Towards Rational Design for FRP Reinforced Concrete in Fire

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Fire Hazard

Buildings need to be designed for fire safety

- FRP reinforced concrete buildings need design procedures for fire

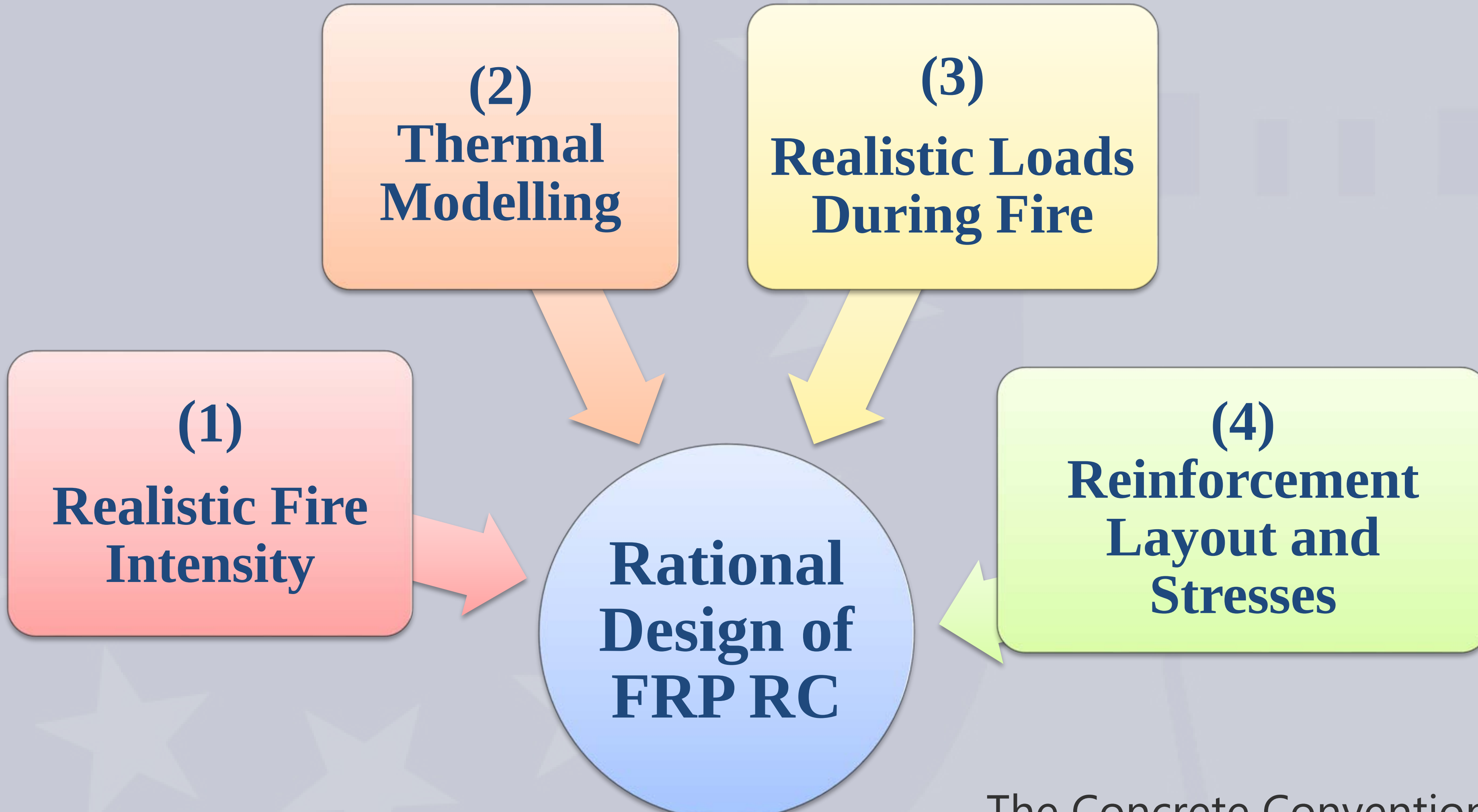
US Bridges (1980 to 2012)

- 30 failures due to fire
- 20 failures due to earthquake

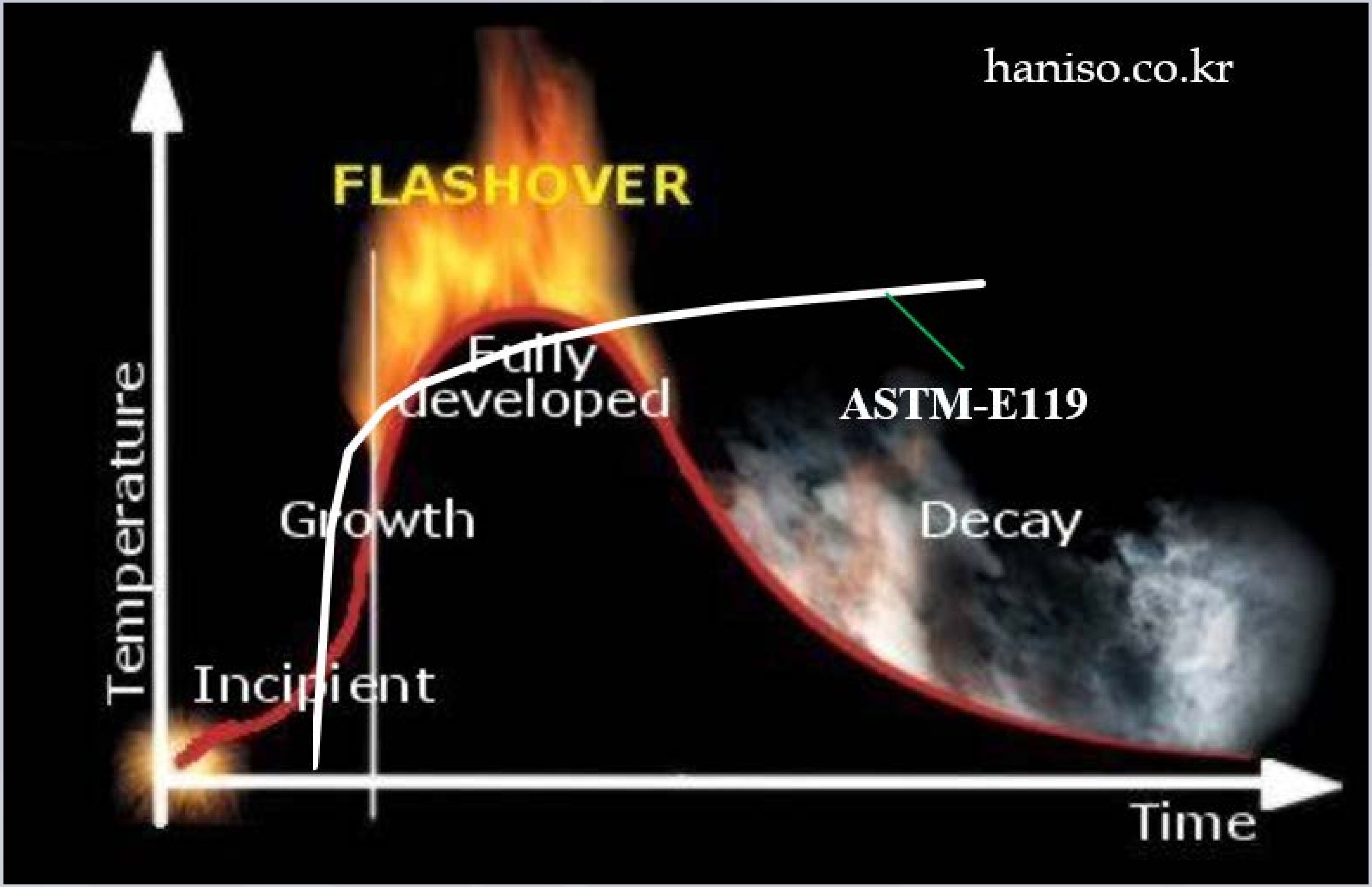
(Lee et. al. A study of US bridge failures)

An aerial view of the collapsed freeway overpass near downtown Oakland

Effective Application of FRP Reinforcement

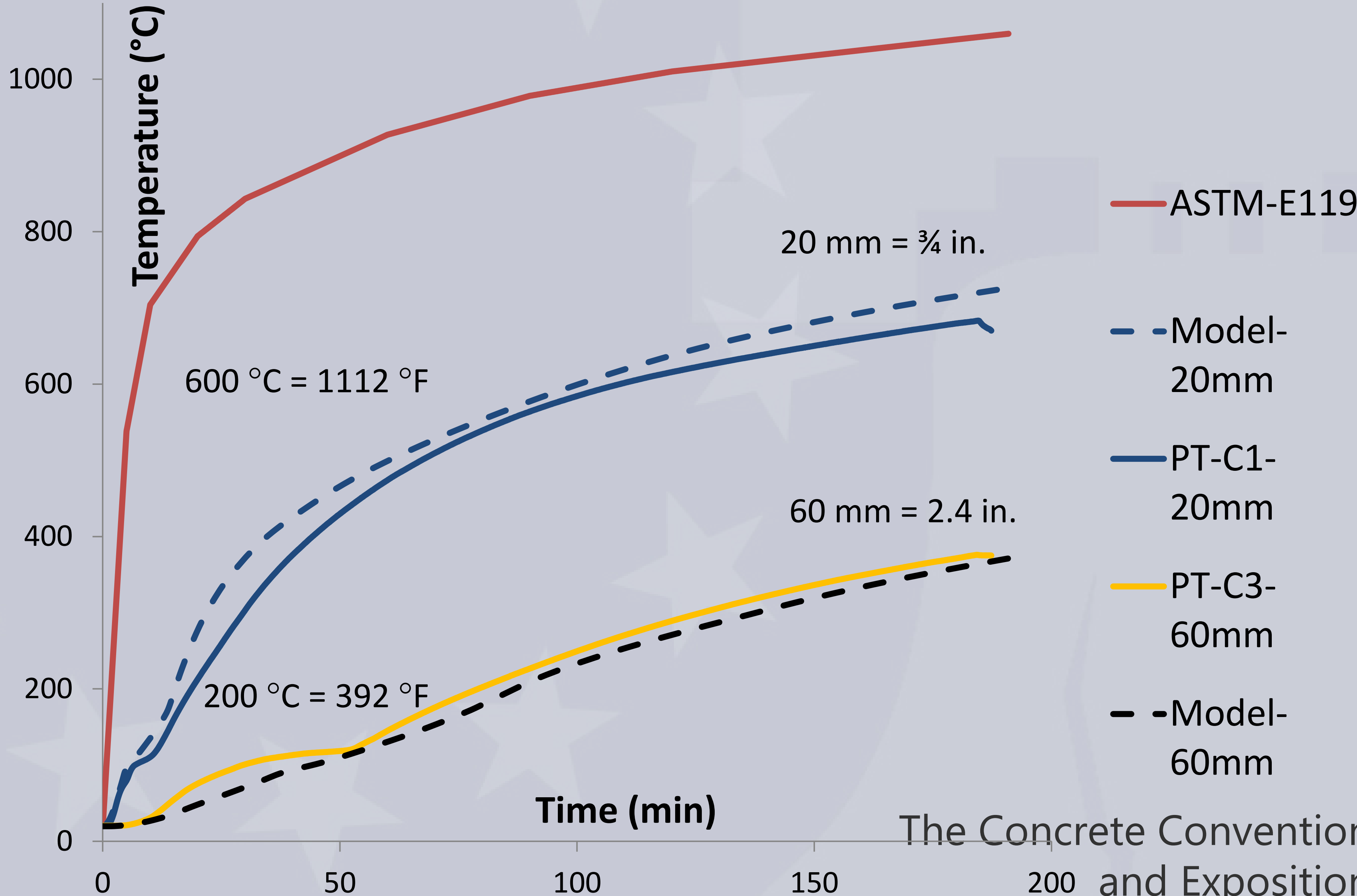


(1) Realistic Fire Intensity



After haniso.co.kr and Bisby and Stratford (2013)

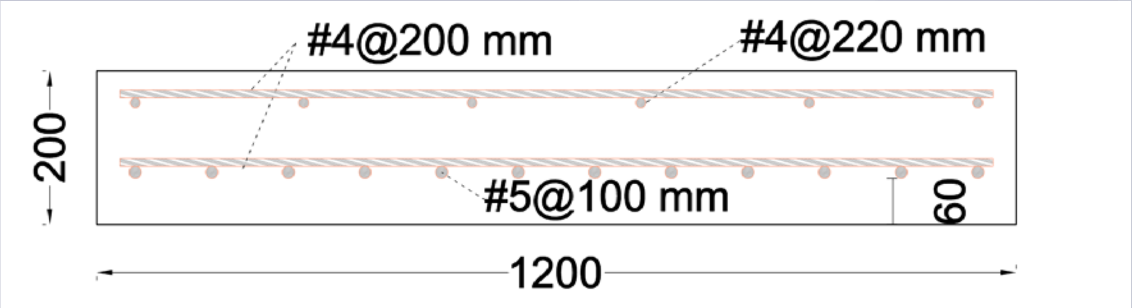
(2) Thermal Modelling



(3) Realistic Loads During Fire

The significance of realistic loads are discussed using the results of the latest fire tests on FRP RC slabs at NRC, Ottawa.

Full-scale slabs with 60 mm clear concrete cover:



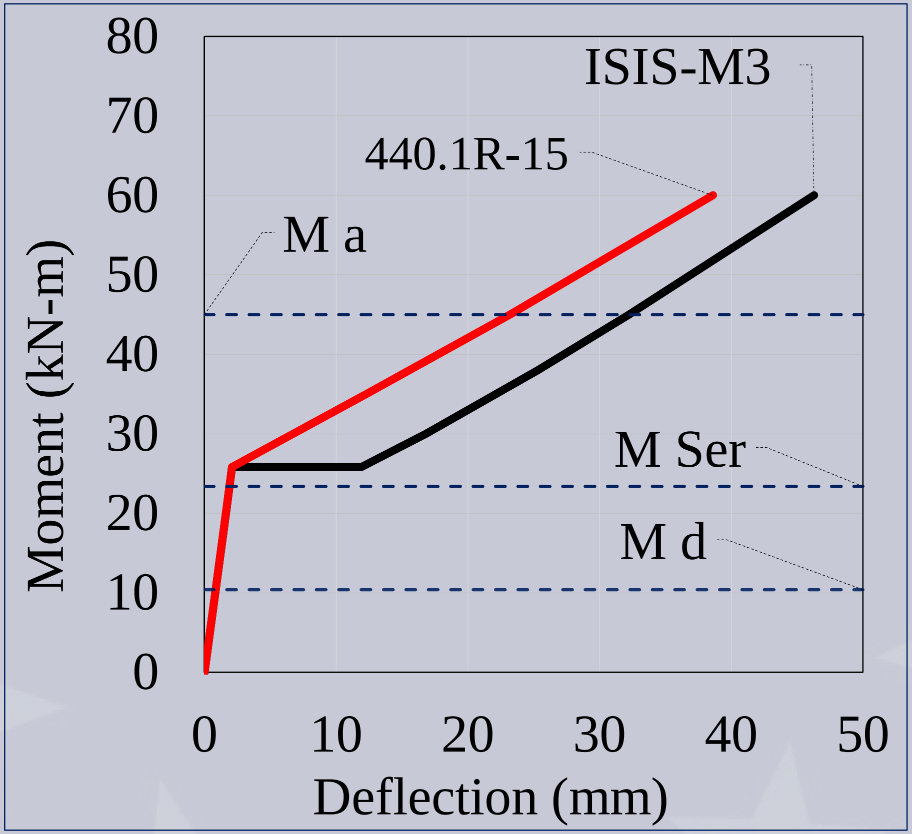
Width	Thickness	Clear Cover	Span	M_f	M_{Ser}	M_{cr}	M_r
mm	mm	mm	m	kN-m	kN-m	kN-m	kN-m
1200	200	60	3.8	32.5	23.4	25.8	84

The moment in fire was 45 kN.m (33 kip.ft)

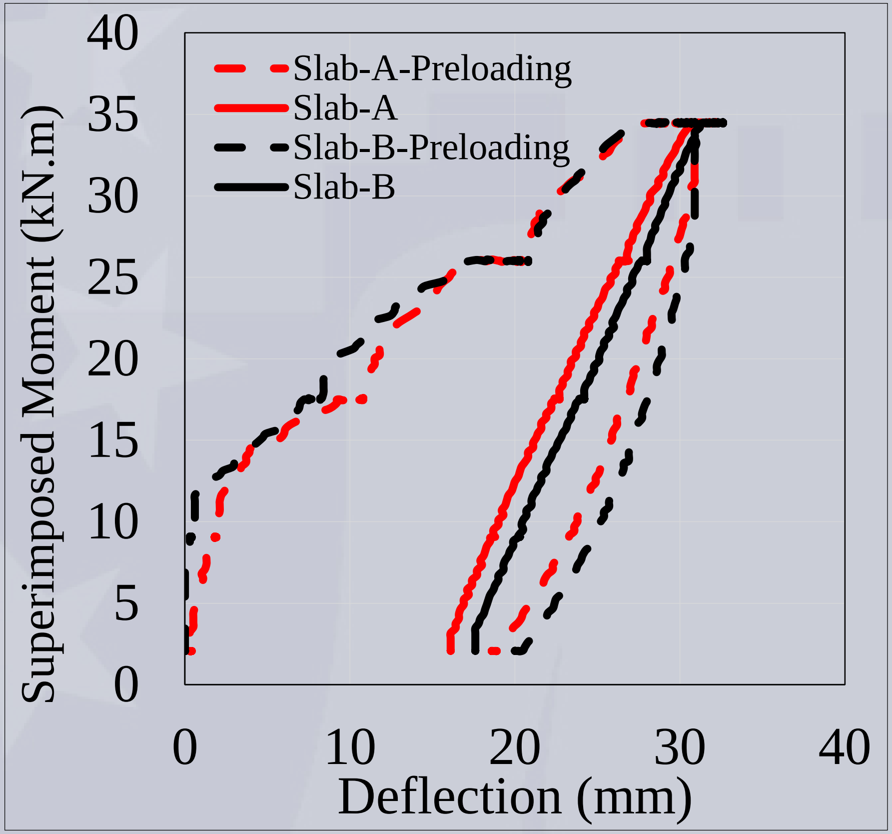
Overloaded by 90% with respect to service moment.

(3) Calculated (design) and measured deflections

Live load deflection limit $l_n/360$ = 10.5 mm (0.4 in.)



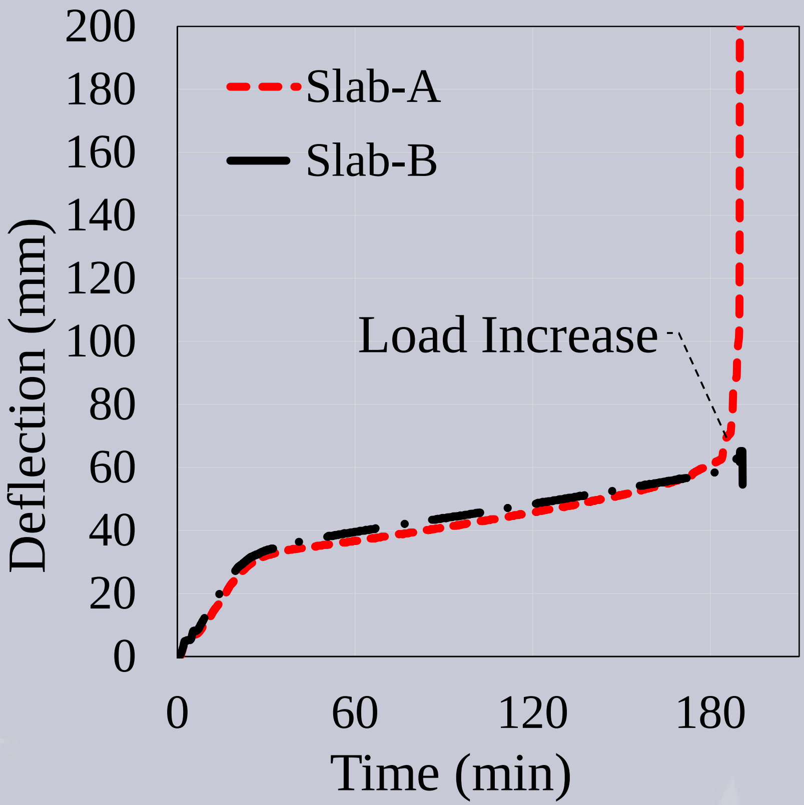
Calculated Deflections



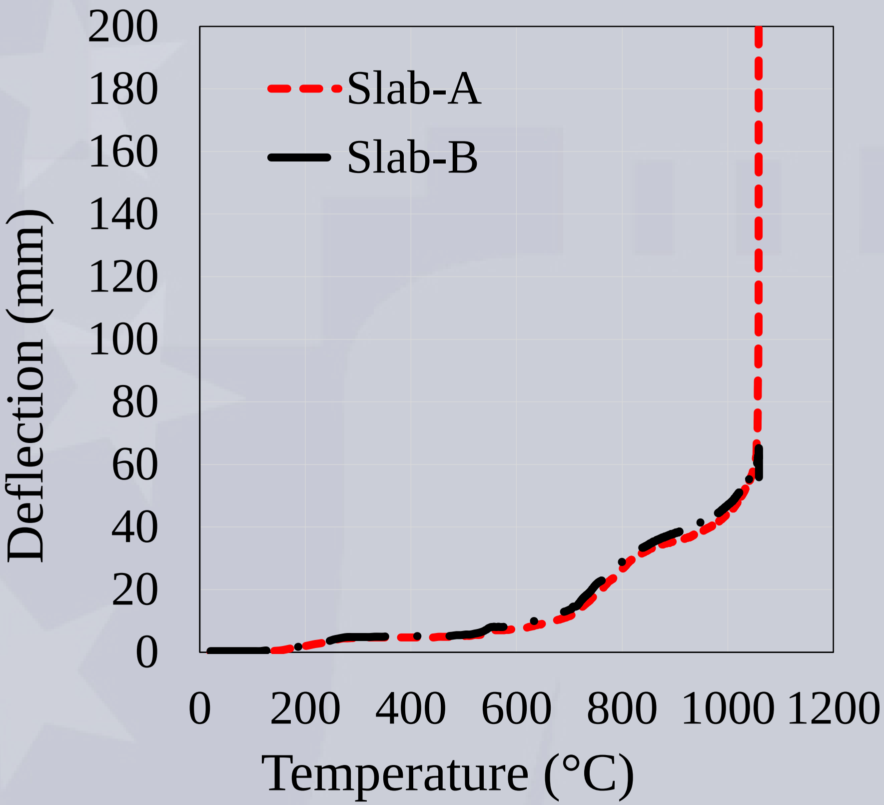
Measured Deflections

(3) Realistic Loads During Fire

Full-scale slabs with 60 mm clear concrete cover:



Deflection vs time during fire test

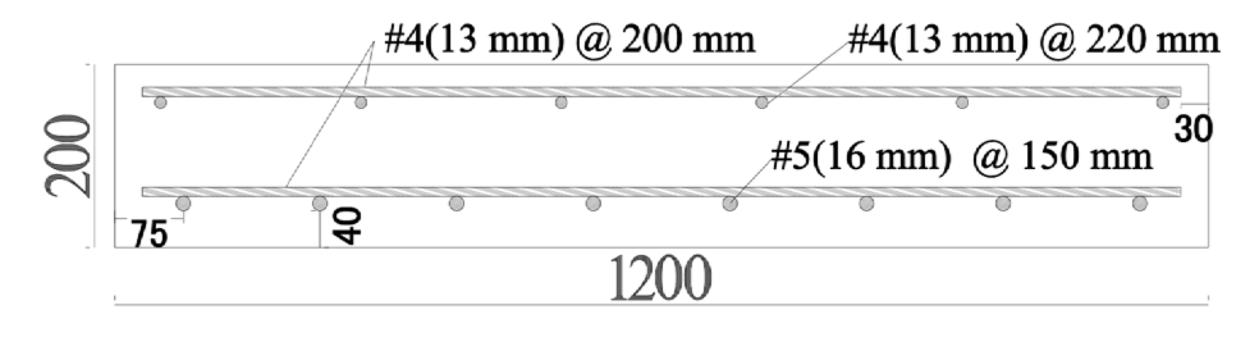


Deflection vs furnace temperature

NOTE: Deflections in the above curves are due to only fire plus the effect of load increase at the end of test.

(3) Realistic Loads During Fire

Full-scale slabs with 40 mm clear concrete cover:



Design of a FRP reinforced concrete slab

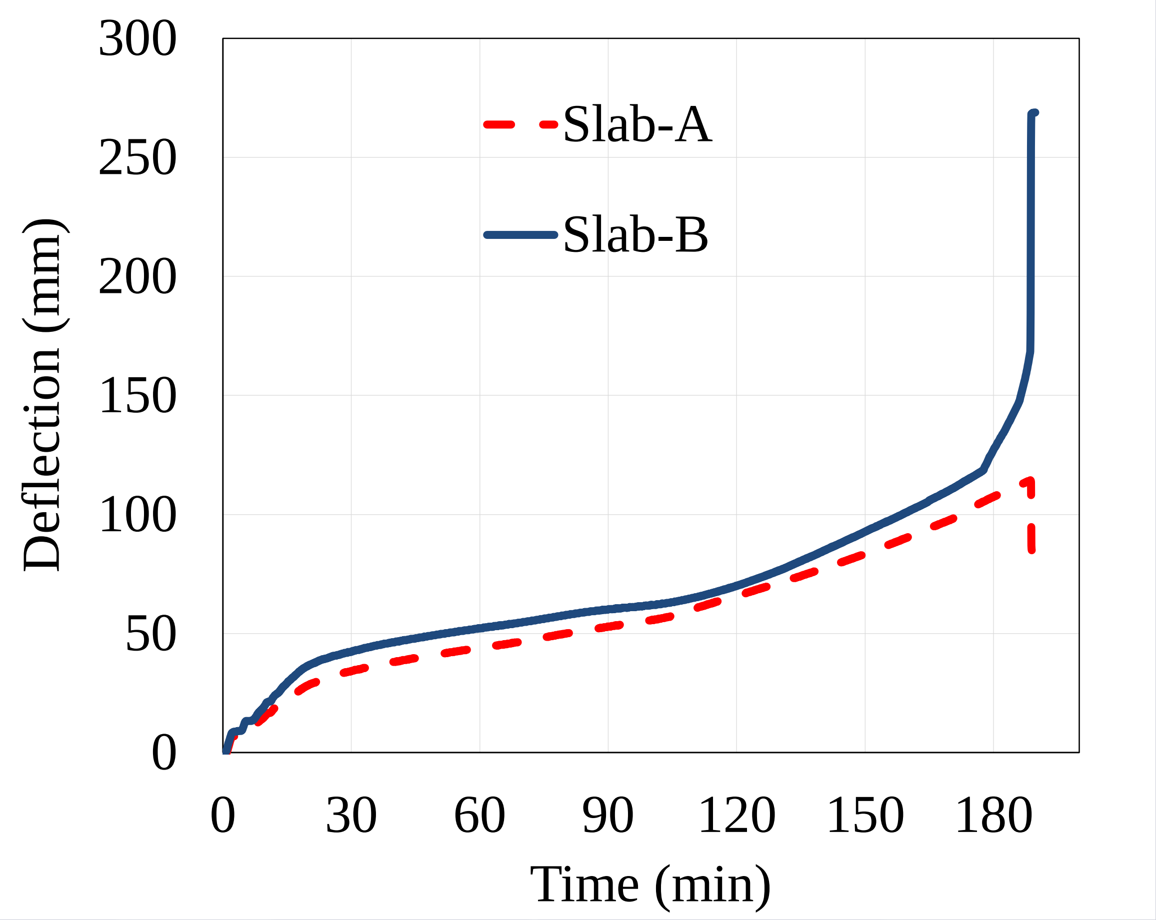
Width	Thickness	Clear Cover	Span	M_f	M_{Ser}	M_{cr}	M_r
mm	mm	mm	m	kN-m	kN-m	kN-m	kN-m
1200	200	40	3.8	32.5	23.4	26.3	92

The moment in fire was 45 kN.m.

Overloaded by 90% with respect to service moment.

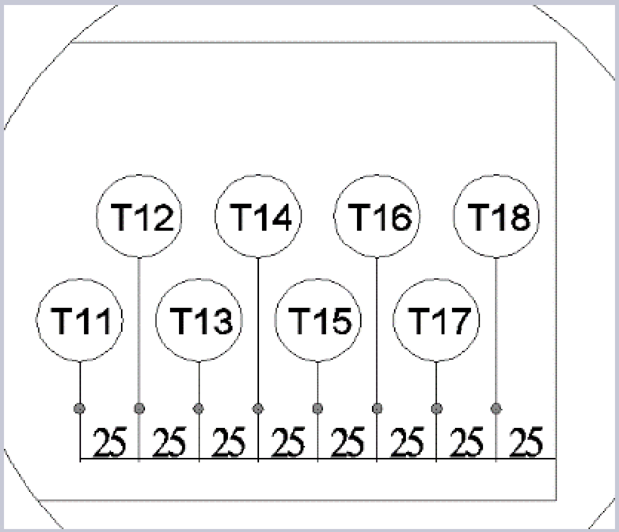
(3) Realistic Loads During Fire

Full-scale slabs with 40 mm clear concrete cover:

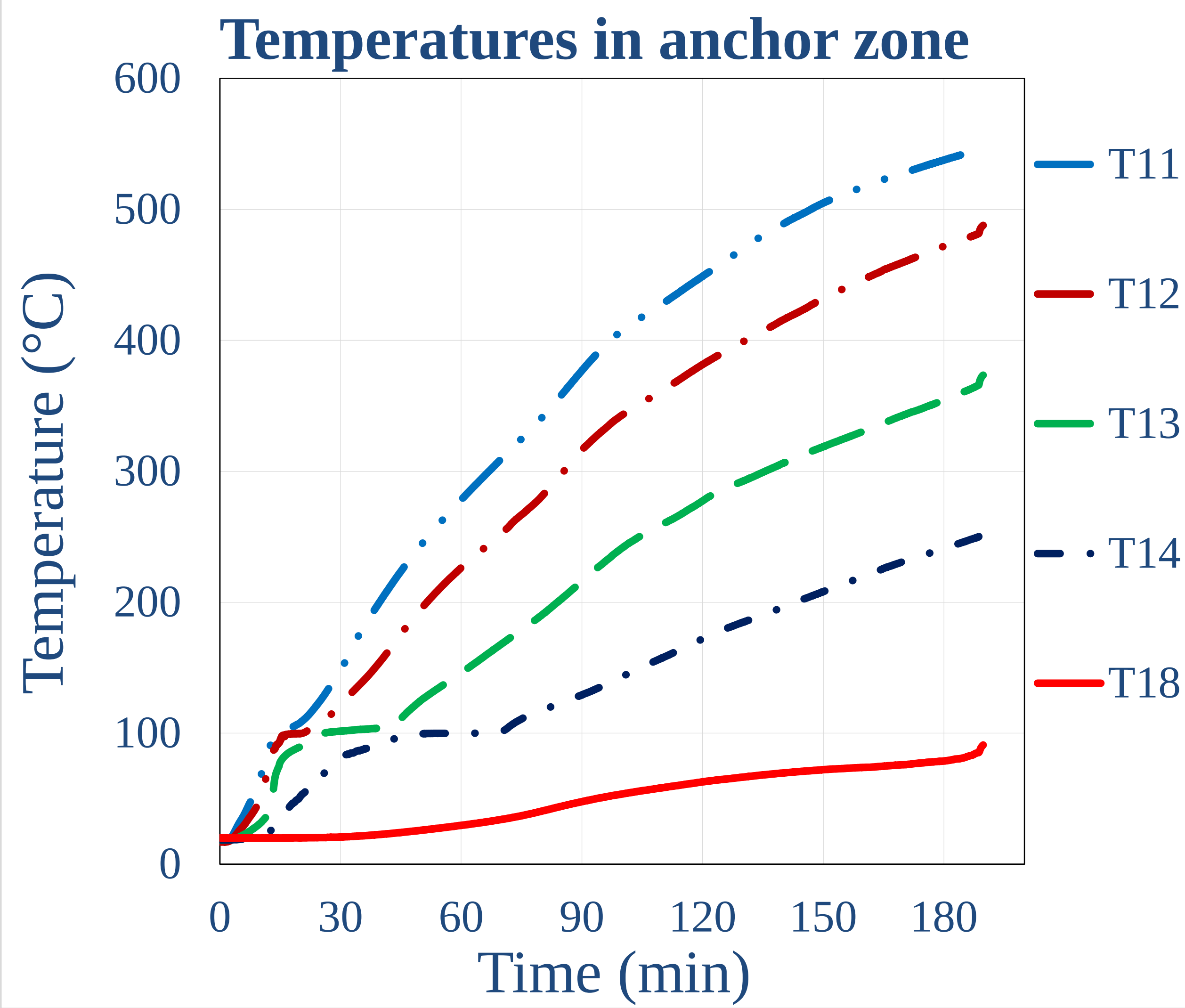


Deflection vs time during fire test

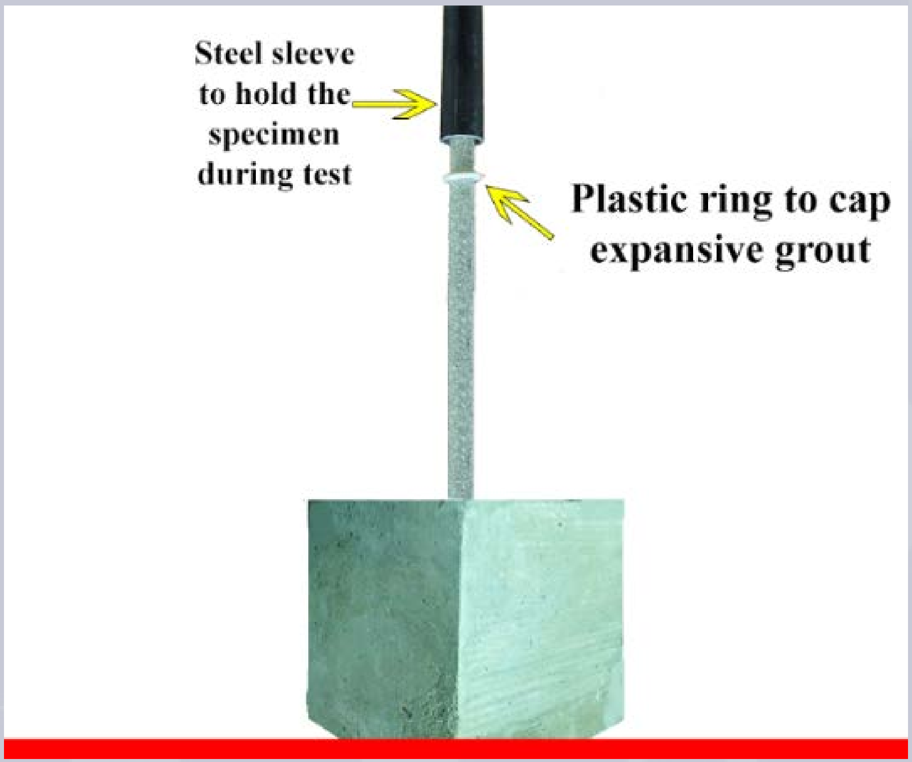
Temperatures reduce towards the end of slab



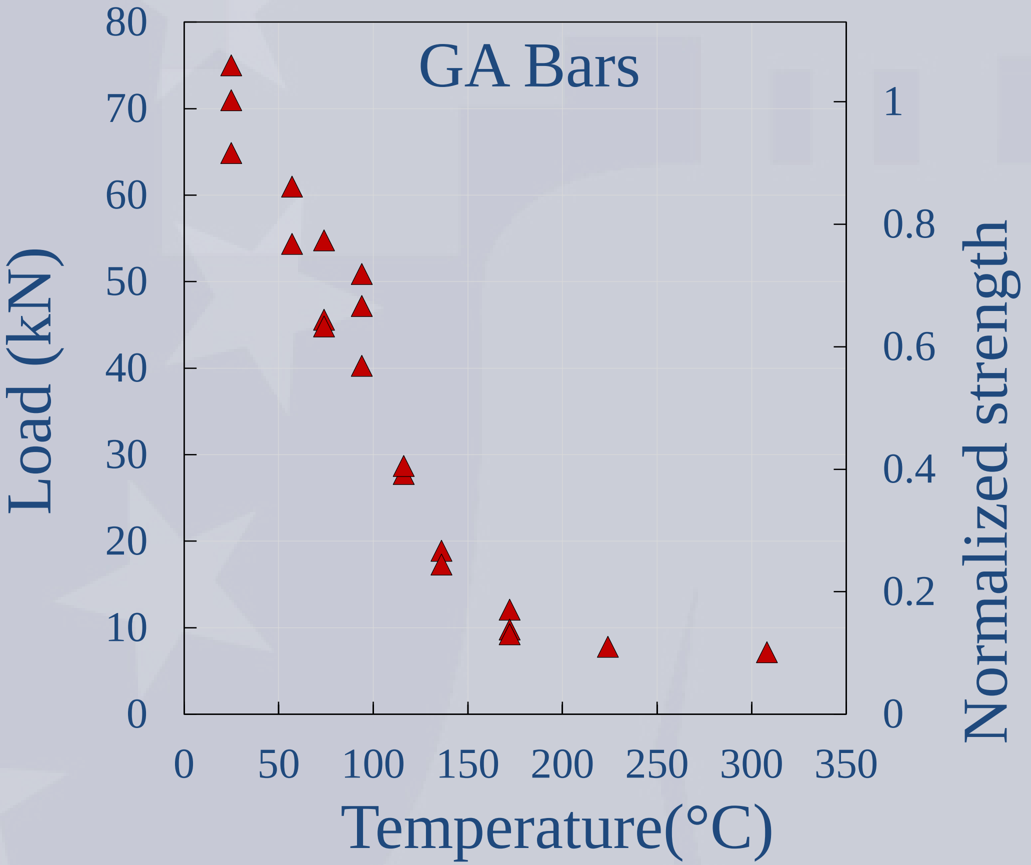
Closely placed thermocouples in anchor zone (200 mm)



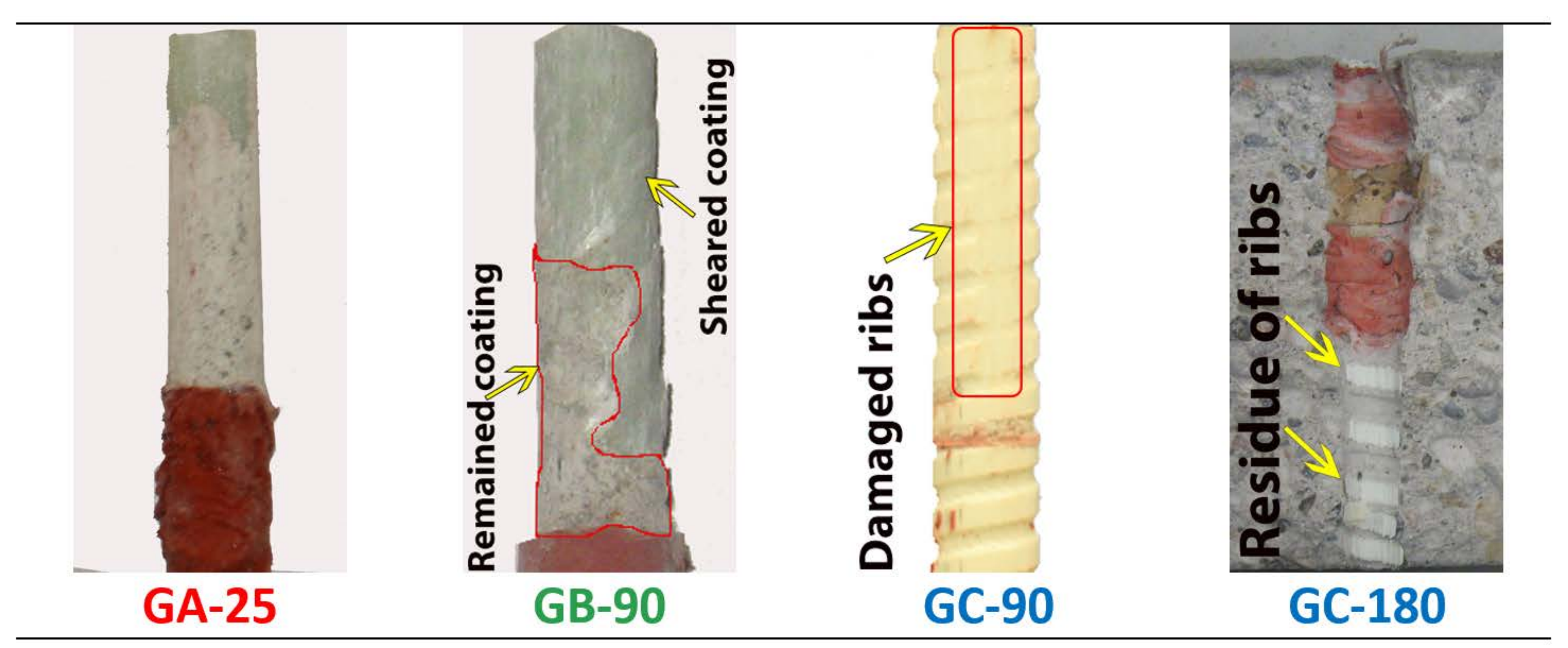
Material tests conducted on bond strength of FRP reinforcements at elevated temperatures



Some of pullout tests results:



(4) Reinforcement Layout



Various types of failure in steady-state temperature tests

Vulnerability of FRP reinforcing bars to bond loss:

All FRP bars were pulled out at one end of Slab-B.

Post-fire condition of FRP bar in cool zone

(4) Reinforcement stresses

- All bars embedded in support
- First test 160 MPa (23 ksi) and 2600 με
- Second test 200 MPa (30 ksi) and 3300 με
- ACI 440 stress limits (GFRP)
  - 0.2 f_{fu} = 200 to 340 MPa (30 to 50 ksi)
- CSA S806/S6 strain limits for crack control
  - 2000 με

CONCLUSIONS AND FUTURE DIRECTIONS

- Realistic fires include cooling phase
  - For short-term, focus on standard fire
  - Longer-term, Eurocode approach
- Thermal modelling
  - Reasonable approaches and information
  - *What about spalling?*
- Realistic loads for FRP reinforced
  - Strength does not govern design
  - *How to establish design loads?*
- Anchorage and stress levels
  - *How to design appropriate anchorage?*

Acknowledgments

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Thank you for your attention