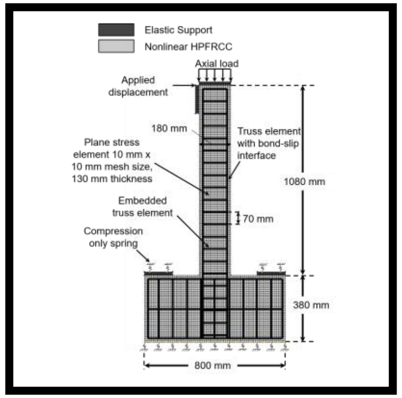
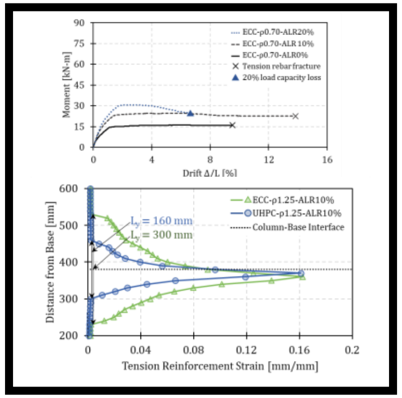
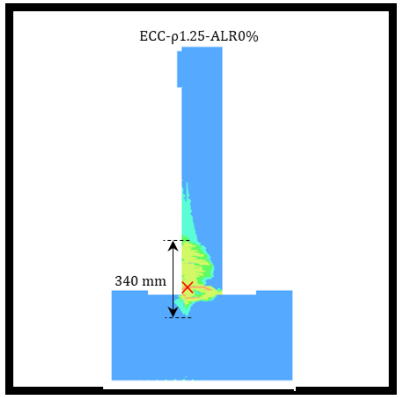
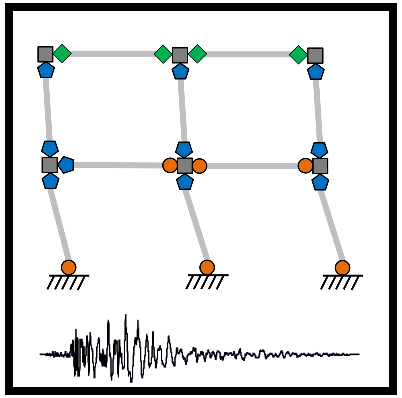
Moment-Rotation Response of Reinforced UHPC Columns under Varying Axial Loads









Joseph A. Almeida, Ronit Sthapit, Matthew J. Bandelt Ph.D. P.E.

J.A. Reif, Jr., Department of Civil and Environmental Engineering

New Jersey Institute of Technology

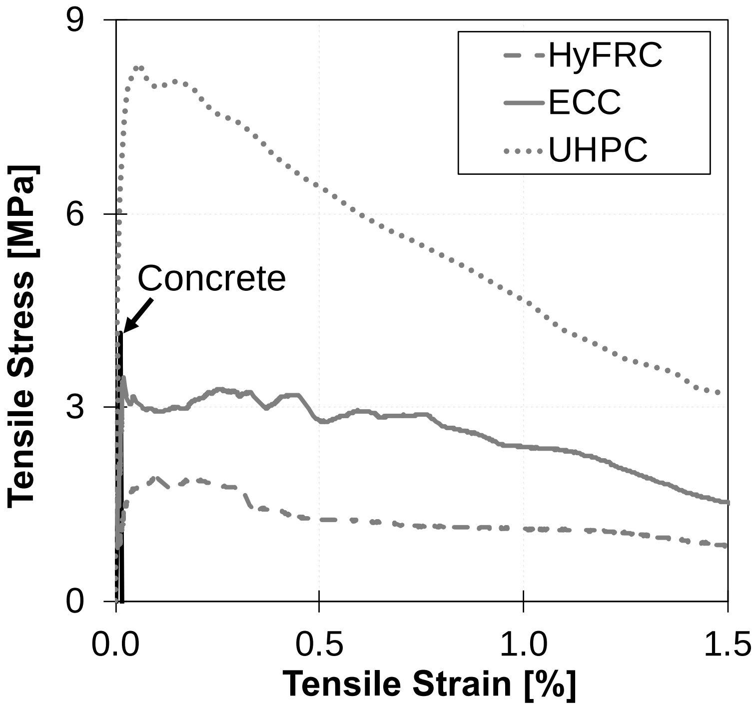
matslab materials and structures laboratory at NJIT

NJIT

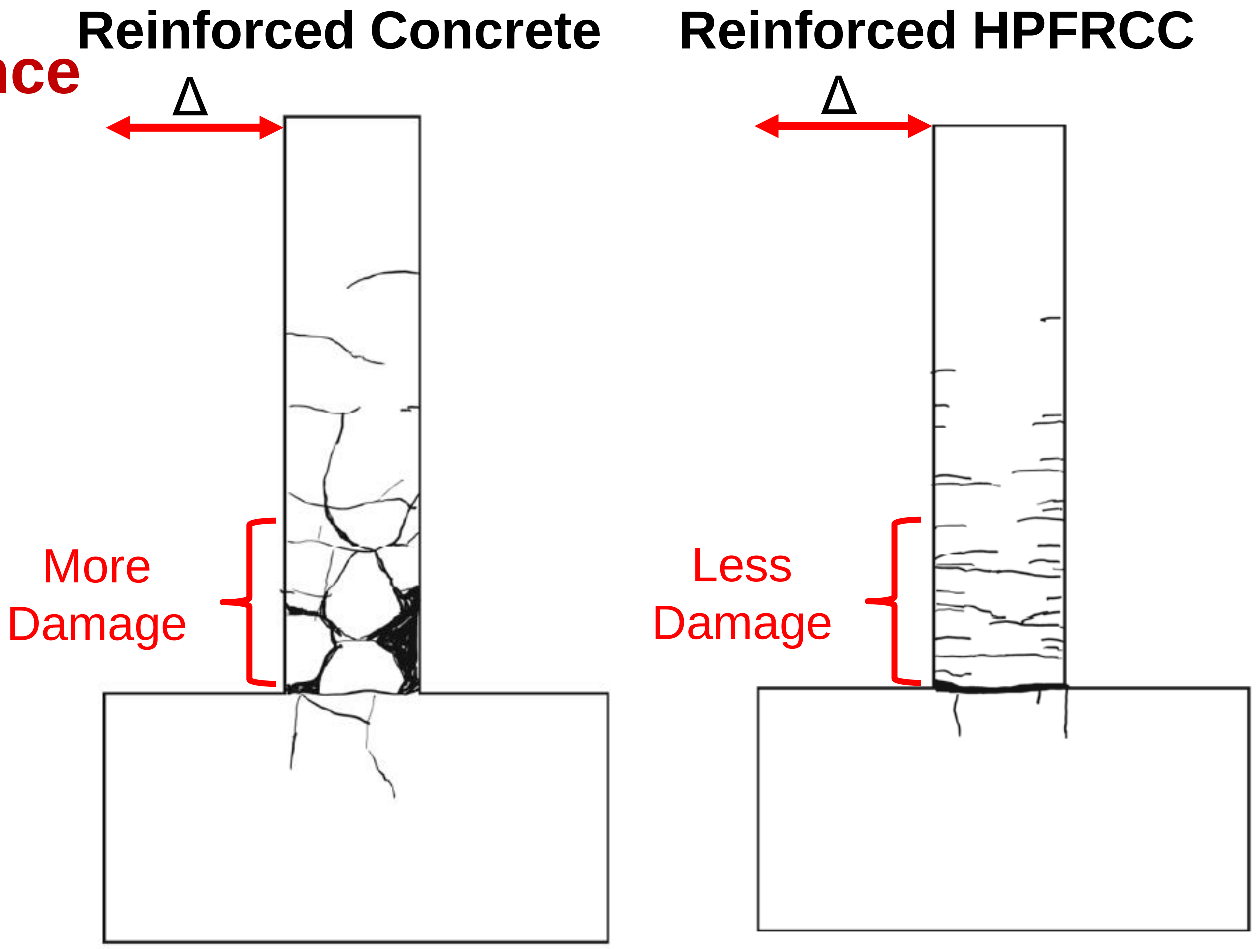
ACI Convention – Fall 2023
Innovative Applications of UHPC in Columns, Part 1 of 2
Boston, Massachusetts
29 October 2023

ULTRA-HIGH PERFORMANCE CONCRETE (UHPC) AND HIGH PERFORMANCE FIBER REINFORCED CEMENTITIOUS COMPOSITES (HPFRCCS)

- What we know of UHPCs:
  - **Enhanced mechanical performance**
  - **Improved damage tolerance**
  - High durability

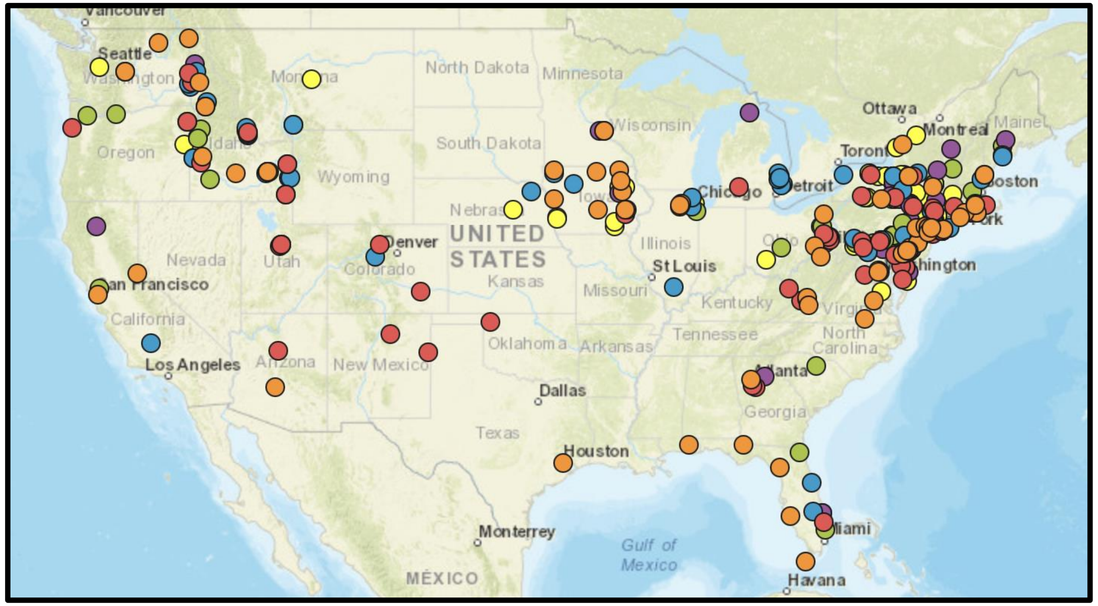


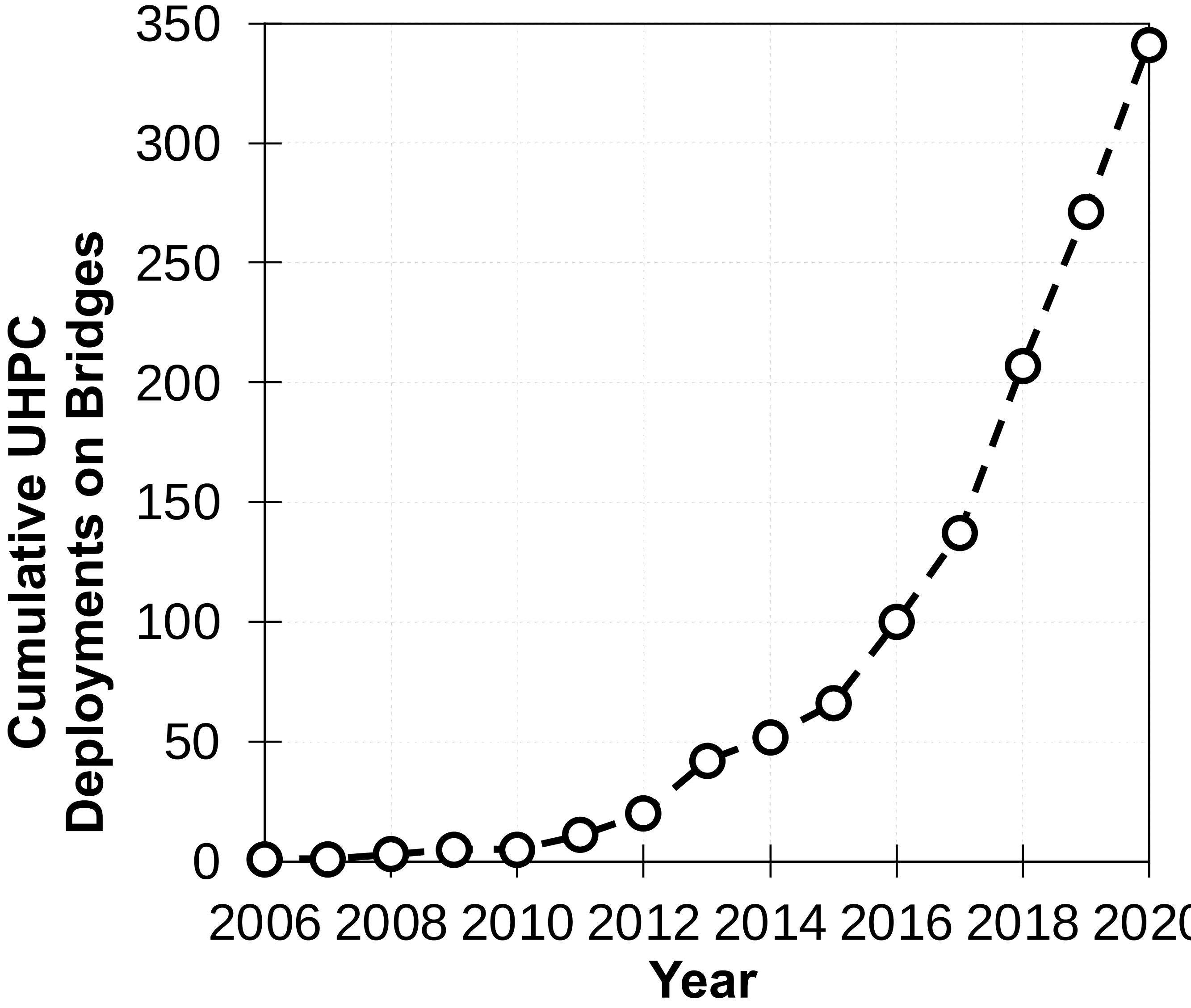
(Moreno et al., 2014; Jen et al., 2014; Wille et al., 2010)



(Frank et al., 2017)

GROWTH OF UHPCS: EXAMPLE IN BRIDGES





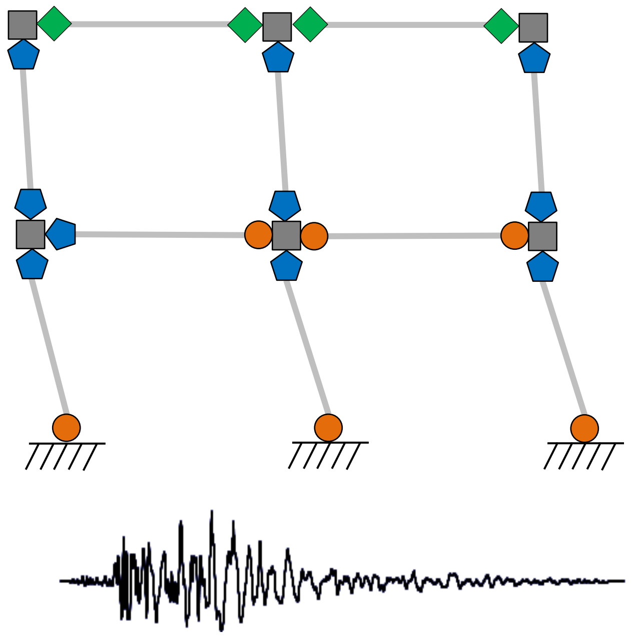
- UHPC has grown substantially in bridge construction

- What are the obstacles preventing growth in seismic design?

RESEARCH QUESTIONS AND OBJECTIVES

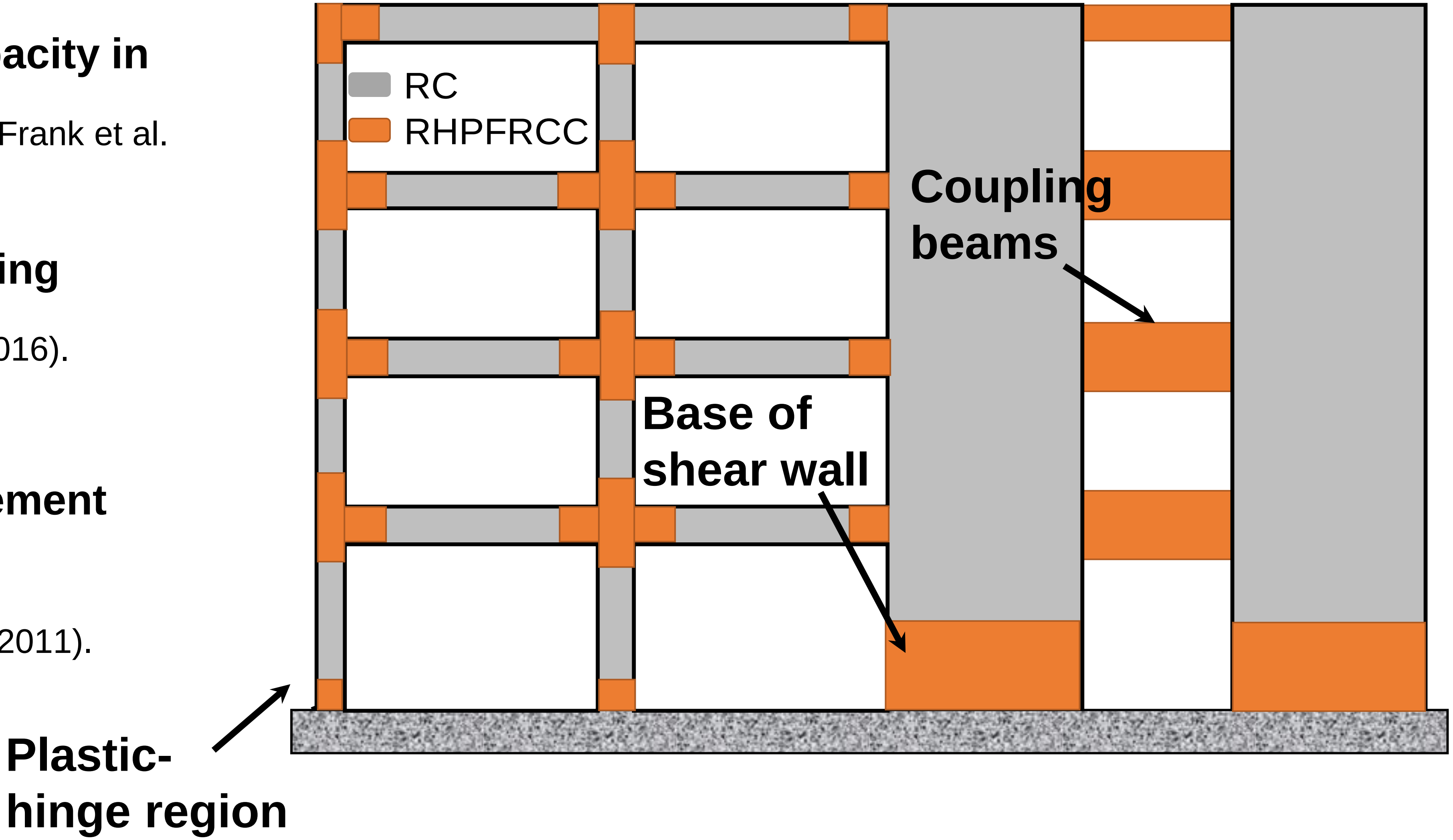
Research questions:

- What gaps exist to characterize **system level** behavior of HPFRCC systems?
- How do **HPFRCC structural systems compare** to **traditional concrete** systems?



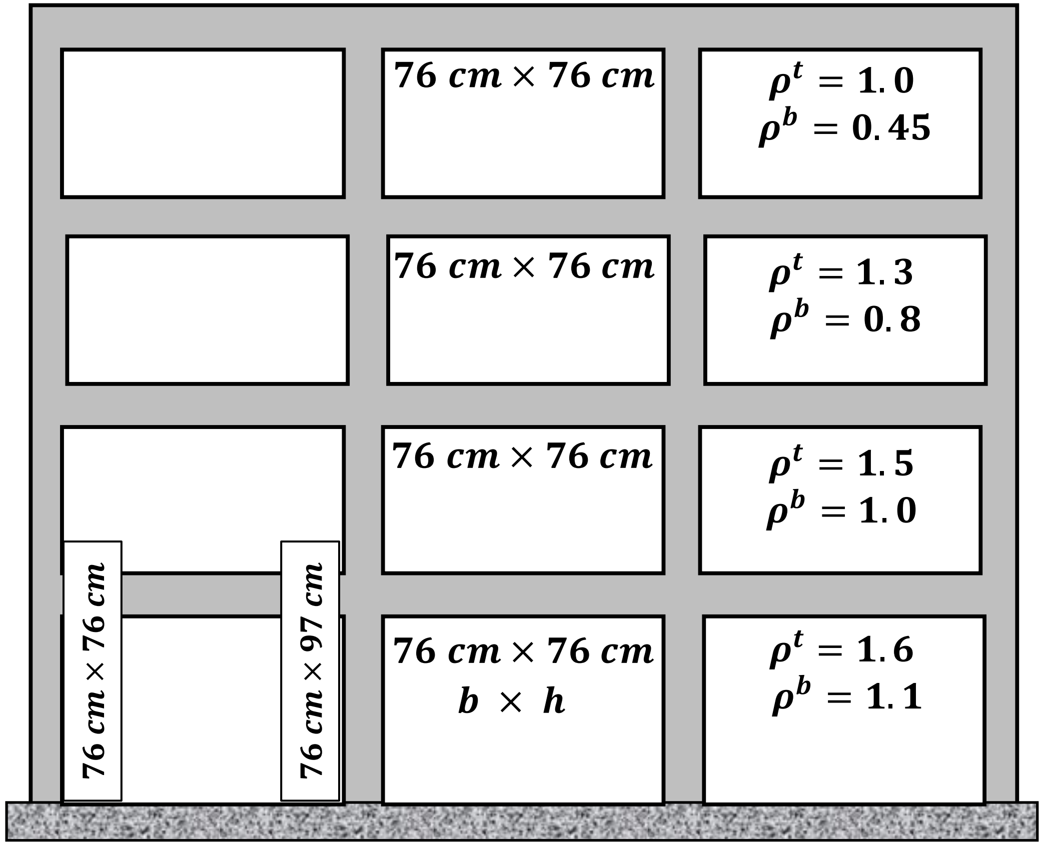
Representative Experimental Seismic Research

1. **High deformation capacity in beams and columns** (Frank et al. 2015, Wu et al. 2017).
2. **High Shear and Bending deformations** (Zheng, 2016).
3. **Reduce transverse reinforcement requirement** (Lequesne, 2010).
4. **Structural fuse** (Oslen, 2011).



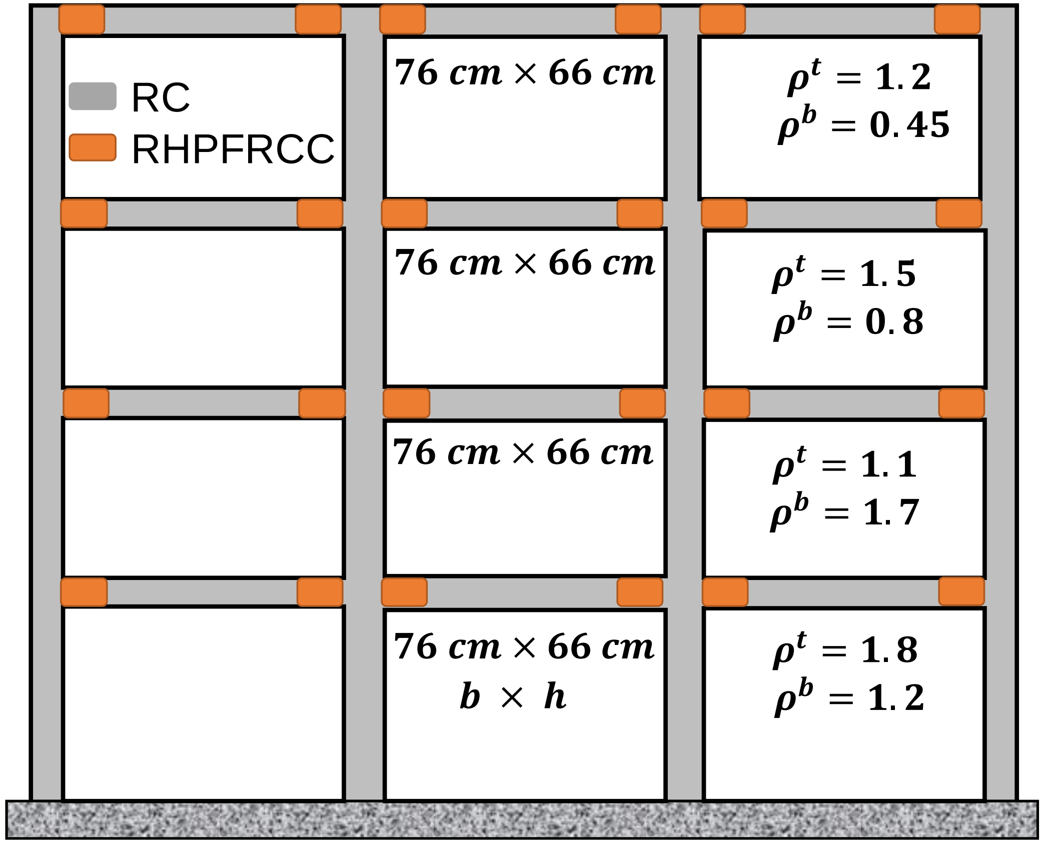
DESIGN ILLUSTRATION OF 4 STORY FRAME

(a) RC Frame



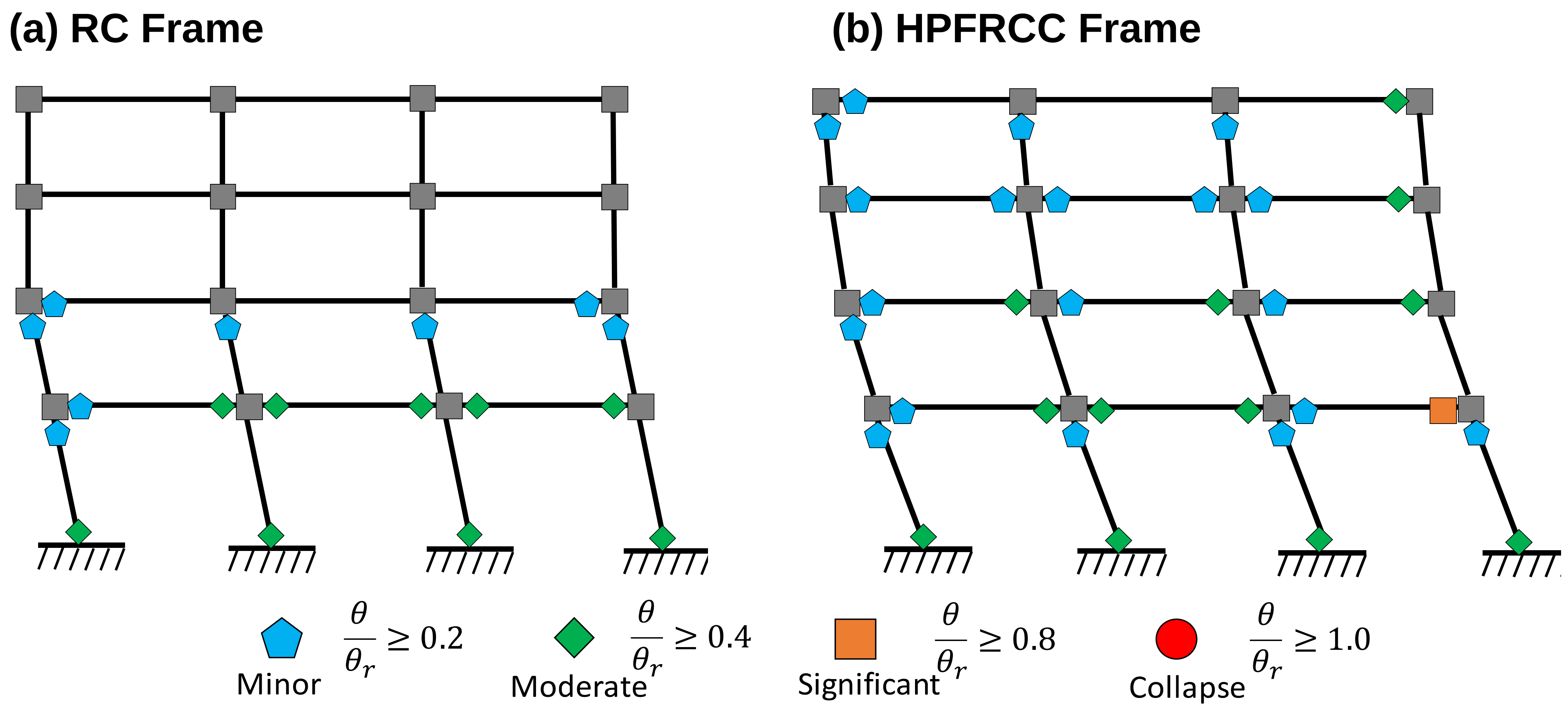
Code confirming R/C structure

(b) HPFRCC Frame



Replace concrete with HPFRCC in beam regions. Resize members to maintain strong-column weak-beam.

Seismic System Analysis

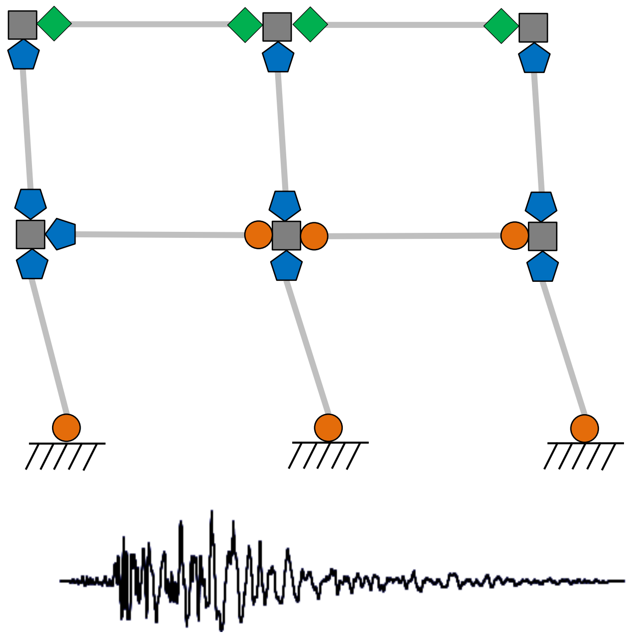


- When engineered for strong-column weak beam behavior, structure was **38% less likely to collapse compared to R/C using IDA**

Research Questions and Objectives

Research questions:

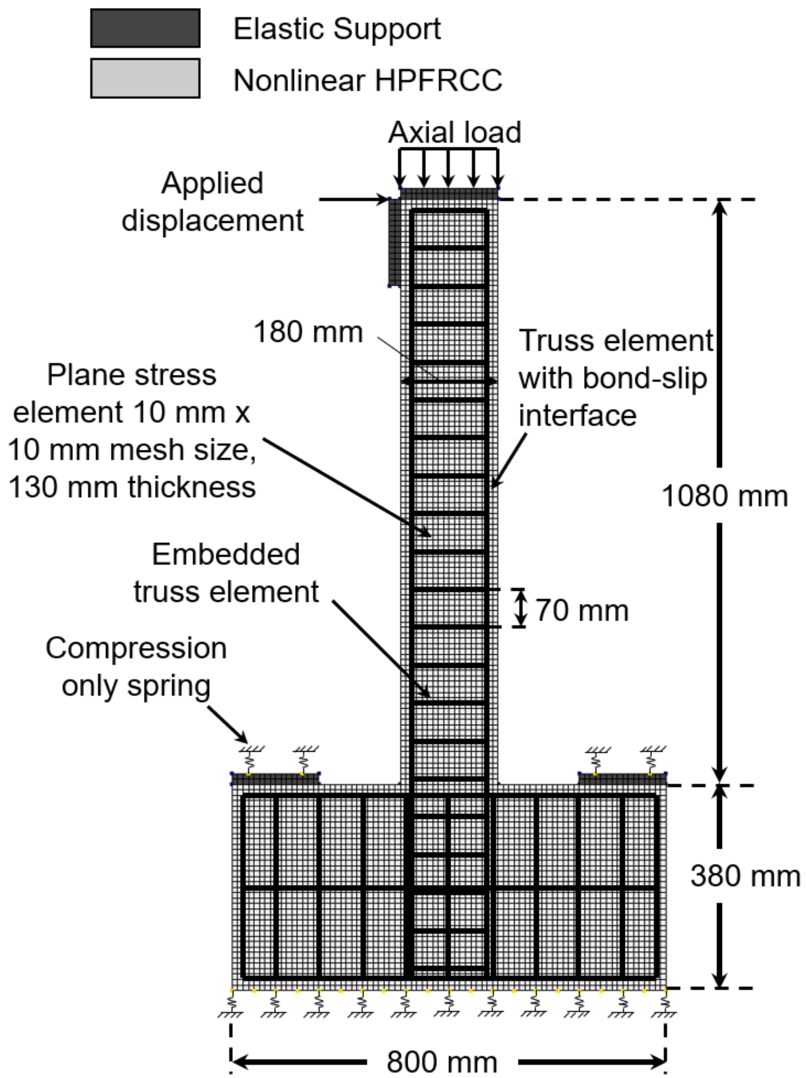
- What gaps exist to characterize **system level** behavior of HPFRCC systems?
- How do **HPFRCC structural systems compare** to **traditional concrete** systems?



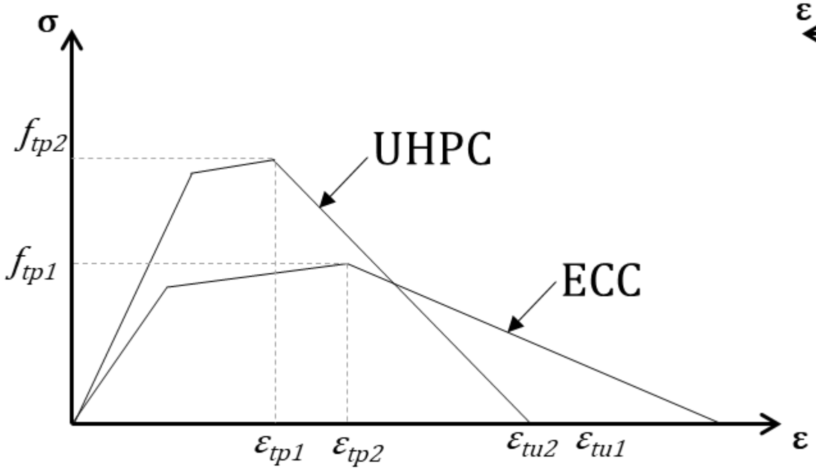
Research objectives:

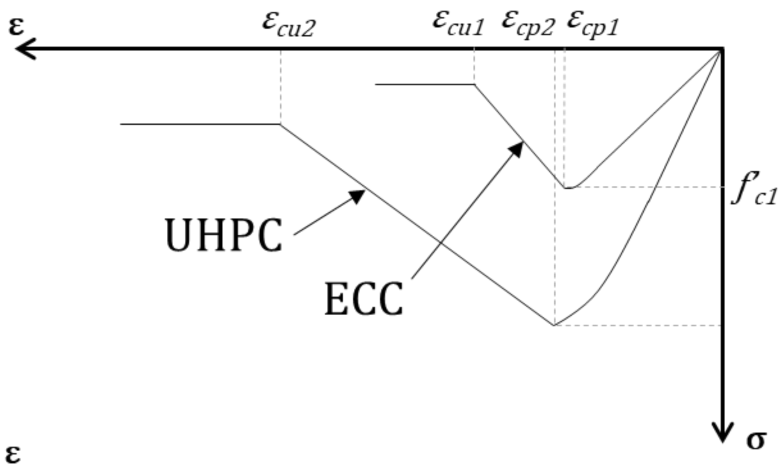
- Identify factors that influence structural response of columns
- Develop tools to efficiently simulate response

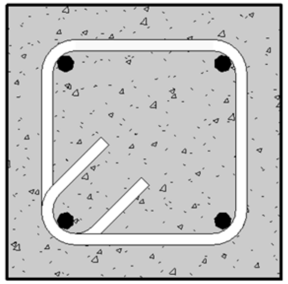
Numerical Modeling of Columns

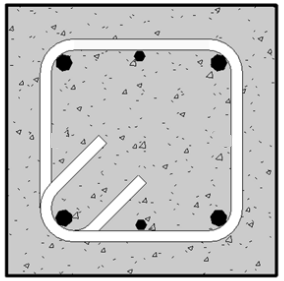


Main design variables



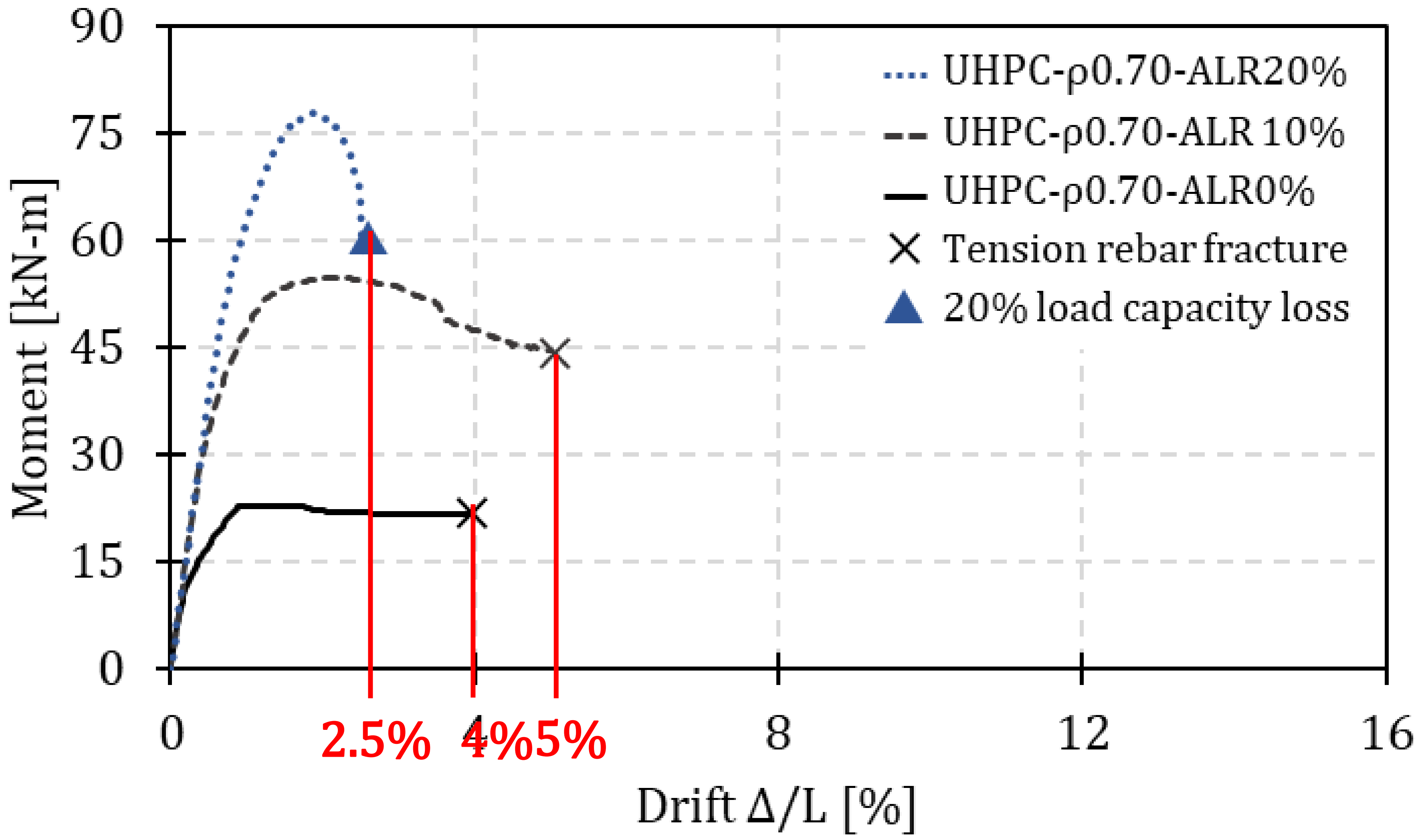




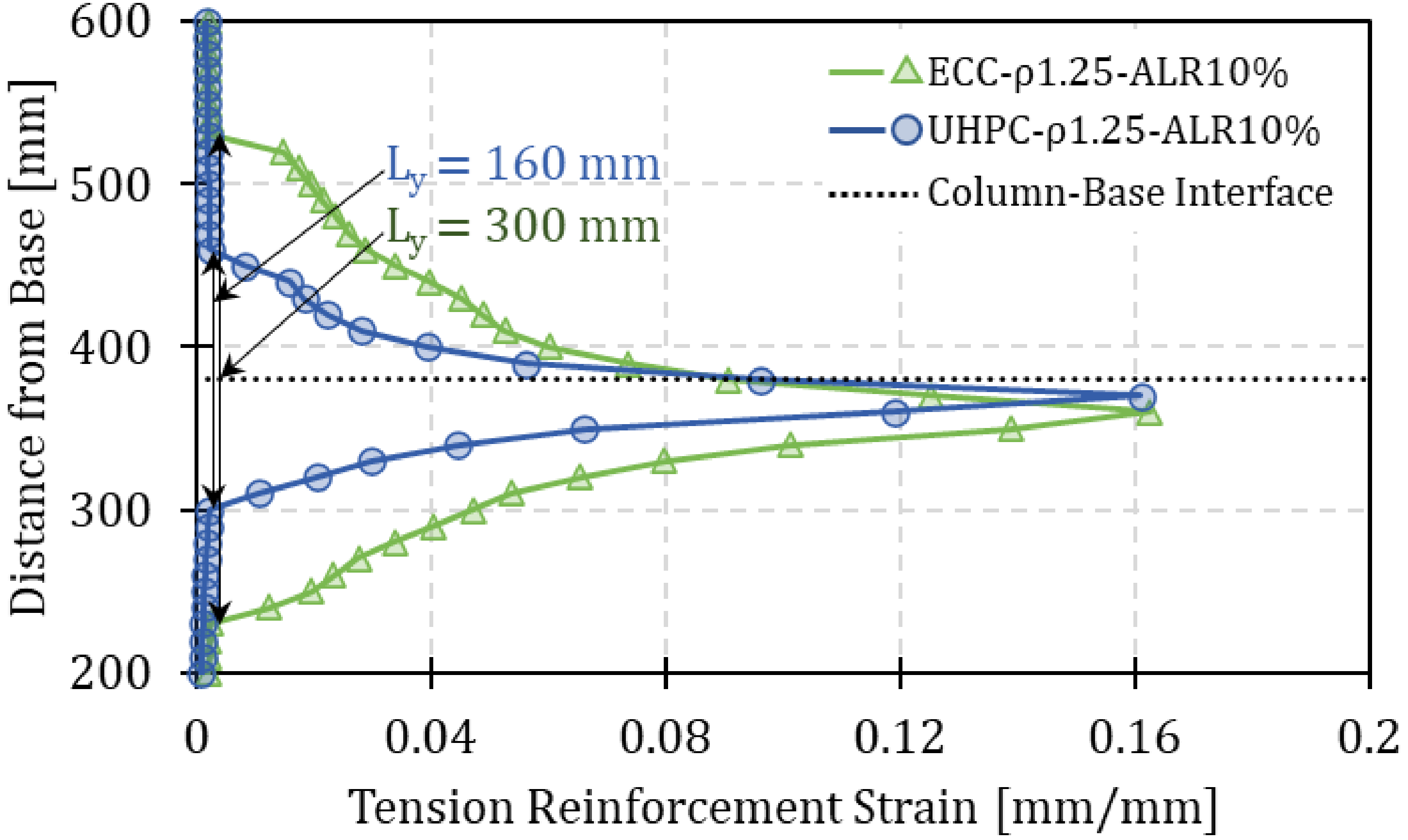


Varying Axial Load

MOMENT-DRIFT RESPONSE

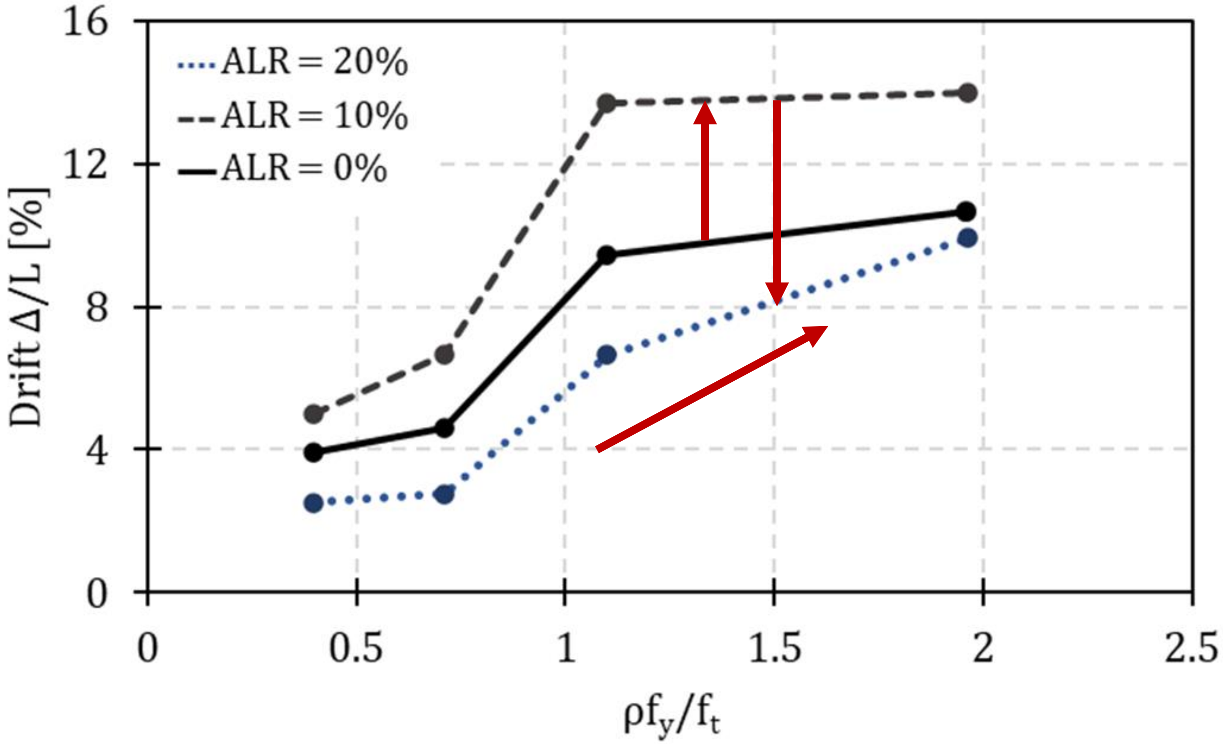


MECHANICS AFFECTING DRIFT CAPACITY



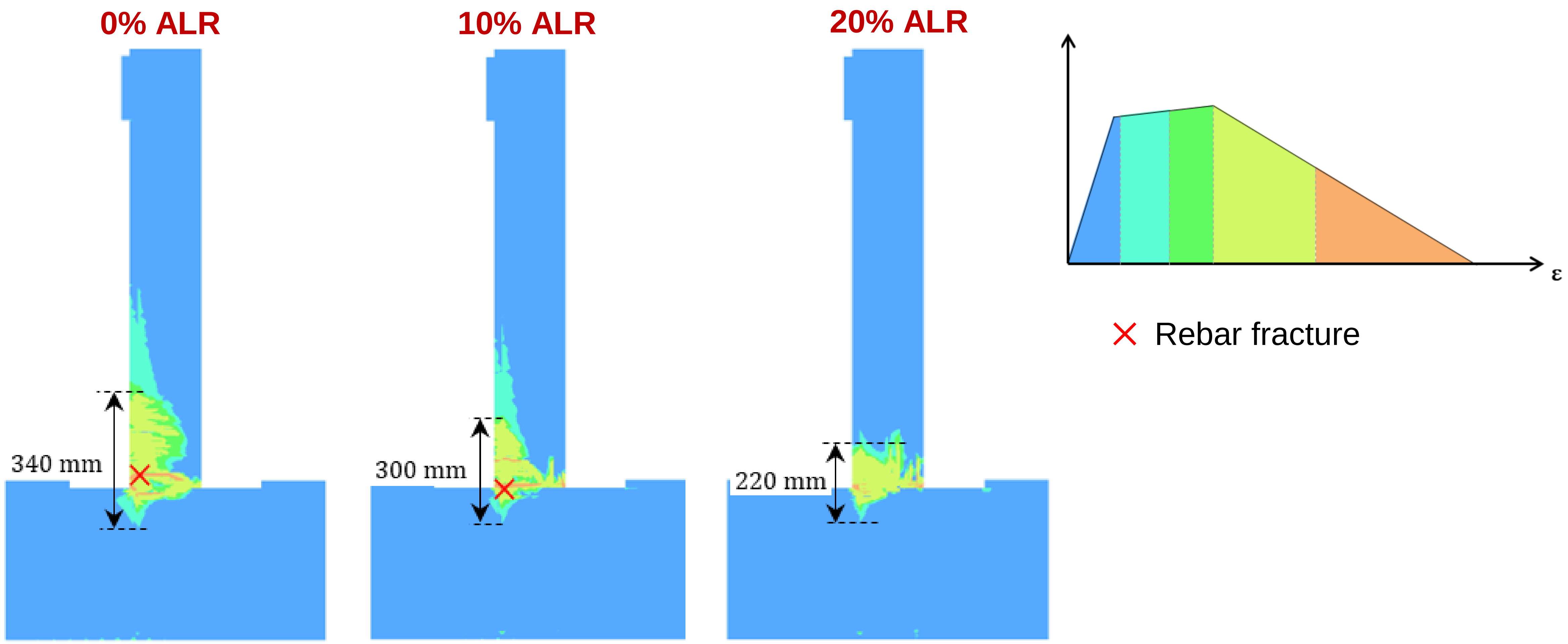
- Increase in tensile strength → high bond stresses → more concentrated plastic strain distribution

COMBINED EFFECTS OF ρ, f_t, AND AXIAL LOAD



- Drift capacity is a function of **relative tensile strengths**
- Higher relative reinforcement ratios → higher bond stress demands → higher plastic stain distributions → higher drift capacities
- Increase in axial load ratio (ALR) increases and then decreases drift capacity

Failure Mechanisms and Damage Patterns

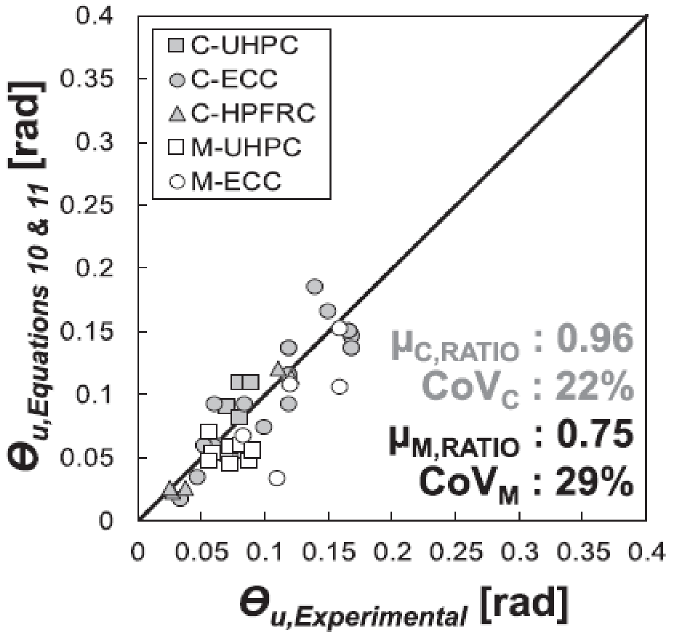


- Increase in axial load → smaller damage area and drift capacity
- Failure mechanism shift from tension to compression between 10%-20% ALR

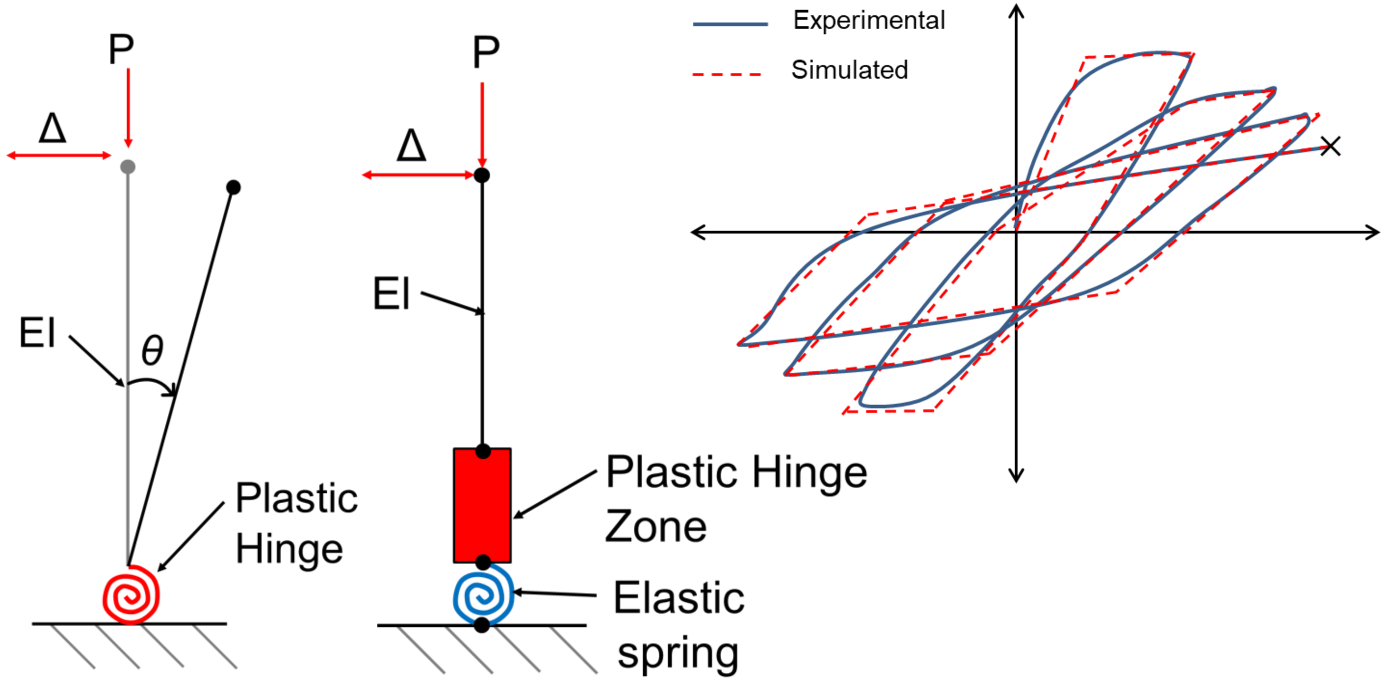
STRUCTURAL MODELING OF HPFRCC SYSTEMS

Characterize component level behavior and damage patterns to develop accurate expressions

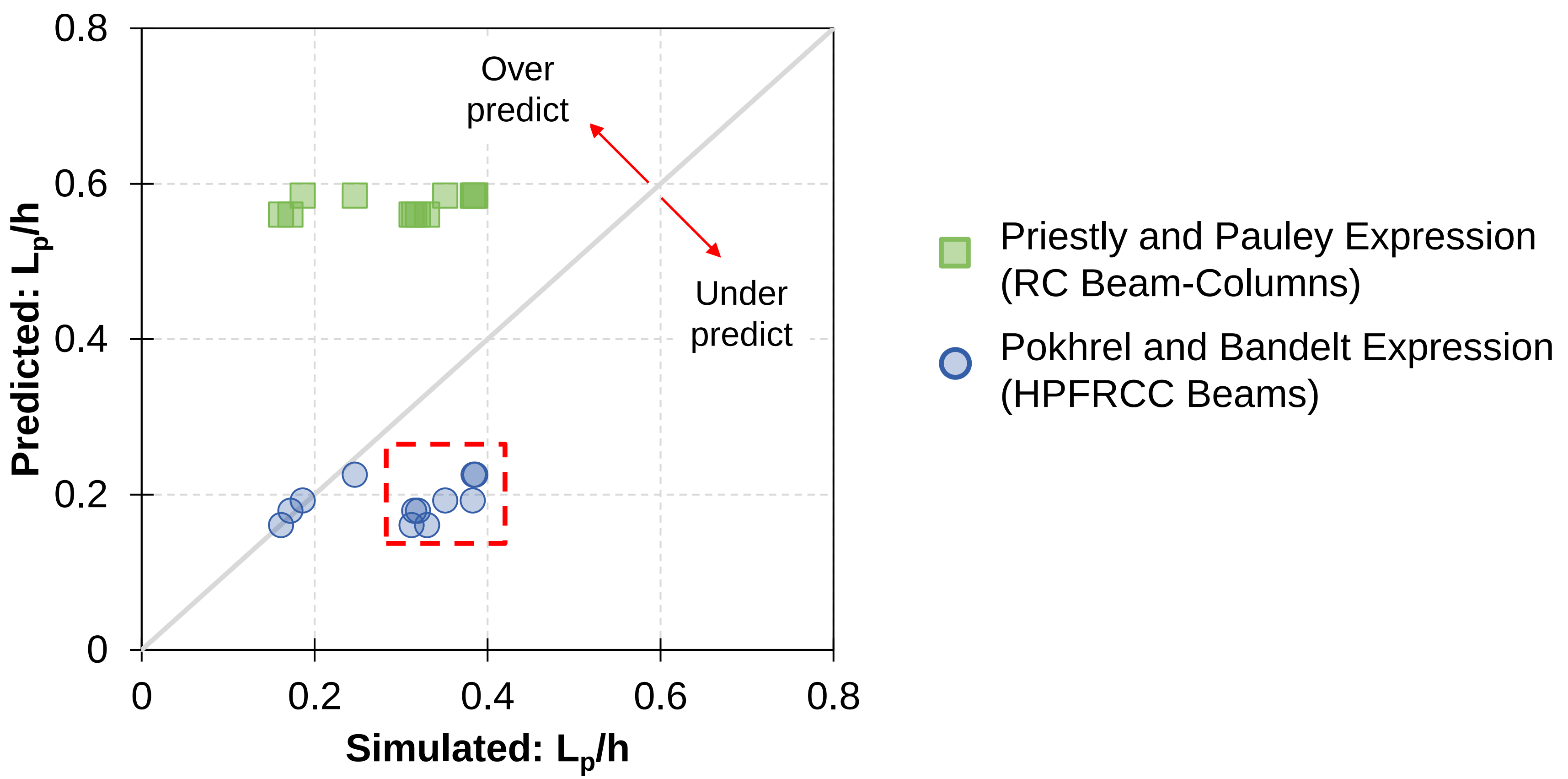
$$L_p = \beta_0 \frac{\rho}{f_t} + \beta_1 \frac{P}{A_g f'_c} + \ldots.$$



Accurately model component level response

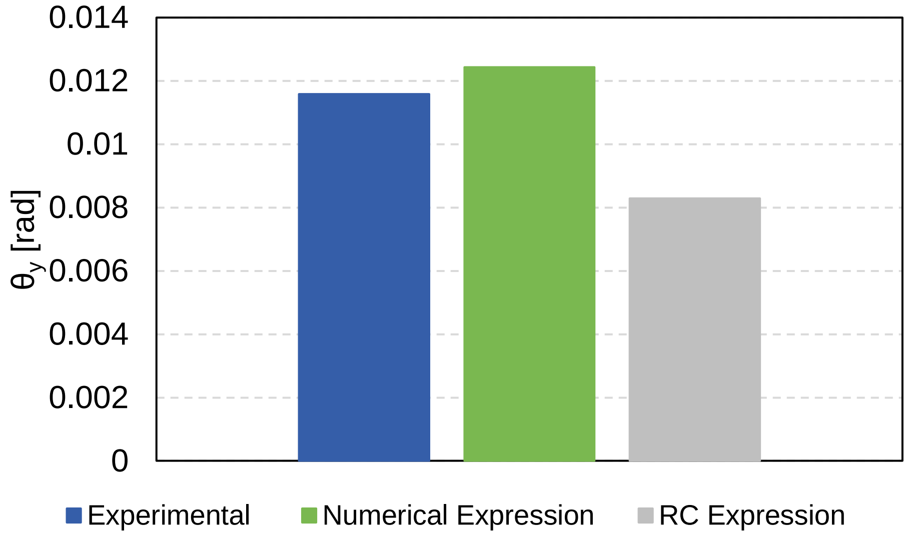


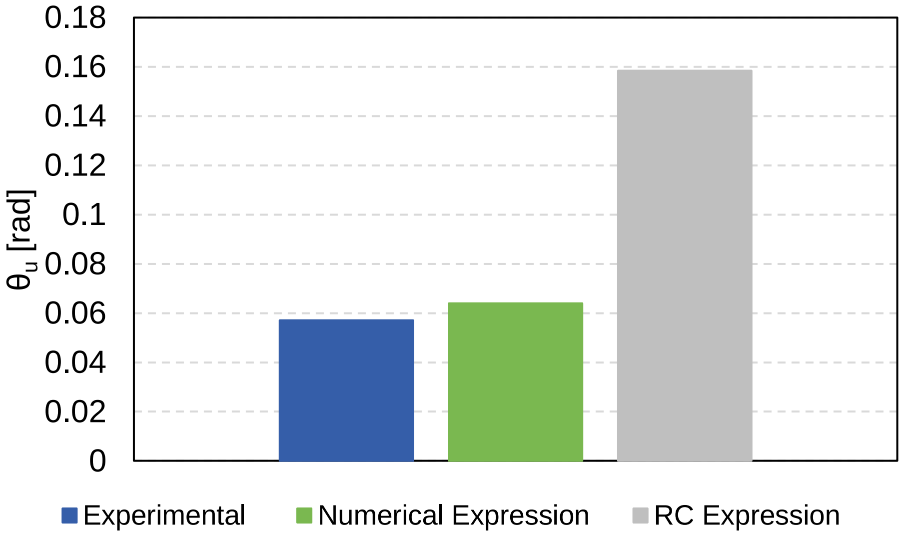
Existing Plastic Hinge Length Expressions



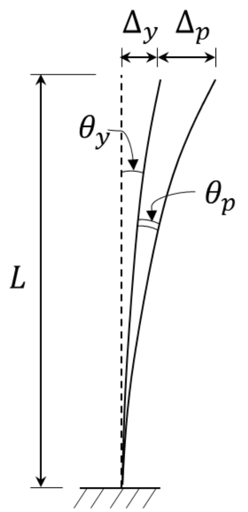
- Existing RC expression significantly over predicts simulated values
- HPFRCC expression diverges as axial load increases

COMPARISON TO EXPERIMENTAL RESPONSES





$$\theta_u = \theta_y + \theta_p$$



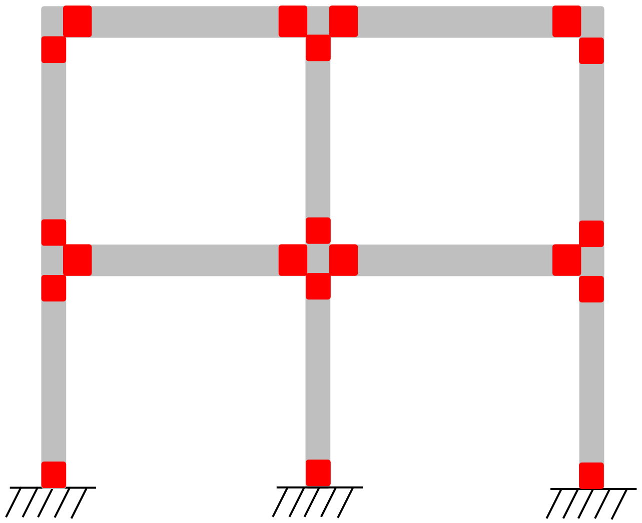
- Numerically calibrated expression reasonably predicts deformation capacity
- Existing RC expressions do not accurately predict deformation capacity

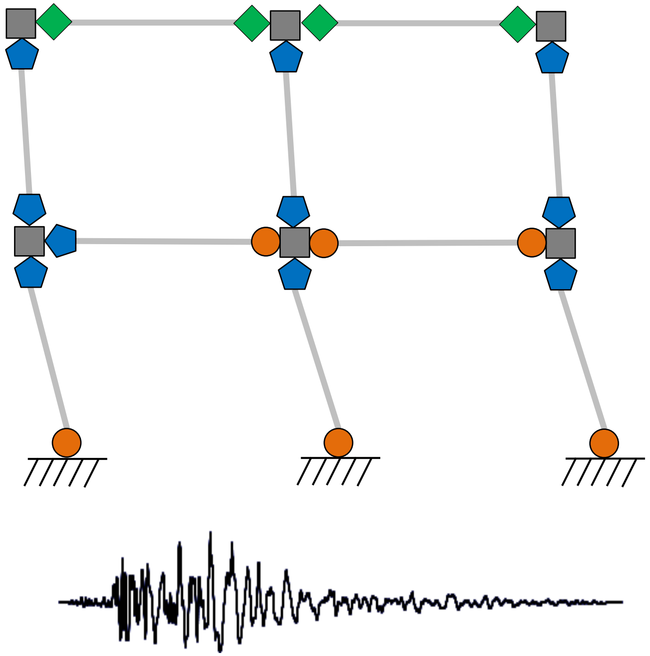
STRUCTURAL MODELING OF HPFRCC SYSTEMS

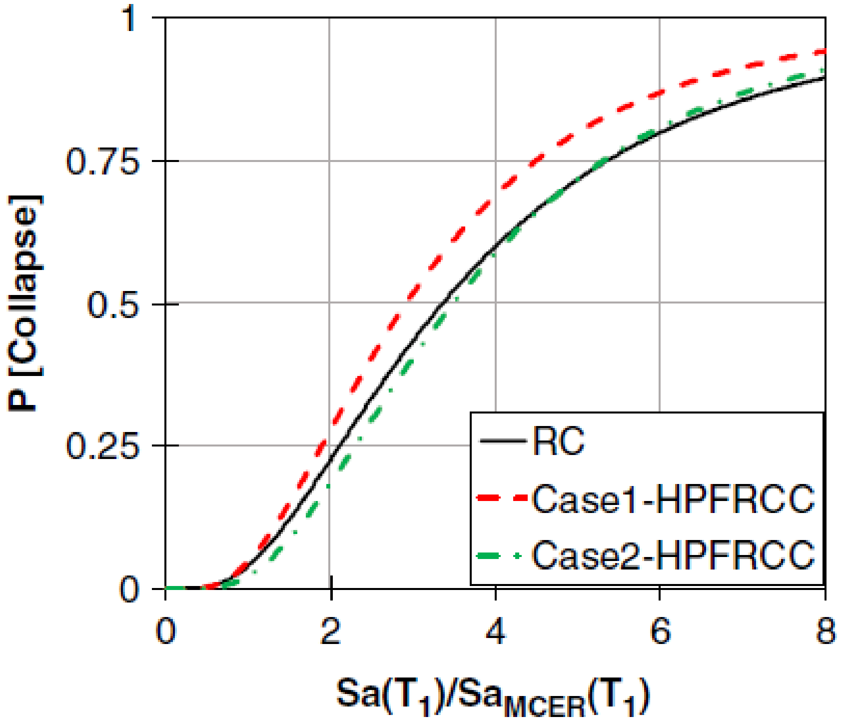
Consider architype structures using HPFRCCs and RC

Model system level behavior

Evaluate HPFRCC and RC systems







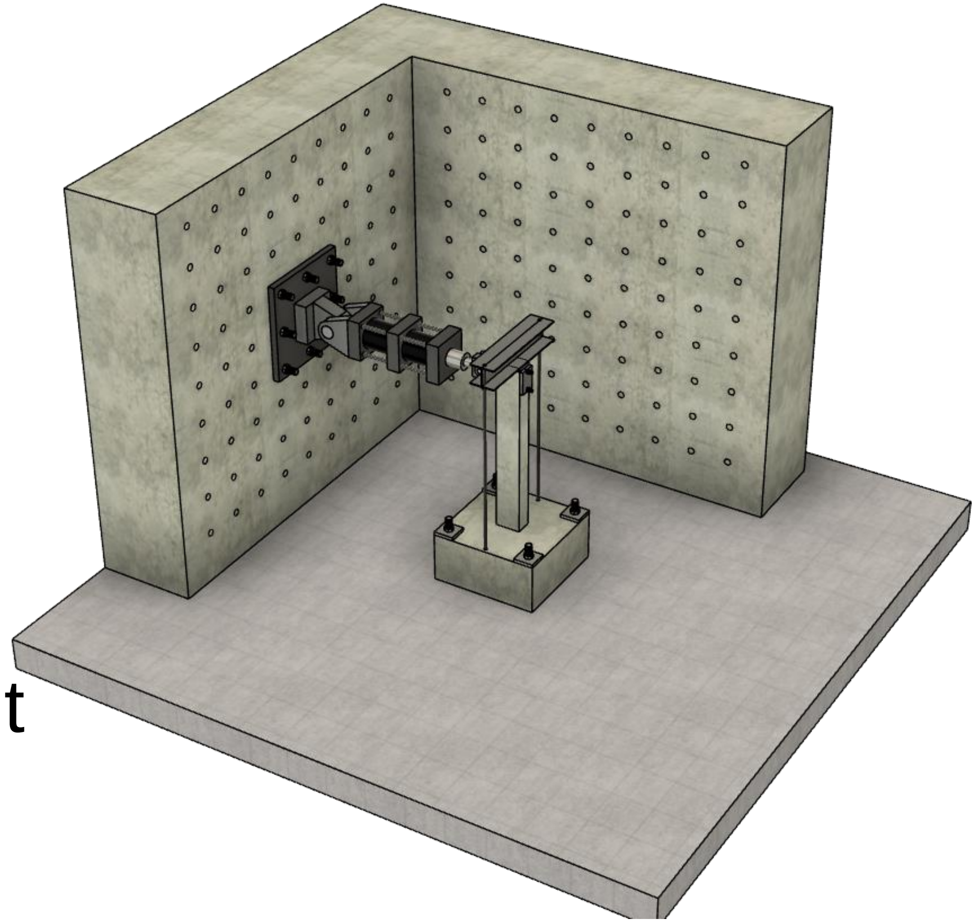
(Tariq et al. 2021)

Key Takeaways

- HPFRCC component drift capacity is a **balance of reinforcement and tensile strength**
- Increases in axial load result in smaller damage areas and drift capacity

Big picture:

- Systematically characterizing component response to develop accurate tools for nonlinear time history analysis
- Evaluate and compare HPFRCC and RC system level responses



Column experiments in 2024

THANK YOU!

bandelt@njit.edu

NJIT
New Jersey's Science & Technology University

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