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A Macroscopic Finite Element based Computer Model for Evaluating the Fire Response of FRP-Strengthened Reinforced Concrete Beams

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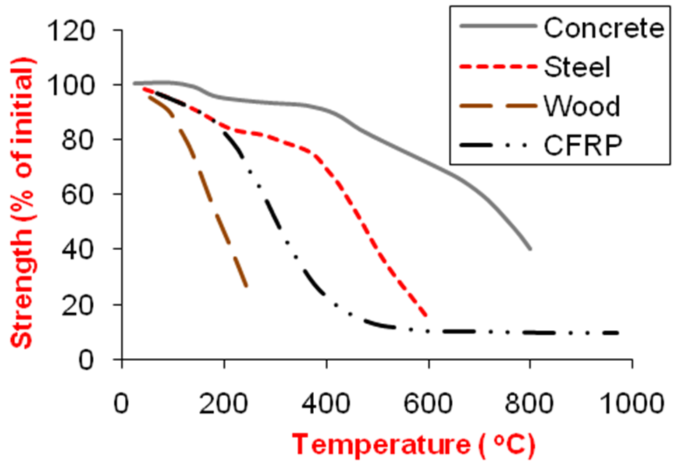
Fire Performance - FRP

- **Fire resistance (FR) information**
  - Critical for building applications
  - **Performance** under **realistic fire** and loading scenarios largely **unknown**
  - Behavior is **complex** under elevated temperatures

- **Performance in fire - Concerns**
  - **Faster degradation** of strength and stiffness
  - **Low** high temperature tolerance
  - **Loss of bond** with concrete
  - Flame spread and Smoke generation (combustible)



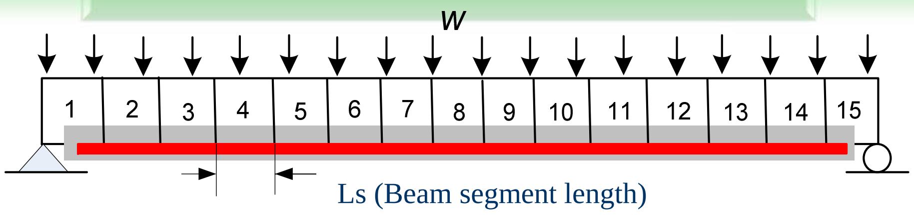
Numerical Model

- Development of numerical model for FRP-strengthened RC beams
  - FEM approach
  - FRP and insulation - HT behavior (mechanical and thermal)
  - Handle beams of different cross section (Rectangular, T, I-section)
  - Bond deterioration
  - Axial restraint
  - Different insulation schemes
  - Failure criteria

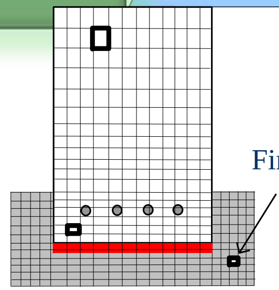
Analysis Procedure

Macroscopic finite element (FE) approach

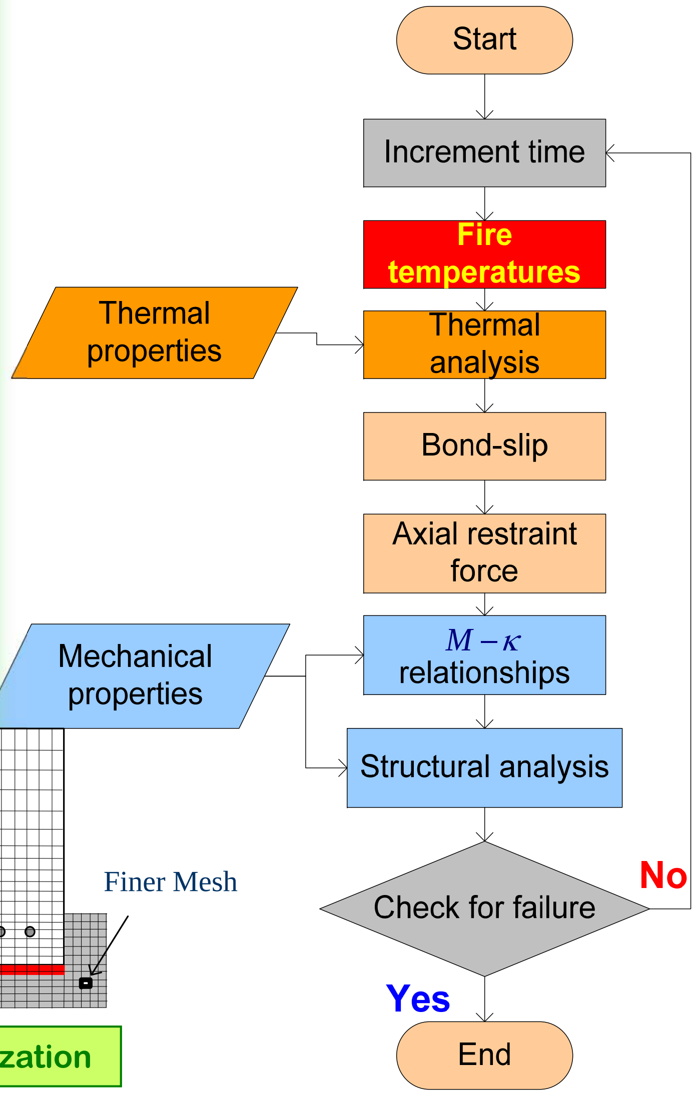
- Discretize the beam into segments & elements
- Time increments
- Estb. fire temp. and cross sectional temp.
- Compute bond-slip & axial restraint force
- Develop M-k relationships for beam segments
- Use M-k relationships to trace structural response



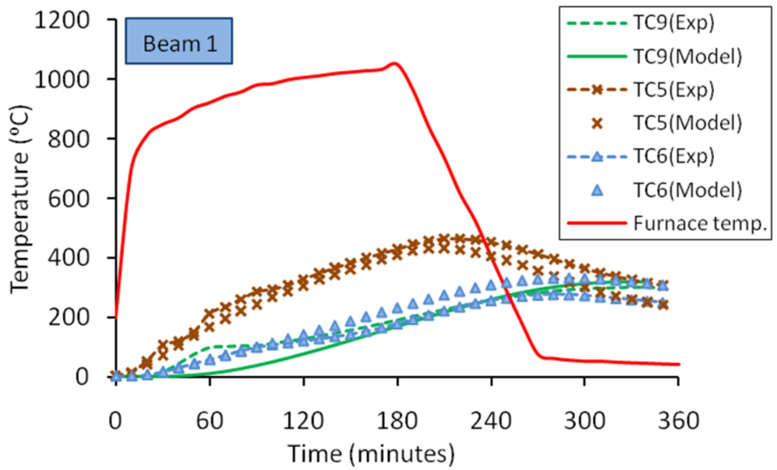
Idealization along the beam span



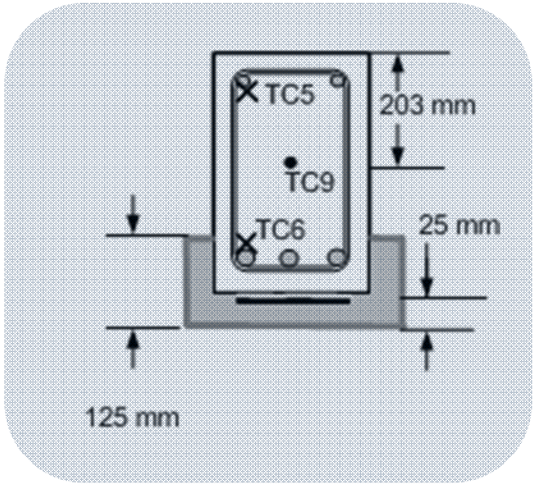
Discretization

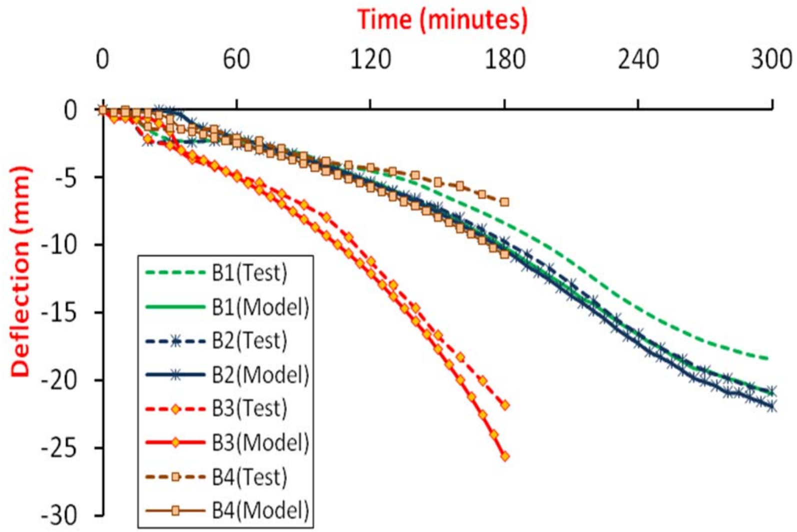


Model Validation (MSU Tests)

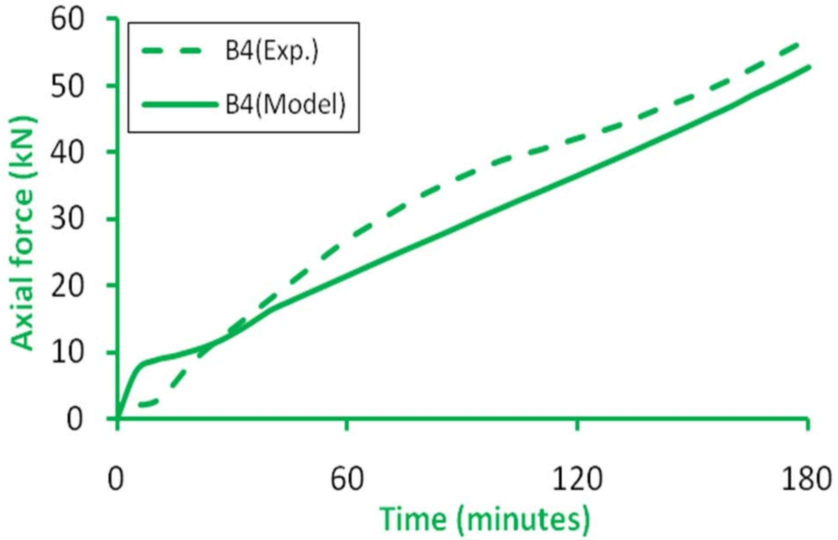


Predicted and measured temperatures



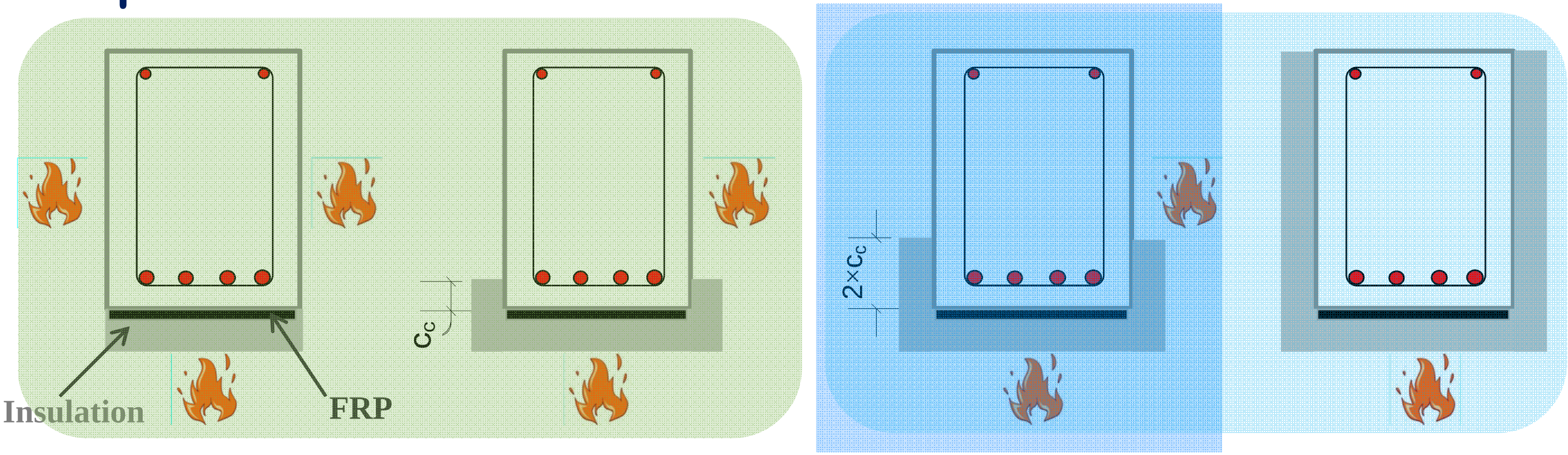


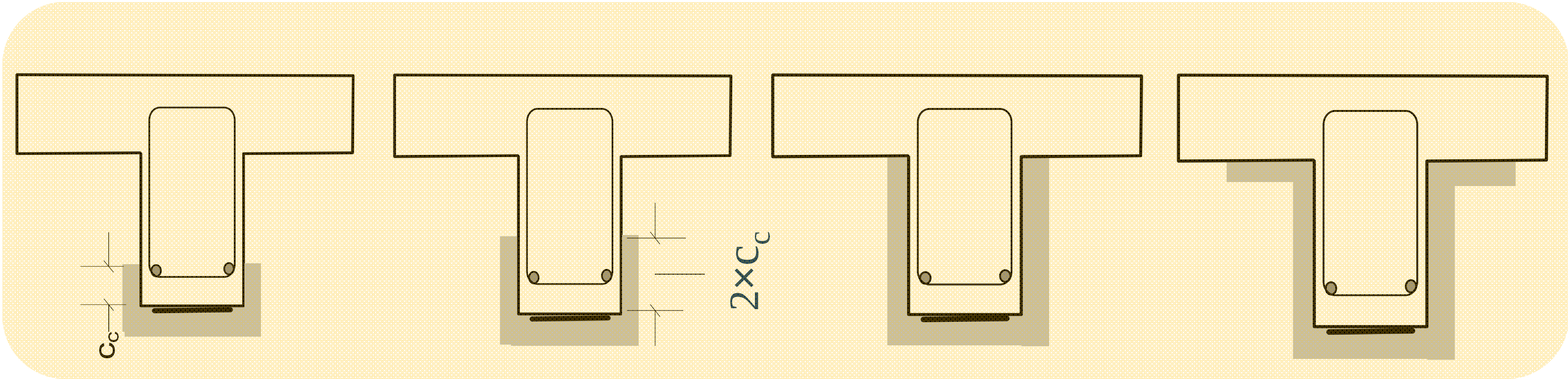
Predicted and measured deflections



Practical Applications for Computer Model

- Effective Insulation Schemes
- Optimum Geometric Configuration
- Optimum Insulation Thickness





Conclusions

- FEM model, based on moment-curvature relationships, is capable of predicting the response of FRP-strengthened RC beams in the entire range from the pre-fire stage to collapse under fire conditions
  - HT material properties and different strain components
  - Fire induced bond degradation and axial restraint force
- Fire resistance in FRP-strengthened RC beams is not only influenced by the thickness of insulation, but also by insulation scheme (*geometric configuration*)
- The computer model can be applied to quantify the influence of various parameters (such as insulation schemes) on the fire response of FRP-strengthened RC beams and recommend broad guidelines for enhancing fire resistance

Thank You !!

QUESTIONS

Objective

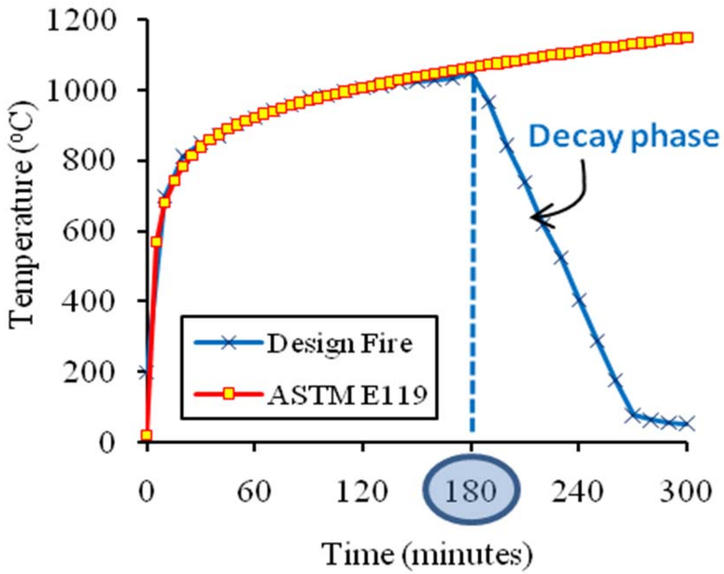
❖ **Develop a FE based computer model for tracing the fire response of FRP-strengthened RC beams**

- **Develop macroscopic finite element based computer model**
- **Undertake fire-resistance tests**
- **Validate the model by comparing thermal and structural response**
- **Conduct case studies and develop design guidelines for incorporation in codes and standard**

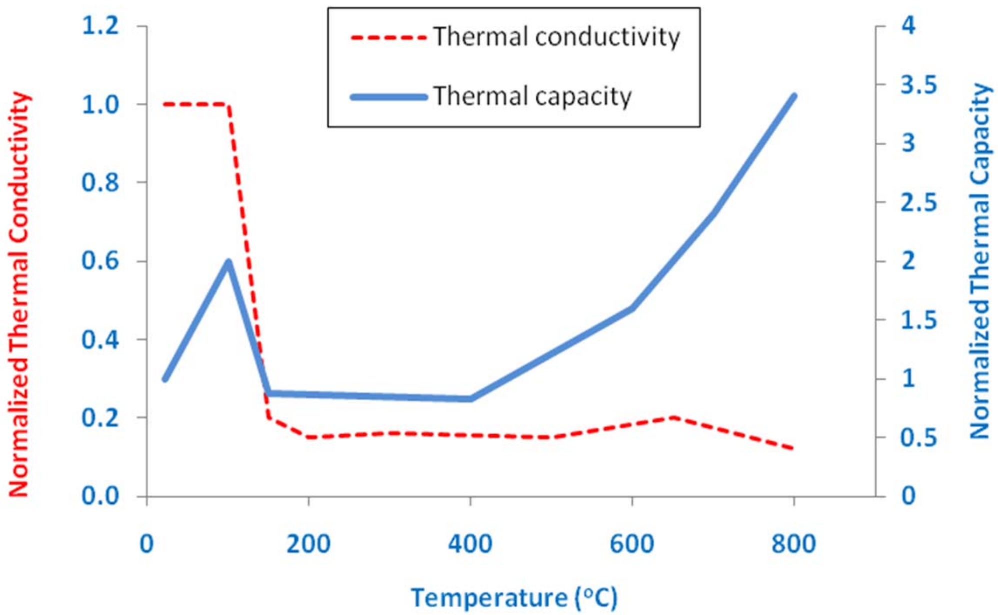
Experimental Studies

Beam designation	CFRP	Insulation type	Insulation thickness (mm)		Fire scenario	Support	Load (kN)	Failure time (min)
			VG	EI-R				
Beam B01	-	-	-	-	ASTM E119	SS	50	180
Beam B1	2×layers of 203 mm wide	Tyfo® Type A	25	0.1	Design	SS	70	NF*
Beam B2		Tyfo® Type B	25	0.1	Design	SS	70	NF*
Beam B3		Tyfo® Type A	25	0.1	ASTM E119	SS**	70	NF*
Beam B4		Tyfo® Type A	25	0.1	ASTM E119	AR***	70	NF*

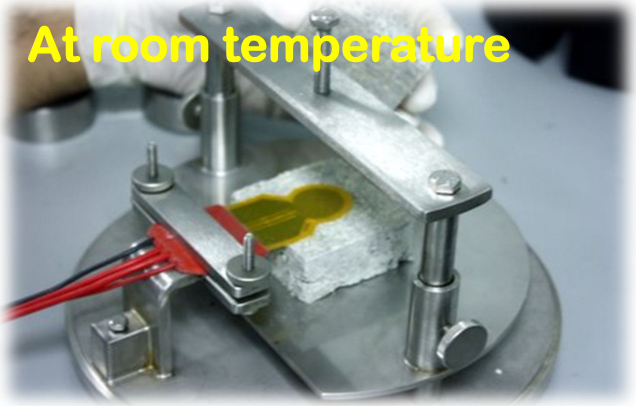
* No Failure ** Simply supported
*** Axially restraint



High Temp. Material Properties

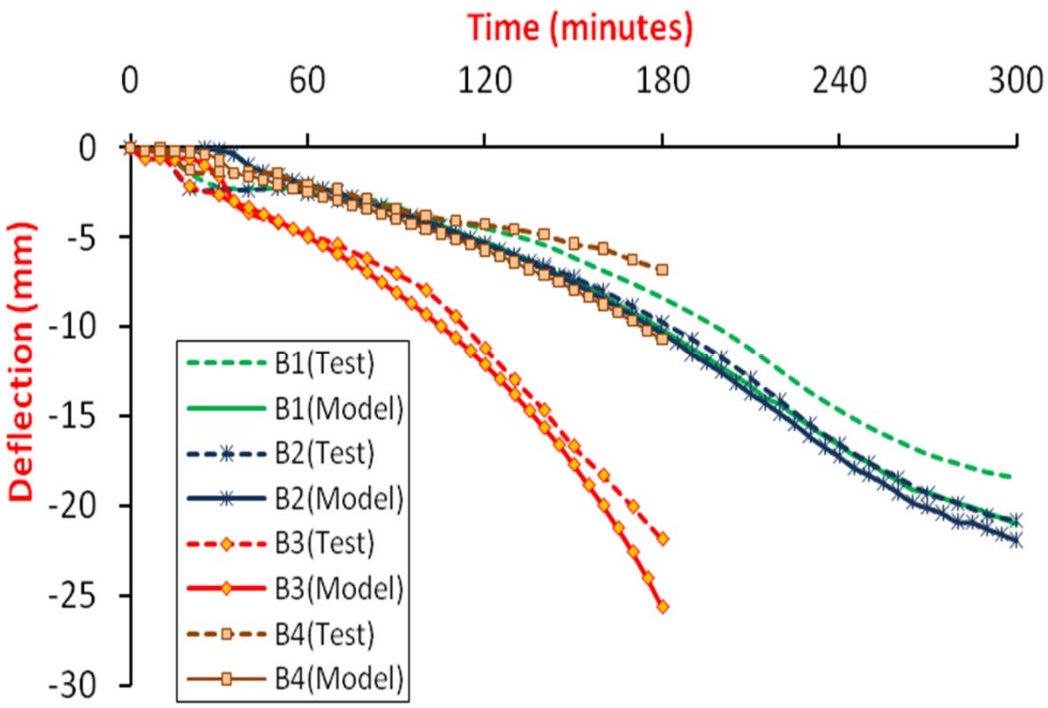


Normalized thermal conductivity & thermal capacity for Tyfo® WR AFP Insulation



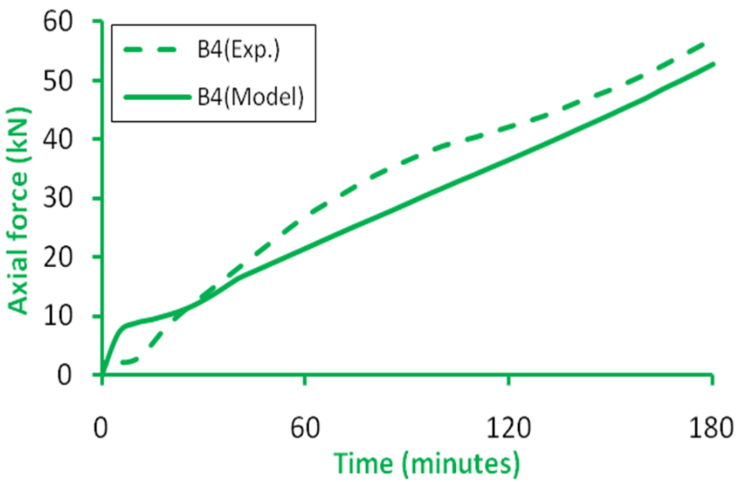
Hot Disk Equipment

Model Validation (MSU Tests)

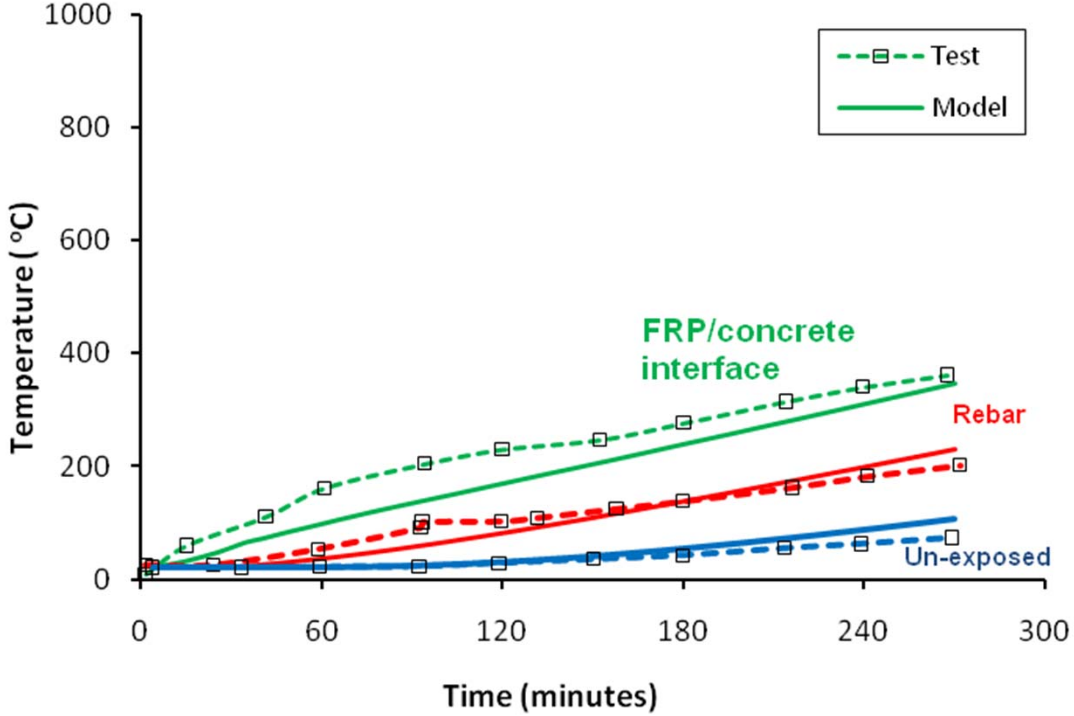


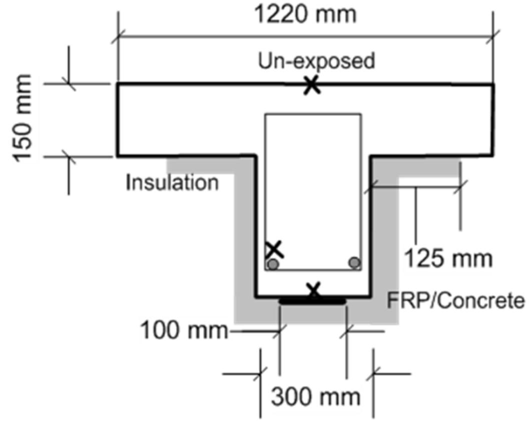
Predicted and measured deflections

Predicted and measured Axial Restraint Force



Model Validation (Williams et al.)

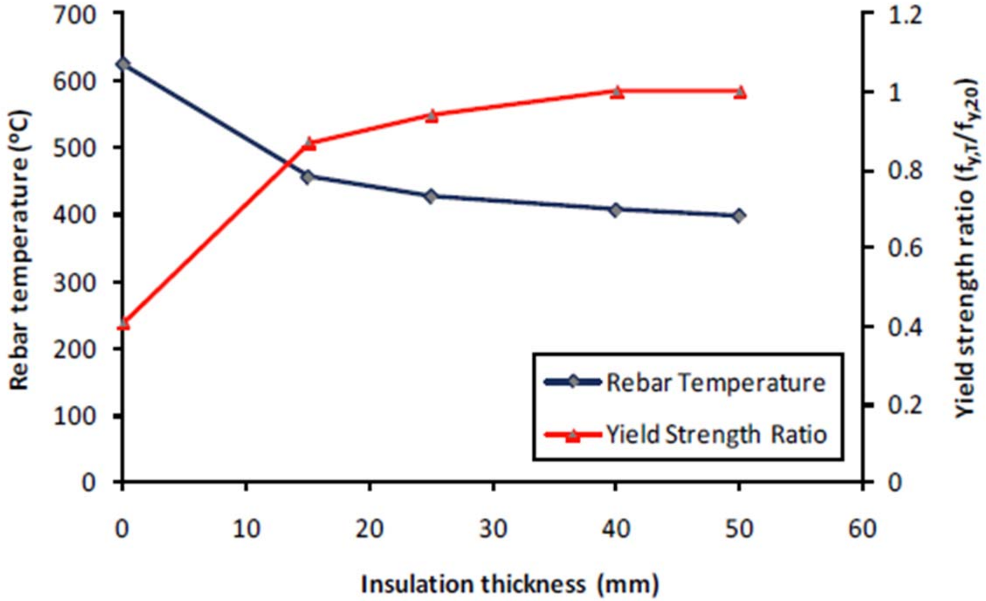


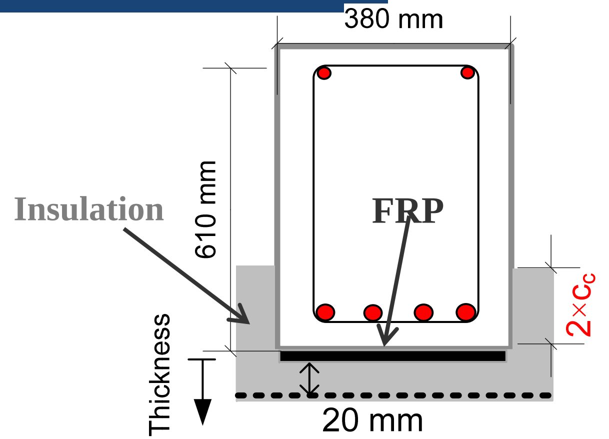


T-beam cross section

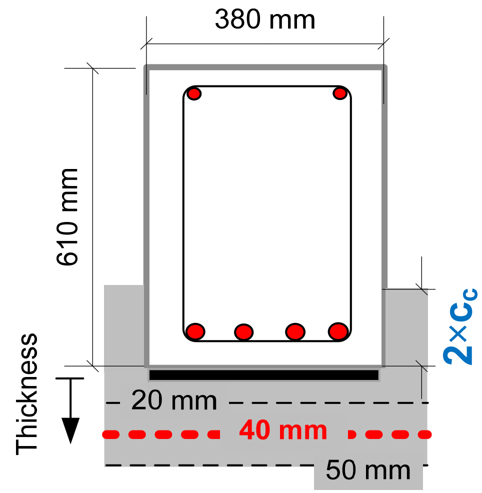
Case Study

❖ **Optimum Insulation Thickness**



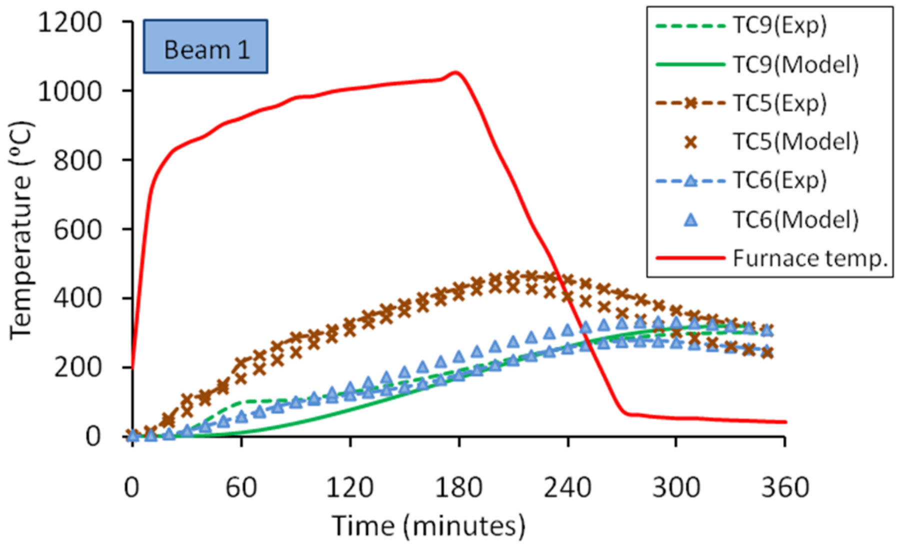


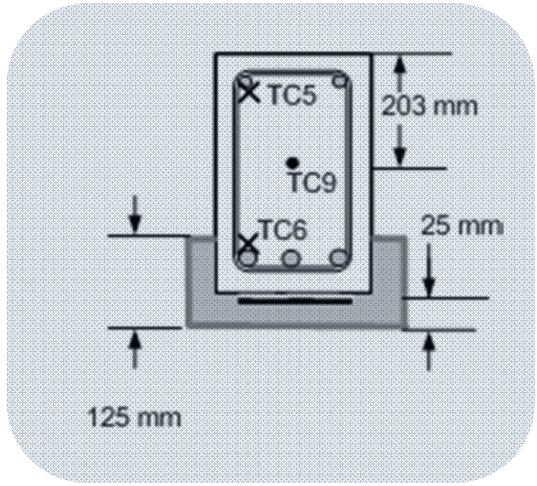
Insulation thickness for 2 hours of fire resistance



Insulation thickness for 3 hours of fire resistance

Model Validation (MSU Tests)





Predicted and measured temperatures