (and regulated) competently.**



# Discussion?

For additional discussion/information please feel free to contact me:

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Web: [www.eng.ed.ac.uk/fire](http://www.eng.ed.ac.uk/fire)