

Experimental Evaluation and Analytical Simulation of Bridge Column-to-footing Joints Connected Using Grouted Splice Sleeves in Seismic Regions

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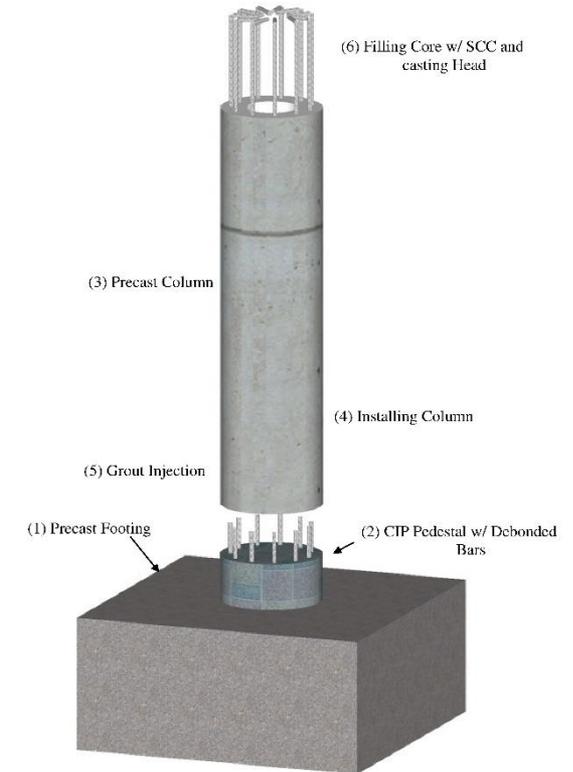
Chris P. Pantelides

Accelerated Bridge Construction

UDOT (2007-2011)



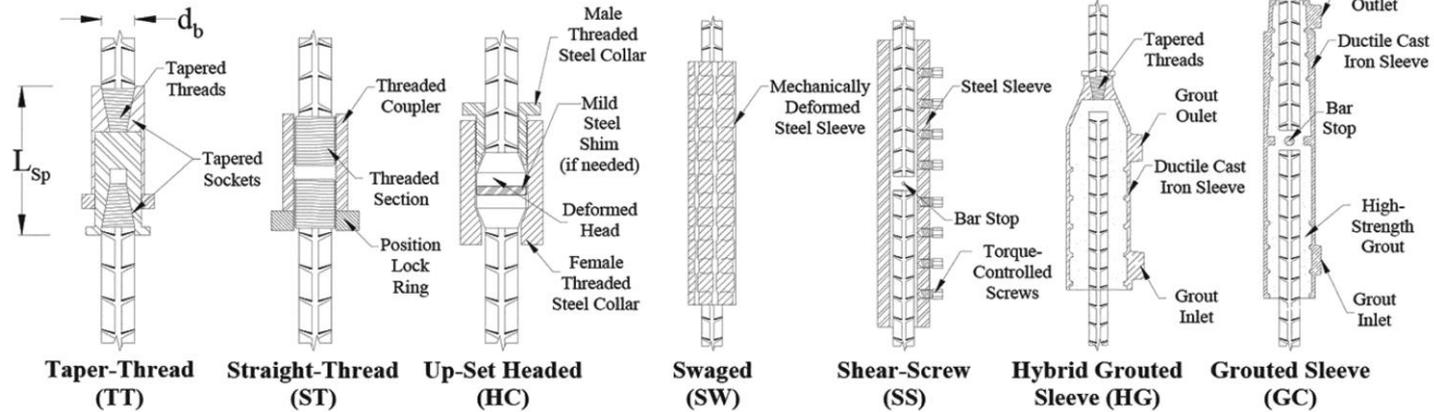
Accelerated Bridge Construction – Bridge Bents



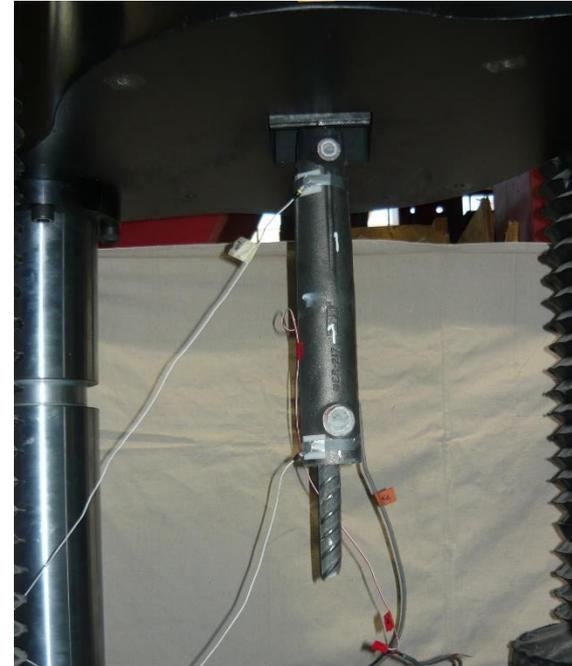
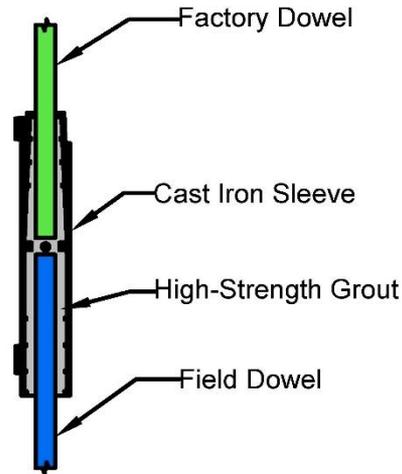
Tazarv et al. (2014)

Mechanical Couplers

Haber et al. (2015)

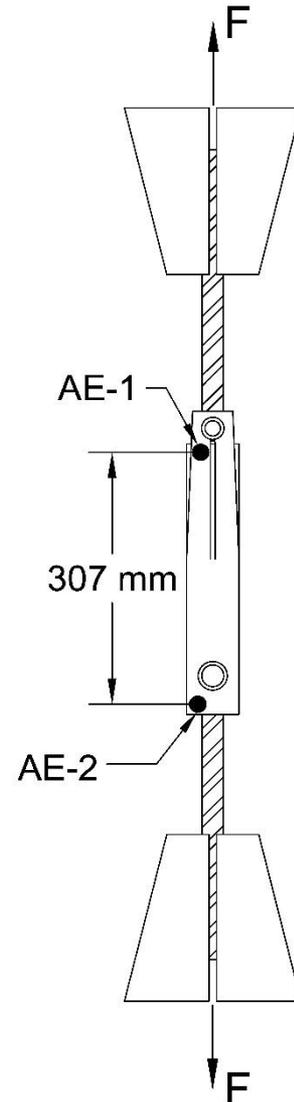
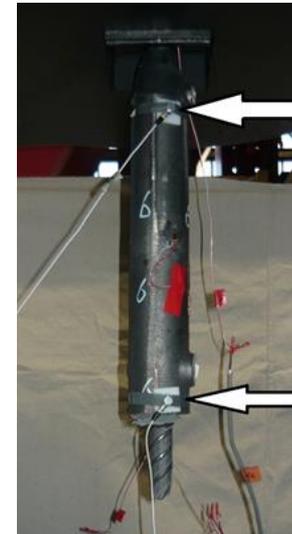
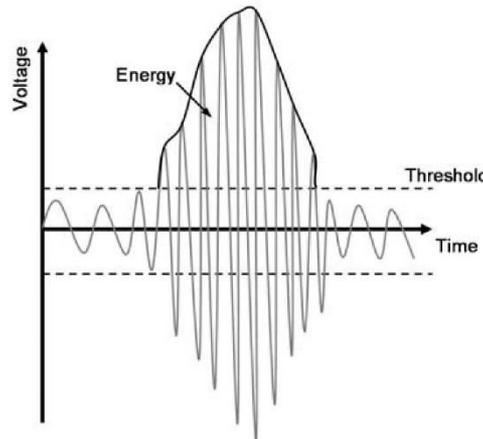


Grouted Splice Sleeve Connectors



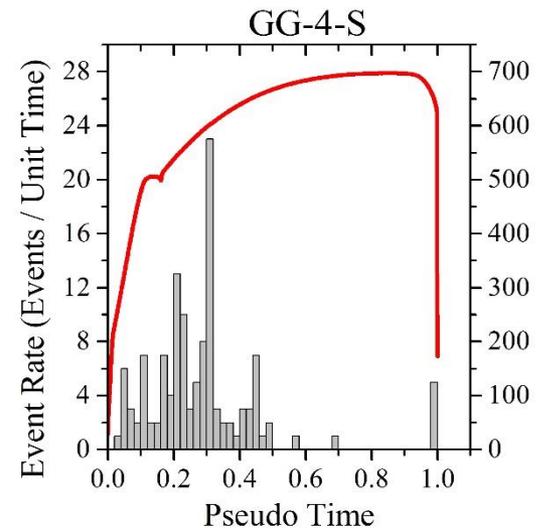
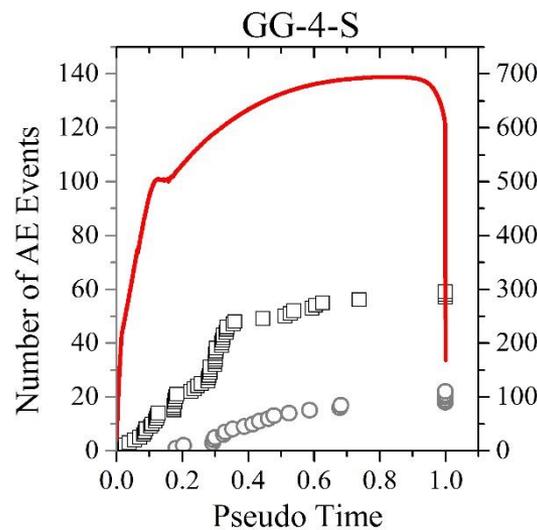
Acoustic Emission (AE) Monitoring

- Non-destructive testing
- AE acquisition system
- Sample AE event
- Sensor type
 - Digital Wave B-1025
- Sensor location



Acoustic Emission (AE) Monitoring

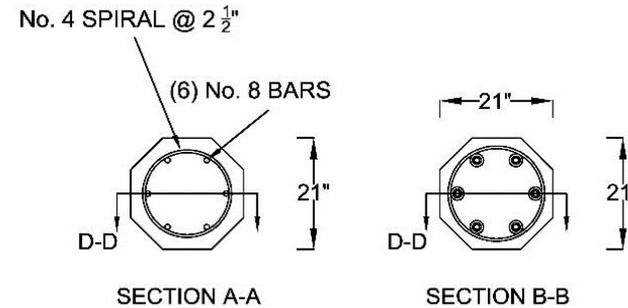
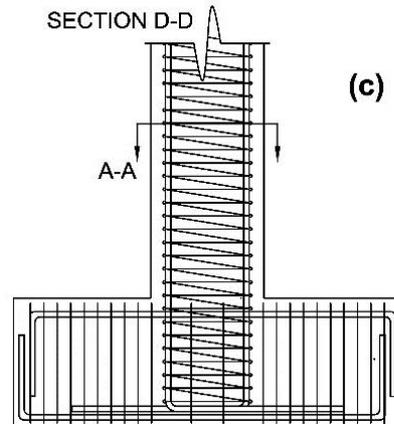
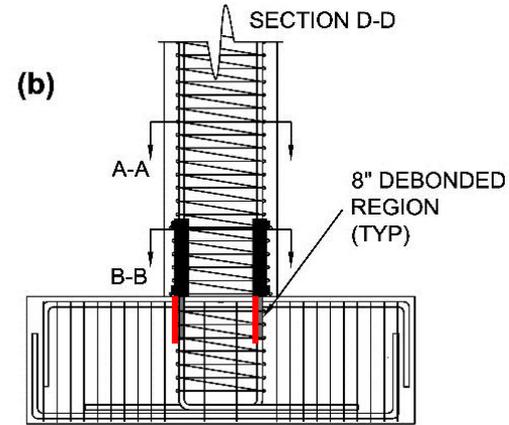
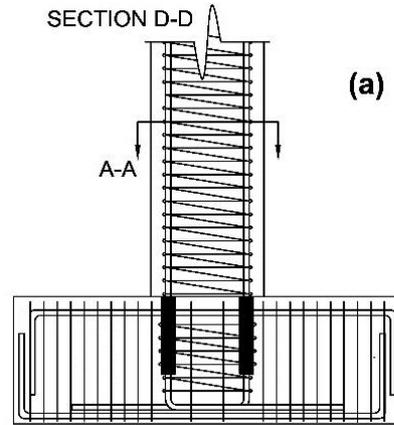
- AE event history
 - More events at field end
- AE event rate history
 - Grout cone formation at $1.2 f_y$
- Gradual response
 - Yielding, hardening, fracture



- Field end
- Factory end

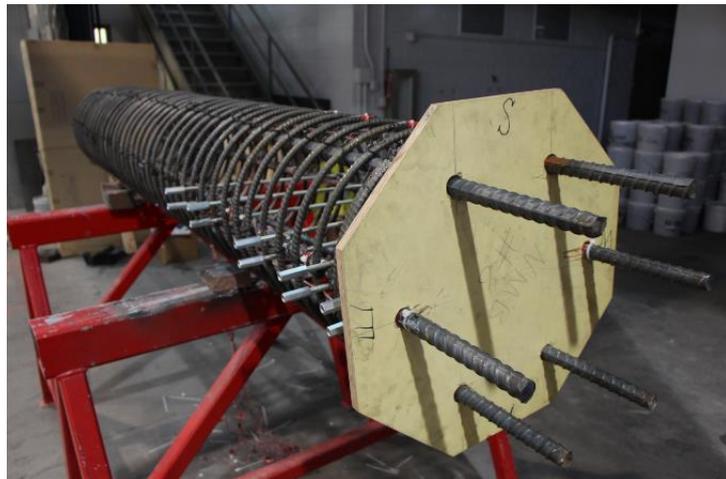
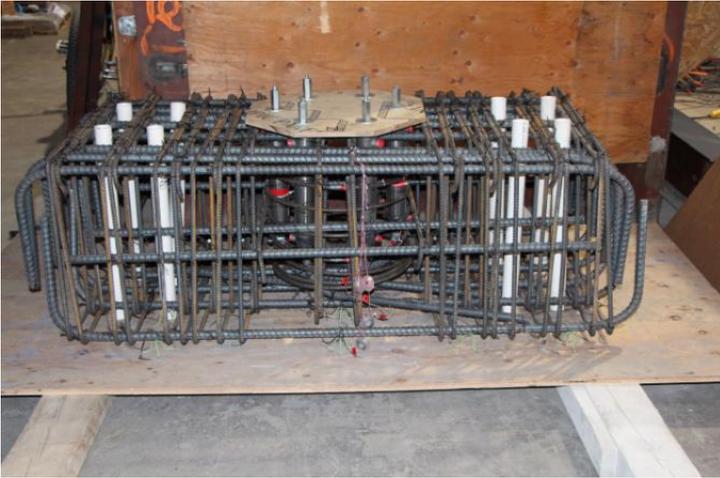
Design and Fabrication

No.	Specimen	Connector Location	Other
(a)	Precast-1	In footing	--
(b)	Precast-2	In column	Debonded bar in footing
(c)	CIP	--	Cast-in-place

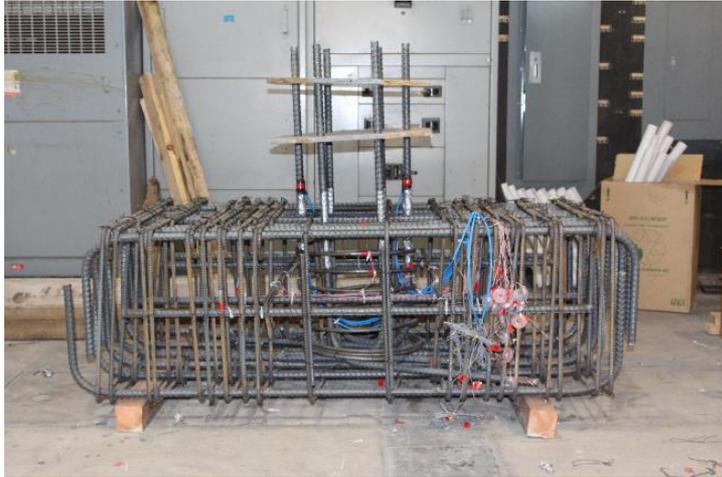


CIP
AASHTO
Seismic

Design and Fabrication/Precast-1



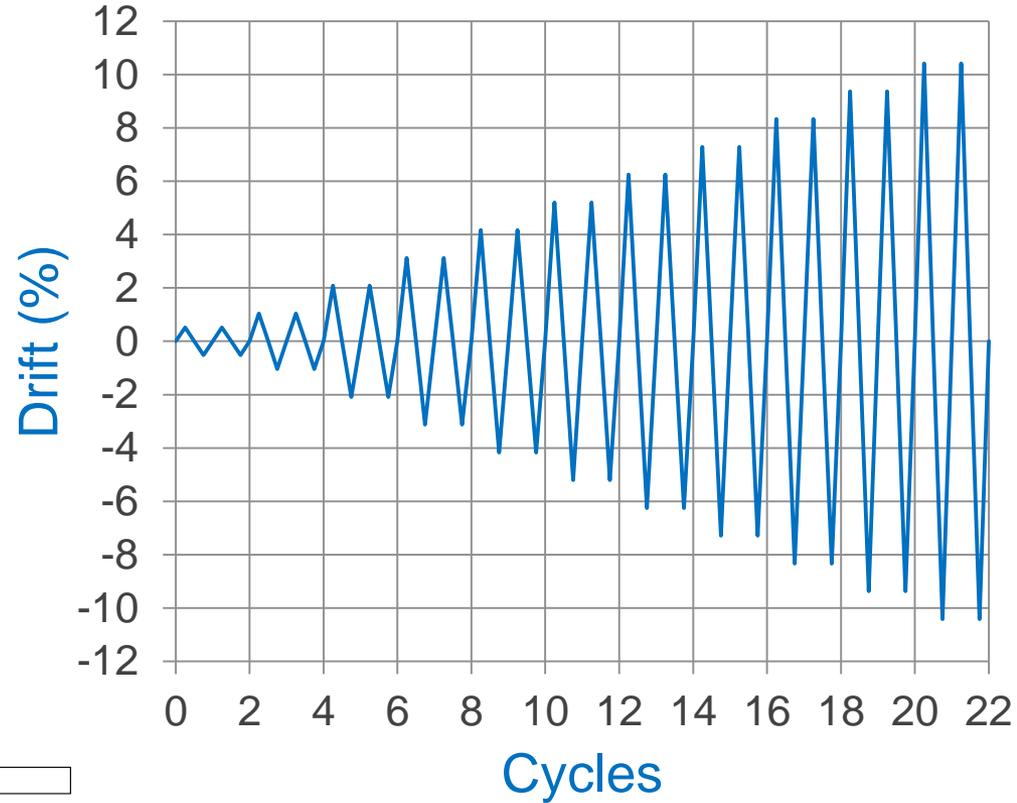
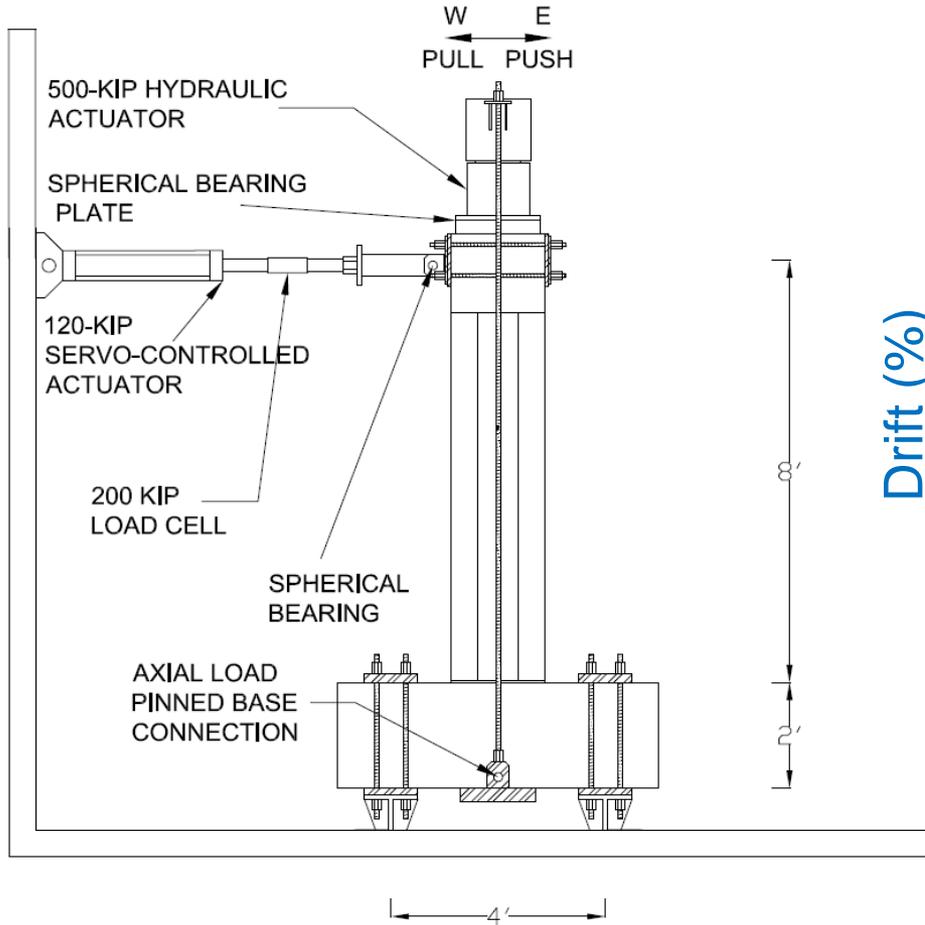
Design and Fabrication/Precast-2



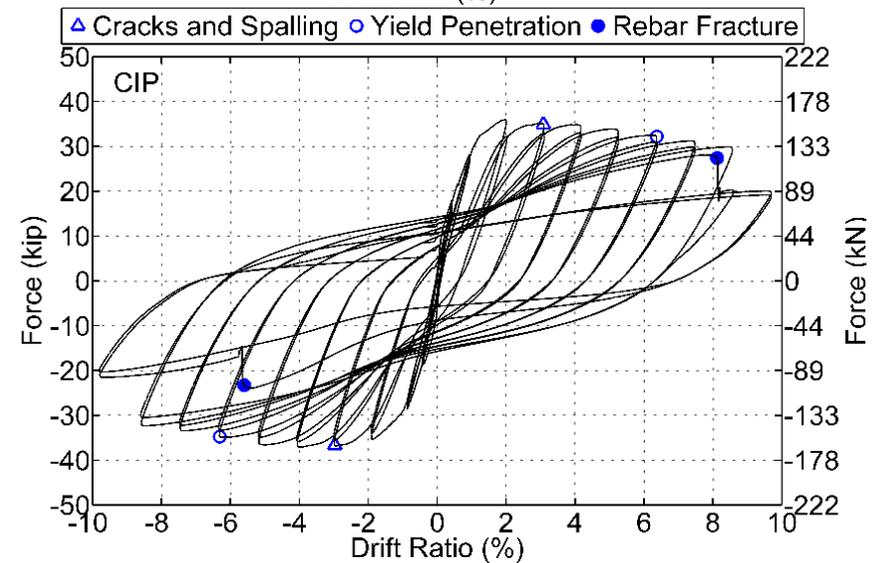
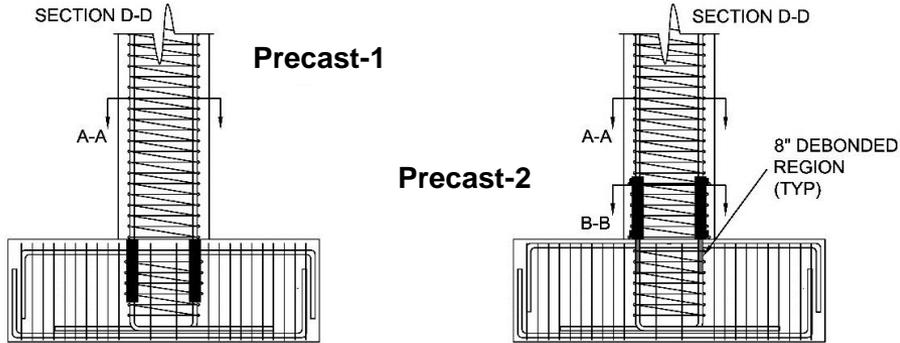
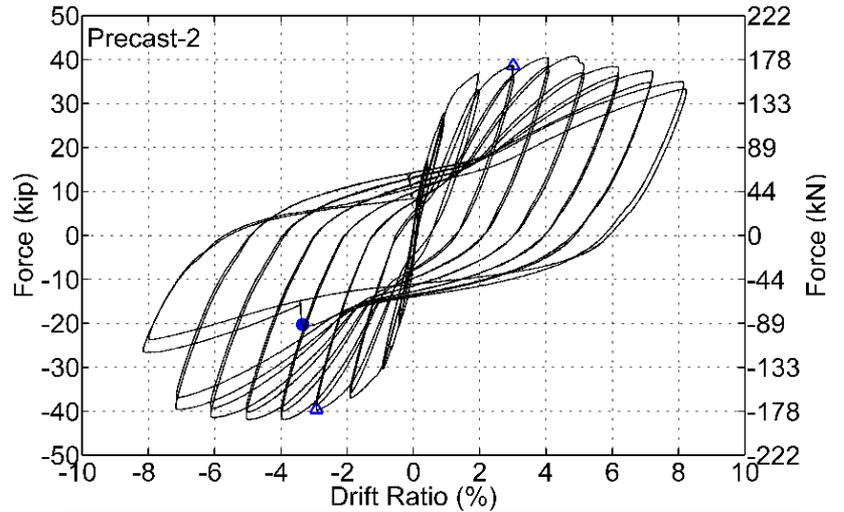
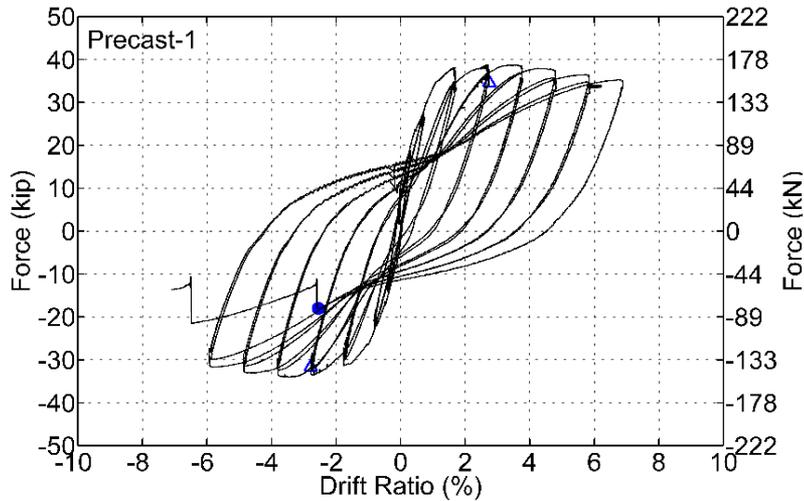
Design and Fabrication/CIP



Test Setup and Drift History



Test Results/Hysteresis Response



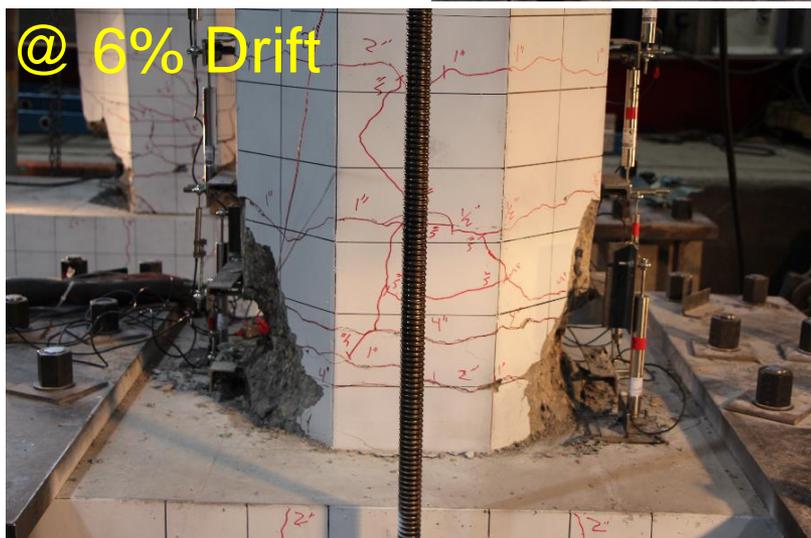
Test Results/Precast-1 Observations



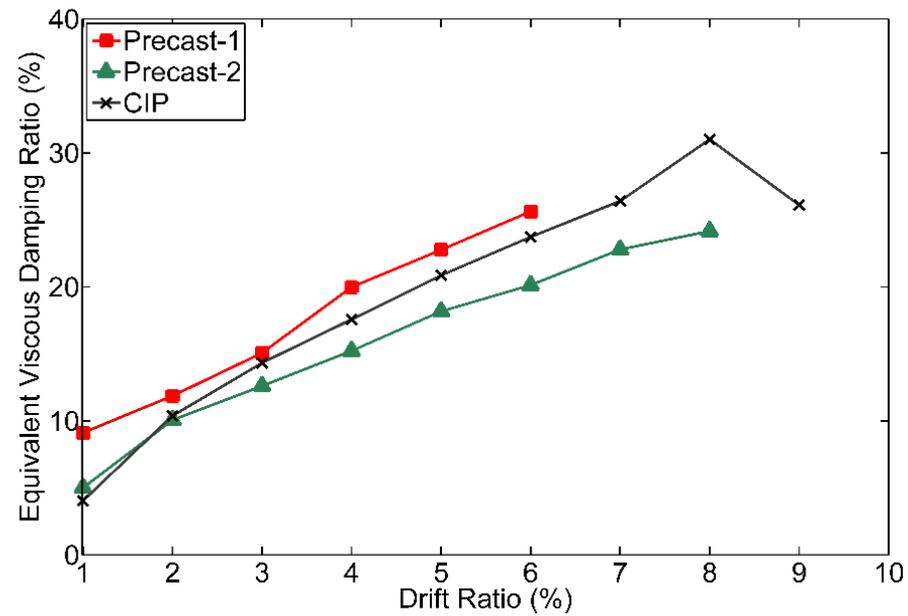
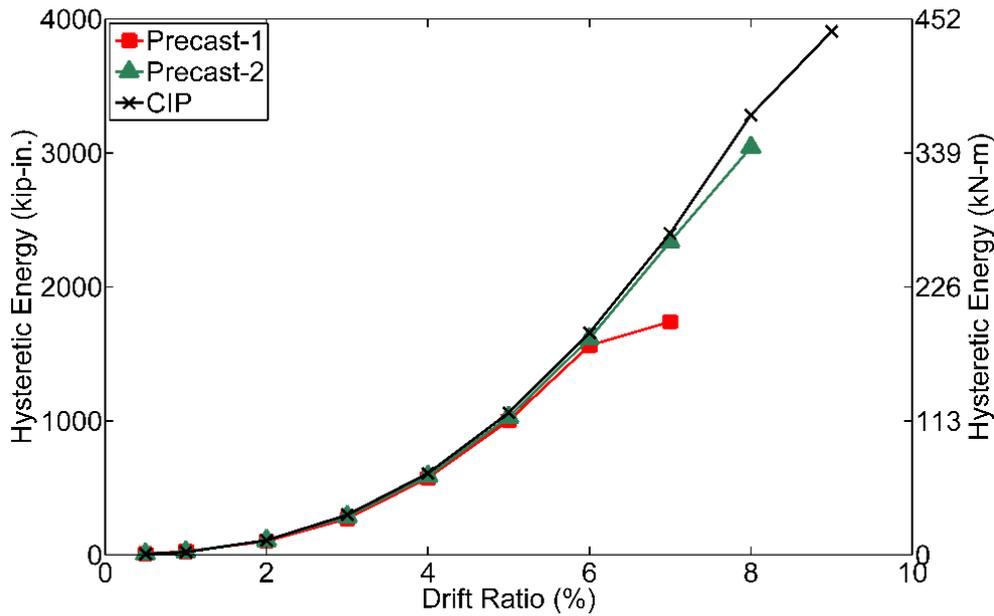
Test Results/Precast-2 Observations



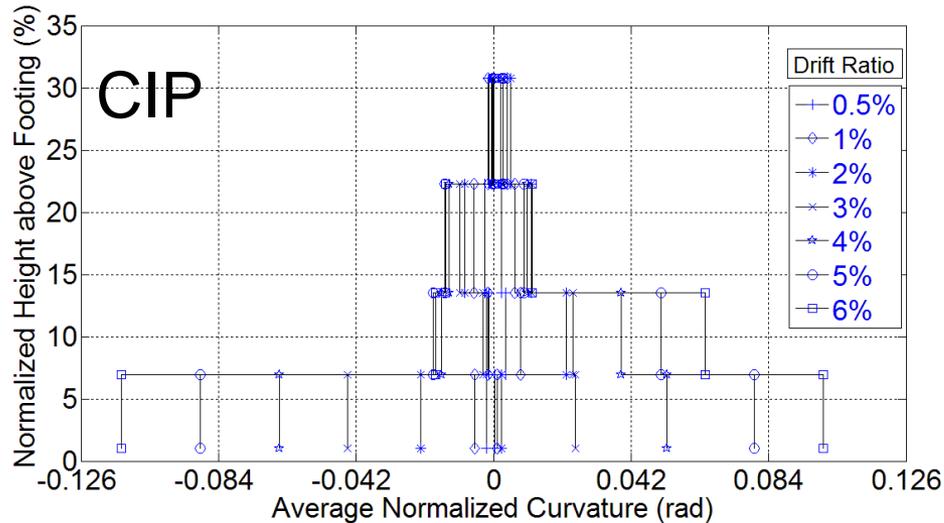
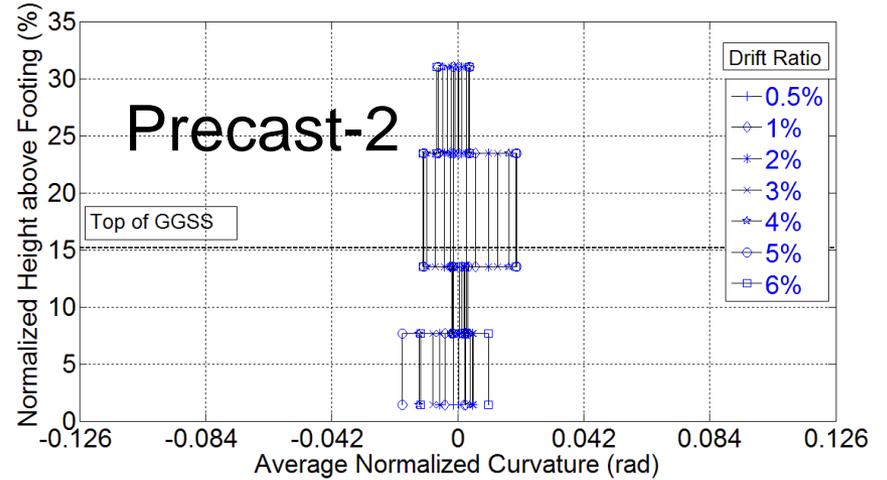
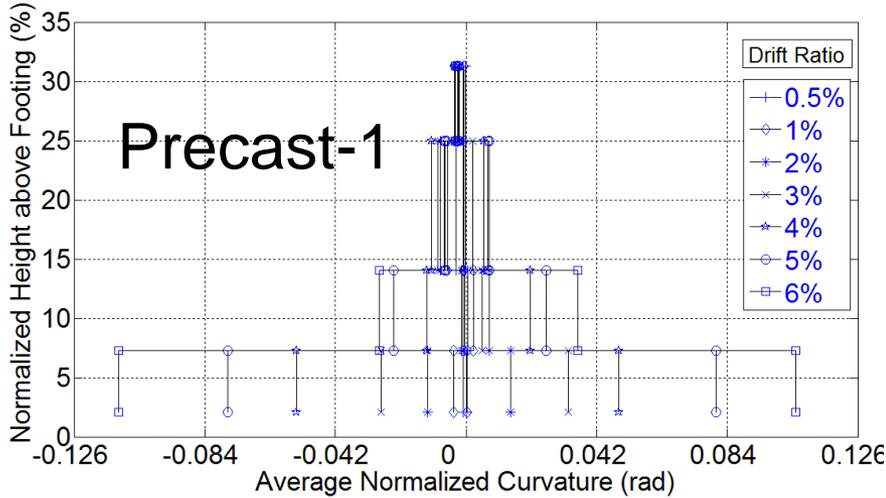
Test Results/CIP Observations



Test Results/Energy



Test Results/Base Curvature

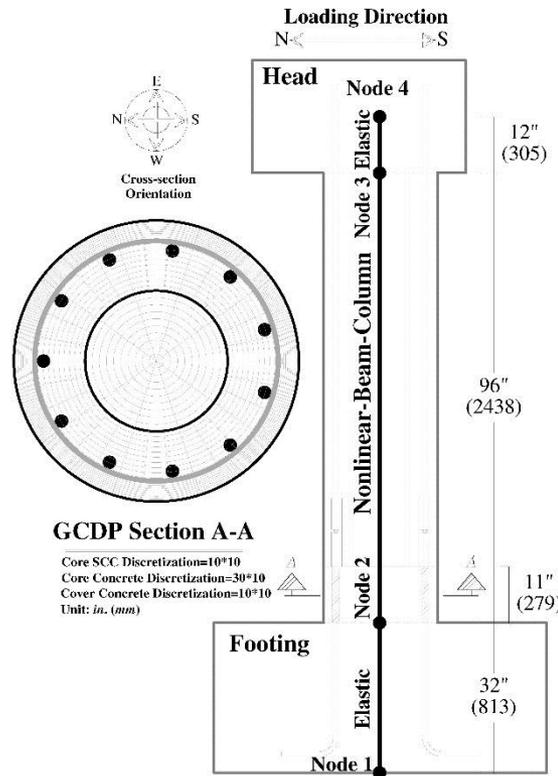


Analysis Objectives/Previous Research

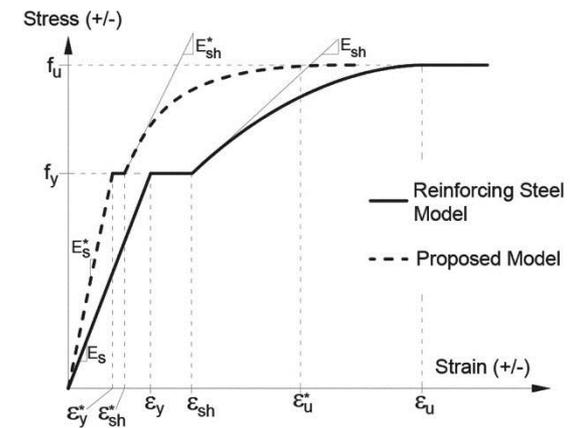
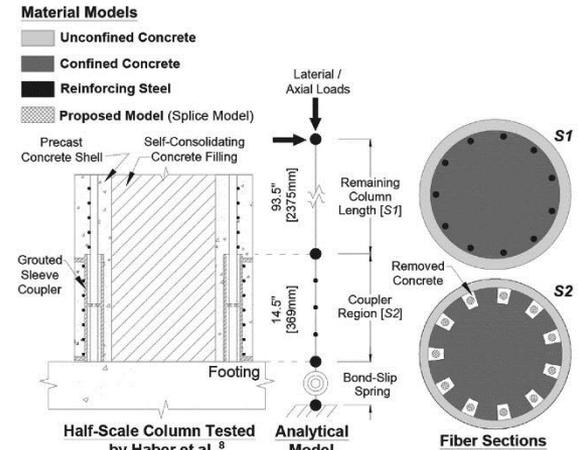
Analysis Objectives

(a) Replicate experimental results for global and objective sectional response

(b) Apply proposed model to columns with actual design details



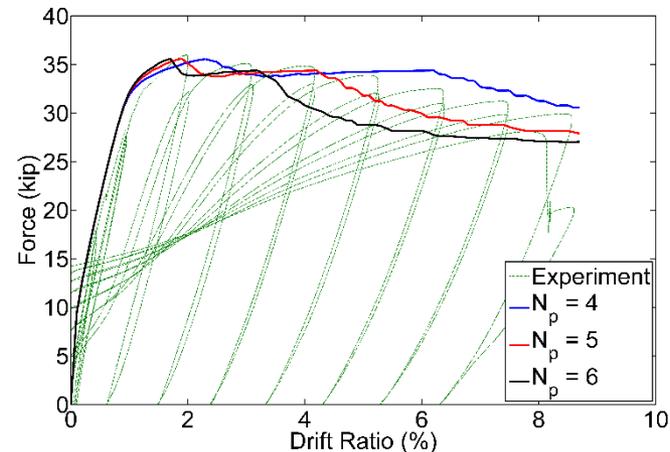
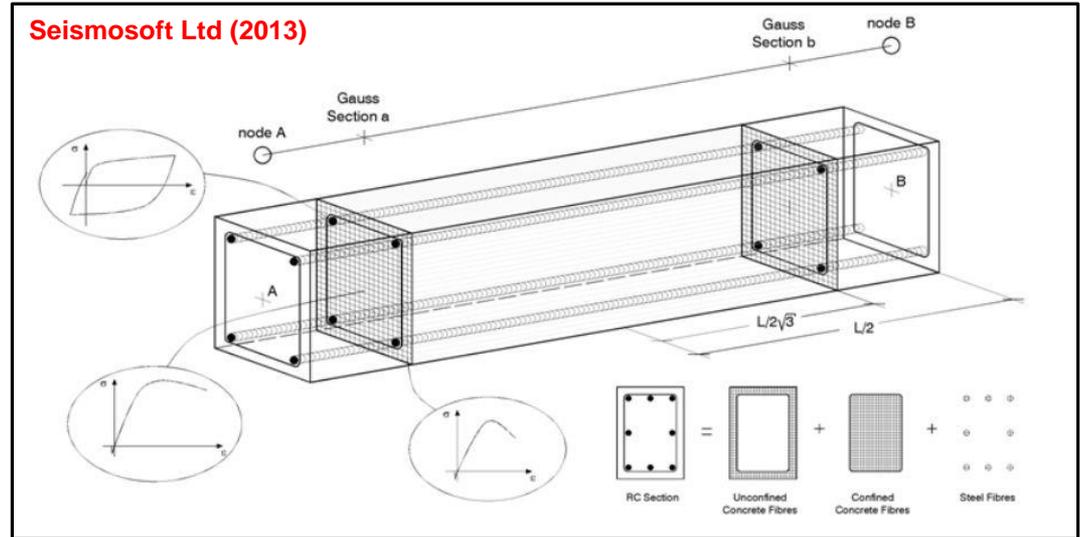
Tazarv et al. (2014)



Haber et al. (2015)

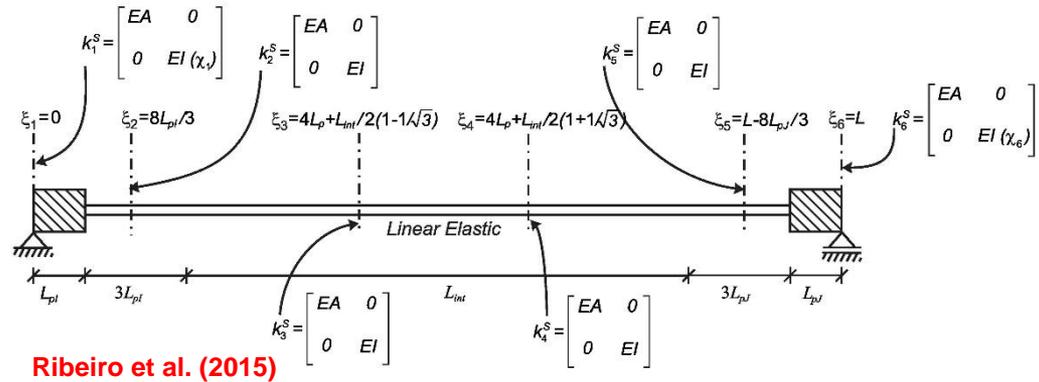
Introduction

- ❑ Distributed plasticity
- ❑ Force-based beam-column element
- ❑ Loss of objectivity for strain softening section response



Proposed Analytical Model

- Force-based beam-column element with plastic hinge integration scheme (Scott and Fenves, 2006)



- Transformation of precast subassembly into equivalent cast-in-place subassembly
- Empirical relationships for plastic hinge length

Paulay and Priestley (1992):

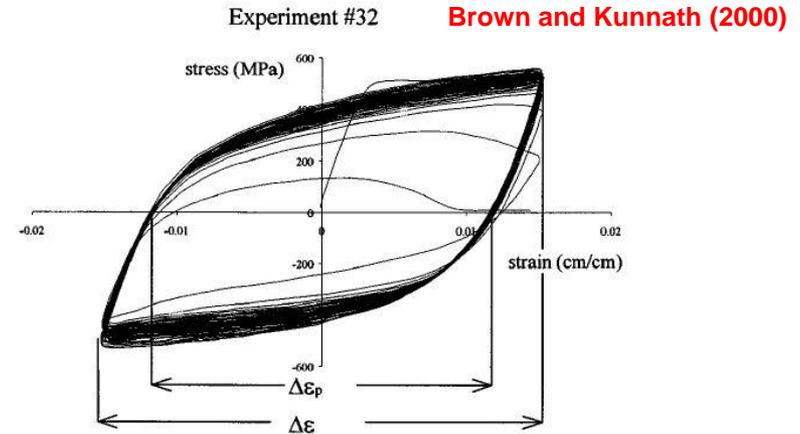
$$L_p = 0.08L_s + 0.022d_b f_y$$

Panagiotakos and Fardis (2001):

$$L_{pl,cy} = 0.12L_s + 0.014a_{sl}d_b f_y$$

Proposed Analytical Model/Low-cycle Fatigue

- ❑ Test assemblies failed due to low-cycle fatigue
- ❑ Coffin-Manson expression with cumulative linear damage rule
- ❑ Reinforcing Steel material in OpenSees capable of predicting low-cycle fatigue life

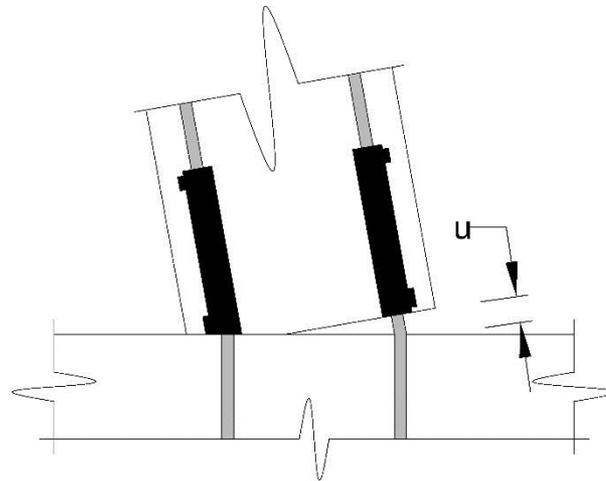


$$\epsilon^p = C_f (2N_f)^{-\alpha}$$

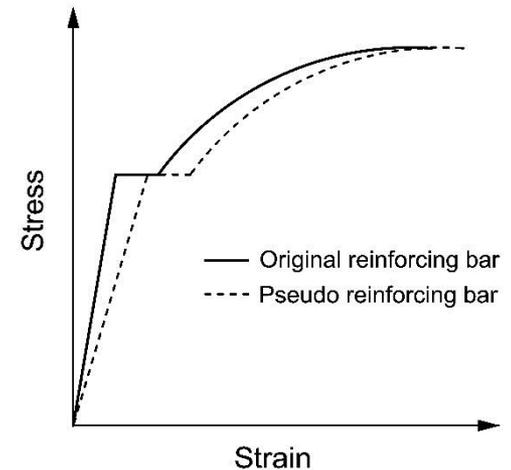
$$D_f = \frac{1}{\sum_{i=1}^n (2N_f)_i}$$

Proposed Analytical Model/Bond-slip

- ❑ Bond-slip may influence local and global response of bridge columns
- ❑ Bond-slip included by deriving pseudo stress-strain relationship for column bars
- ❑ Pseudo stress-strain obtained from end displacement divided by the unique plastic hinge length



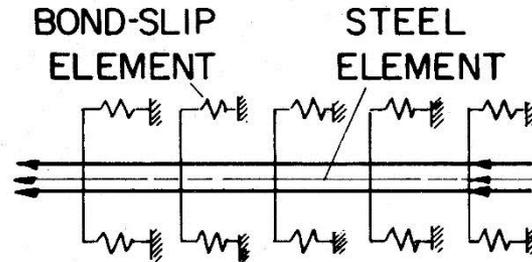
$$\varepsilon = \frac{u}{L_p}$$



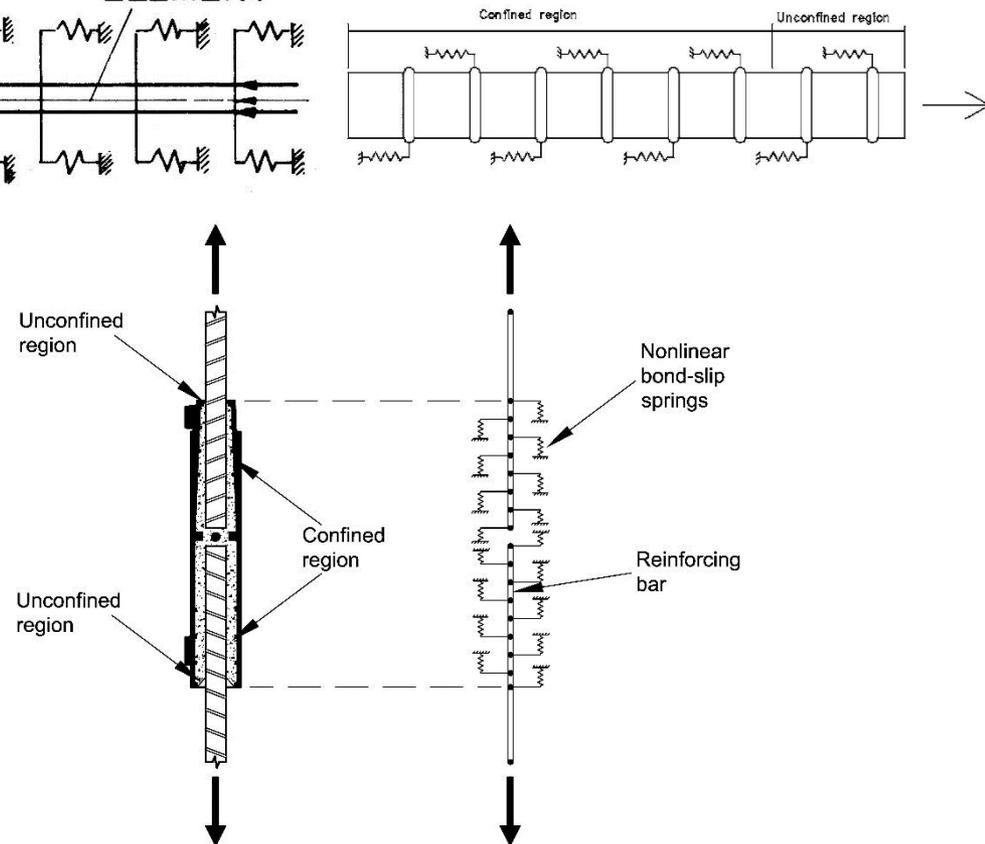
Proposed Analytical Model/Bond-slip

- ❑ Nonlinear one-dimensional model developed following previous studies
- ❑ zeroLength elements with MultiLinear material used to represent bond-slip springs
- ❑ Nonlinear truss elements with ReinforcingSteel material used for bars

Morita's approach in Viathanatepa et al. (1973)



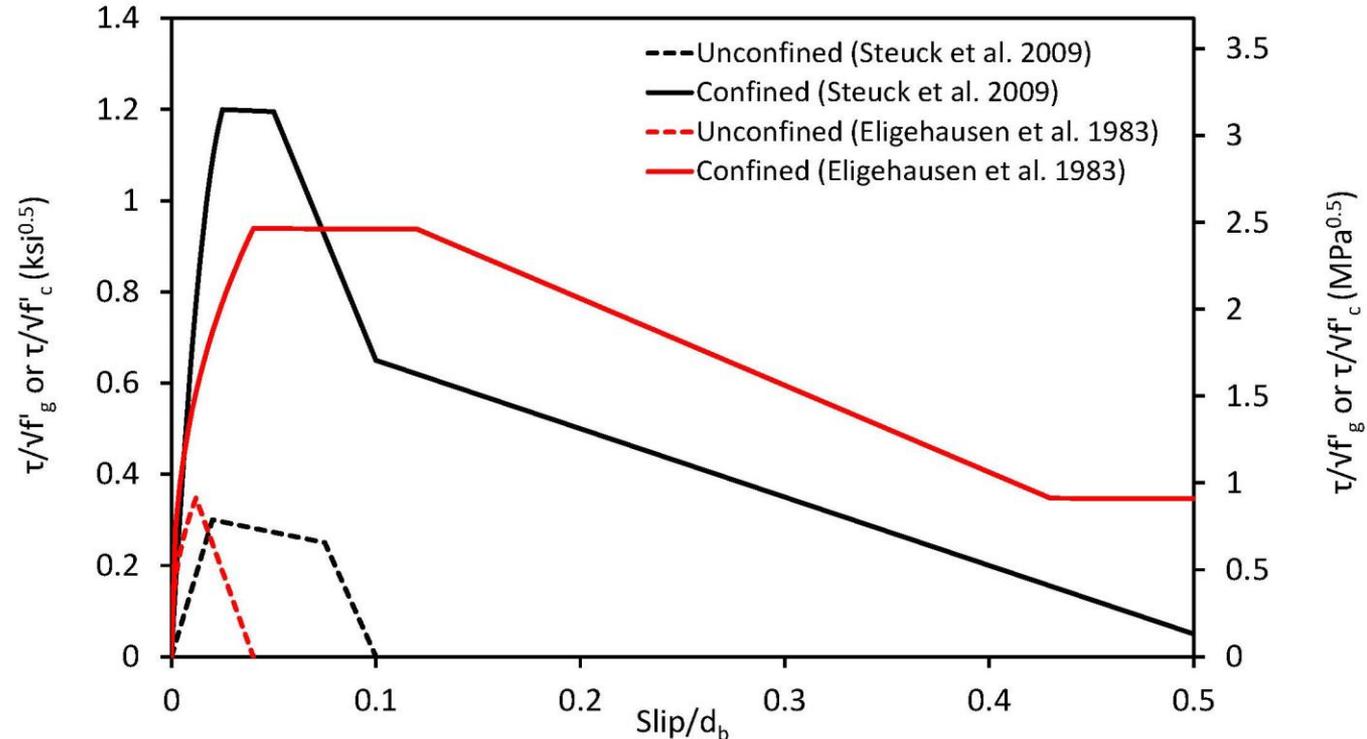
Steuck et al. (2009)



Proposed Analytical Model/Bond-slip

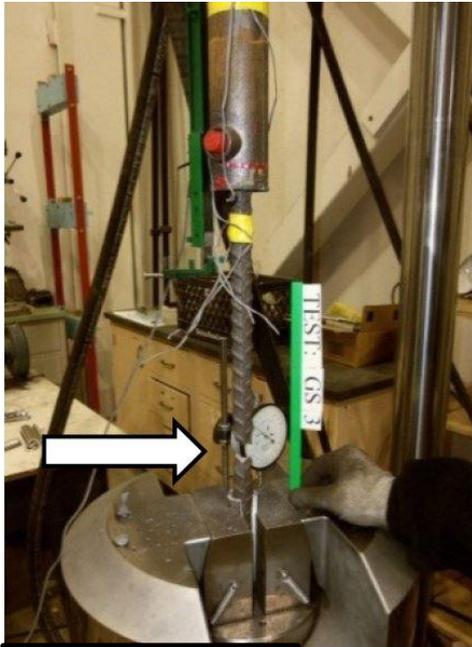
□ Confined and unconfined bond constitutive laws taken from Steuck et al. (2009) for grouted splice sleeves

□ Eligehausen et al. (1983) used for regular concrete

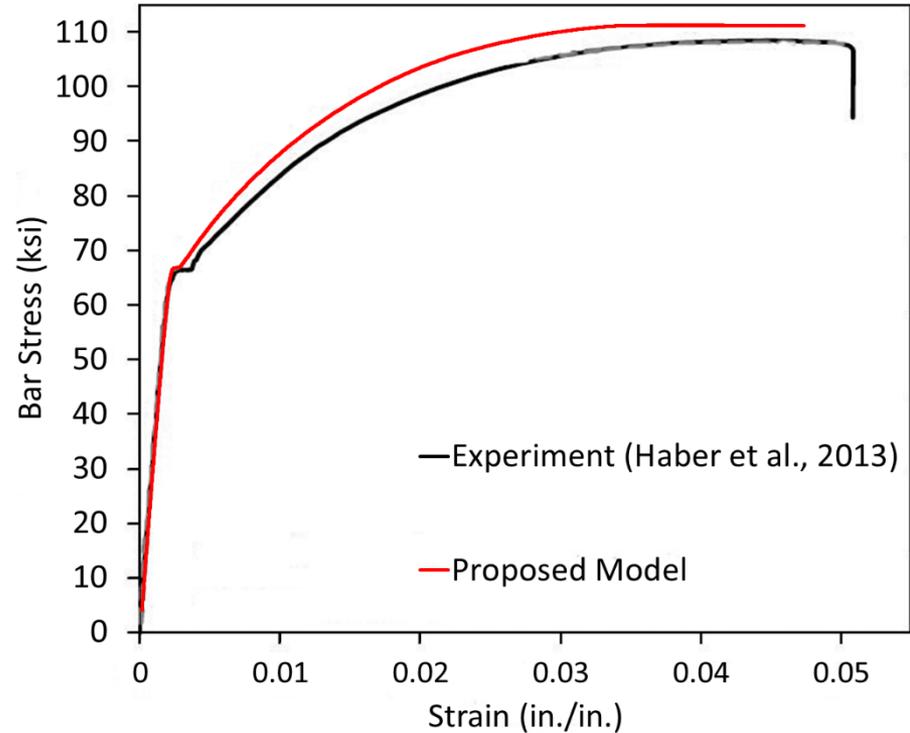


Proposed Analytical Model/Bond-slip

- Validation of proposed one-dimensional model using Haber et al. (2013) GS3 experiment



Haber et al. (2013)



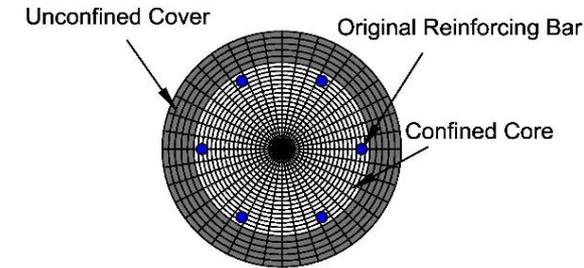
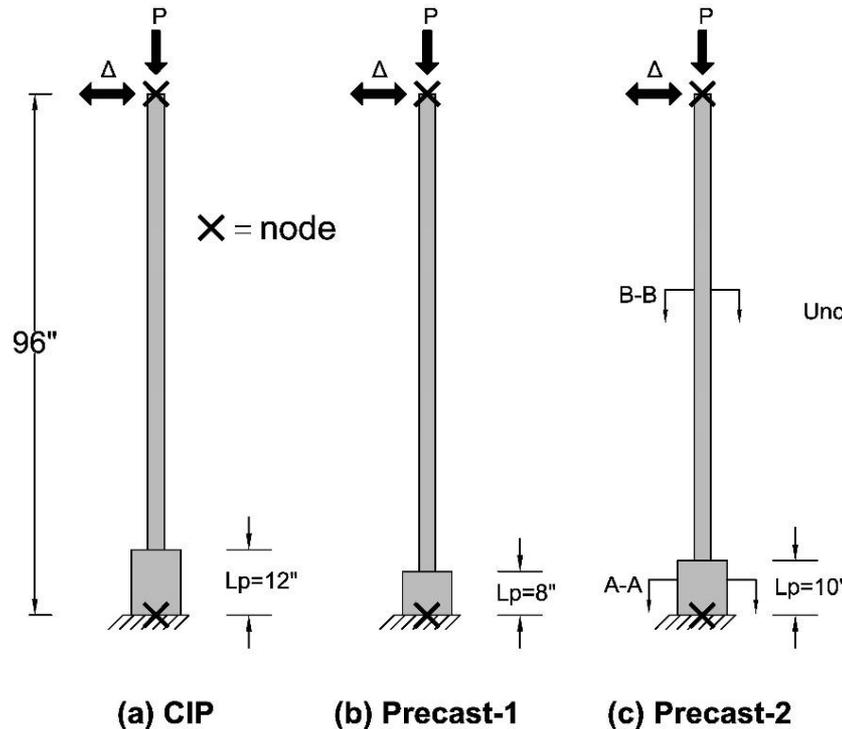
Proposed Analytical Model/Model Layout

- One force-based beam-column element with plastic hinge integration scheme

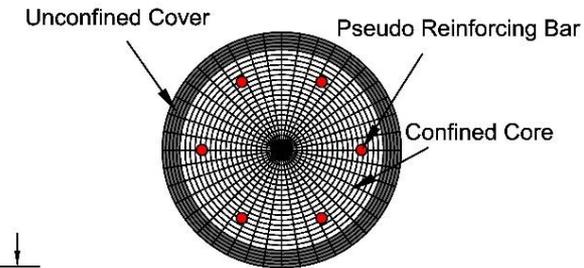
Transform precast columns to equivalent cast-in-place columns with fictitious plastic hinges

- Panagiotakos and Fardis (2001) used to examine L_p for CIP

- $L_p \approx 0.5D$ for CIP, as stated in Priestley and Park (1987)



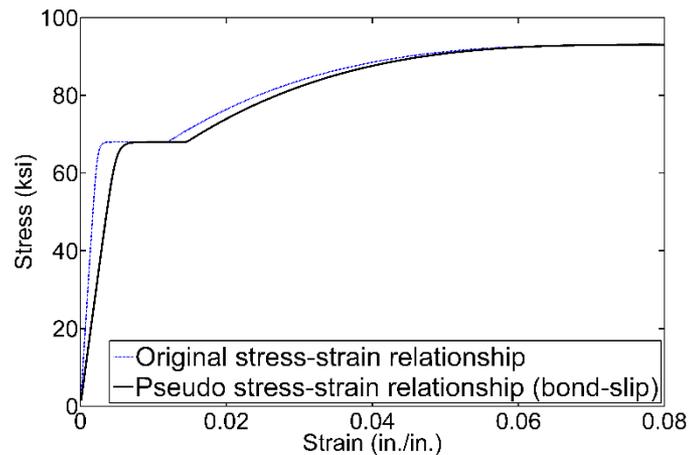
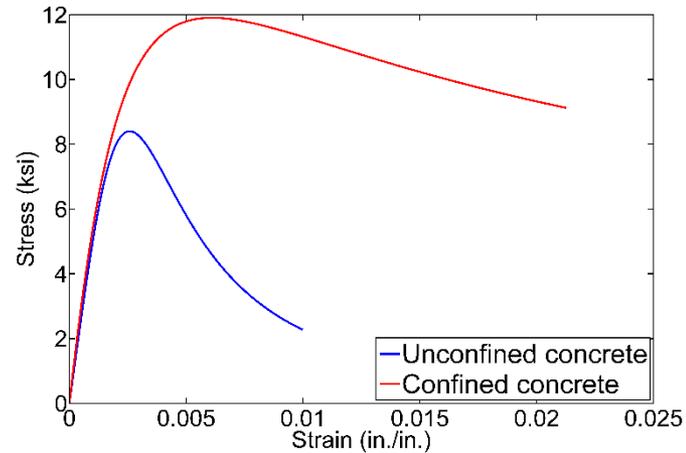
Section B-B (not to scale)



Section A-A (not to scale)

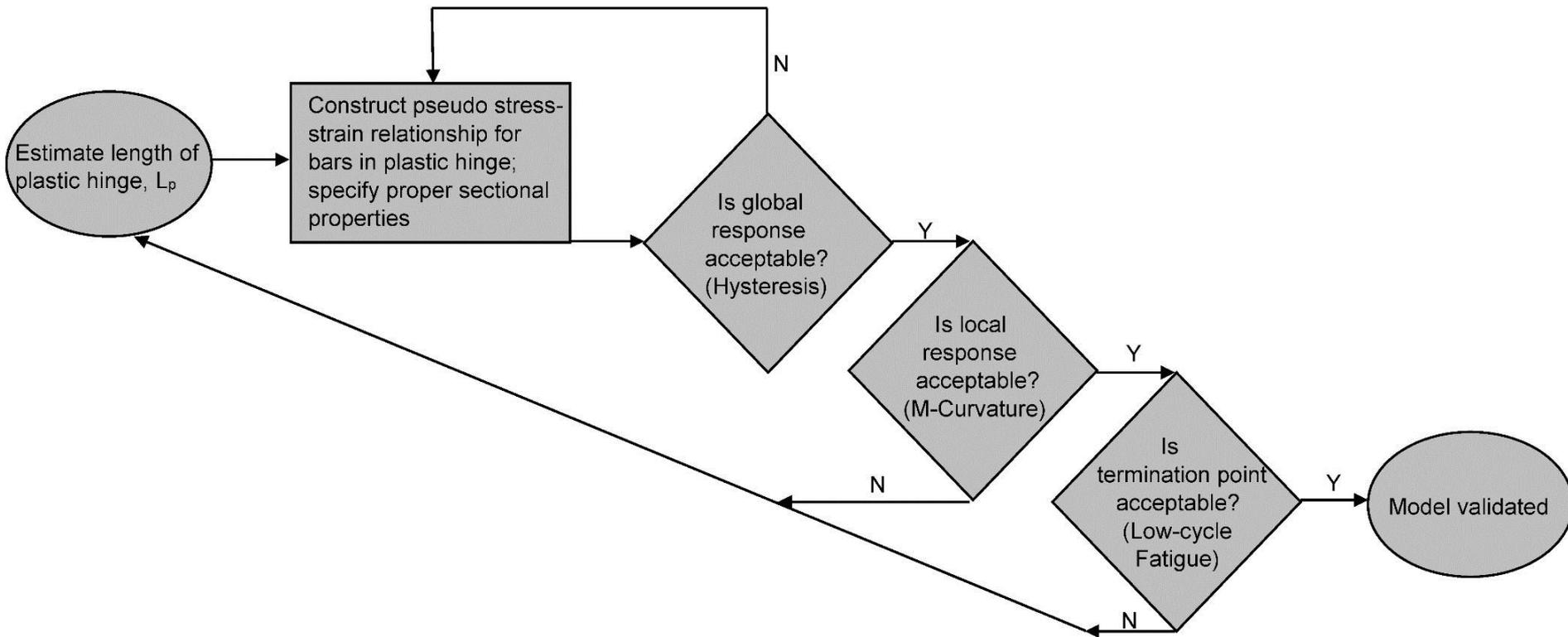
Proposed Analytical Model/Stress-strain Curves

- Concrete04 material used for confined and unconfined concrete
- ReinforcingSteel material used for bars outside PH zone
- ReinforcingSteel material with pseudo stress-strain properties used for bars inside PH zone



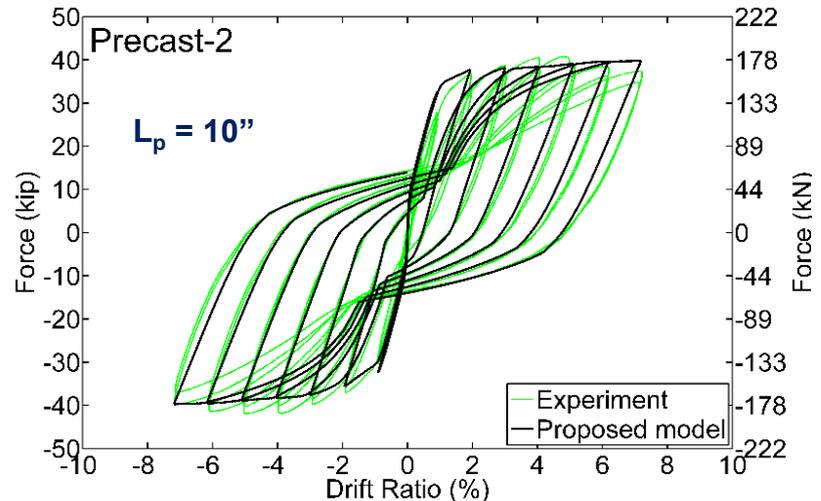
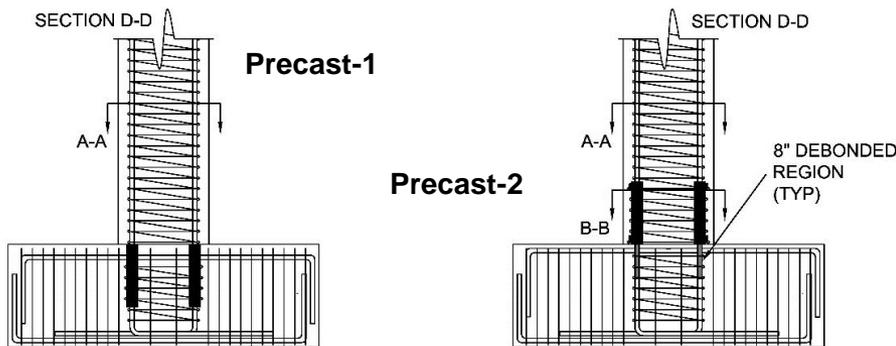
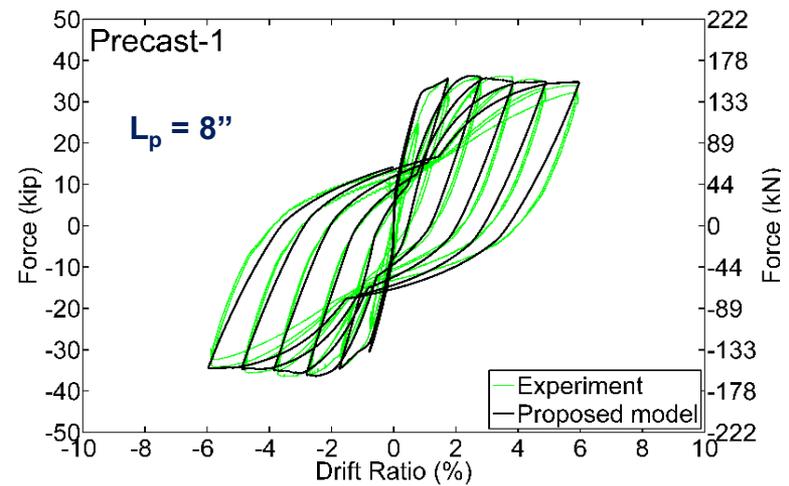
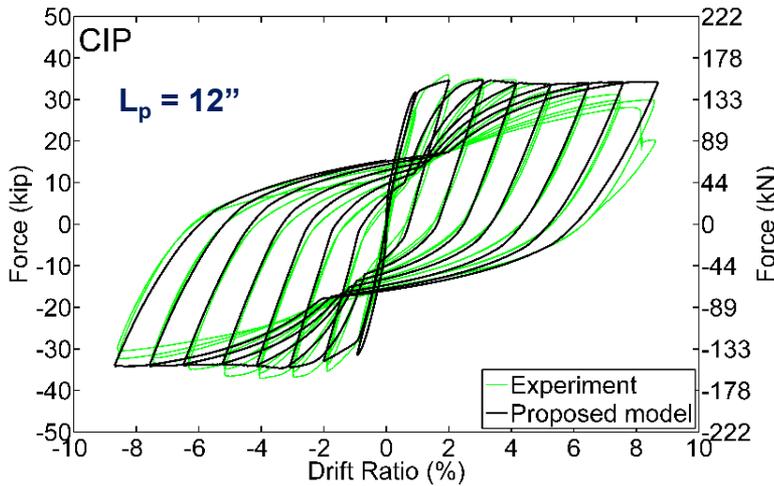
Sample curves for Precast-2

Proposed Analytical Model/Model Layout

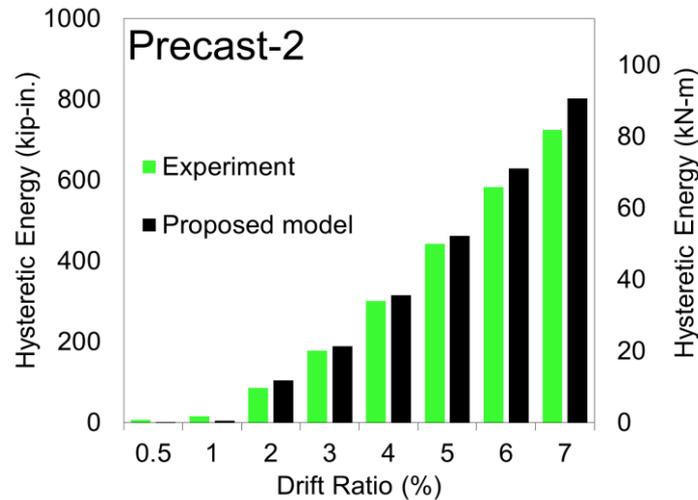
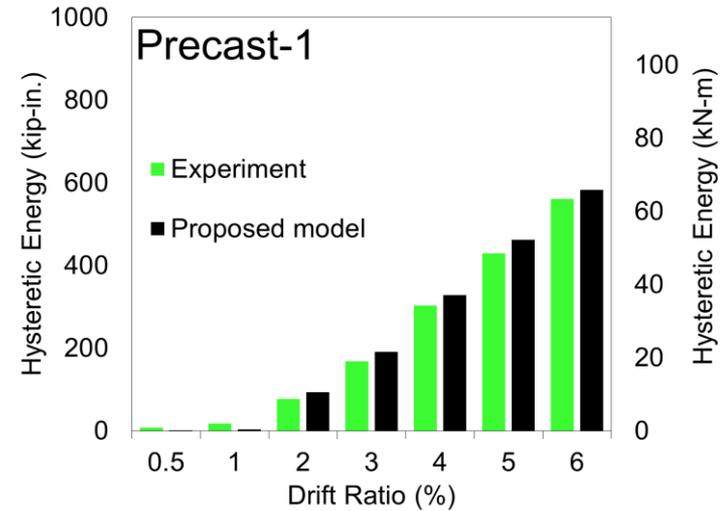
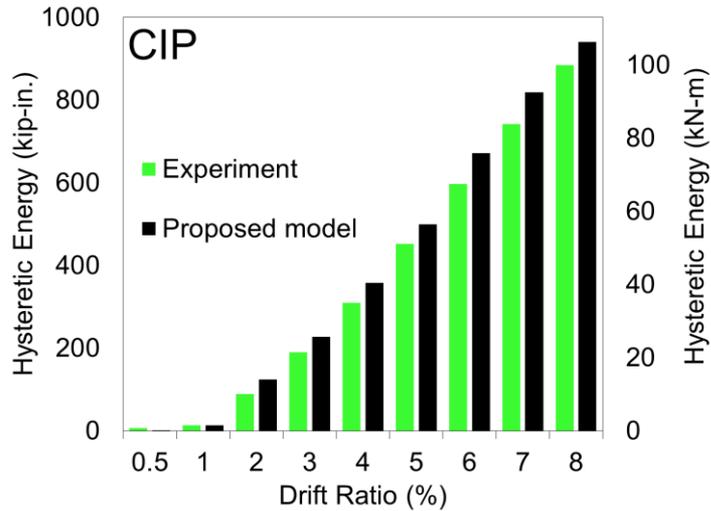


Proposed Analytical Model/Global Response

Results shown up to last drift ratio before bar fracture as predicted by model

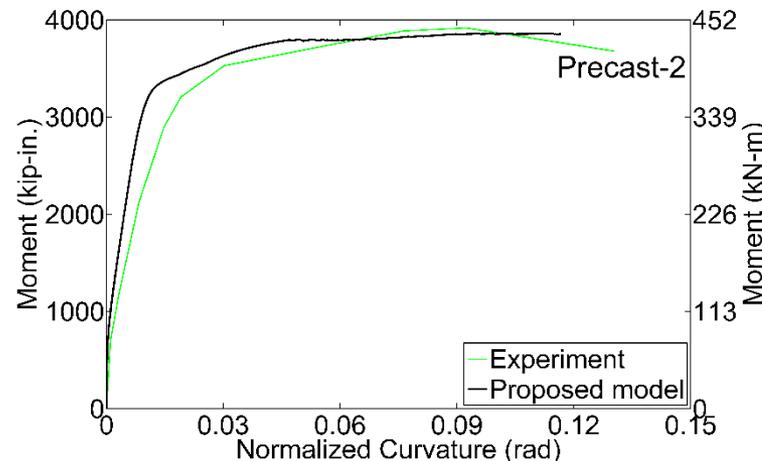
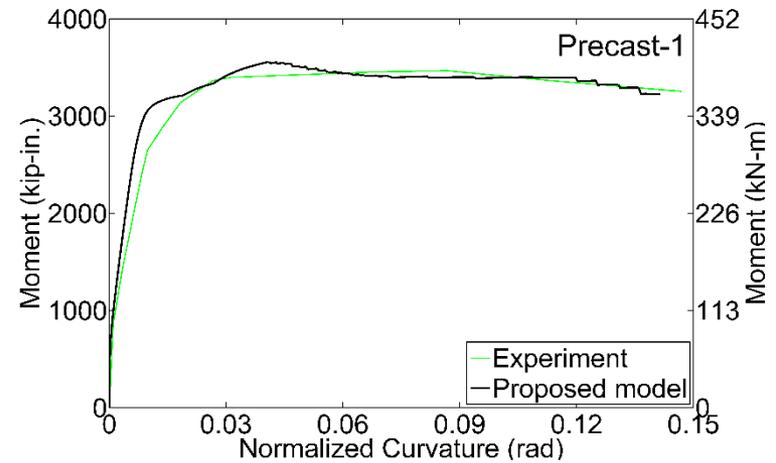
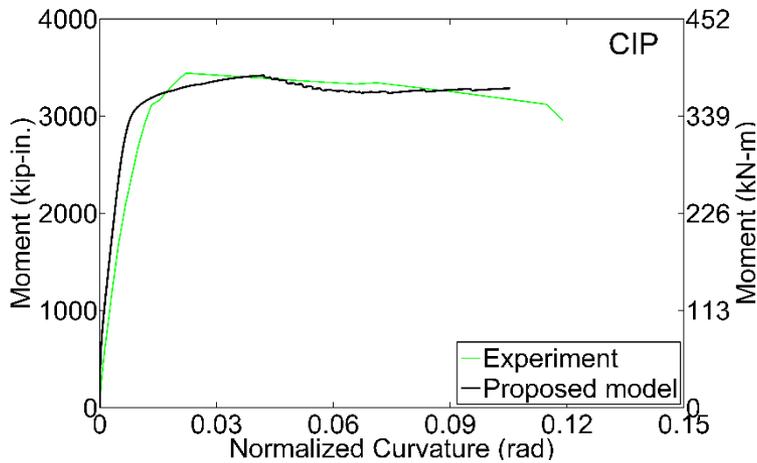


Proposed Analytical Model/Global Response



Proposed Analytical Model/Local Response

Results shown up to 6% drift ratio (LVDT stroke limit)



Experiments

- ❑ CIP had good hysteretic response with ductile performance. Column bars fractured during 8% and 9% drift ratio due to low cycle fatigue.
- ❑ Precast subassemblies failed due to premature bar fracture. Precast-1 failed during 7% and precast-2 failed during 8% drift ratio.
- ❑ Debonding of reinforcing bars for Precast-2 resulted in longer performance life.

Analytical Study

- ❖ Two-dimensional analytical model was developed based on transformation of precast column to equivalent cast-in-place column with plastic hinge.
- ❖ Analytical model was in close agreement with both global and local response of test components.
- ❖ Bond-slip was included by deriving pseudo stress-strain relationship for bars in PH zone, using a one-dimensional bond-slip model.
- ❖ Low-cycle fatigue was implemented as termination criteria as observed in experiments.
- ❖ Plastic hinge length of CIP which was obtained iteratively is in good agreement with empirical relationships.
- ❖ Plastic hinge length obtained for Precast-1 and Precast-2 was found to be 67% and 83% of plastic hinge length obtained for CIP.

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Acknowledgments

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- Texas Department of Transportation
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- Graduate School of the University of Utah
- NMB Splice Sleeve North America

Thank You