Large-Scale, Real-Fire Structural Testing: A unique testing and metrology challenge

7th International Conference on Advances in Experimental Structural Engineering (7AESE)

Sept. 6th – 8th, 2017
Pavia, Italy

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National Institute of Standards and Technology
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Why should we care?

Fires resulting in structural damage are infrequent, but not insignificant

First Interstate Bank, '88
Los Angeles, USA
Credit: Boris Yaro

One Meridian Plaza, '91
Philadelphia, USA
Credit: Michael Wirtz/Phila. Inquirer

WTC Building 7, '01
New York City, USA
Credit: Steve Spak

Why should we care?

Structural collapse as a result of fire continues to occur

Plasco Building collapse, ‘17
Tehran, Iran
Credit: CNN

I-85 collapse, ‘17
Atlanta, USA
Credit: NBC news

What is new

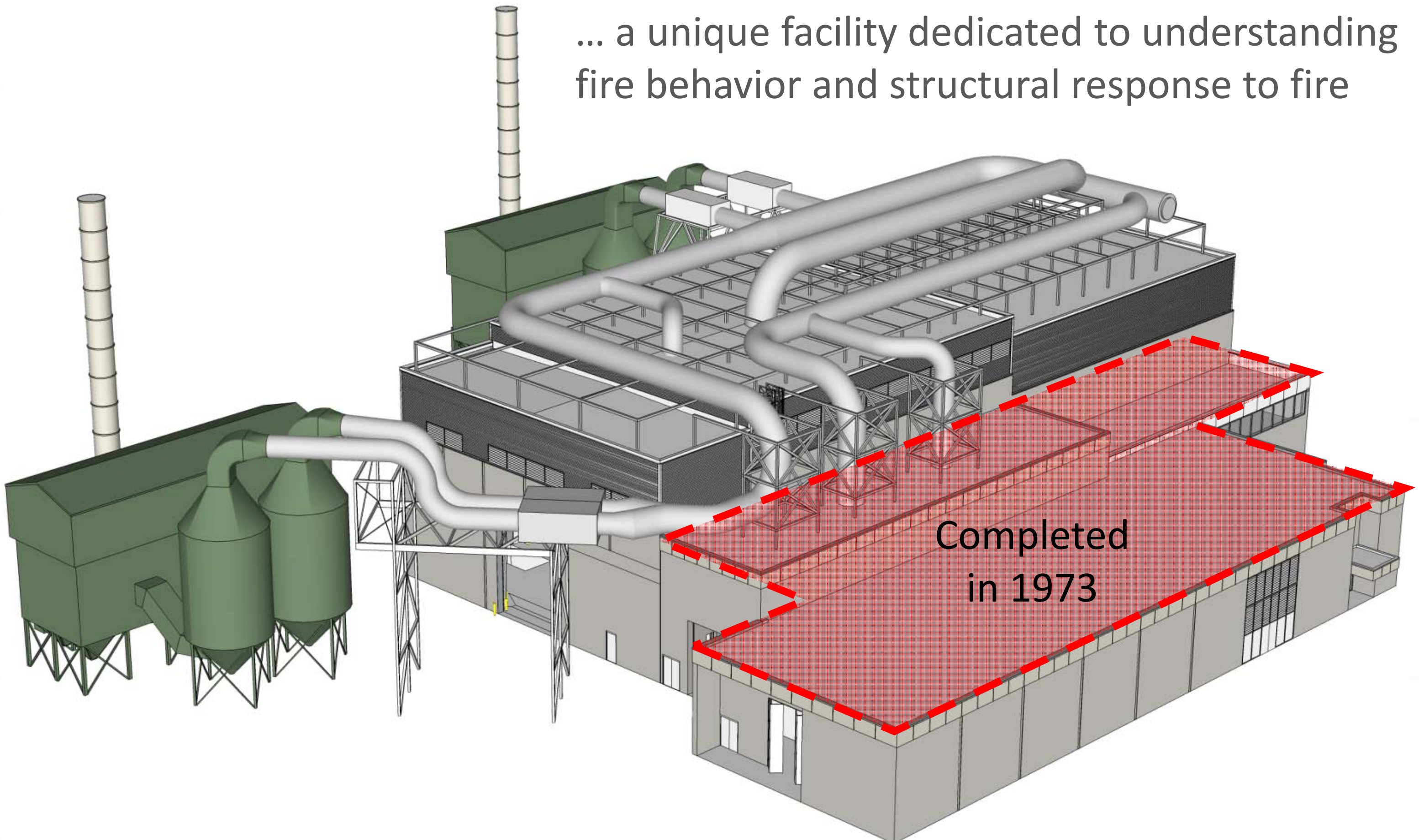
Gap analysis: No … ls and
simultaneous co…

Fire experiment
Washington, DC, U…
Credit: NIST archives

Vulcain furnace
CSTB, France
Credit: CSTB

The National Fire Research Laboratory

… a unique facility dedicated to understanding fire behavior and structural response to fire



Bundy, M; Hamins, A; Gross, J; Grosshandler, W; Choe, L: "Structural Fire Experimental Capabilities at the NIST National Fire Research Laboratory." *Fire Technology*, 52(4), July, 2016, pp 959–966.

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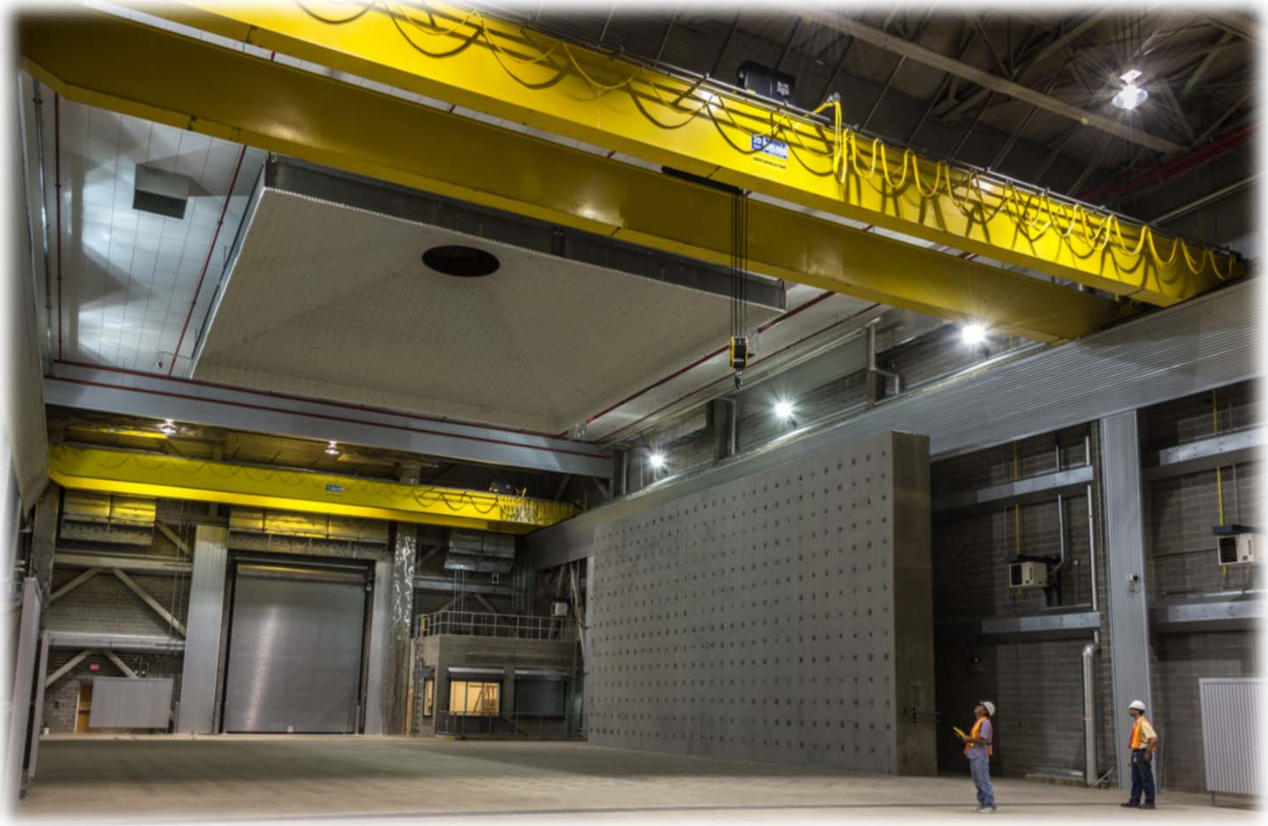
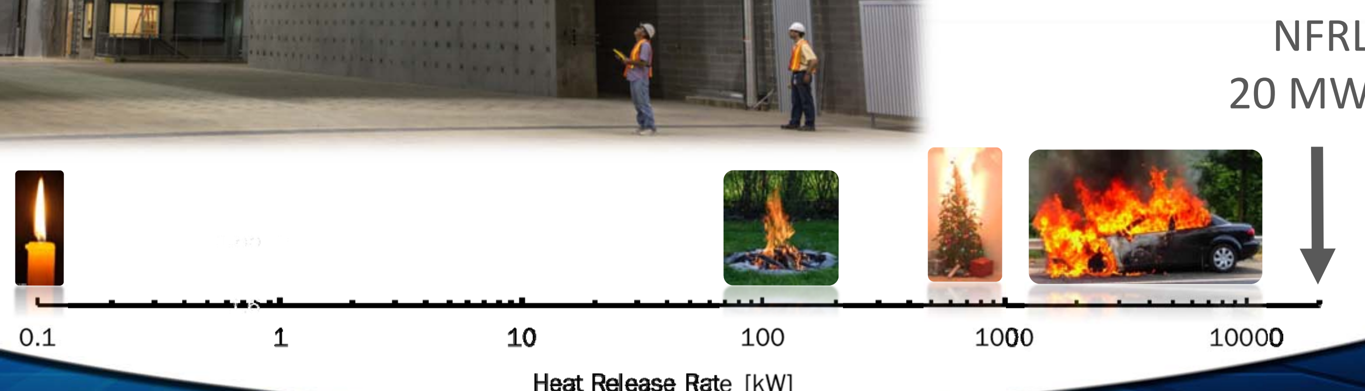
The National Fire Research Laboratory (NFRL)

Combined structural and large fire experimental facility





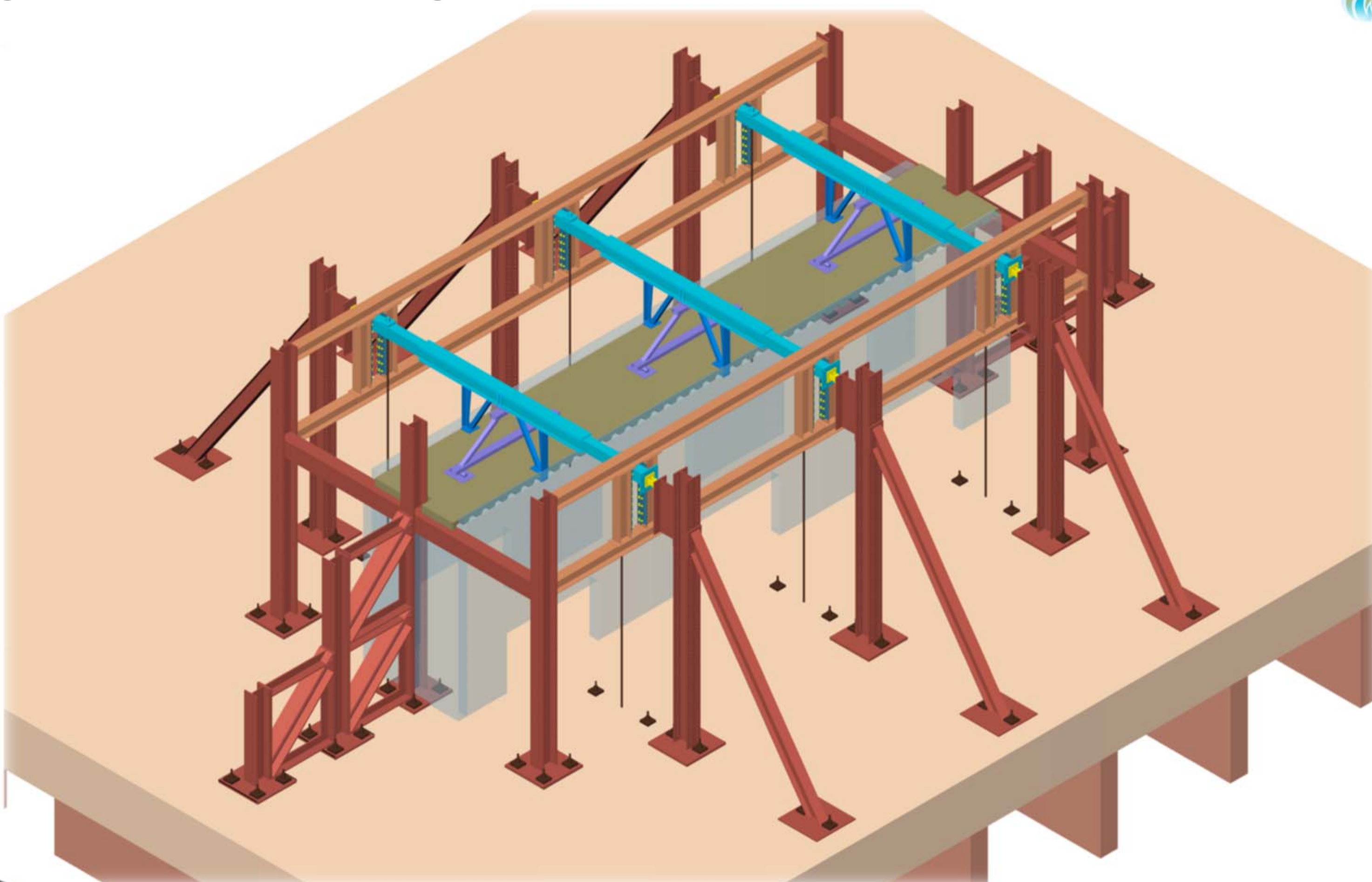
Unique challenges of large-scale real-fire experiments

Challenge 1: Mechanical loading

Principle Investigators: Lisa Choe, John Gross

Unique challenges of large-scale real-fire experiments

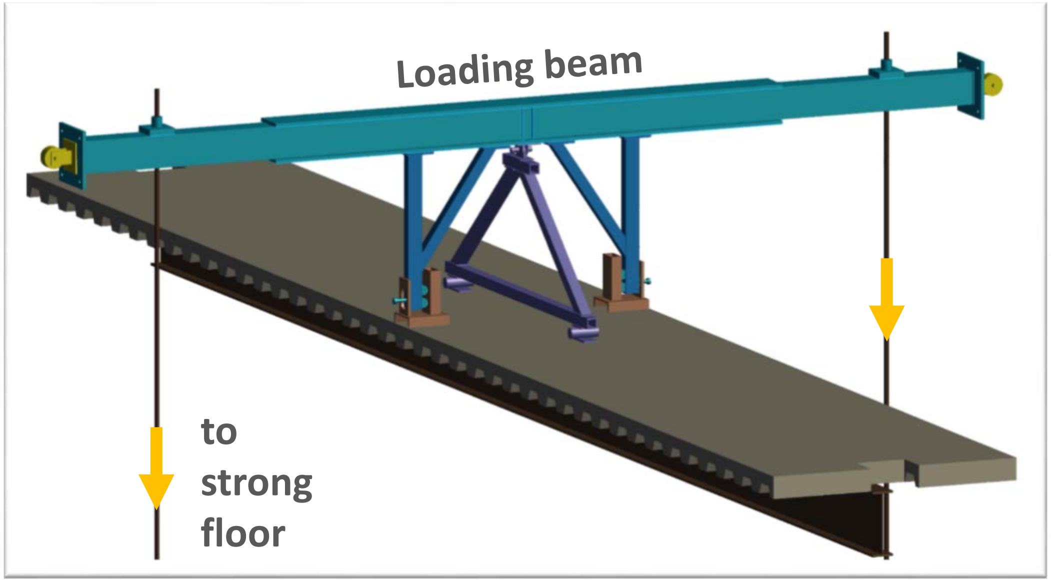
Challenge 1: Mechanical loading



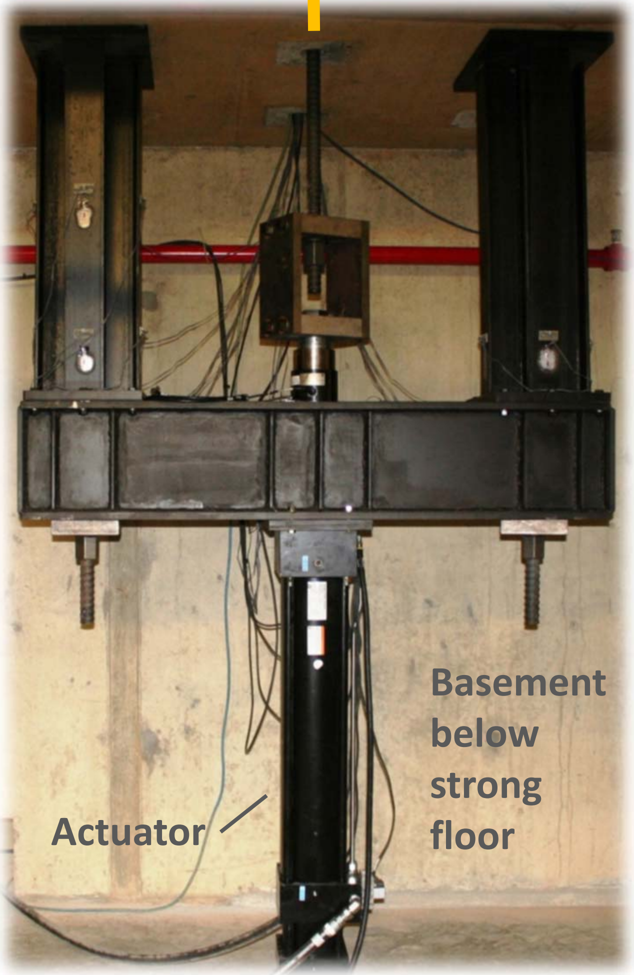
Renderings by Selvarajah Ramesh

Unique challenges of large-scale real-fire experiments

Challenge 1: Mechanical loading



Choe, L; Gross, J: "Introducing a new structural-fire testing capability at NIST and large-scale structural-fire experiments." *Fire Protection Engineering (FPE) magazine*, August, 2017.



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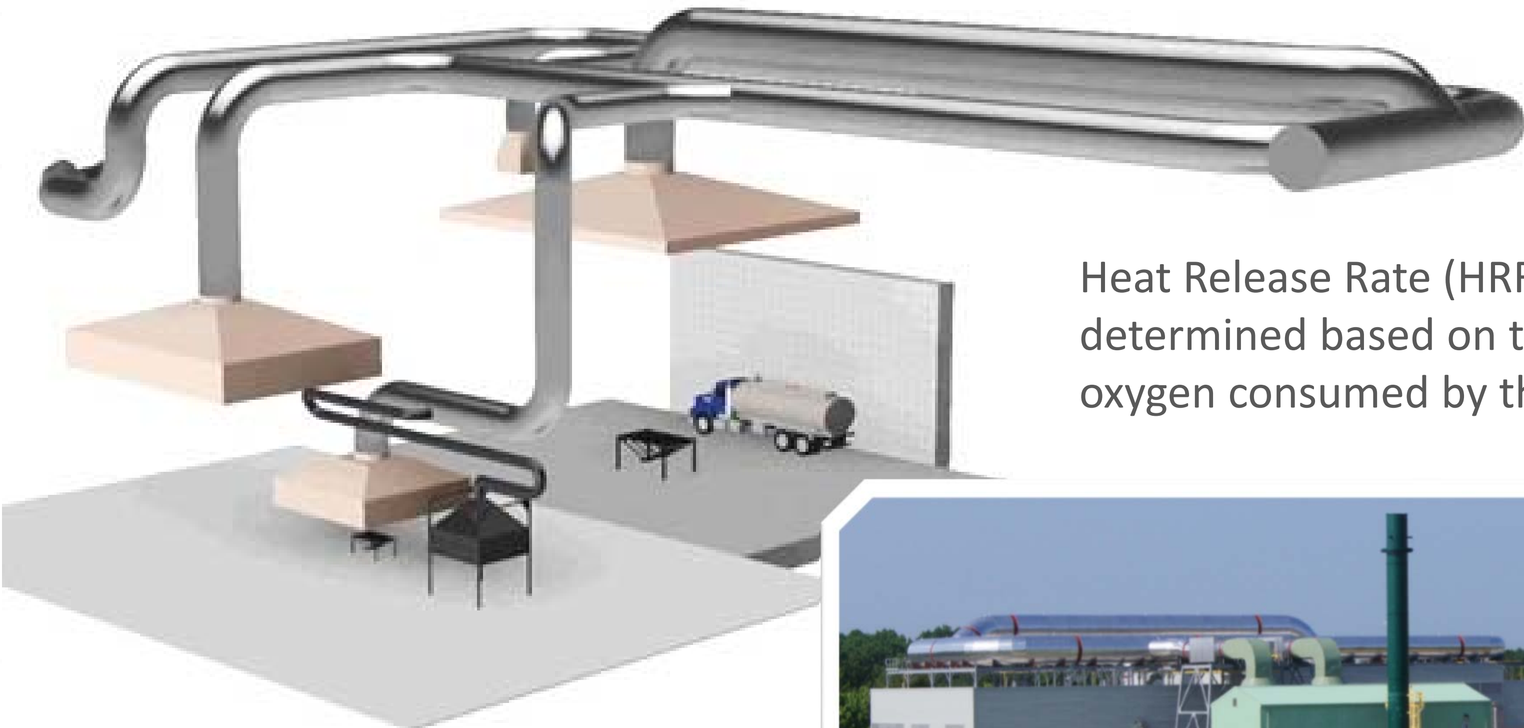
Unique challenges of large-scale real-fire experiments

Challenge 2: Thermal loading

Data overlay by Matthew Bundy

Unique challenges of large-scale real-fire experiments

Challenge 2: Thermal loading

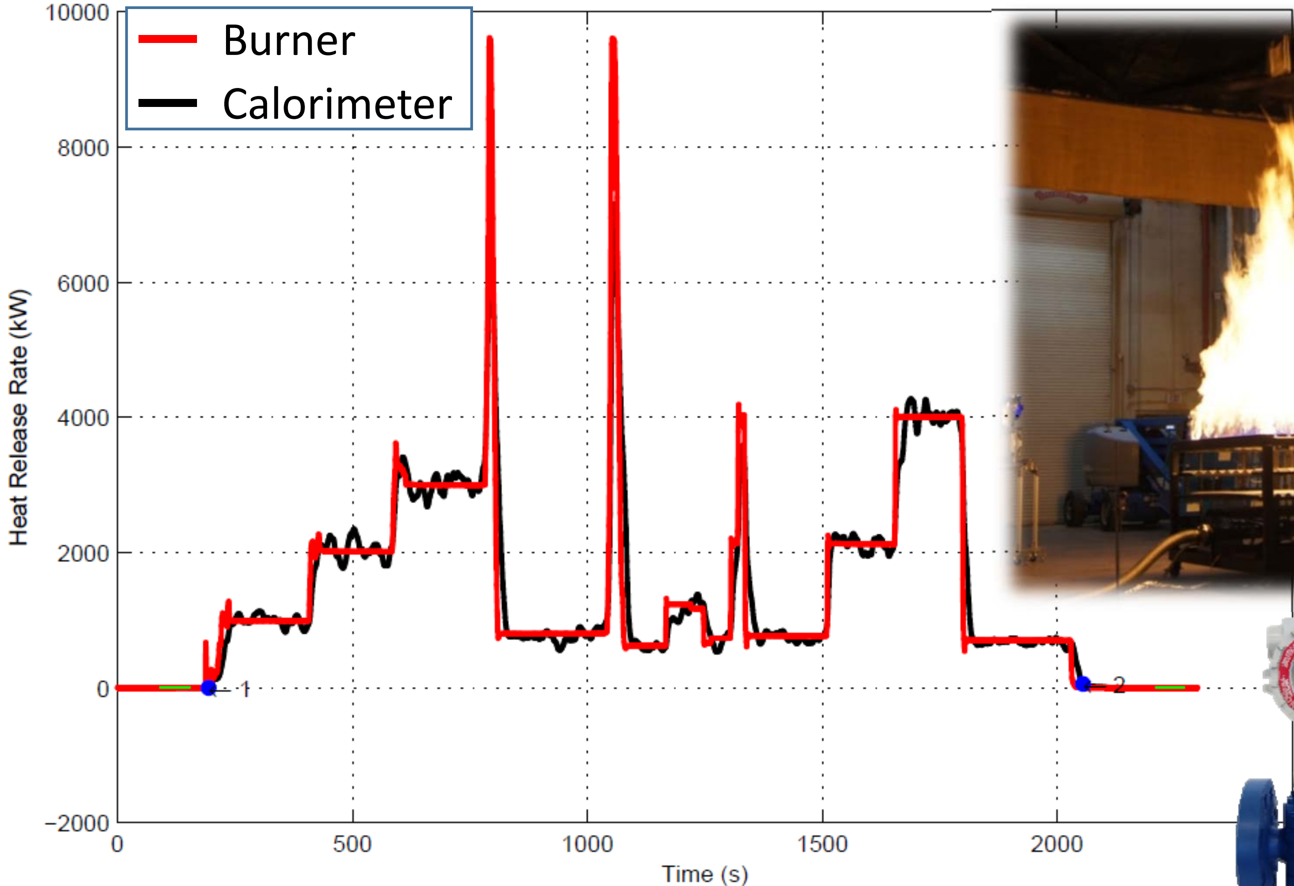


Heat Release Rate (HRR) is determined based on the oxygen consumed by the fire

Rendering by Greg Fiola

Unique challenges of large-scale real-fire experiments

Challenge 2: Thermal loading

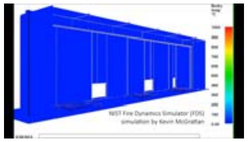


Mass flow

Gas composition

Unique challenges of large-scale real-fire experiments

Challenge 2: Thermal loading

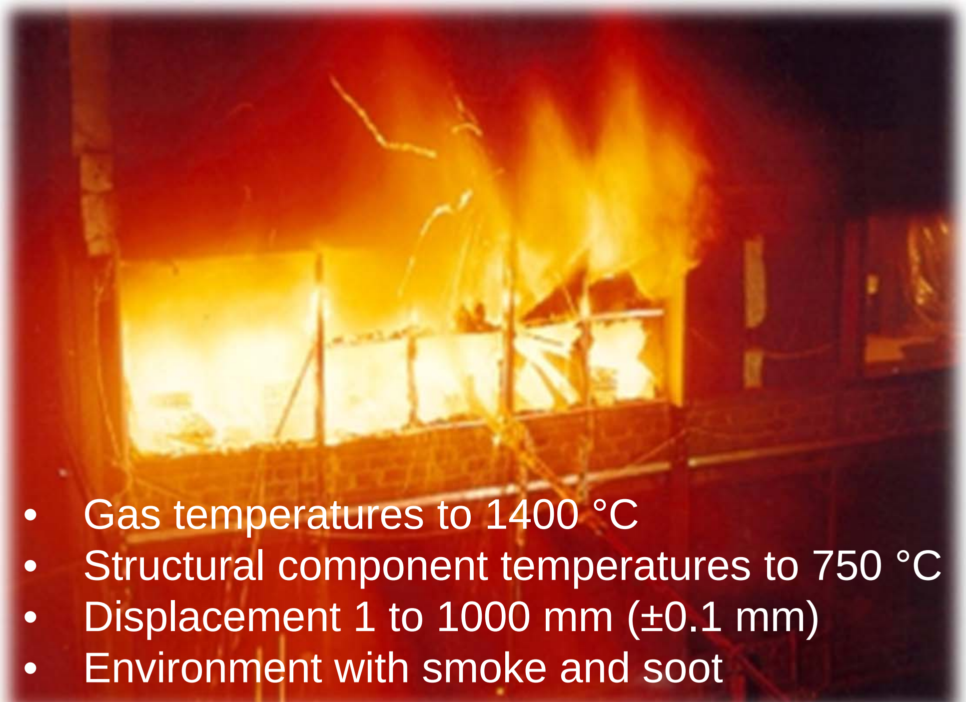


Simulation video

Flame balancing video

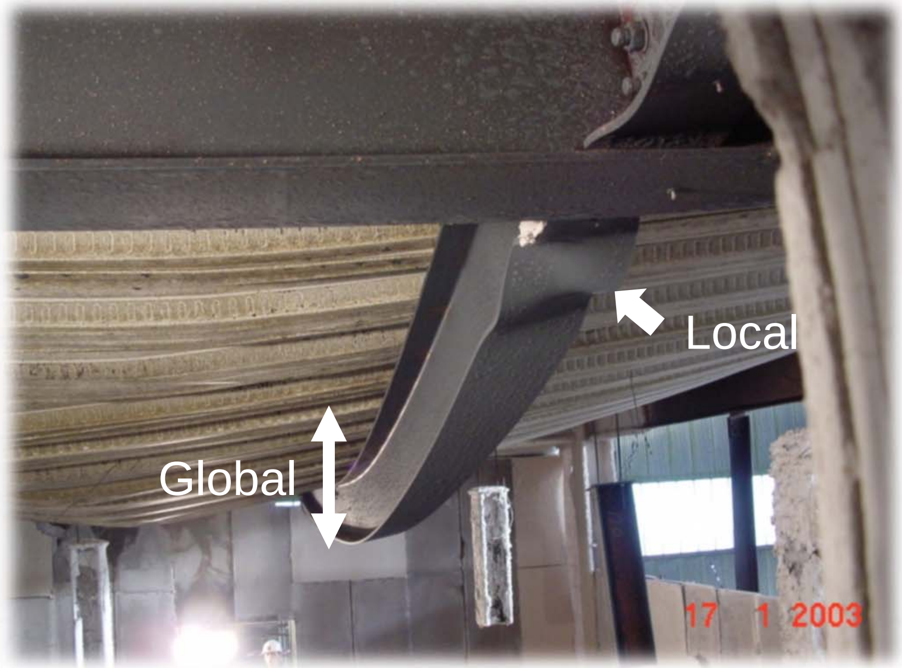
Unique challenges of large-scale real-fire experiments

Challenge 3: Metrology



- Gas temperatures to 1400 °C
- Structural component temperatures to 750 °C
- Displacement 1 to 1000 mm (±0.1 mm)
- Environment with smoke and soot

http://www.steelconstruction.info/Fire_testing



http://www.dec.uc.pt/~lborges/cardington/after/index39.htm

Need **accurate, reliable** and **repeatable**, measurement methods that work in a **hostile environment**

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Unique challenges of large-scale real-fire experiments

Challenge 3: Metrology

- Metrology
  - Structure
    - Force
    - Strain
      - Fiber optic sensors for strain and temperature
    - Displacement
      - Electromechanical displacement
      - Laser-based displacement
      - Imaging through fire and DIC
    - Material temperature
  - Fire
    - Heat release rate
    - Gas temperature
    - Heat flux
    - Chemical species
    - Parameters related to fire growth and spread

Unique challenges of large-scale real-fire experiments

Challenge 3: Metrology

Challenges

1. Thermal radiation
2. Signal distortion by hot gases
3. Smoke and soot

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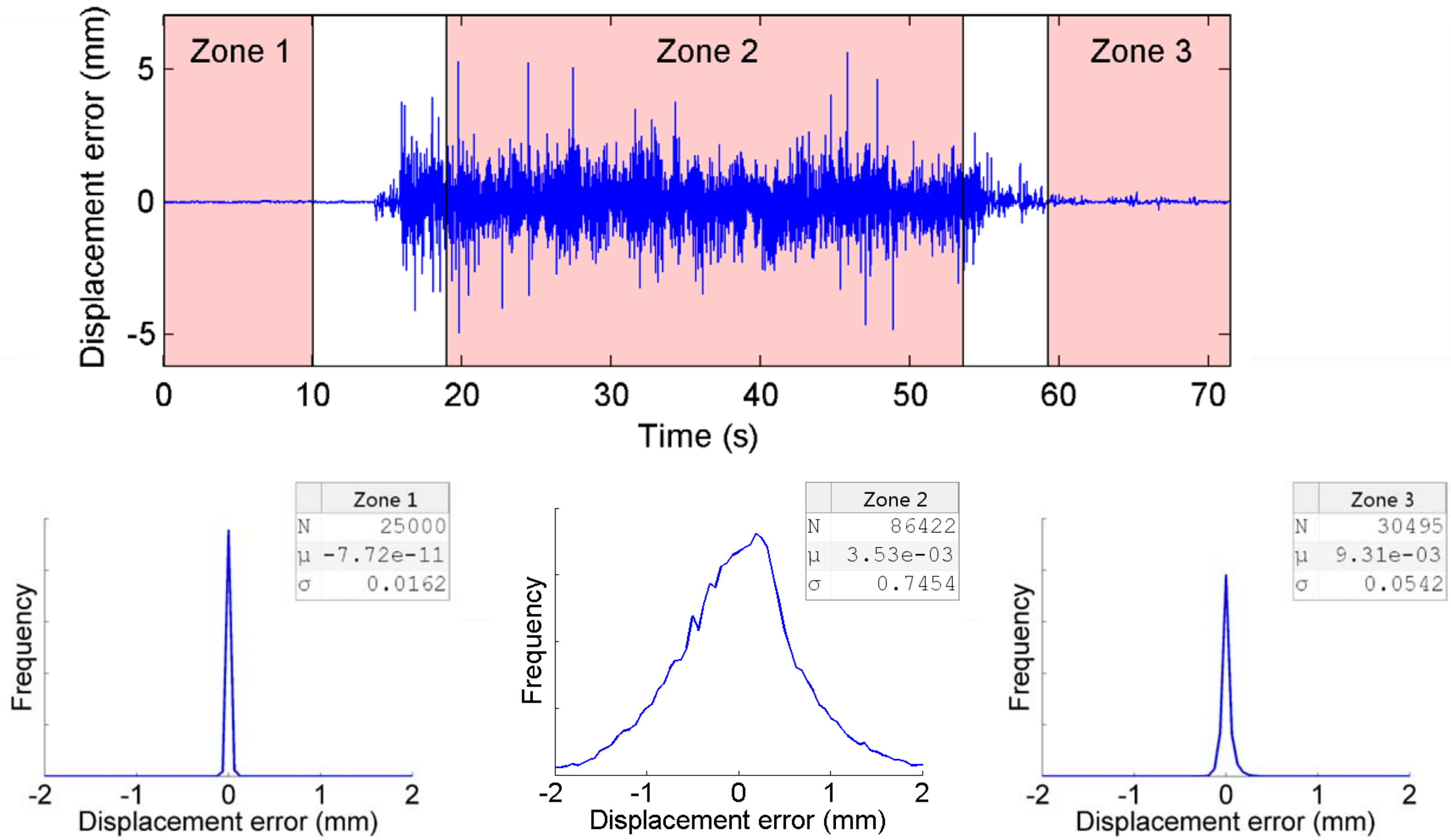
Unique challenges of large-scale real-fire experiments

Challenge 3: Metrology



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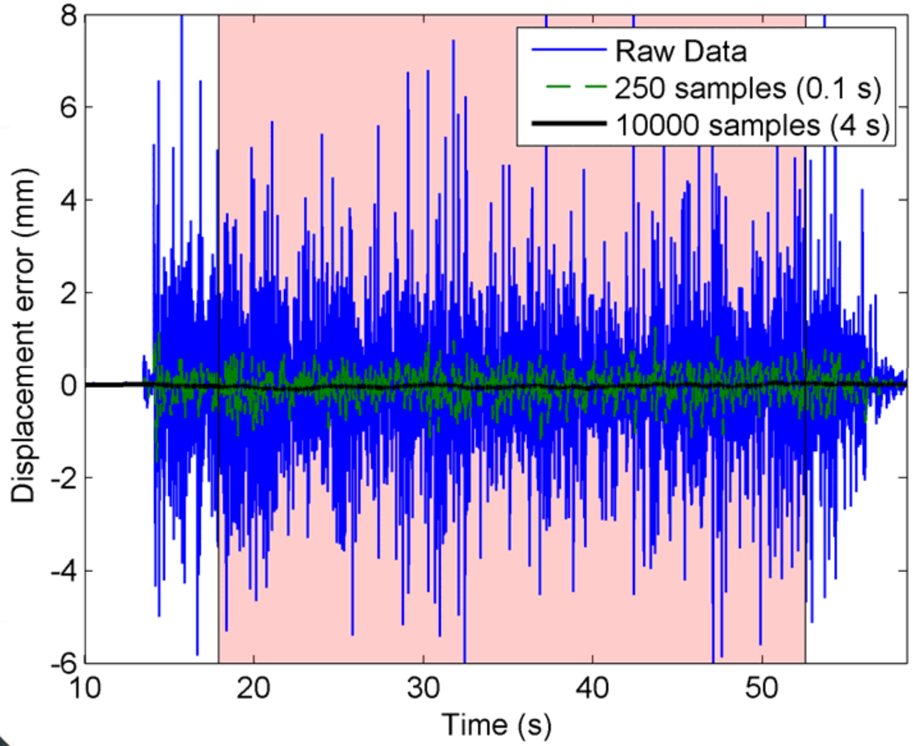
Challenge 3: Metrology



	Displacement error, mm		
	Downsampled (50 Hz)		
Window samples (N_w)	None	5	200
Window duration (t_w), sec		0.1	4.0
Mean (μ)	-0.007	-0.009	-0.016
Standard deviation (σ)	1.023	0.449	0.050
l Maximum l	6.725	2.425	0.147
Combined uncertainty (u_c)	1.023	0.450	0.058

Hoehler, M. S.; Smith, C. M.: "Application of Blue Laser Triangulation Sensors for Displacement Measurement Through Fire." *Measurement Science and Technology*, 27(11) 2016.

engineering laboratory

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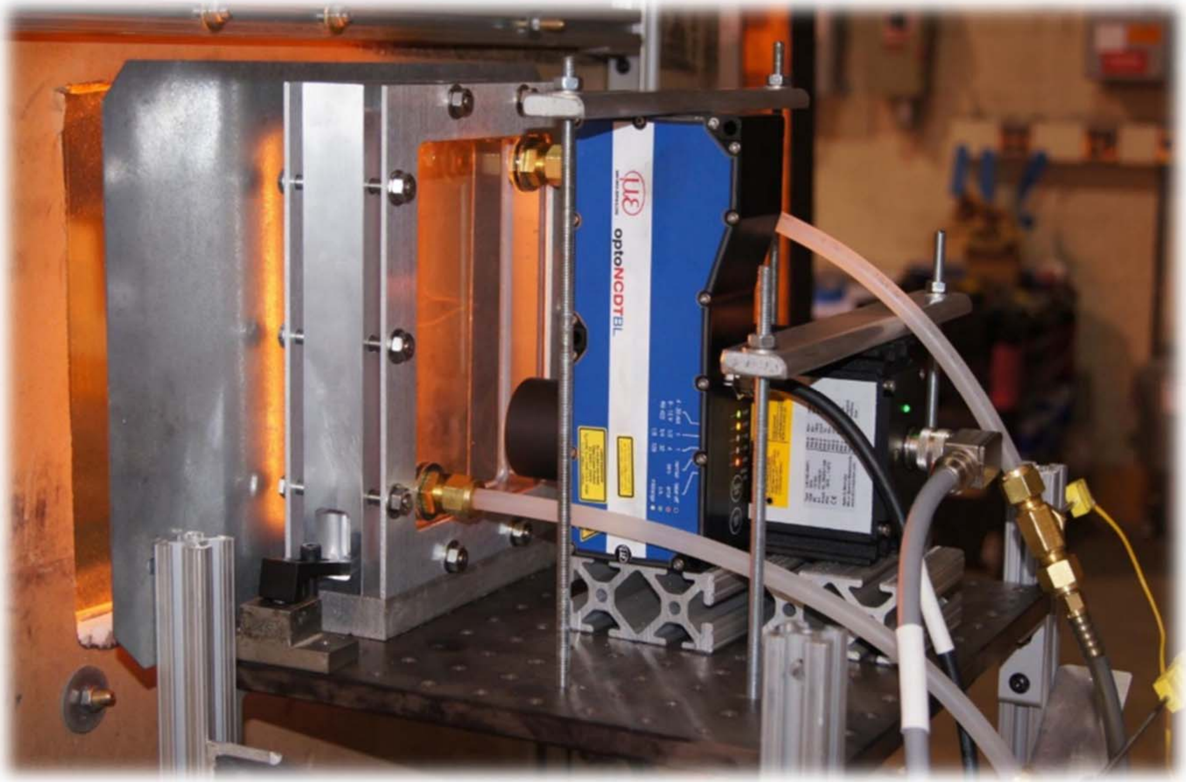
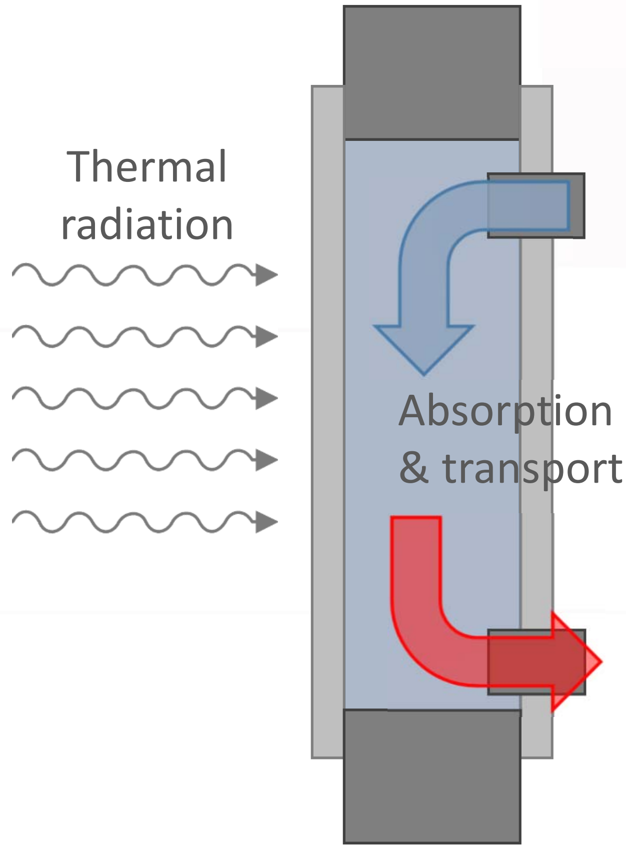
Unique challenges of large-scale real-fire experiments

Challenge 3: Metrology





Unique challenges of large-scale real-fire experiments

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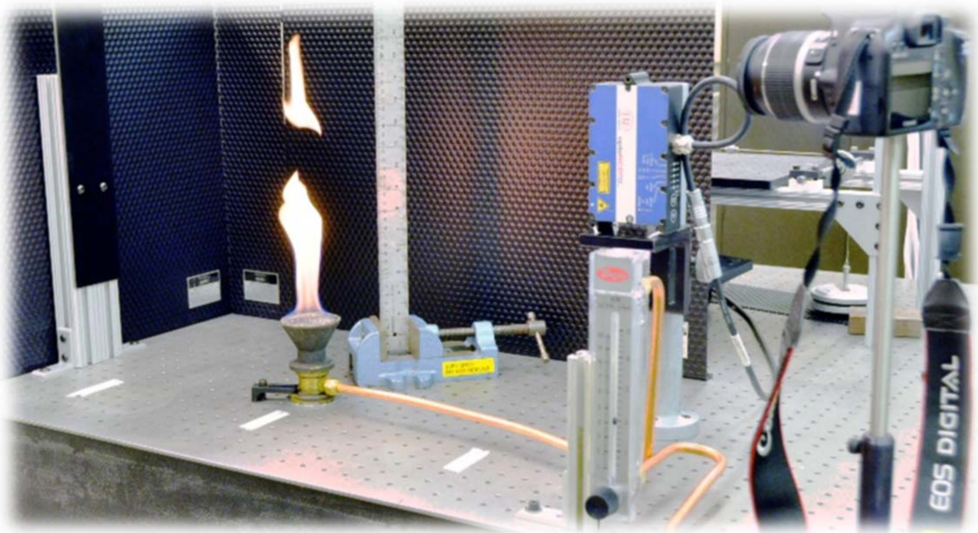

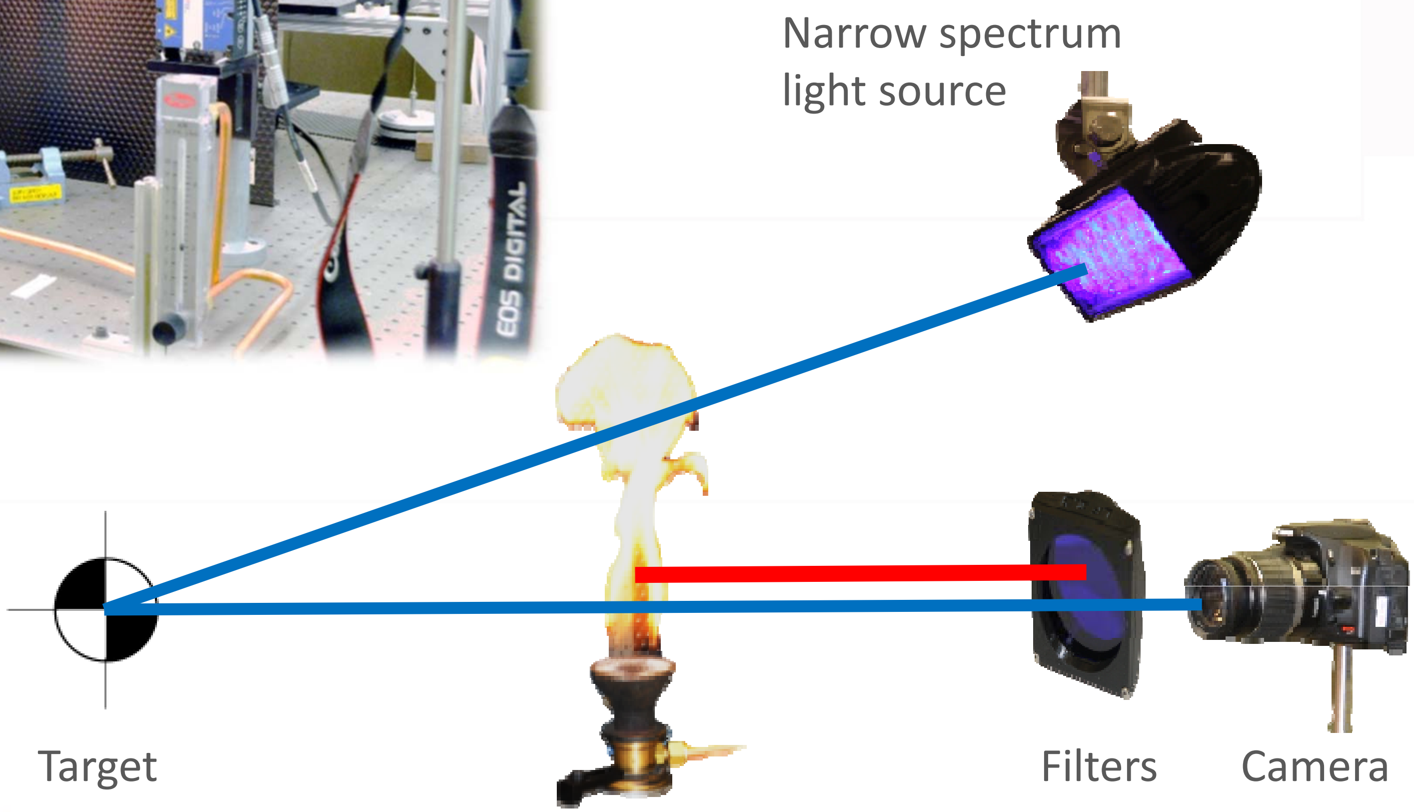

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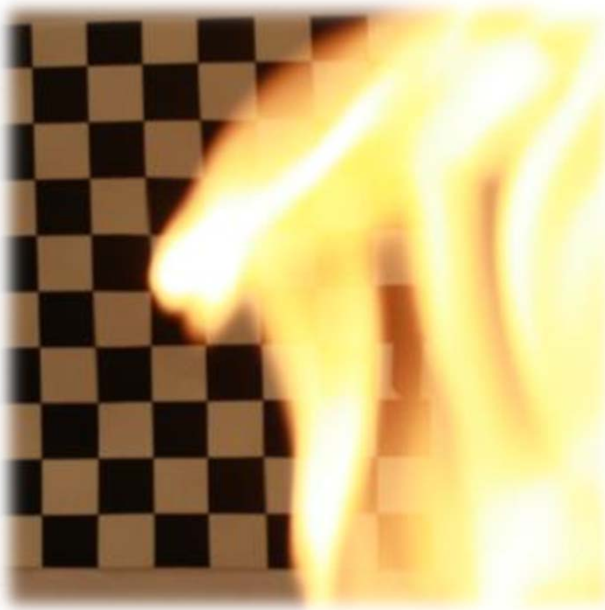
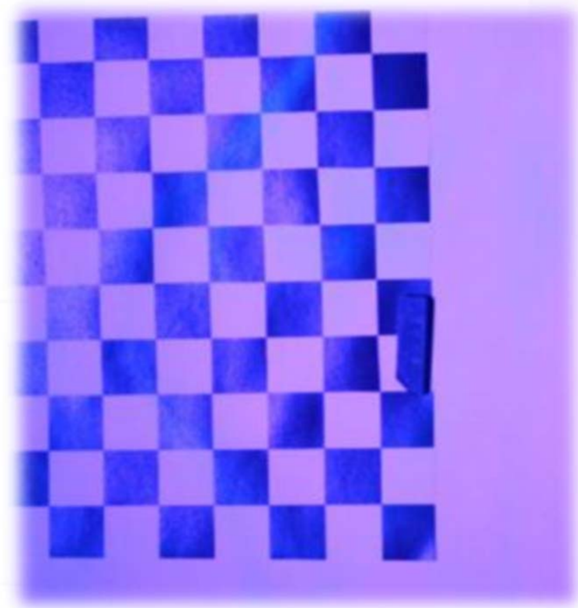
Challenge 3: Metrology



Target obstructed

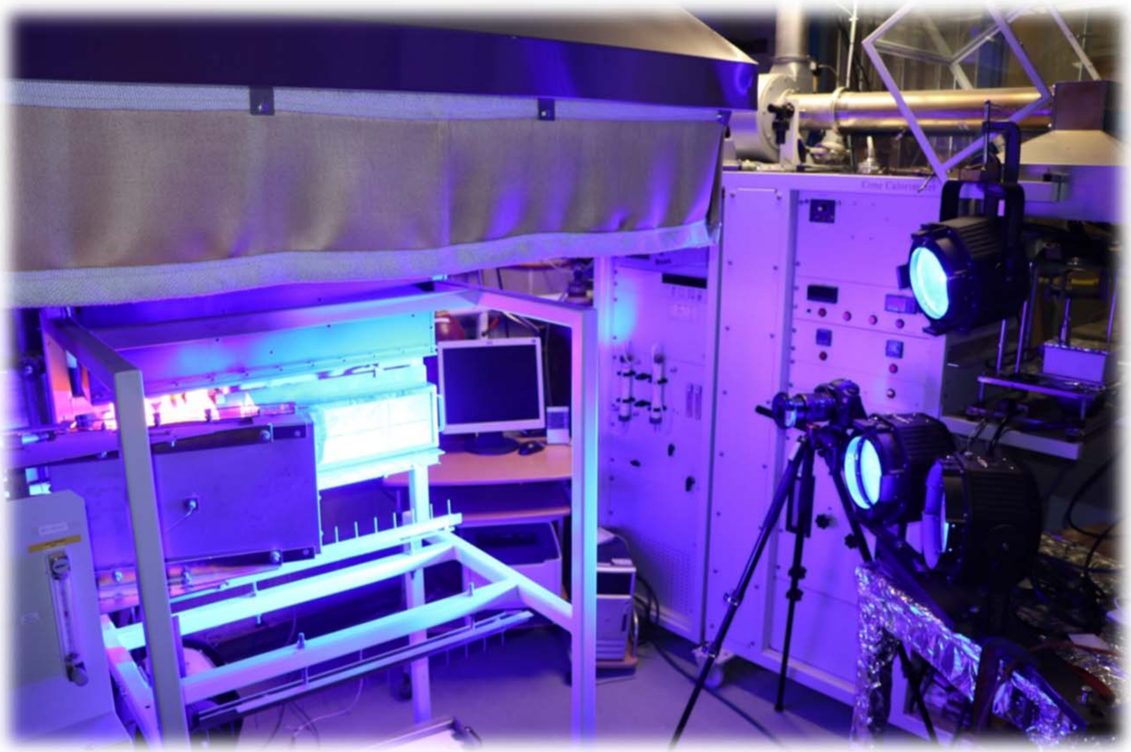
Addition of blue 450nm light

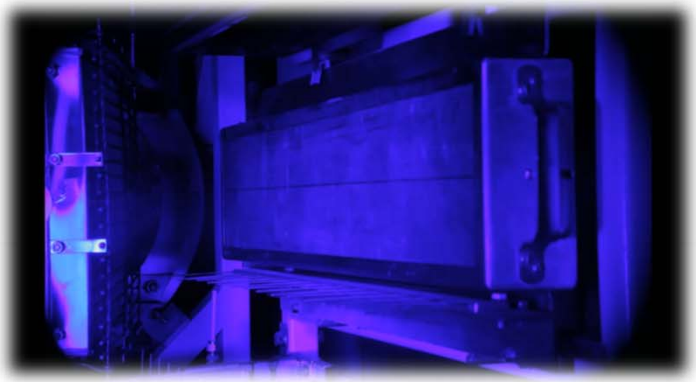


Red light removed with narrow band filter

Unique challenges of large-scale real-fire experiments

Challenge 3: Metrology





Collaboration with John Gales

Carleton UNIVERSITY

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engineering laboratory

Steel-Sheathed Shear Walls: Seismic and Fire Loads

To experimentally determine the influence of a specific fire load on the lateral load resistance of steel-sheathed cold-formed steel shear walls

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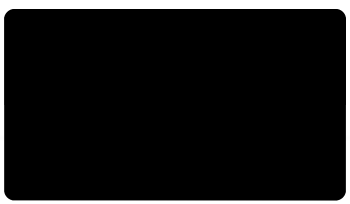
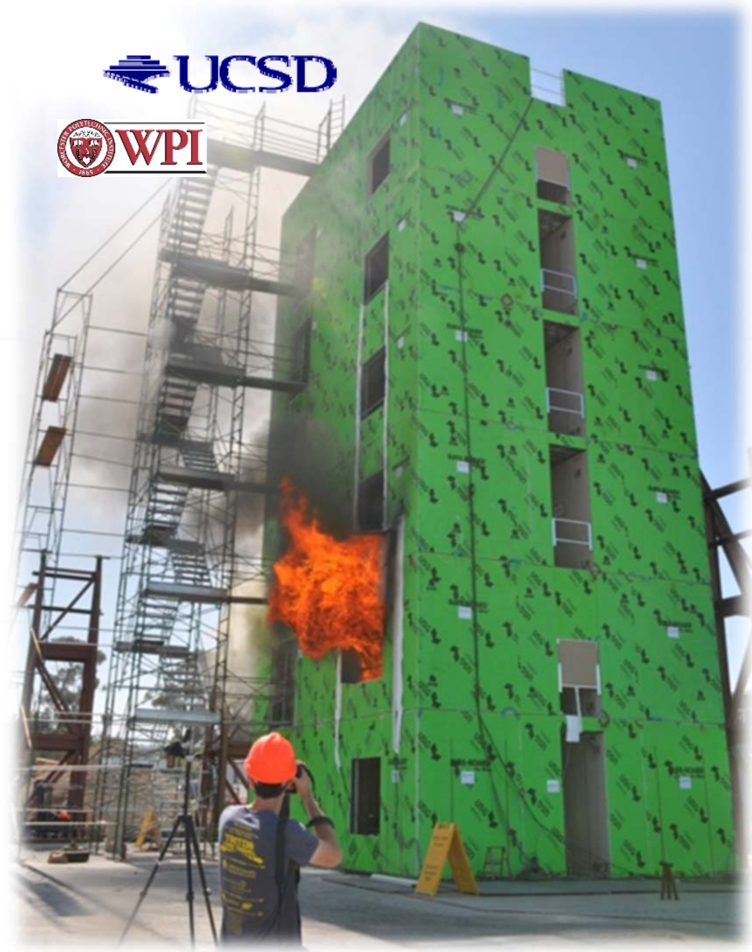
- Simulate corridor of UCSD building
- Varied sequence of mechanical and fire loading
- Compressed timeframe (6 weeks start-to-finish)



UCSD construction time lapse

UCSD Testing sequence



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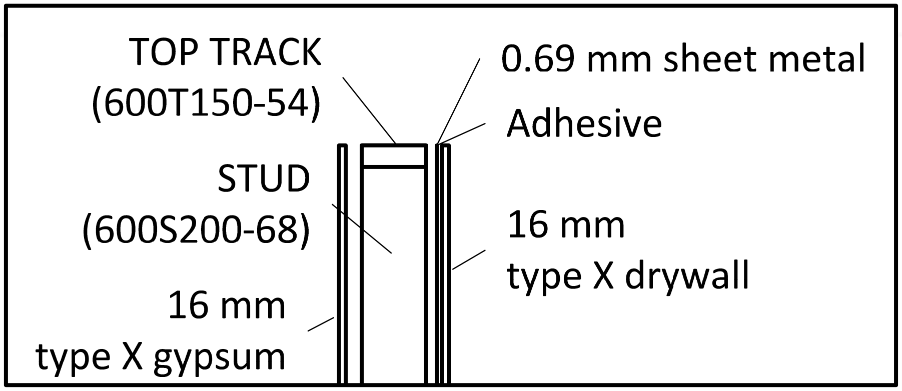
Steel-Sheathed Shear Walls: Seismic and Fire Loads

Test specimens: 2.7 m × 3.7 m



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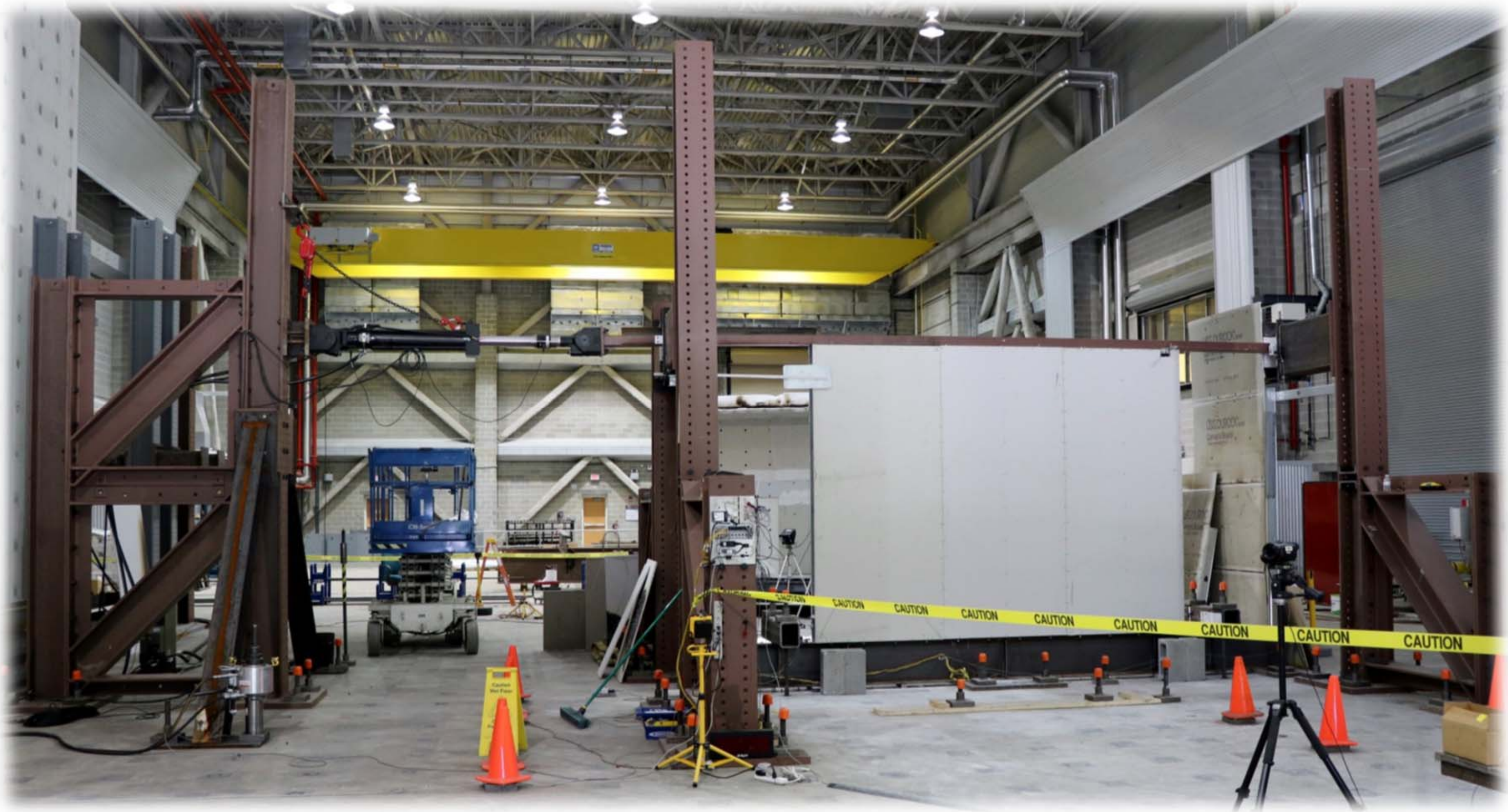
Steel-Sheathed Shear Walls: Seismic and Fire Loads

Mechanical loading setup



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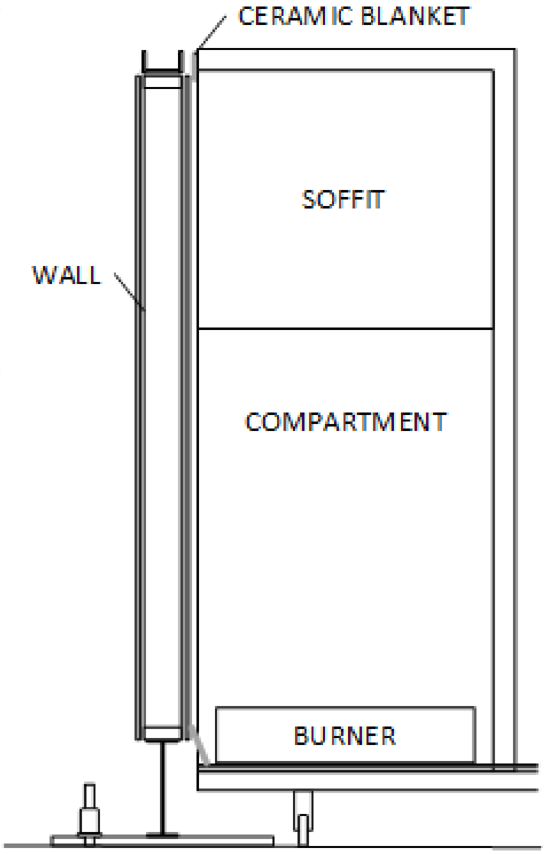
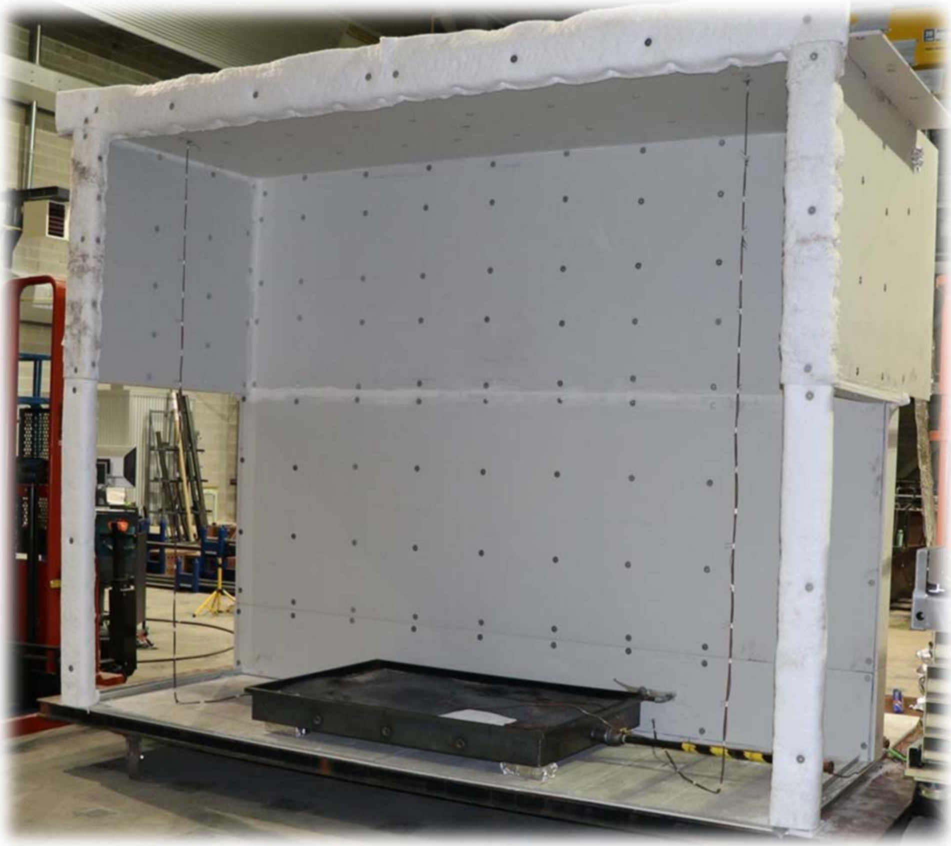
Steel-Sheathed Shear Walls: Seismic and Fire Loads

Thermal loading setup

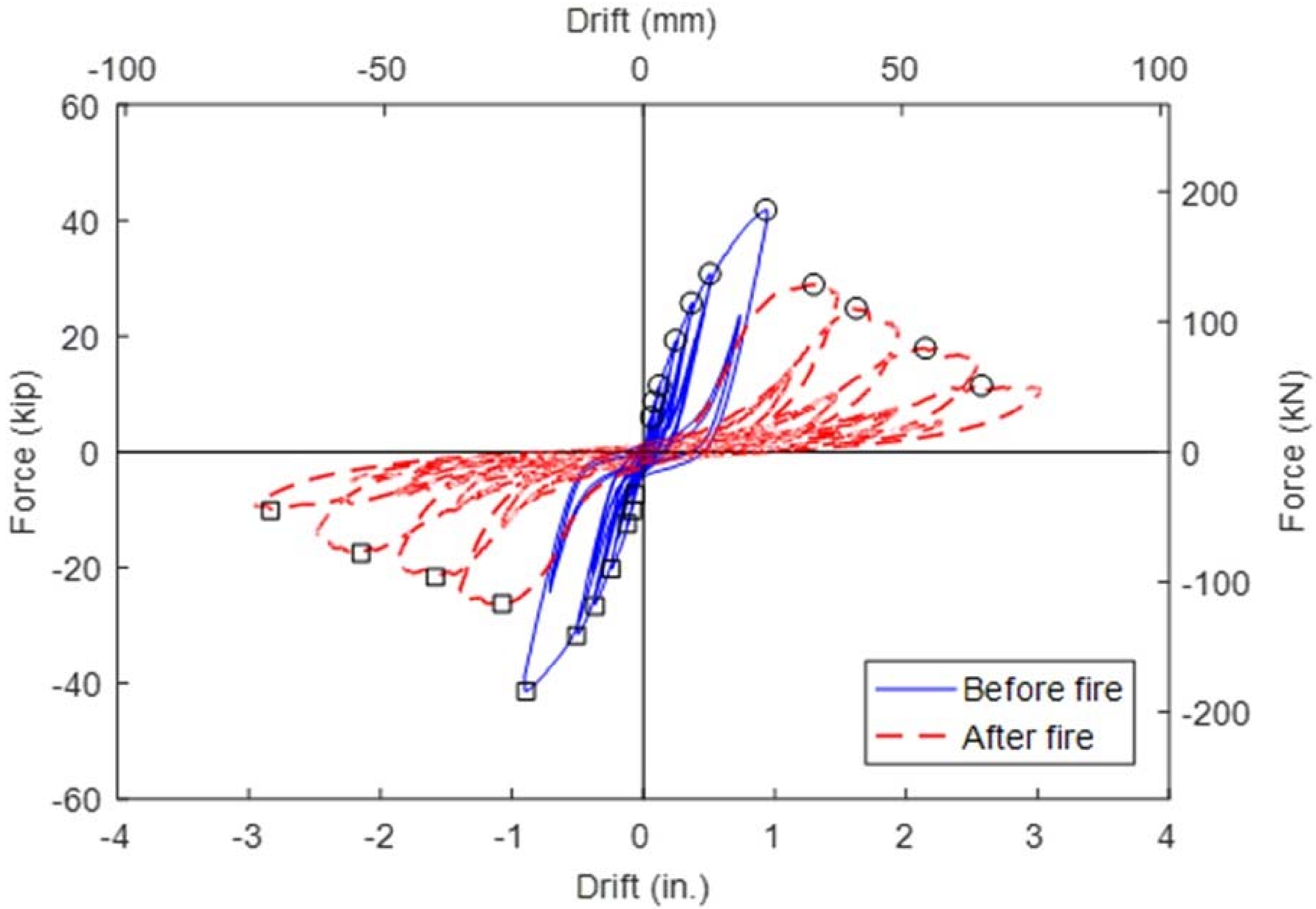




Steel-Sheathed Shear Walls: Seismic and Fire Loads

Test CFS03 (cycle to 1 % → burn → cycle to 3 %)

Video



Steel-Sheathed Shear Walls: Seismic and Fire Loads

Shift of failure mode from local buckling to global buckling

Test CFS02
(cycle to 3 % w/o burn)

Test CFS03
(cycle to 1 % → burn → cycle to 3 %)

Hoehler, M. S.; Smith, C. M.; Hutchinson, T. C.; Wang, X.; Meacham, B. J.; Kamath, P.:
"Behavior of steel-sheathed shear walls subjected to seismic and fire loads." *Fire Safety Journal*, Volume 91, 2017, Pages 524-531.

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Fire Safety Challenges of Tall Wood Buildings

To quantify the contribution of cross-laminated timber building elements to compartment fires with varied ventilation, encapsulation and exposure

Image: kihusa.com

RESEARCH FOUNDATION

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www.woodusematrix.com

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Fire Safety Challenges of Tall Wood Buildings

No sprinkler system… No firefighting intervention until end of tests

Structure

- 9.1 m x 4.6 m x 2.7 m compartments (studio apartment)
- 175-mm thick 5-ply CLT structural panels (35 mm per ply)
- Multiple layers of 15.9 mm (5/8 in.) Type X gypsum board for full or partial encapsulation

Ventilation

- 1.8 m x 2.0 m opening (4 tests)
- 3.6 m x 2.0 m opening (2 tests)
- Leakage area to simulate door

Structural Load

- 20 psf (0.96 kN/m^2)

Fire Safety Challenges of Tall Wood Buildings

Compartment construction

Fire Safety Challenges of Tall Wood Buildings

View of a furnished compartment & instrumentation

Fire Safety Challenges of Tall Wood Buildings

Test 1-1: Narrow opening; no exposed CLT (reference)

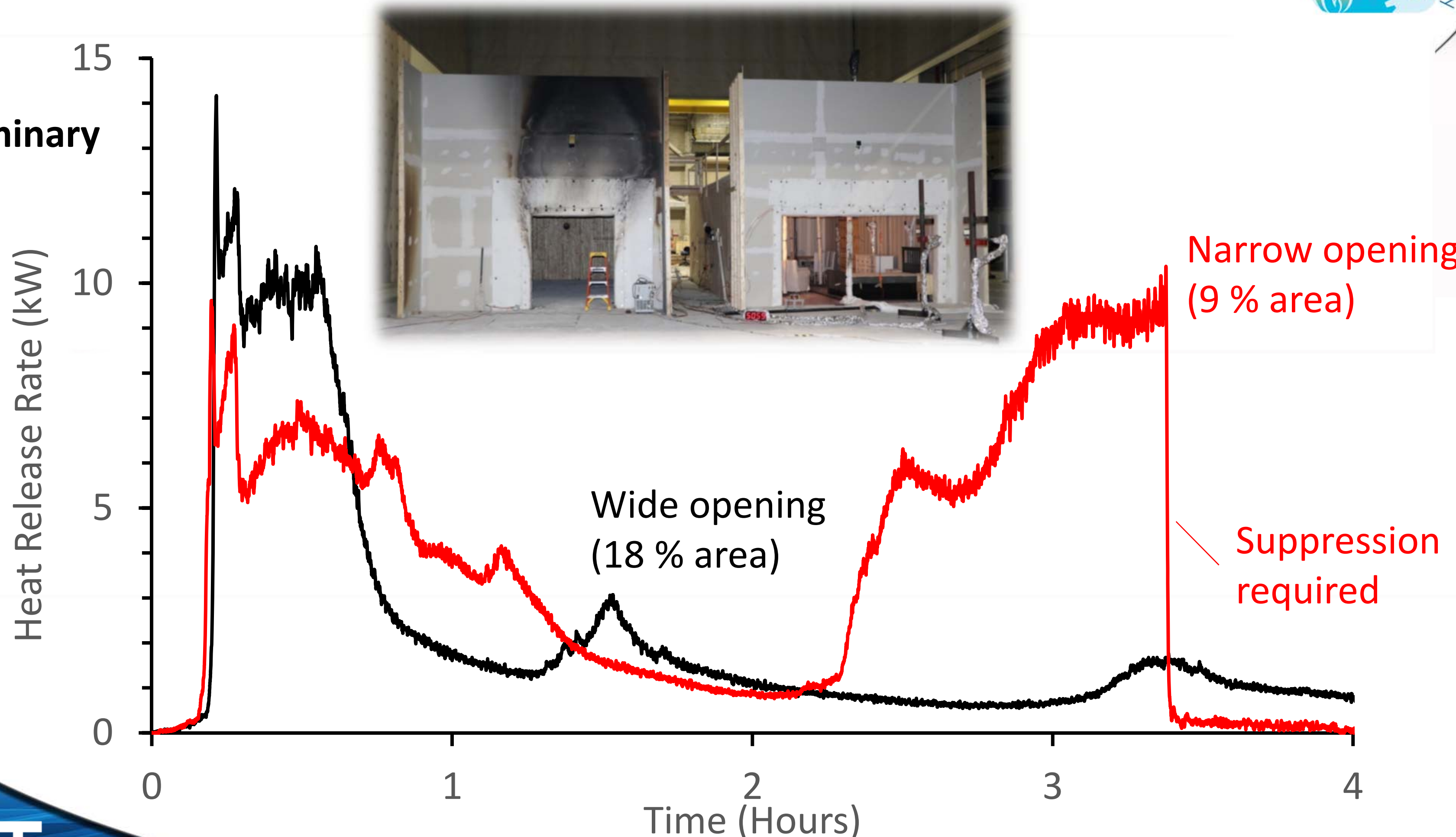
Fire Safety Challenges of Tall Wood Buildings

Test 1-3: Wide opening; exposed wall

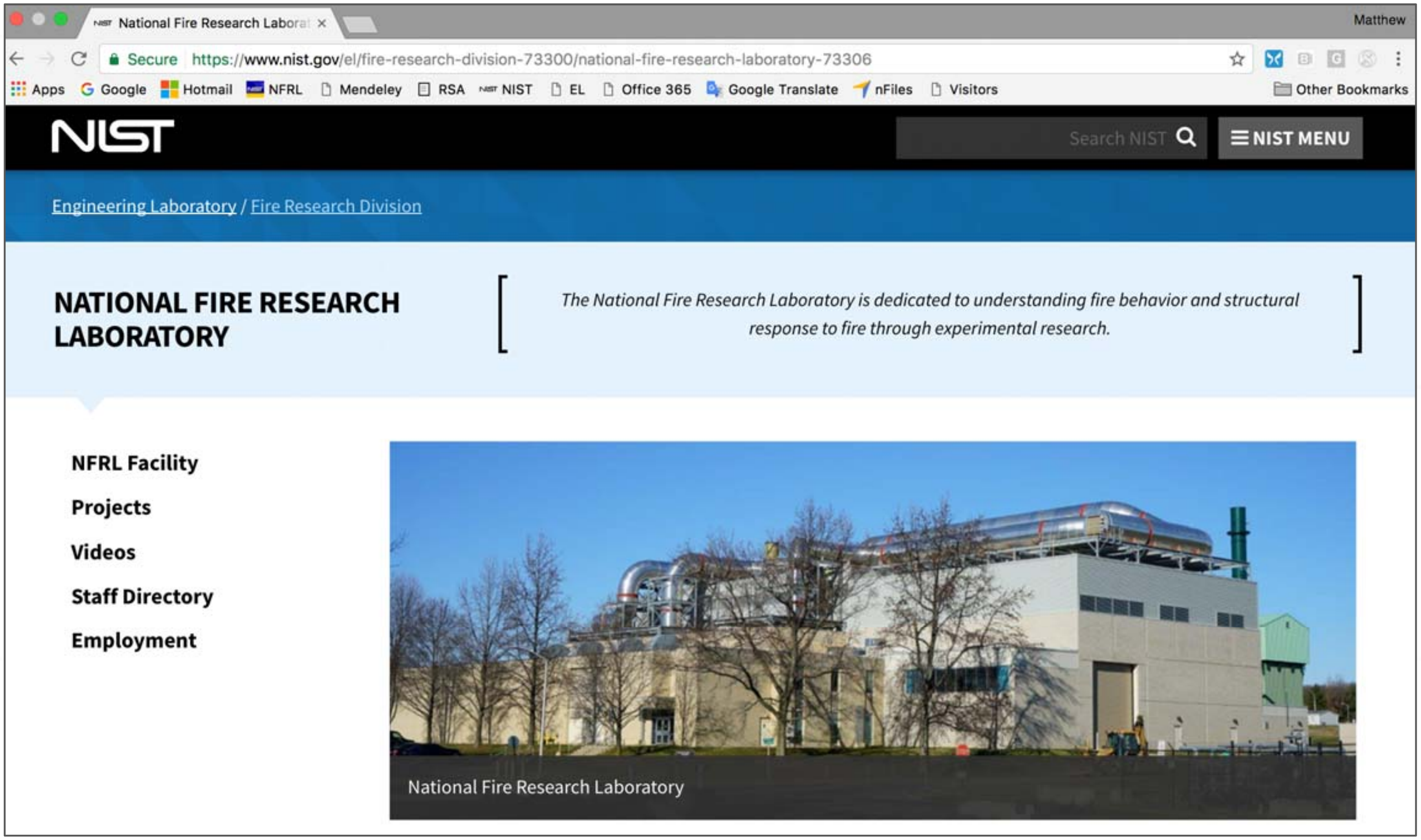
Fire Safety Challenges of Tall Wood Buildings

Heat release rate comparison for one exposed wall

Preliminary data



www.nist.gov



matthew.hoehler@nist.gov

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