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

MICHIGAN STATE UNIVERSITY

Ahmed, A. and Kodur, V.K.R.
Civil and Environmental Engineering,
Michigan State University, East Lansing, MI 48824-1126

CIVIL & ENVIRONMENTAL ENGINEERING

Objective

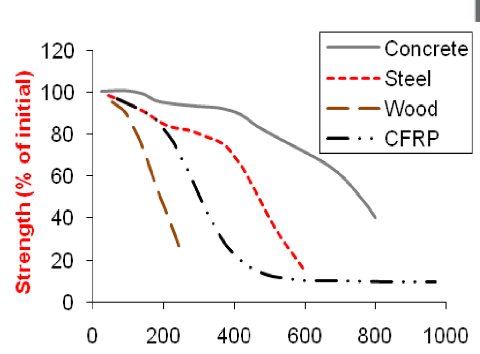
Develop a FE based computer model for tracing the fire response of FRP-strengthened RC beams:

- Develop a moment –curvature based approach for fire resistance analysis
- 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 standards

Fire Performance of FRP

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

- FRP performance in fire - Concerns
  - Faster degradation of strength and stiffness
  - Loss of bond with concrete
  - Low high temperature tolerance
  - Toxicity
  - Flame spread (combustible)
  - Limited information in literature



State-of-the-Art Review

- Two major numerical studies reported in the literature
  - Brea Williams (2004)
    - Developed a 2-D heat transfer model
    - Focused on T-beam cross section
    - Standard fire exposure
  - Hawileh et al. (2009)
    - ANSYS commercial software
    - Thermal and structural analysis of T-beam
- Limitations - Commercial computer programs
  - Complex – not validated
  - Do not account for:
    - Bond degradation at FRP-concrete interface
    - Thermally induced axial restraint force
    - High temperature properties (strains)
    - Various failure criteria

Proposed Computer Model

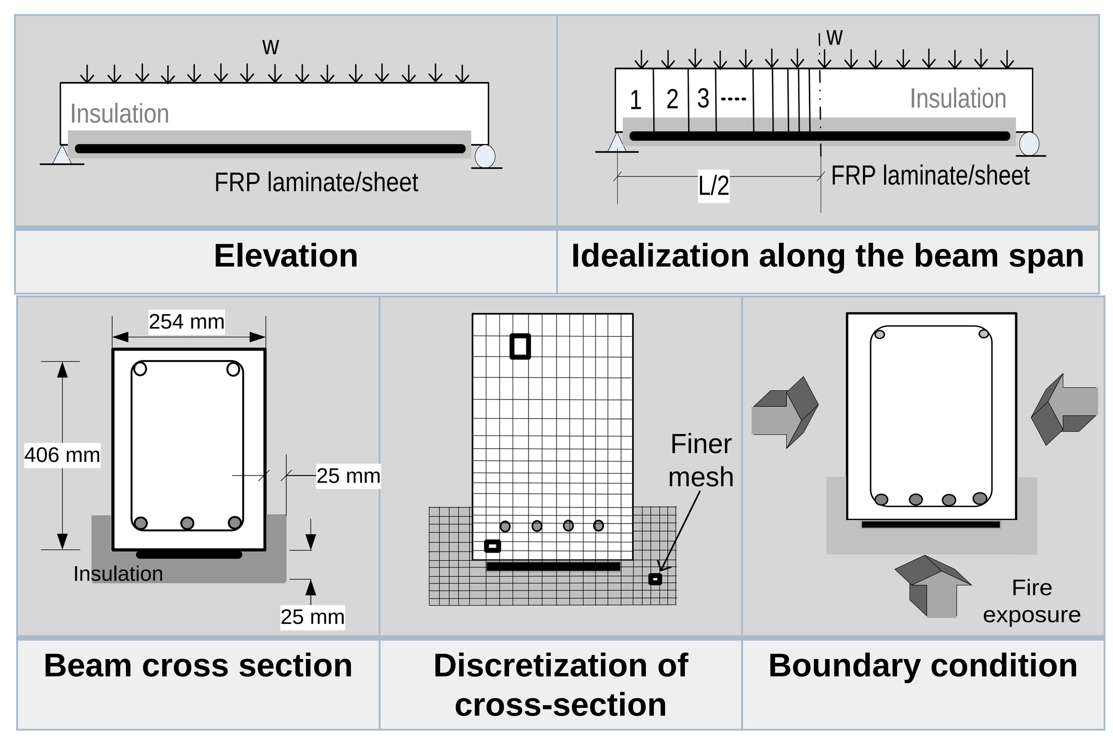
General Methodology

- Based on macroscopic FEM approach
- Utilizes sectional moment-curvature relationships
- HT properties (mechanical and thermal) - Concrete, rebars, FRP and insulation
- Can handle beams of different cross section (Rectangular, T, I-section)
- Account s for:
  - Design fire scenarios
  - Bond deterioration
  - Axial restraint
  - Different insulation schemes, and
  - Different failure criteria

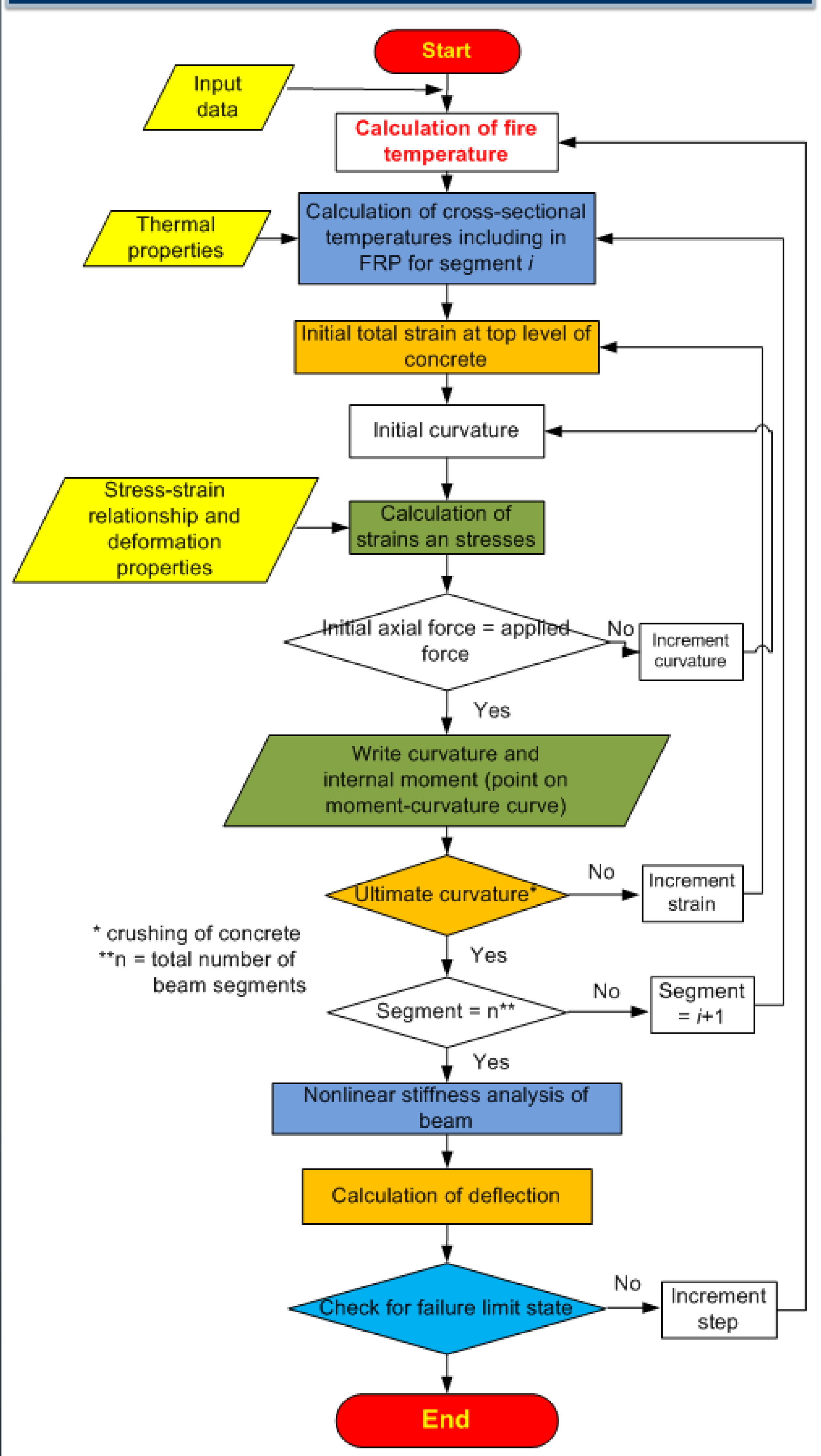
Computer Model - Approach

Steps involved in the model

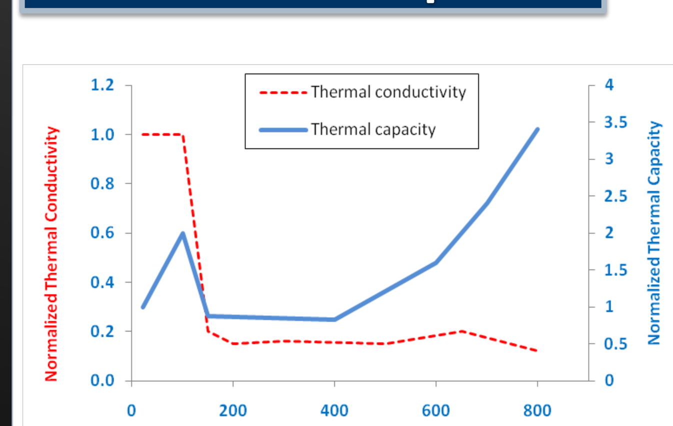
- Discretize the beam into various segments & segments into elements
- Device total time in to increments
- At time 't' generate fire temp. and cross sectional temp
- Compute bond-slip & axial restraint force
- Develop M-k relationships for beam segments
- Use M-k relationships to trace structural response



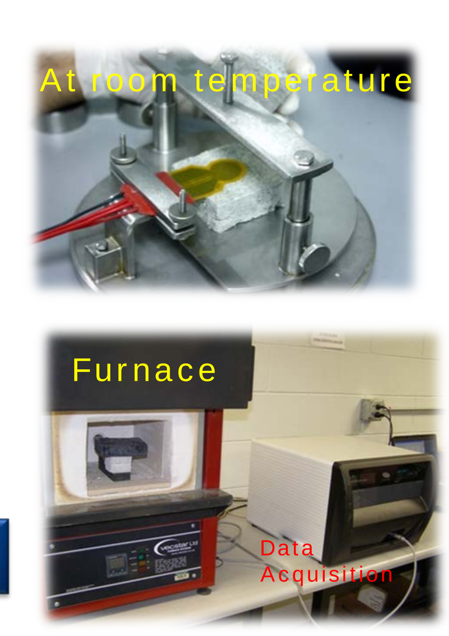
Flow Chart – Numerical Procedure used in the Model



HT Thermal Properties



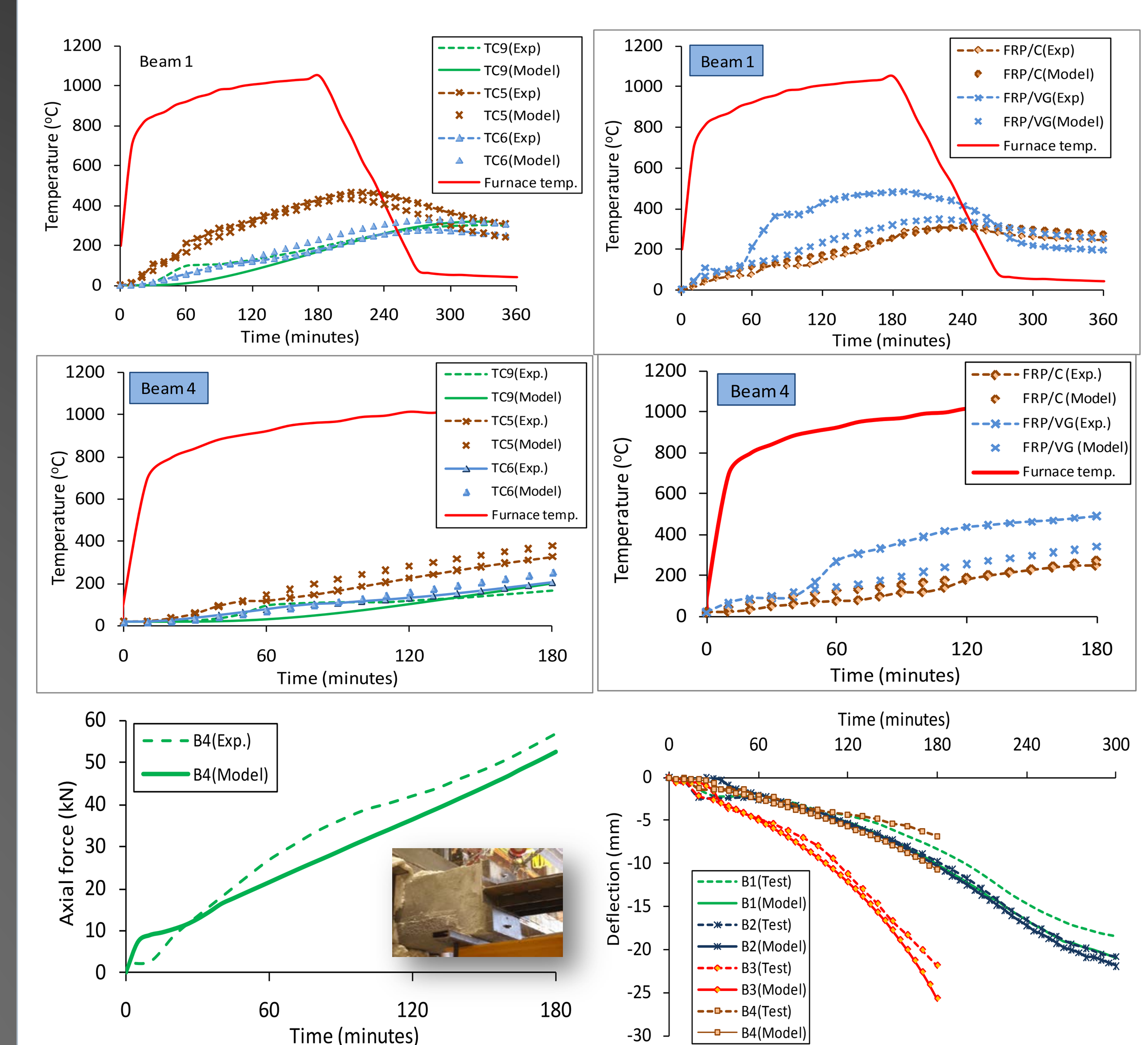
Normalized thermal conductivity & thermal capacity for Tyfo® WR AFP Insulation



Hot Disk Equipment

Validation of Model

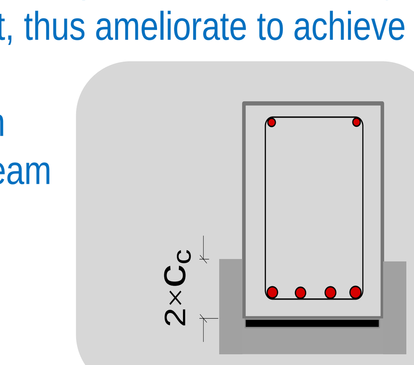
- Validated the model against data from fire tests conducted at :-
  - MSU and Univ of Ghent, Belgium - Rectangular beams
  - Queens Univ, NRC Canada – T-beams
- The validation result (illustrated below) shows that predicted and measured temperatures across the beam cross-section, deflections, and axial restraint force are in good agreement for entire duration of the test .



Case Study

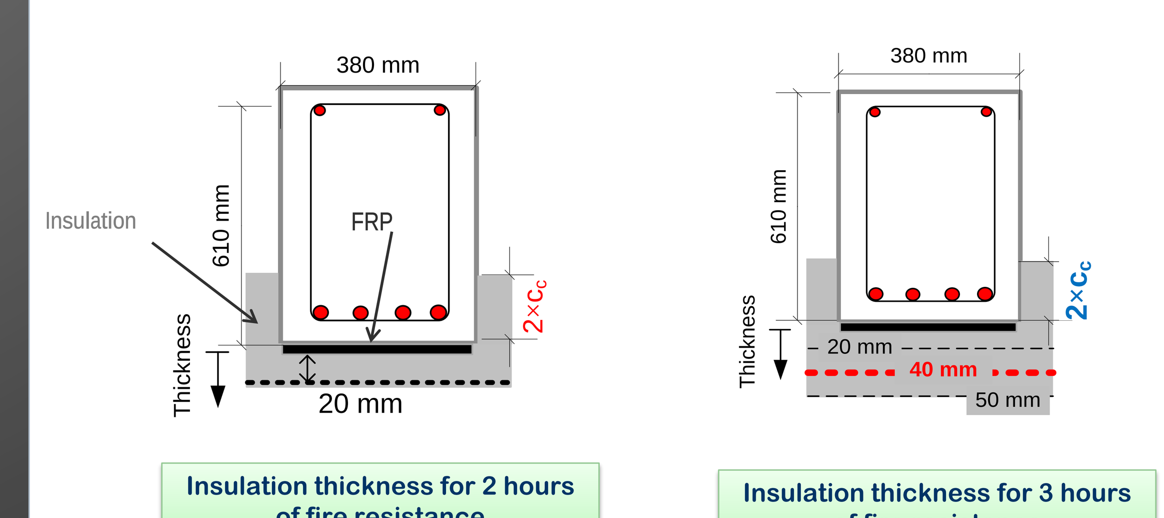
Insulation Configuration

- Insulation layout is an important consideration for achieving fire resistance.
- Proper detailing of insulation helps to keep the temperatures low not only in FRP but also in tension steel reinforcement, thus ameliorate to achieve optimum insulation levels
- Extending the insulation to two time the depth of concrete cover (2Cc) from bottom of the beam cross section (on either side) is required to achieve optimum fire resistance



Insulation Optimum Thickness

- An increase in insulation thickness beyond certain level of thickness is not beneficial. This level of insulation thickness is referred to as "optimum insulation thickness"
- An optimum insulation thickness of 40 mm is required to achieve 3 hours of fire resistance while a minimum of 20 mm thickness is needed to achieve a fire resistance up to 2 hours.



Conclusion

- The proposed FE 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
- The model accounts for high temperature material properties of constitutive materials, fire induced bond degradation, axial restraint force, and different strain components.
- 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.

Acknowledgements

This research is supported by the National Science Foundation (Grant No. CMMI 0855820) and Michigan State University through Strategic Partnership Grant (Award No. SPG 71-4434).