Laterally loaded light timber frame fire experiments

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Background

Stability of External Walls in Single-Storey Buildings

- Protection of firefighters
  - Outside a building due to failure of walls
  - Inside the building, during and after fire-fighting
- Protection of neighbouring property
  - Wall collapse could damage adjacent property

New Zealand Building Code (NZBC) requirements

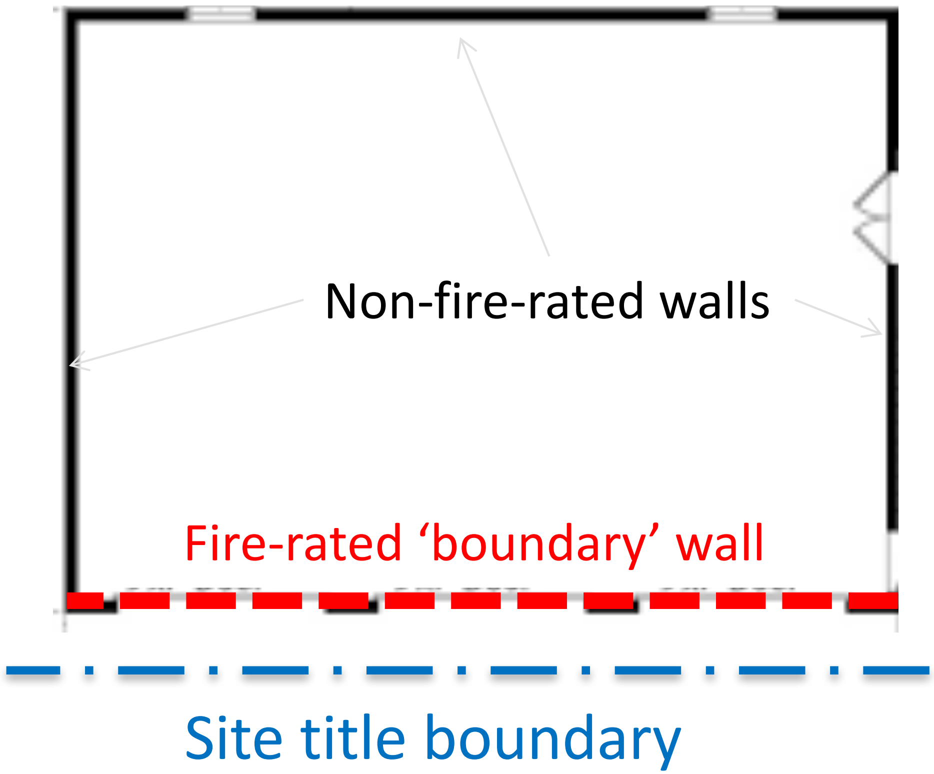
- Exterior walls must have stability during and after fire
- Prevention of collapse, outwards and inwards
- All materials (concrete, masonry, light timber, light steel)

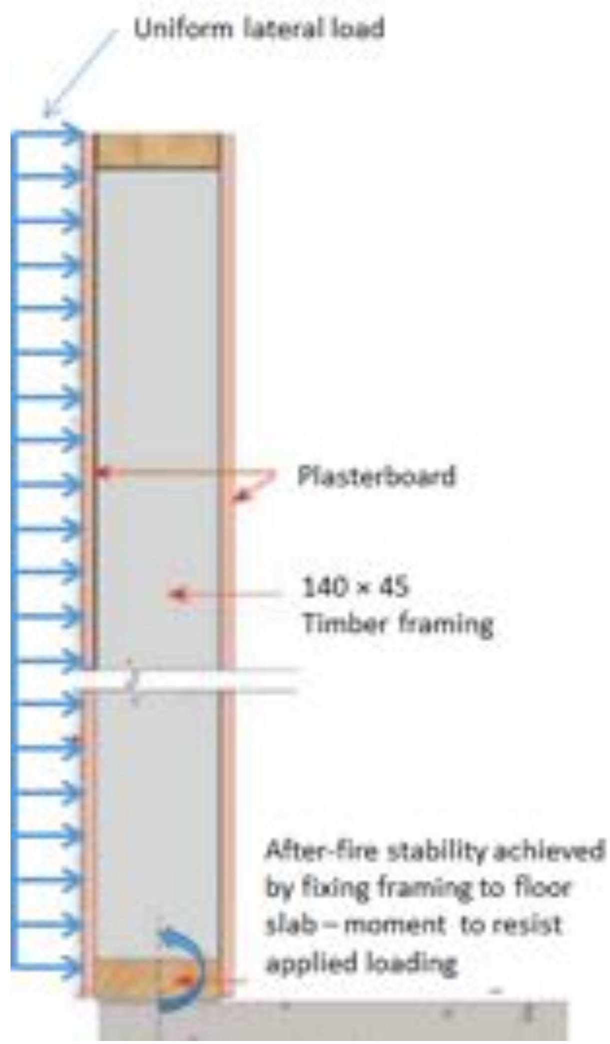
Background

NZBC – Residential buildings

Walls within 1 metre of boundary require fire-rating

Walls must remain standing with 0.5 kPa lateral load (≈ 100 km/h wind)



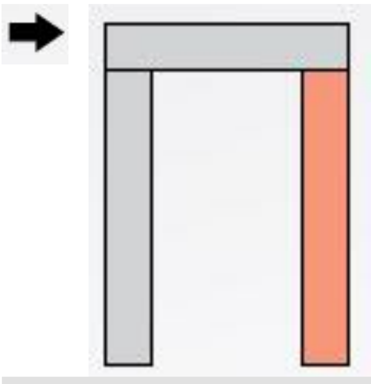


Assumed non-fire-rated elements do not provide support to fire-rated elements. Fire-rated external walls of single-storey buildings designed to be self-supporting with full base-fixity

Background

Before Fire

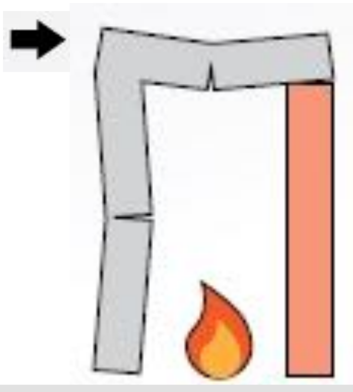
- Stability achieved by support from walls and roof structure
- Normal design loads (wind, earthquake) are greater than 0.5 kPa after-fire load



Wall supported by non fire rated structure

During Fire

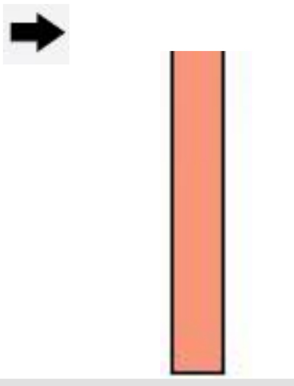
- Wall & ceiling plasterboard linings fail
- Timber framing exposed directly to fire, charring occurs, reducing strength



Wall supported by degraded structure

After Fire

- Only fire-rated elements remain
- Lateral 0.5 kPa load applied to external wall. Assume that wall linings are intact.



One wall only remaining

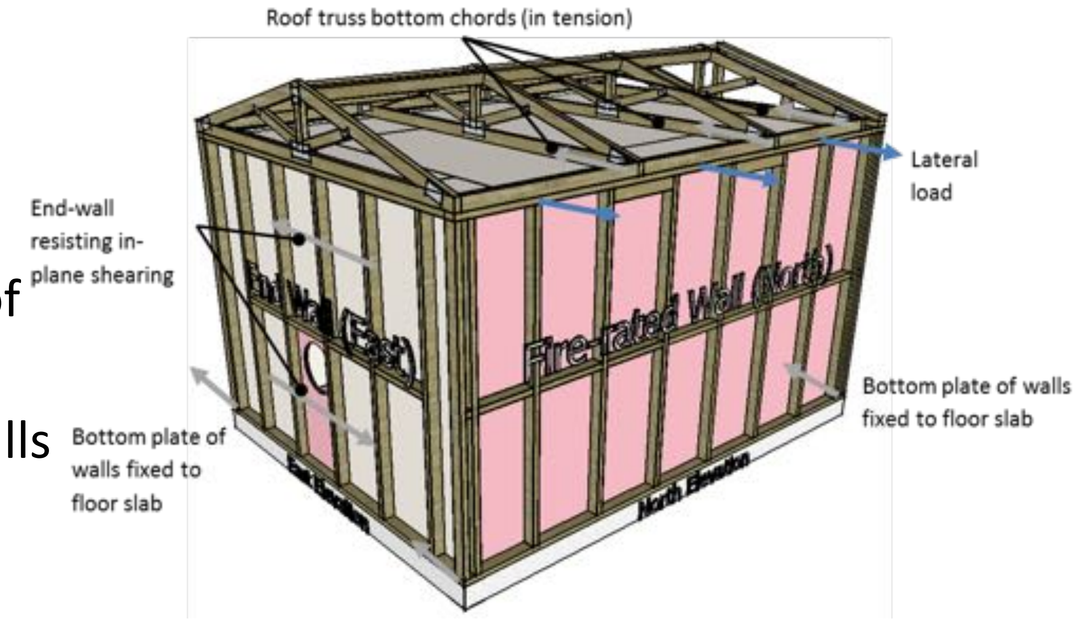
Research question

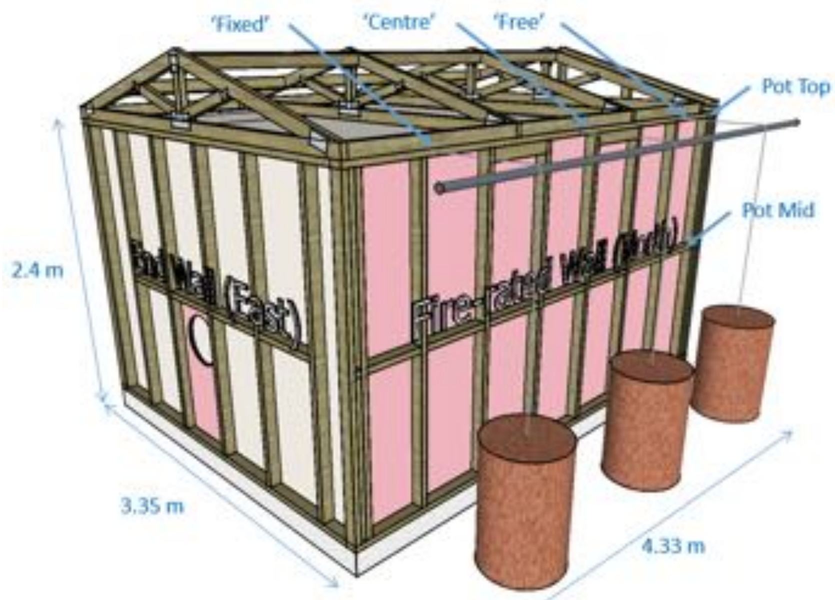
- For a light timber frame building can the non-fire-rated walls & roof provide lateral load resistance for the duration required by NZBC (i.e. 30-min FRR)?

- Two full-scale experiments
  - Horizontal furnace test to ISO 834 / AS 1530.4
  - Natural fire experiment
- B-RISK modelling
  - Design of natural fire experiment
  - Post-experiment comparison

Test specimen

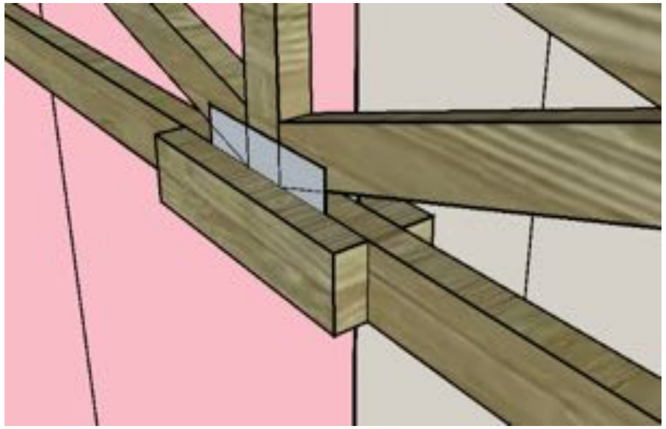
- Lateral restraint provided by non-fire-rated building elements
  - Lateral load resisted by roof truss
  - Load transferred to end walls
- Compartment
  - Dimensions: 4.3 m × 3.3 m, stud height 2.4 m
  - Wall studs: 90 mm × 45 mm timber
  - 30-min firewall using 10 mm fire-rated plasterboard both sides
  - Other walls and ceiling lined with 10 mm standard plasterboard





Test specimen

- Larger compartment represented by
  - Not fixing one end of the FRR-wall to the perpendicular wall
  - Using a splice in the roof truss, unprotected in the furnace experiment but protected in the natural fire



Furnace test

- Approx. 16 minutes – ceiling system fails and falls into furnace

Set-up

End wall, 16 minutes

End wall, 19 minutes

Furnace test

- 20 minutes – evidence of wall lining failure
  - Small deflections in fire-rated wall
  - Furnace pressure reduced, to clear smoke
- 25 minutes – notable deflection in firewall
- 30.5 minutes – Run-away deflection, furnace shut-off

Furnace test

After fire - roof sagging, no support from roof truss

Views inside the compartment

- Failure of spliced connection
- Roof sagging, no support from roof truss
- Walls remain upright (note: no lateral load)

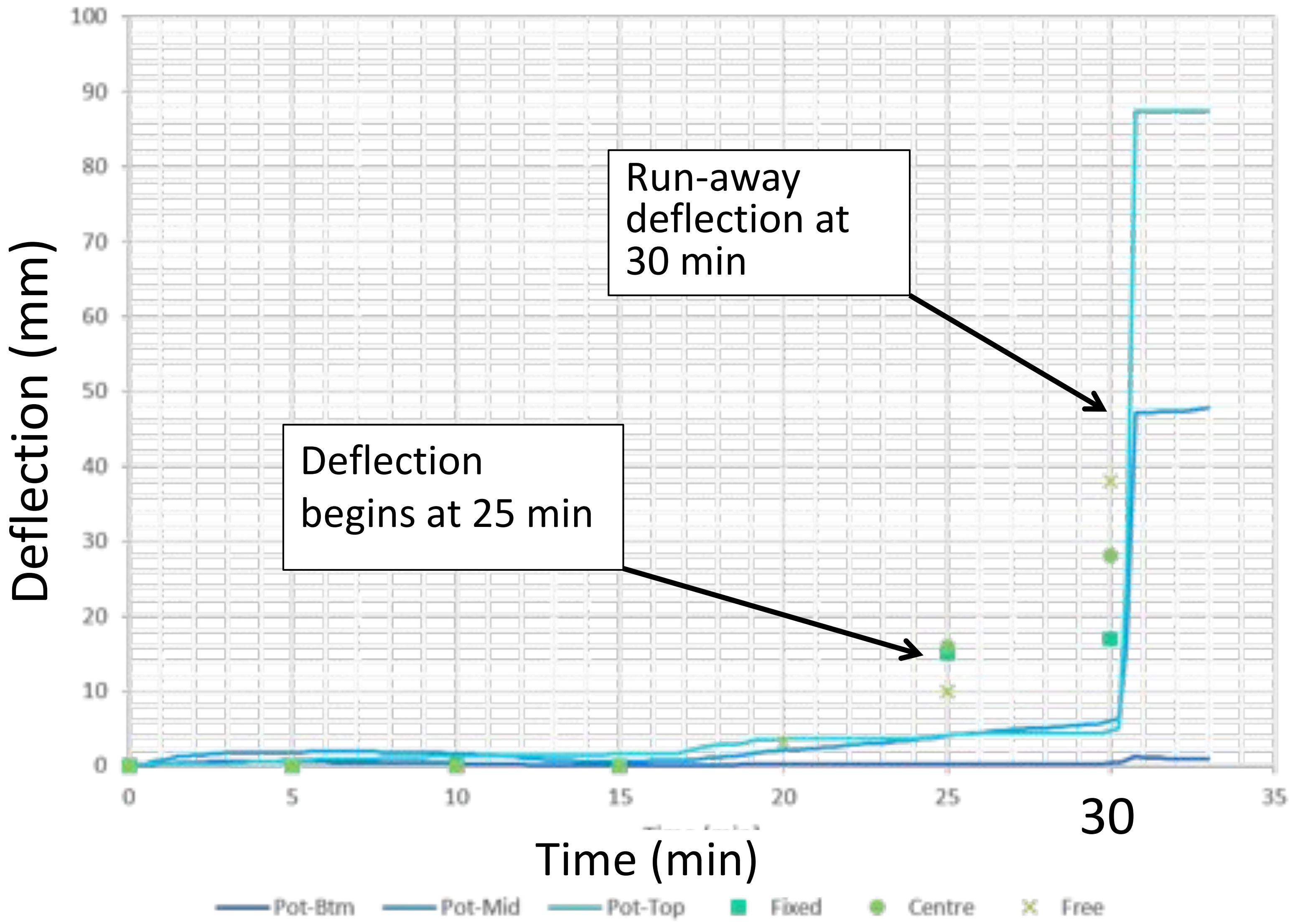
‘Centre’ roof truss

‘Free’ roof truss

‘Fixed’ roof truss

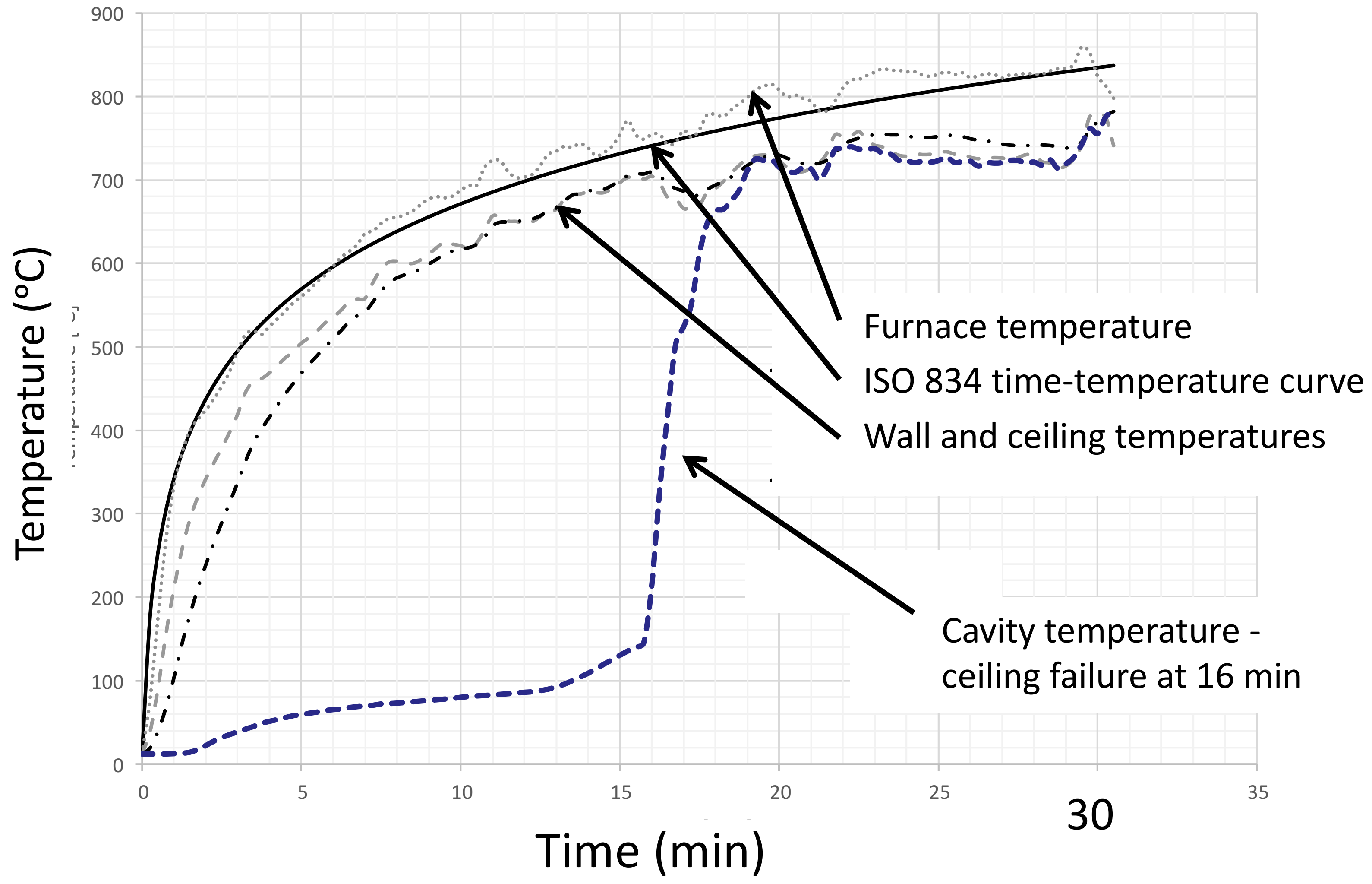
Furnace test

Deflections



Furnace test

Temperatures



Natural fire experiment

Ignition of cribs, t = 0 min

Fire growth, t ≈ 3 min

t ≈ 5 min

Natural fire experiment

Approx. time of ceiling failure, t ≈ 13 min

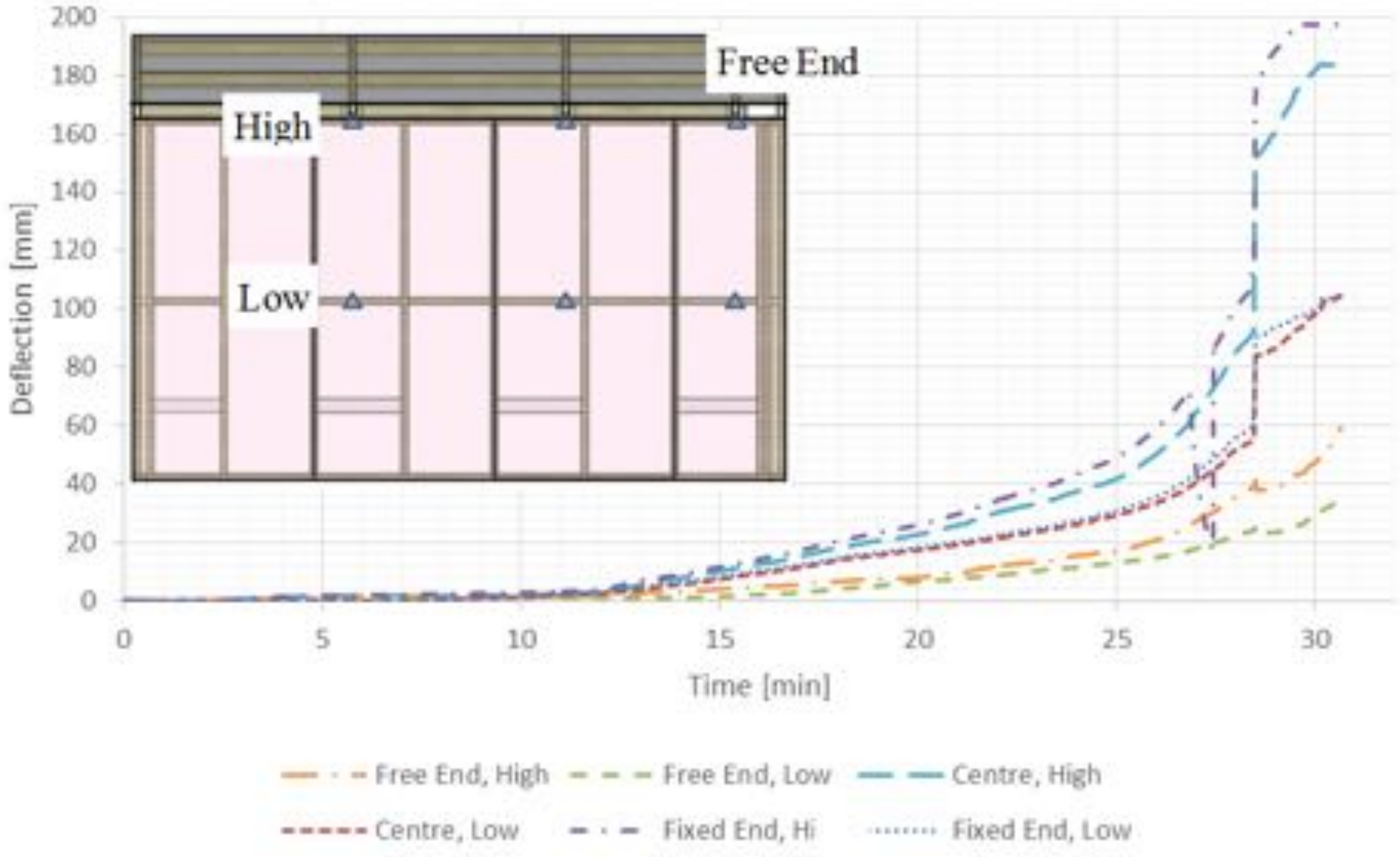
External flaming visible, t ≈ 16 min

Non-rated wall, t ≈ 28 minutes

Fire-rated wall failed under lateral load & roof partially collapsed, photo at t ≈ 30 min

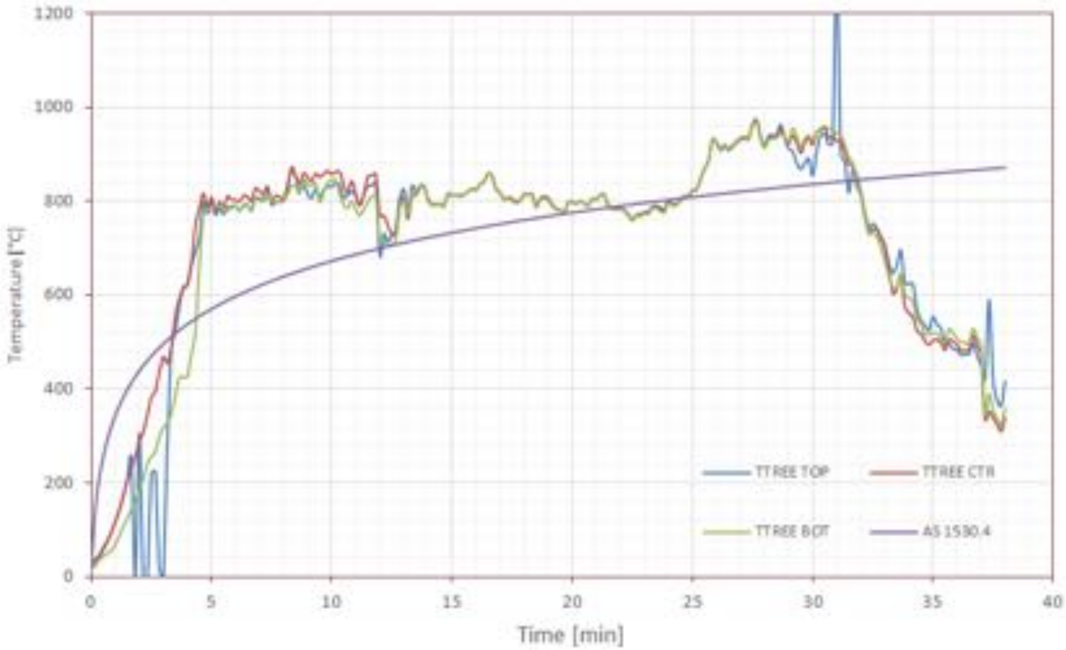
Natural fire experiment

Deflections



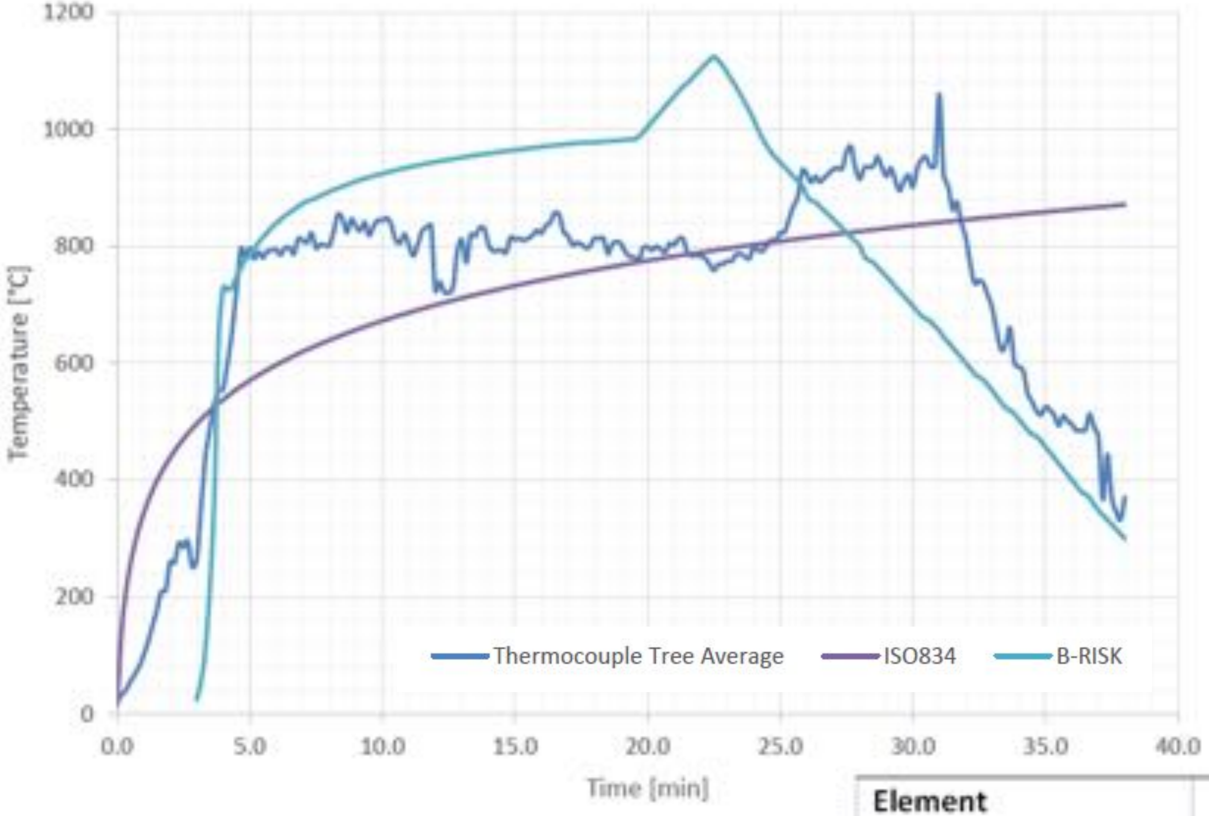
Natural fire experiment

Temperatures



Element	Natural fire experiment observed time [min]	Equivalent failure time exposed to standard time-temperature curve using cumulative radiant energy comparison [min]	Furnace test observed time [min]
Ceiling lining	12	17	16
Fire-rated wall lateral stability failure	28	33.5	30.5
Fire-rated wall insulation failure	33	39	Did not occur

B-RISK modelling



Temperatures

Element	Natural fire experiment observed time [min]	Failure time exposed to B-RISK predicted gas temperatures using cumulative radiant energy comparison [min]
Ceiling lining	12	10
Fire-rated wall lateral stability failure	28	18
Fire-rated wall insulation failure	33	Not calculated

Conclusions

- Small timber-framed compartment with 10 mm standard plasterboard linings and a suitable roof truss structure can achieve stability for a 30-min FRR equivalent duration
- No need to provide moment-resisting fixity at the connection between the studs and bottom plate of the fire-rated wall
- Unlined compartment of otherwise similar construction and lateral load configuration unlikely to achieve a nominal 30-min FRR.

…and other antipodean developments

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Thermal exposures in fully developed compartment fires

$$\dot{m}''_p = \dot{m}''_{freeburn}\left(\frac{Y_{ox}}{0.233}\right) + \frac{\dot{q}''_{rad,net}}{L_g}$$

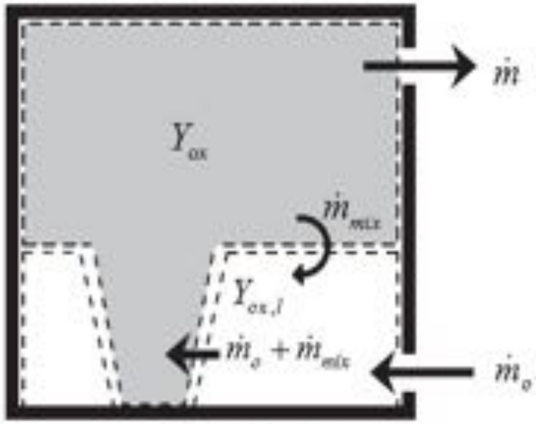
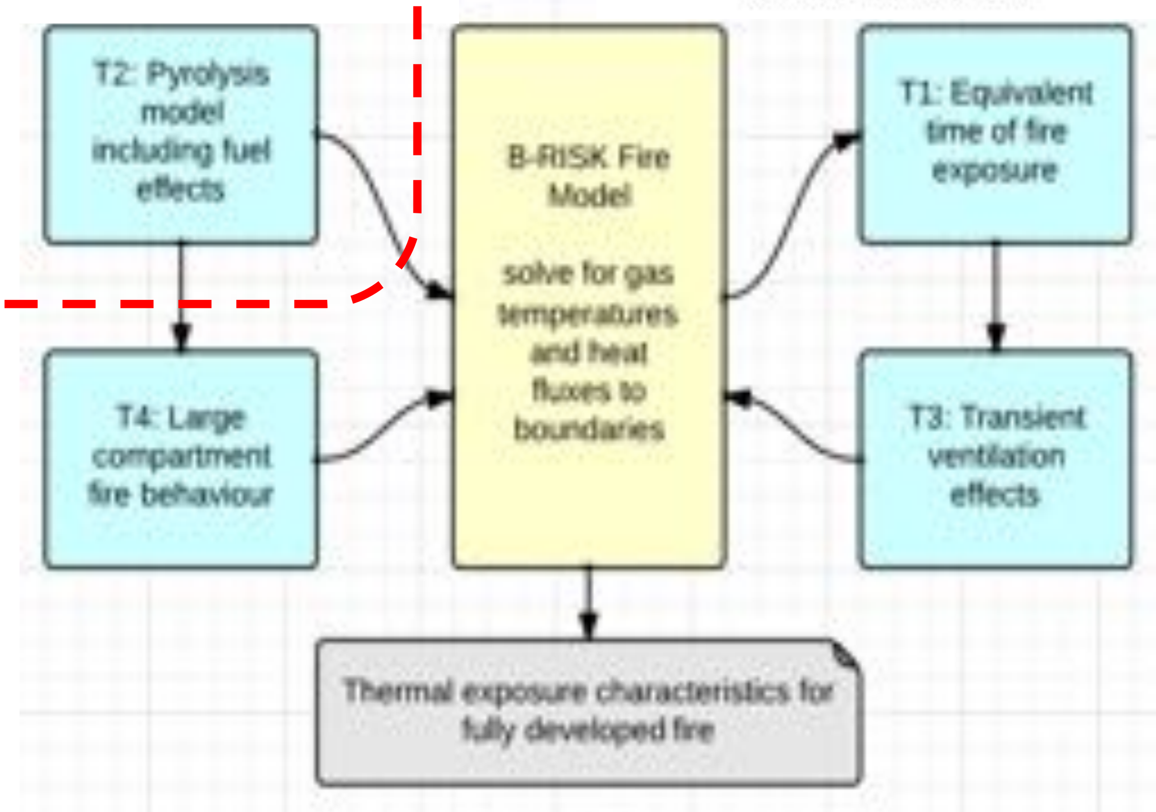


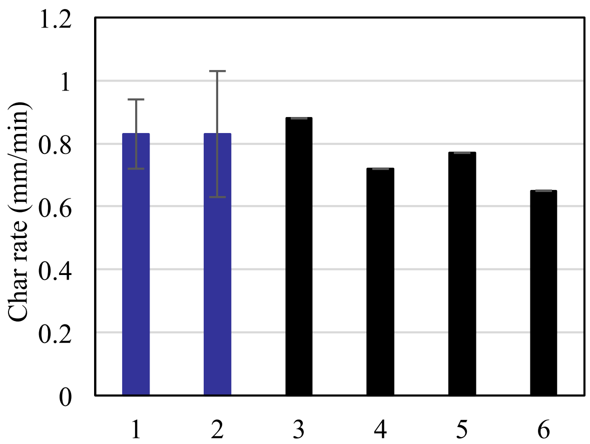
Fig. 3. Layer mixing for experiment



Ref: Wade

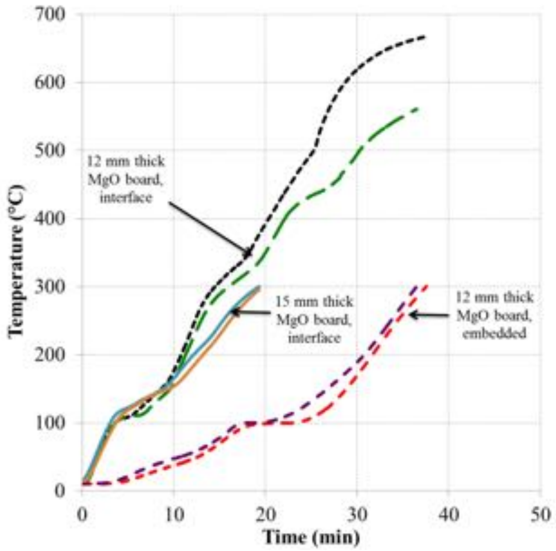
Charring and encapsulation of CLT

Typical char profile of sample before removing the char layer

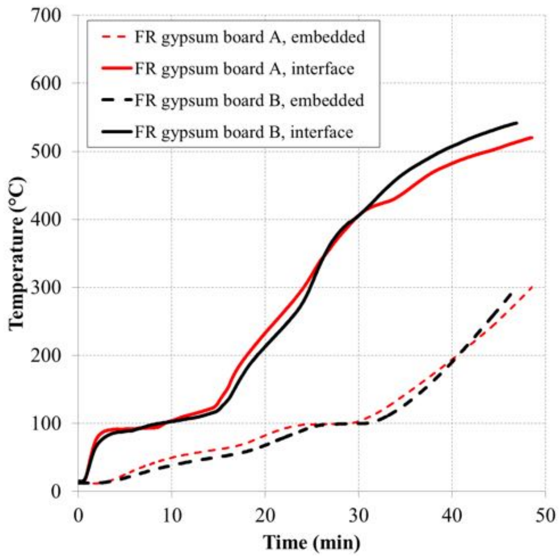


Key:
1: Manual Measurements
2: Thermocouple Measurements
3: McTavish and Palmer, 35 kW/m², 2013 (CLT)
4: Lane, 2005 (LVL)
5: Collier, 1992 (Glulam)
6: Timber Structures Standard (radiata pine)

Ref: Moser & Aiken



Temperature profiles for two 12 mm and 15 mm MgO board at 65 kW/m²



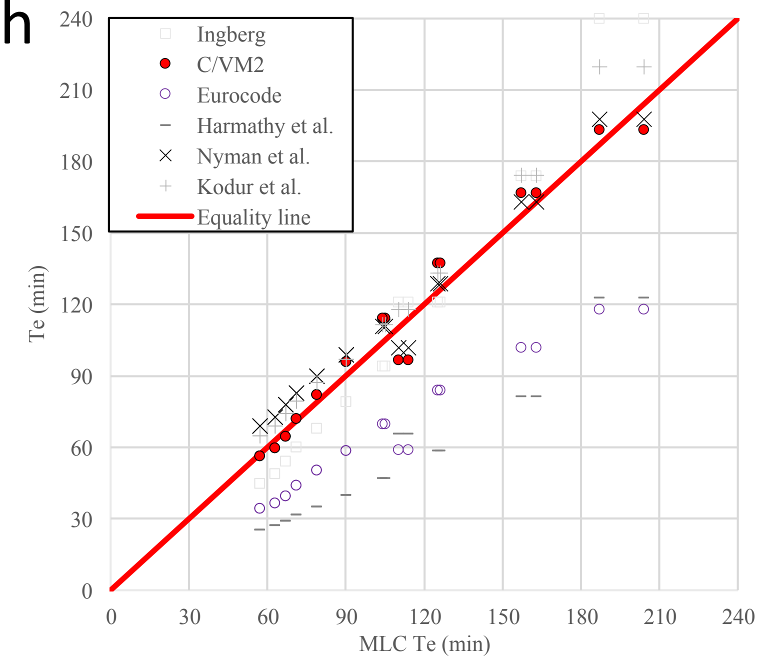
Temperature profiles for 13 mm thick FR gypsum boards at 65 kW/m²

Char on 15 mm thick MgO board samples when the interface thermocouple reached 300 ˚C

Failure of 12.5 mm thick standard gypsum board exposed at 50 kW/m²

Time equivalence, T_e

- New equivalent fire severity approach using the minimum load capacity (MLC) for structural adequacy of
  - protected/unprotected steel
  - reinforced concrete
  - composite steel and concrete
  - (maybe timber)
- Obtain MLC of a member under a compartment fire exposure using thermal and mechanical response models
- Derive T_e from the equivalent time it takes for the same member to reach this minimum capacity when exposed to the standard fire



Comparisons between MLC and existing time equivalence methods for reinforced concrete beams

Ref: Xie

Optimising decision-making for structures

Structural engineer → **Protected steel** (Extra 'self-weight') → **Unprotected steel** (Less weight)

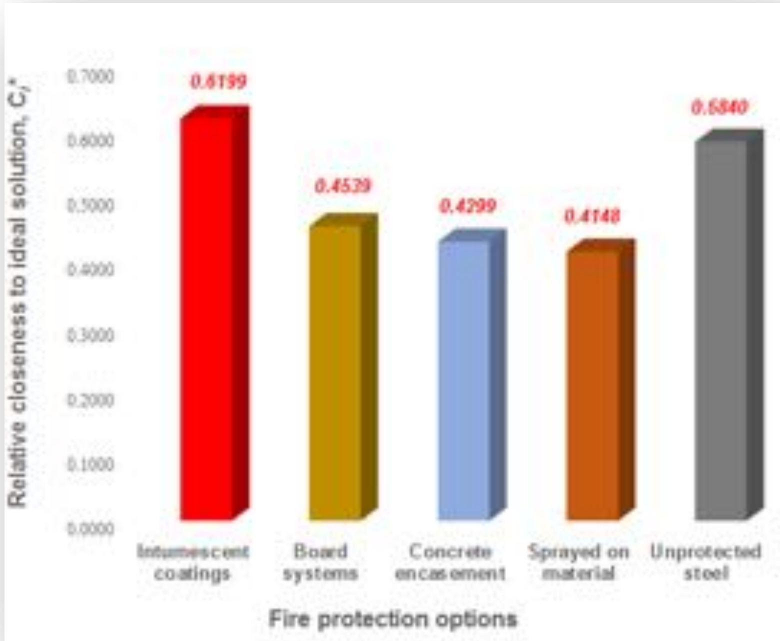
Insurer → **Unprotected steel** (No fire protection) → **Protected steel** (Confidence)

Building owner → **Intumescent paints & boards** (high cost) → **Sprayed on material** (low cost)

Building contractor → **Sprayed on material** (Wet application) → **Boards** (Dry on-site fixing)

Architect → **Sprayed on material** (Poor visual appeal) → **Intumescent paints** (aesthetics)

Fire engineer



Performance of passive fire protection defects exposed to a standard fire test

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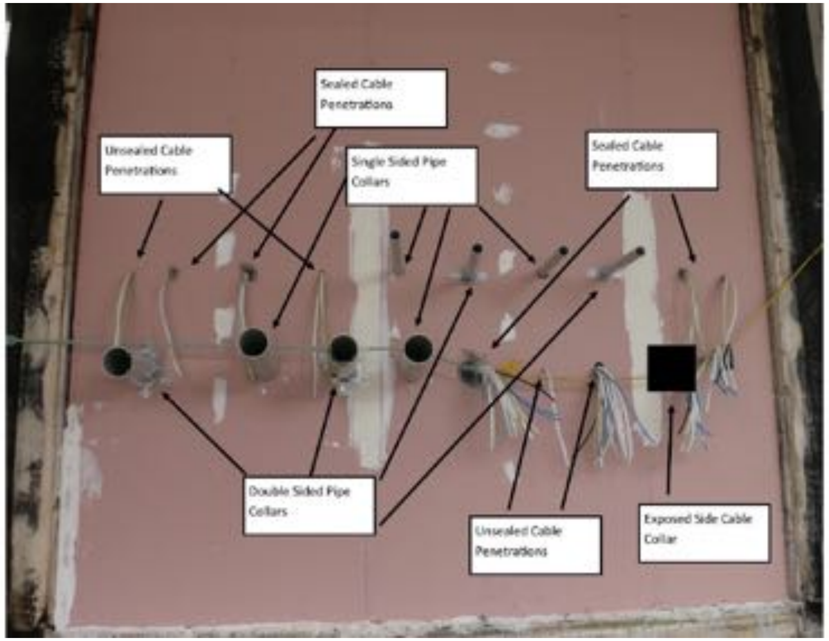
- Inadequate fire stopping of penetrations found during building renovations
- Standard fire exposure tests to 60 min on different defect types
- A total of 9 out of 19 failed the insulation criteria and 2 also failed the integrity criteria
- The two integrity failures that occurred were on the two penetrations that failed on insulation within the first 10 min



- More tests planned