Modeling of Reinforced Concrete Bridge Columns

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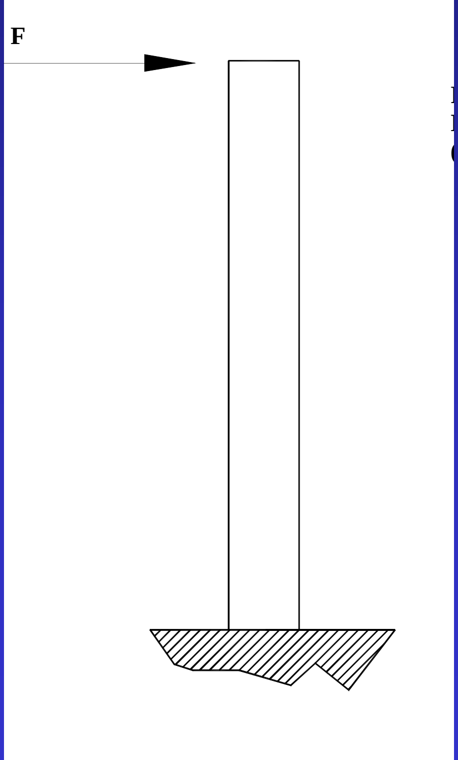
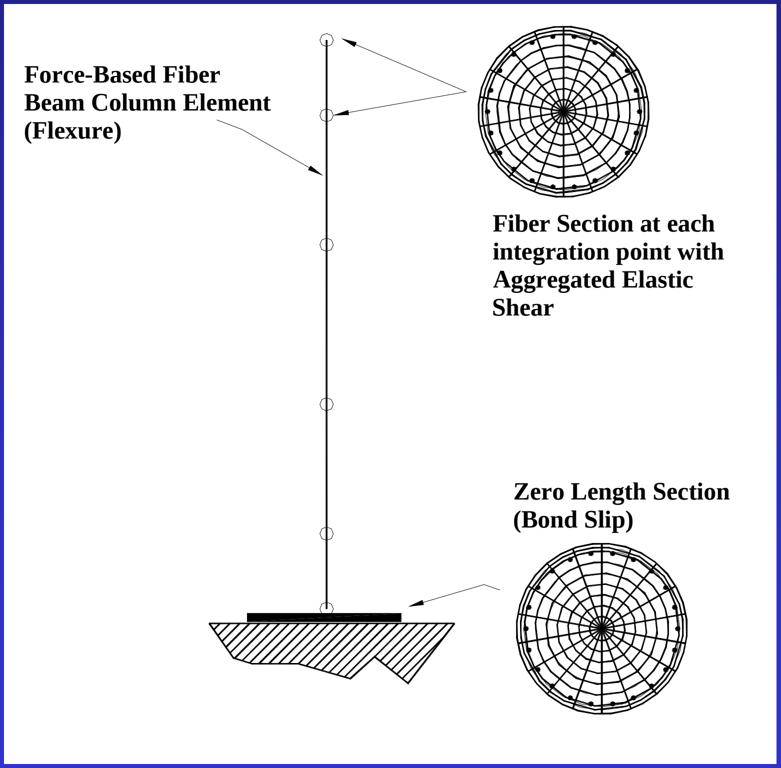
Nonlinear Modeling Strategies

Distributed-Plasticity

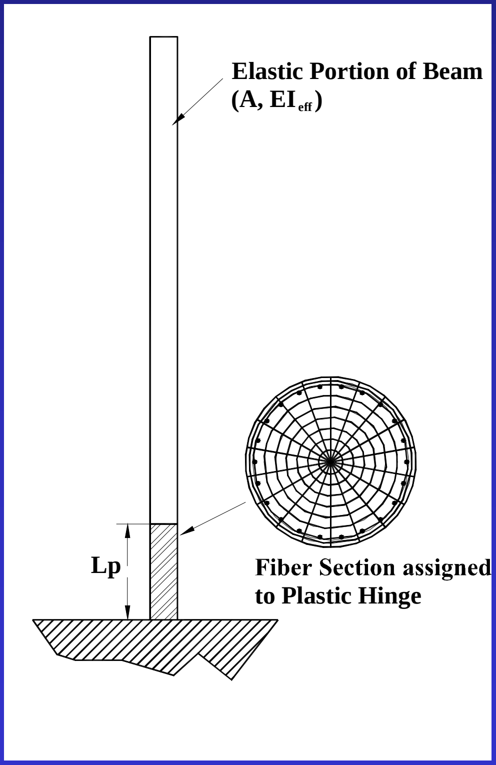
Lumped-Plasticity




Force-Based Fiber Beam Column Element (Flexure)

Fiber Section at each integration point with Aggregated Elastic Shear

Zero Length Section (Bond Slip)


Elastic Portion of Beam (A, EI_{eff})

Lp

Fiber Section assigned to Plastic Hinge

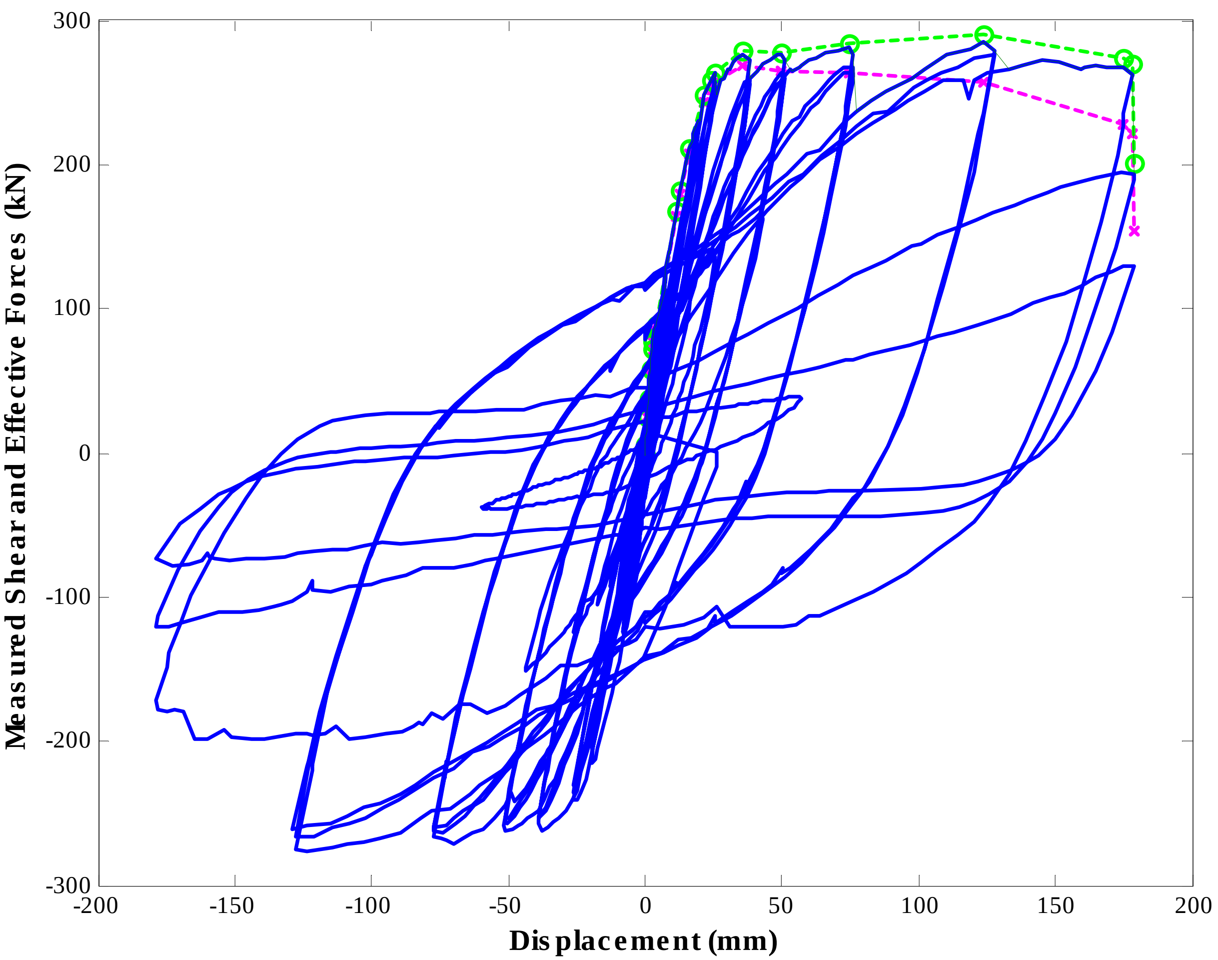
Outline

- Column Data
- Cross-Section Modeling
- Modeling with Distributed-Plasticity Element
- Modeling with Lumped-Plasticity Element
- Predicting Damage
- Continuing Challenges
- Summary

PEER Structural Performance Database

- Nearly 500 Columns
  - spiral or circular hoop-reinforced columns (~300)
  - rectangular reinforced columns (~180)
- Column geometry, material properties, reinforcing details, loading
- Observations of column damage
- http://nisee.berkeley.edu/spd
- User’s Manual (Berry and Eberhard, 2004)

Force-Displacement Histories



Screening Criteria

- Representative of modern bridge construction in high seismic zones
- Damage observations available
- Flexural damage
- Axial-load ratio ≤ 0.3
- Displacement-ductility capacity ≥ 6.0
- Longitudinal-reinforcement ratio ≤ 4%

45 Columns

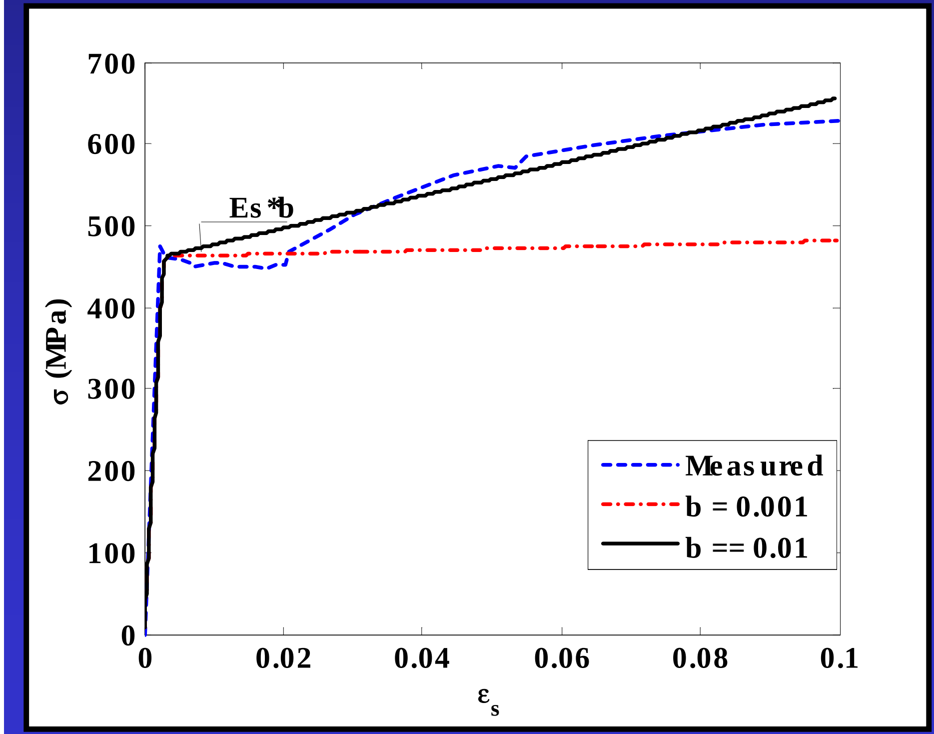
Cross-Section Modeling

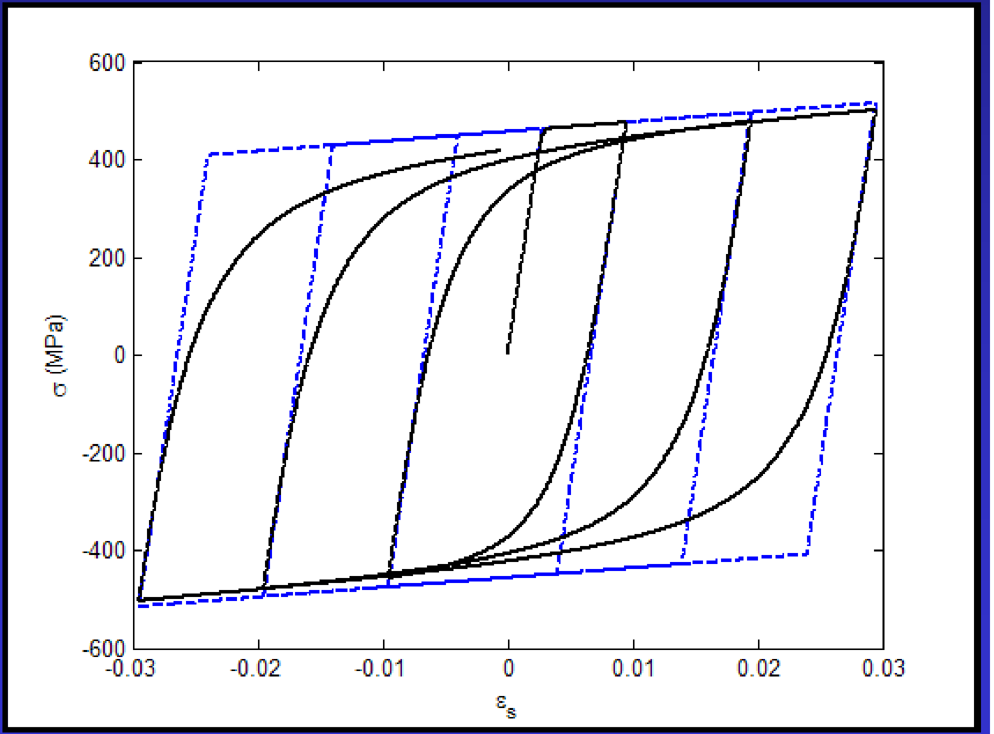
Reinforcing Steel Model

Giufre-Menegotto-Pinto

OpenSees Model: *Steel 02*

Model Parameter: b = 0.01



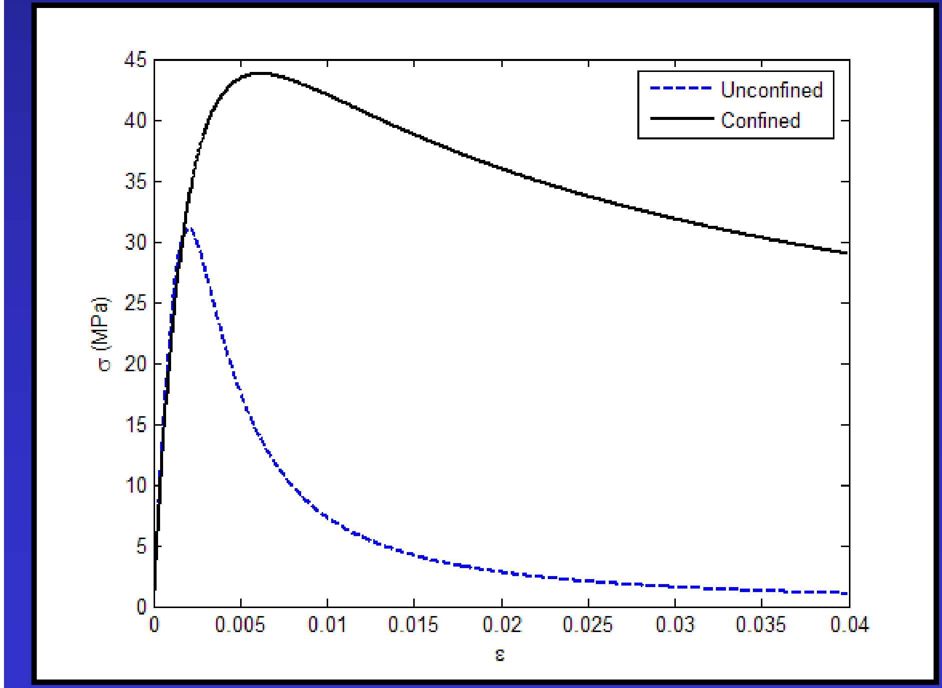


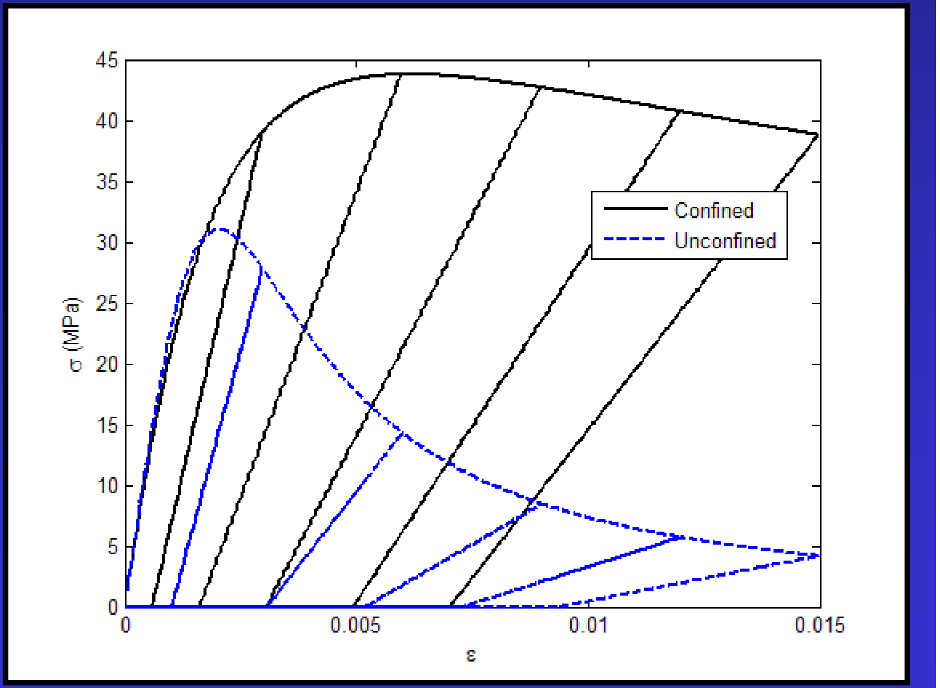
Concrete Model

Popovics Curve

OpenSees Model: *Concrete04* (*Mitra and Lowes 2005*)

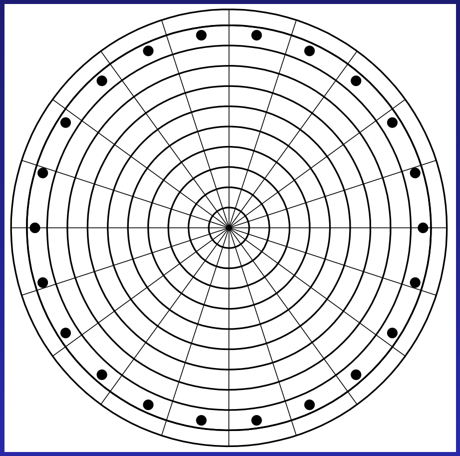
Model Parameters: Mander et. al. (1988) Coefficients





Cross-Section Fiber Discretization

Uniform (220 Fibers)



Confined

$$n_c^r = 10$$

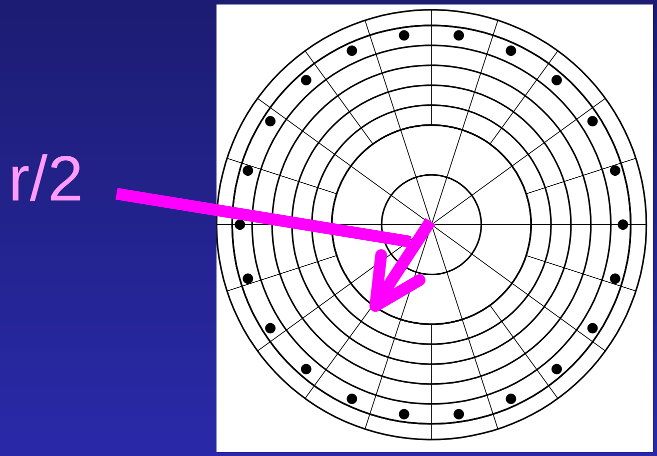
$$n_c^t = 20$$

Unconfined

$$n_u^r = 1$$

$$n_u^t = 20$$

Reduced (140 Fibers)



Confined

$$n_{fine}^r = 5$$

$$n_{fine}^t = 20$$

$$n_{coarse}^r = 2$$

$$n_{coarse}^t = 10$$

Unconfined

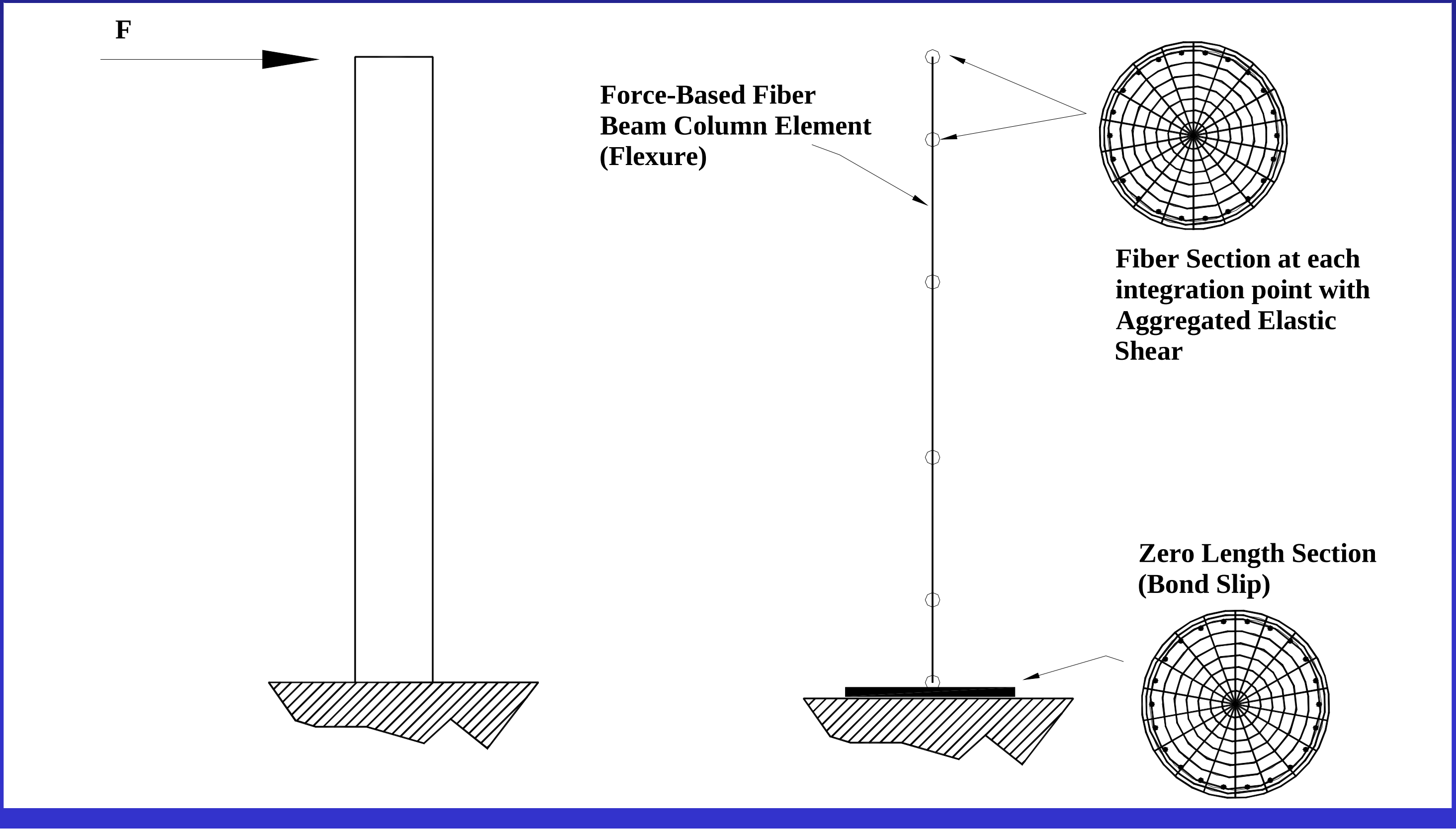
$$n_u^r = 1$$

$$n_u^t = 20$$

Modeling with Distributed-Plasticity Element

Model Components

- Force-Based Fiber Beam-Column Element (Flexure)
- Elastic Shear Deformation
- Zero-Length Bond-Section

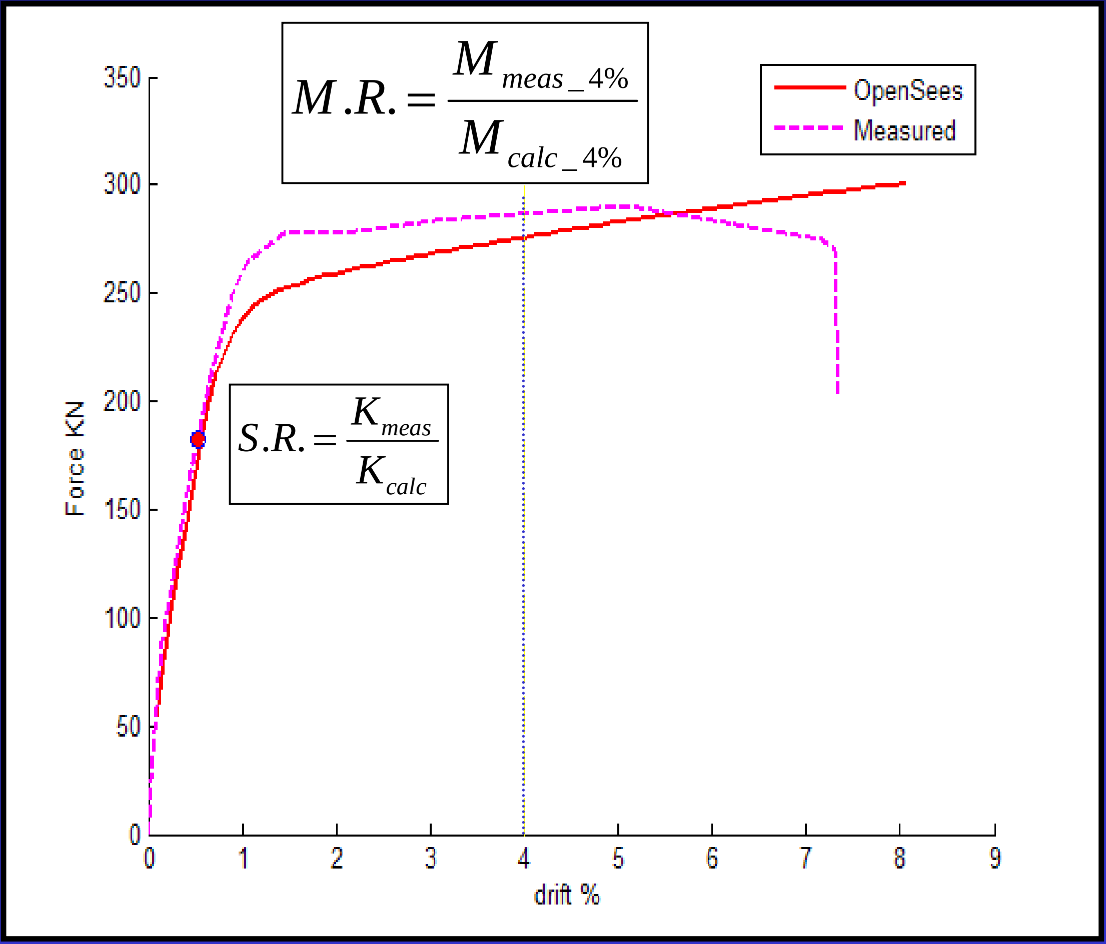


Model Components

- **Flexure Model (Force-Based Beam-Column)**
  - *nonlinearBeamColumn*
  - 5 integration points for cantilever (6 for double-curvature)
  - Fiber section
  - Concrete04 (Mander constants)
  - Steel02 (Bilinear), b=0.01
- **Anchorage-Slip Model**
  - *zeroLengthSection*
  - Fiber section
  - Reinforcement tensile stress-deformation response from Lehman et. al. (1998) bond model,
  - Effective depth in compression (c)
- **Shear Model**
  - *section Aggregator*
  - Elastic Shear, $G = 0.4 * E_c$

Model Accuracy

Optimal model based on accuracy of F-Δ and Δ-ε



$$M.R. = \frac{M_{meas\_4\%}}{M_{calc\_4\%}}$$

$$S.R. = \frac{K_{meas}}{K_{calc}}$$

Without Anchorage Slip

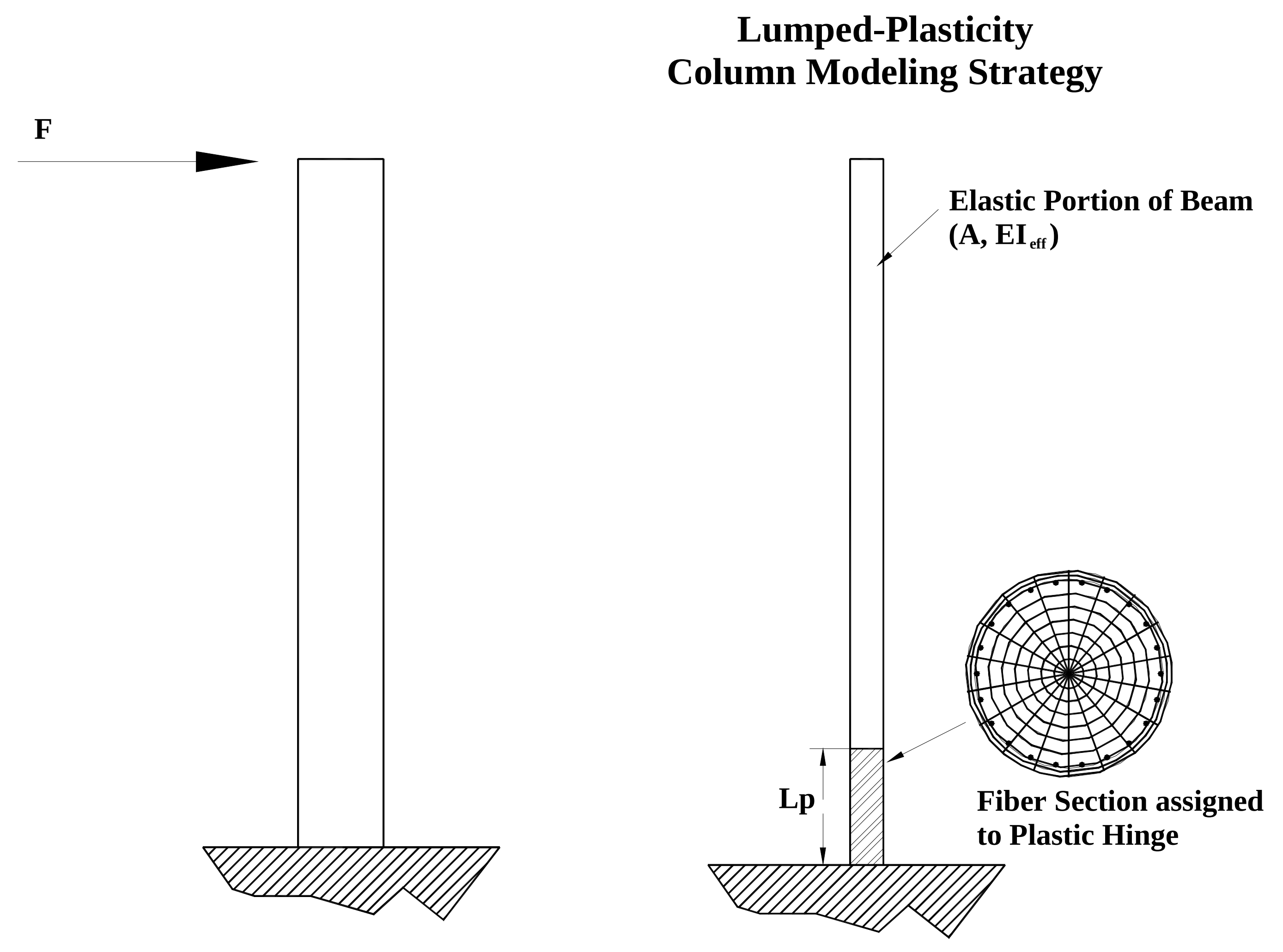
	S.R.	*M.R.*
mean	0.78	1.03
cov	0.20	0.09

With Anchorage Slip

	S.R.	*M.R.*
mean	0.96	1.04
cov	0.16	0.09

Modeling with Lumped-Plasticity Element

Lumped-Plasticity Model



Lumped-Plasticity Model

- *beamwithHinges3*
- Elastic Section Properties, A_g and EI_{eff}
- Fiber Section
- Concrete04 (Mander constants)
- Steel02 (Bilinear), b=0.01
- Plastic-Hinge Length, L_p

Lumped-Plasticity Model

- $EI_{eff} = \alpha EI_{\sec} = \alpha \dfrac{M_y}{\phi_y}$ (Berry, Lehman, Lowes)

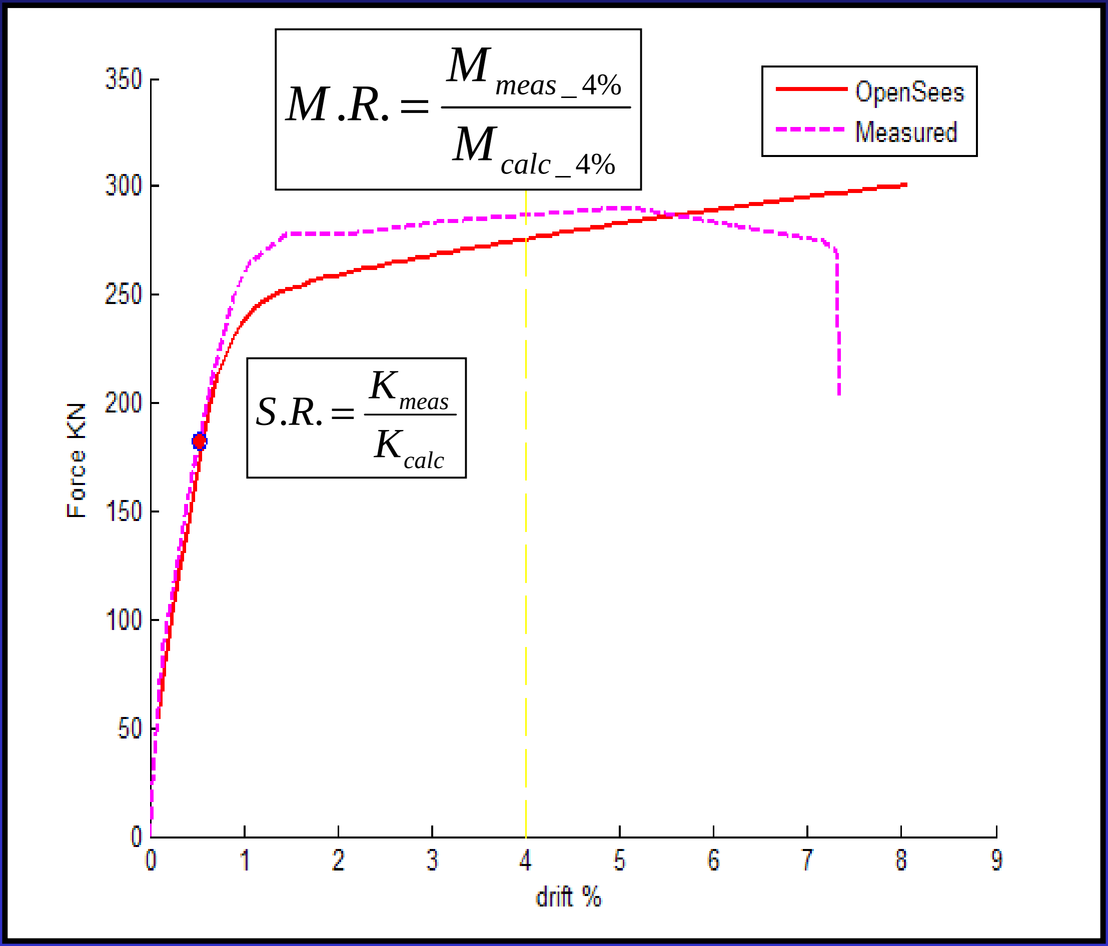
  $\alpha = 0.45 + 0.1\dfrac{L}{D} \leq 1.0$ (modify for beamwithHinges3)

- $L_p = 0.025L + 0.3D$ (Berry, Lehman, Lowes preliminary results)

L/D = 4 → Lp = 0.4D

L/D = 8 → Lp = 0.5D

Model Accuracy



$$M.R. = \frac{M_{meas\_4\%}}{M_{calc\_4\%}}$$

$$S.R. = \frac{K_{meas}}{K_{calc}}$$

Without α

	S.R.	*M.R.*
mean	0.86	1.06
cov	0.20	0.09

With α

	S.R.	*M.R.*
mean	1.00	1.06
cov	0.17	0.09

Column Damage

Cover Spalling (Lp = 0.025L + 0.3 D)

	Distributed-Plasticity	*Lumped-Plasticity*	*Drift Ratio* (*Berry-Eberhard, 2003*)
Compressive Strain in Cover	0.011±0.008	0.0094±0.005	NA
$\Delta_{calc}/\Delta_{spall}$	0.98±0.37	0.99±0.34	1.07±0.37

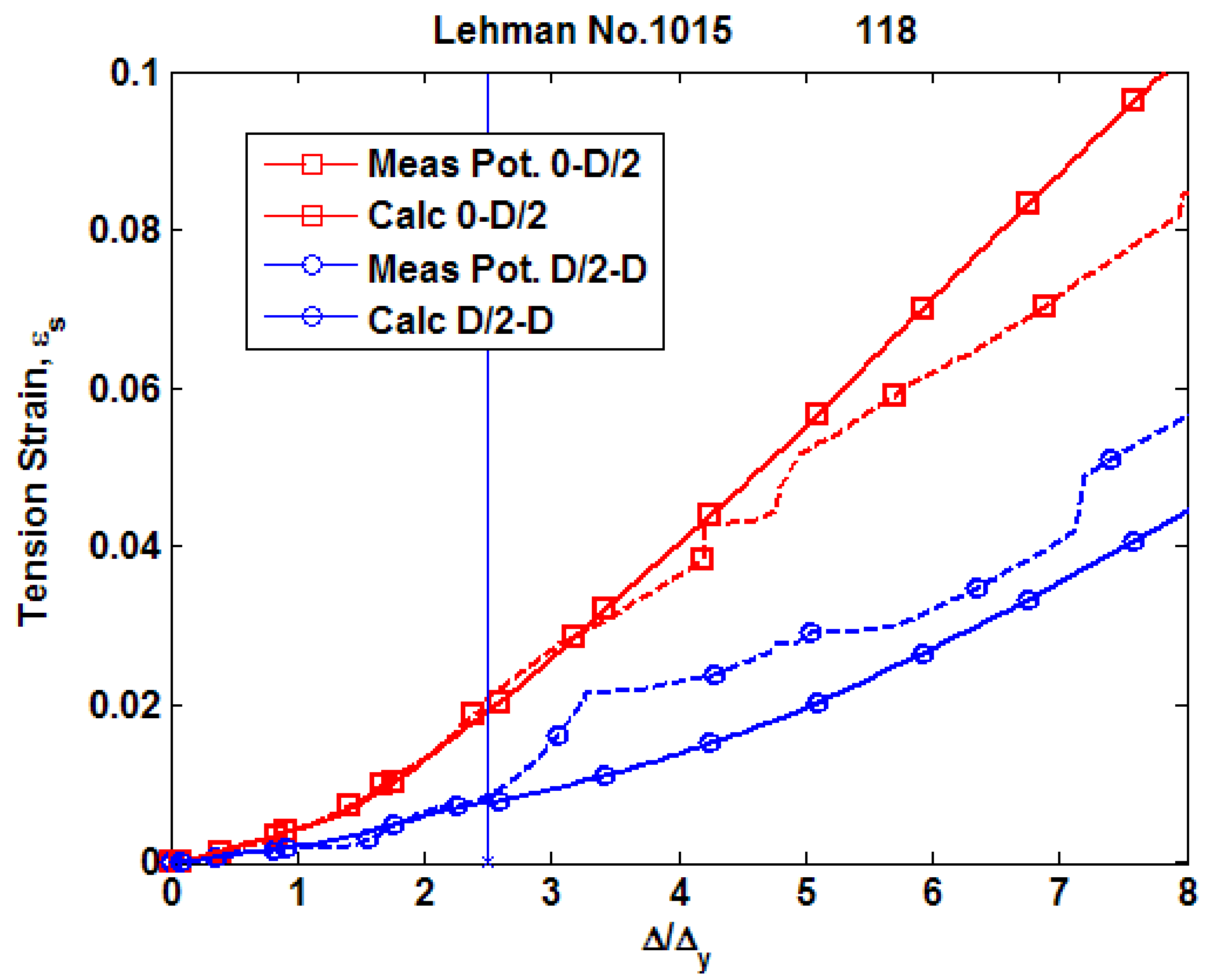
Bar Buckling (Lp = 0.025L + 0.3 L)

	Distributed-Plasticity	*Lumped-Plasticity*	*Drift Ratio* *(Berry-Eberhard, 2005)*
Compressive Strain in Bar	0.043±0.024	0.037±0.014	NA
$\Delta_{calc}/\Delta_{bb}$	0.95±0.45	0.99±0.31	0.97±0.25

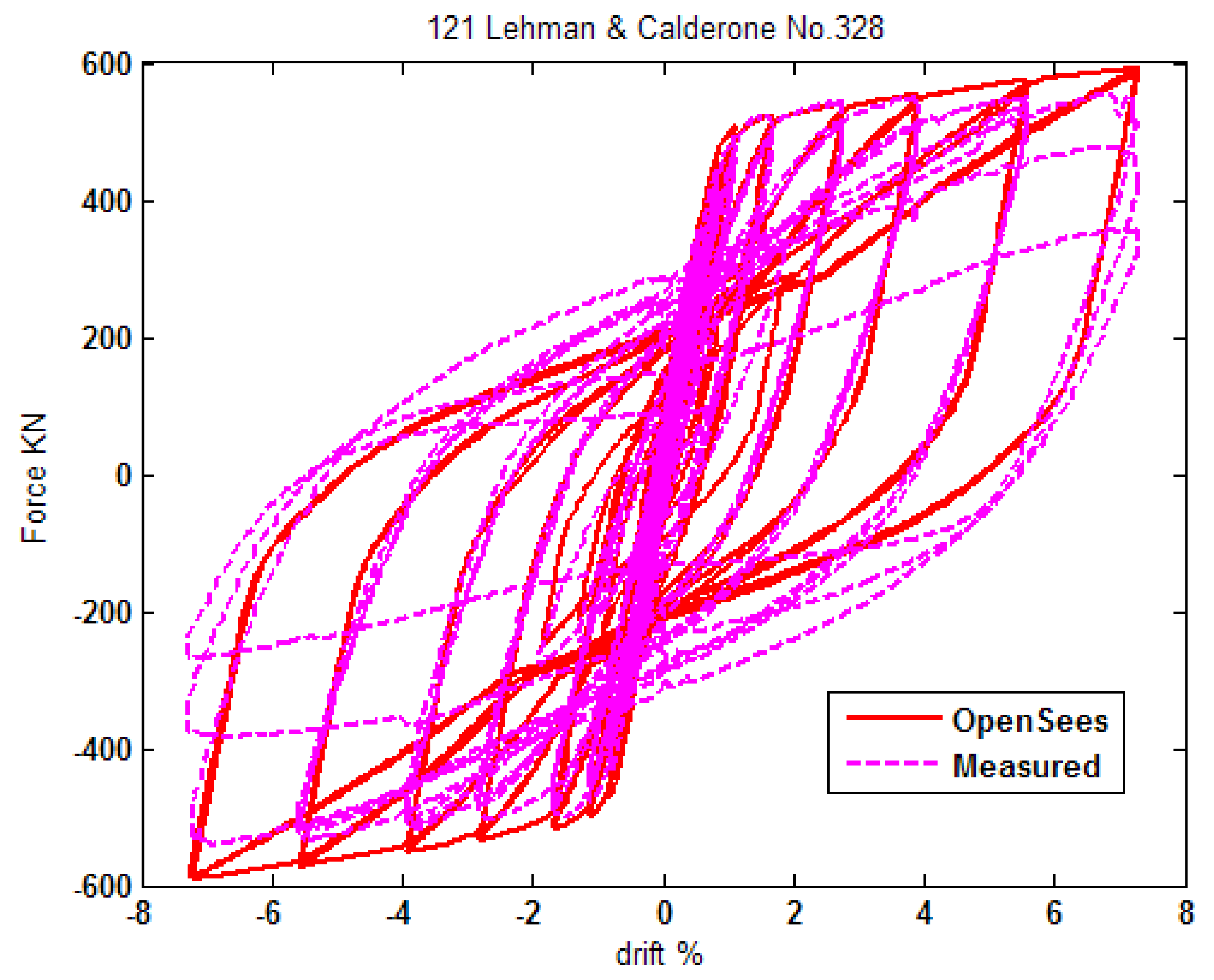
	Distributed-Plasticity	*Lumped-Plasticity*	*Drift Ratio* *(Berry-Eberhard, 2005)*
Tensile Strain in Bar	0.10±0.029	0.096±0.032	NA
$\Delta_{calc}/\Delta_{bb}$	1.02±0.34	1.00±0.34	0.97±0.25

Continuing Challenges

Strains at High Ductilities



Cyclic Response



Summary

- Both distributed- and lumped-plasticity strategies are available for modeling RC bridge columns.
- Recommendations have been developed for:
  - material models
  - fiber section discretization
  - integration of deformations along member
- Model force-deformation accuracies are similar:
  - $F_{meas}/F_{calc} \sim 1.05 \pm 0.09$
  - $K_{meas}/K_{calc} \sim 1.00 \pm 0.16$

Summary

- Damage Estimates
  - accuracies similar to semi-empirical relationships
  - More versatile (biaxial deformations, varying P)
- Current Work:
  - strain calculations after spalling
  - column degradation with cycling

Thank you

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Cover Spalling (Lp = 0.5D)

	Distributed-Plasticity	*Lumped-Plasticity*	*Drift Ratio* *(Berry-Eberhard, 2003)*
Compressive Strain in Cover	0.011±0.01	0.008±0.0038	NA
$\Delta_{calc}/\Delta_{spall}$	0.98±0.37	0.99±0.34	1.07±0.37

Bar Buckling (Lp = 0.5D)

	Distributed-Plasticity	*Lumped-Plasticity*	*Drift Ratio (Berry-Eberhard, 2005)*
Compressive Strain in Bar	0.043±0.024	0.031±0.014	NA
$\Delta_{calc}/\Delta_{bb}$	0.95±0.45	0.98±0.34	0.97±0.25

	Distributed-Plasticity	*Lumped-Plasticity*	*Drift Ratio (Berry-Eberhard, 2005)*
Tensile Strain in Bar	0.10±0.029	0.083±0.031	NA
$\Delta_{calc}/\Delta_{bb}$	1.02±0.34	0.99±0.34	0.97±0.25

Strains at Low Ductilities