Seismic Design and Stability Assessment of Composite Framing Systems

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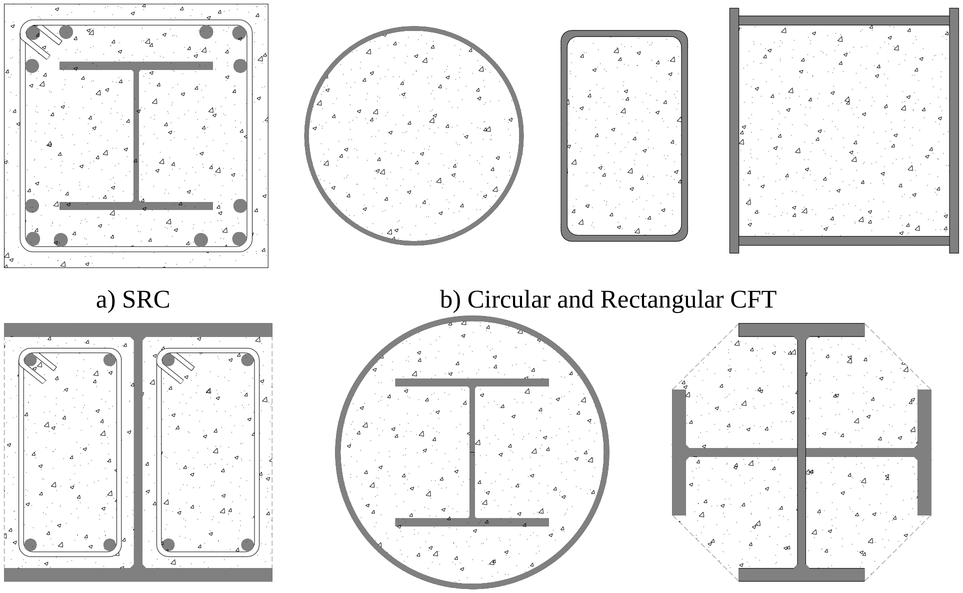
Research on Composite Systems: Project Phases

- Phase 1: Full Scale Slender CFT Beam-Column Tests
- Phase 2: Mixed Finite Element Modeling of Composite Frame Systems
- Phase 3: Stability Analysis and Seismic Response Factors for Composite Frame Systems

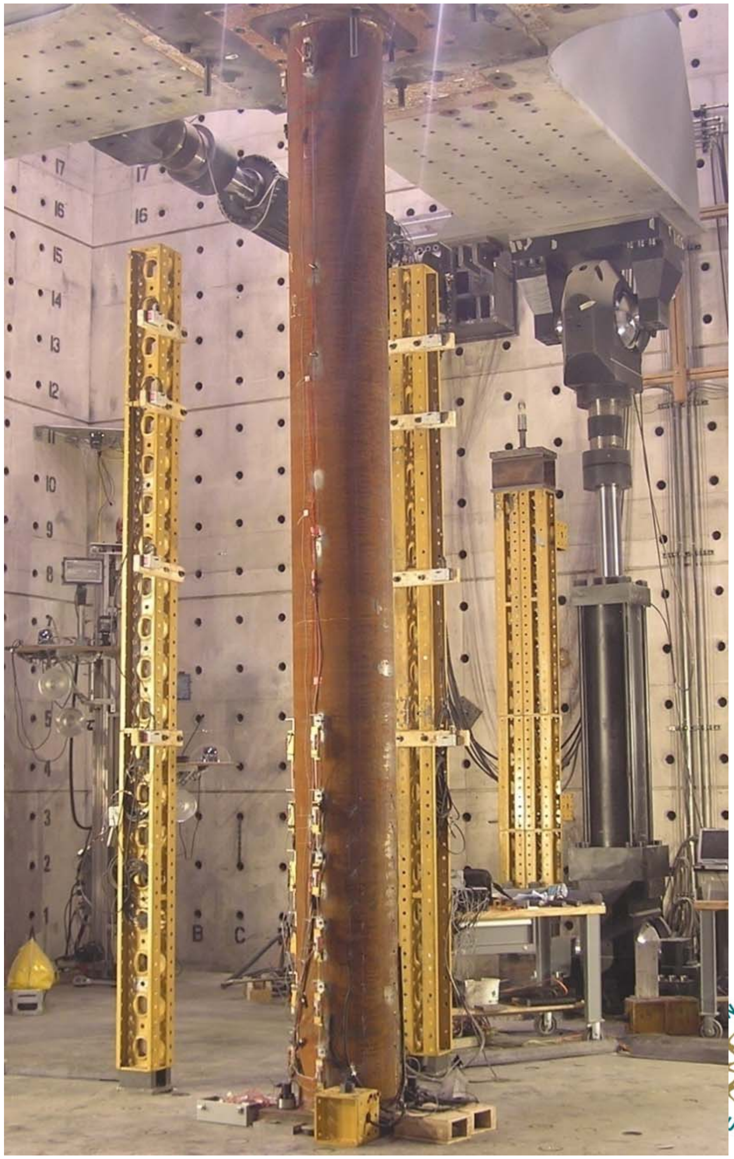


a) SRC b) Circular and Rectangular CFT

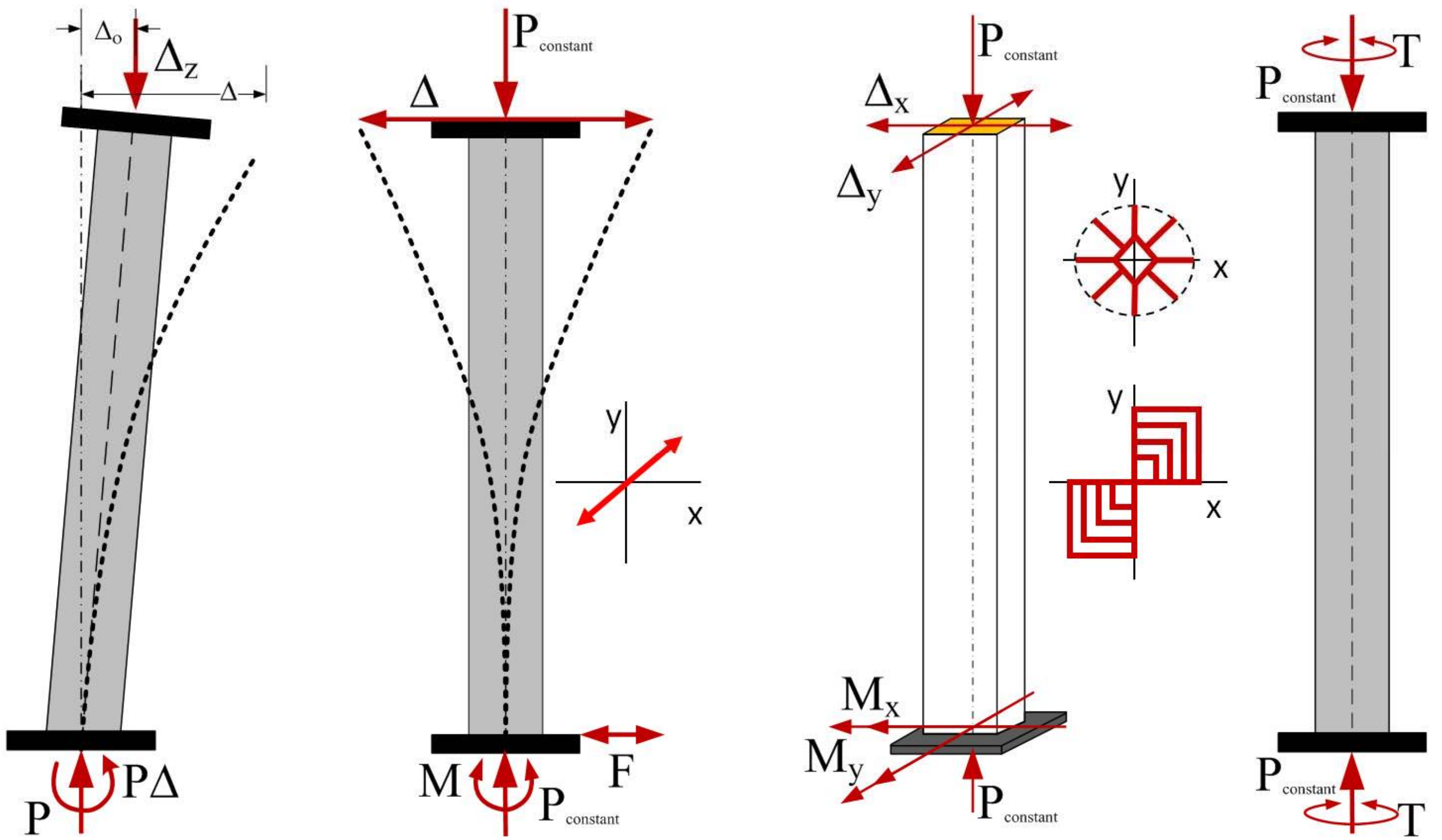
c) Combinations between SRC and CFT

Slender Beam-Column Tests

Specimen name	L (ft)	Steel section HSS D x t	*Fy* (ksi)	f_c' (ksi)	*D/t*
1-C5-18-5	18	HSS5.563x0.134	42	5	45
2-C12-18-5	18	HSS12.75X0.25	42	5	55
3-C20-18-5	18	HSS20x0.25	42	5	86
4-Rw-18-5	18	HSS20x12x0.25	46	5	67
5-Rs-18-5	18	HSS20x12x0.25	46	5	67
6-C12-18-12	18	HSS12.75X0.25	42	12	55
7-C20-18-12	18	HSS20x0.25	42	12	86
8-Rw-18-12	18	HSS20x12x0.25	46	12	67
9-Rs-18-12	18	HSS20x12x0.25	46	12	67
10-C12-26-5	26	HSS12.75X0.25	42	5	55
11-C20-26-5	26	HSS20x0.25	42	5	86
12-Rw-26-5	26	HSS20x12x0.25	46	5	67
13-Rs-26-5	26	HSS20x12x0.25	46	5	67
14-C12-26-12	26	HSS12.75X0.25	42	12	55
15-C20-26-12	26	HSS20x0.25	42	12	86
16-Rw-26-12	26	HSS20x12x0.25	46	12	67
17-Rs-26-12	26	HSS20x12x0.25	46	12	67
18-C5-26-12	26	HSS5.563x0.134	42	12	45



Typical Load Protocol



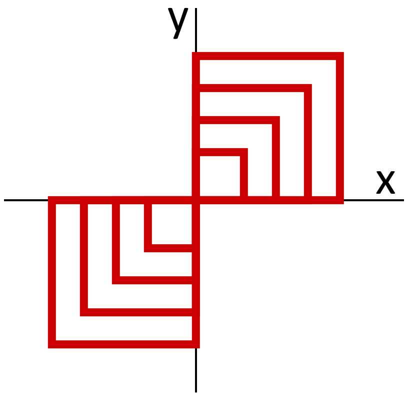
LC1: Compression

LC2: Uniaxial bending

LC3: Biaxial bending

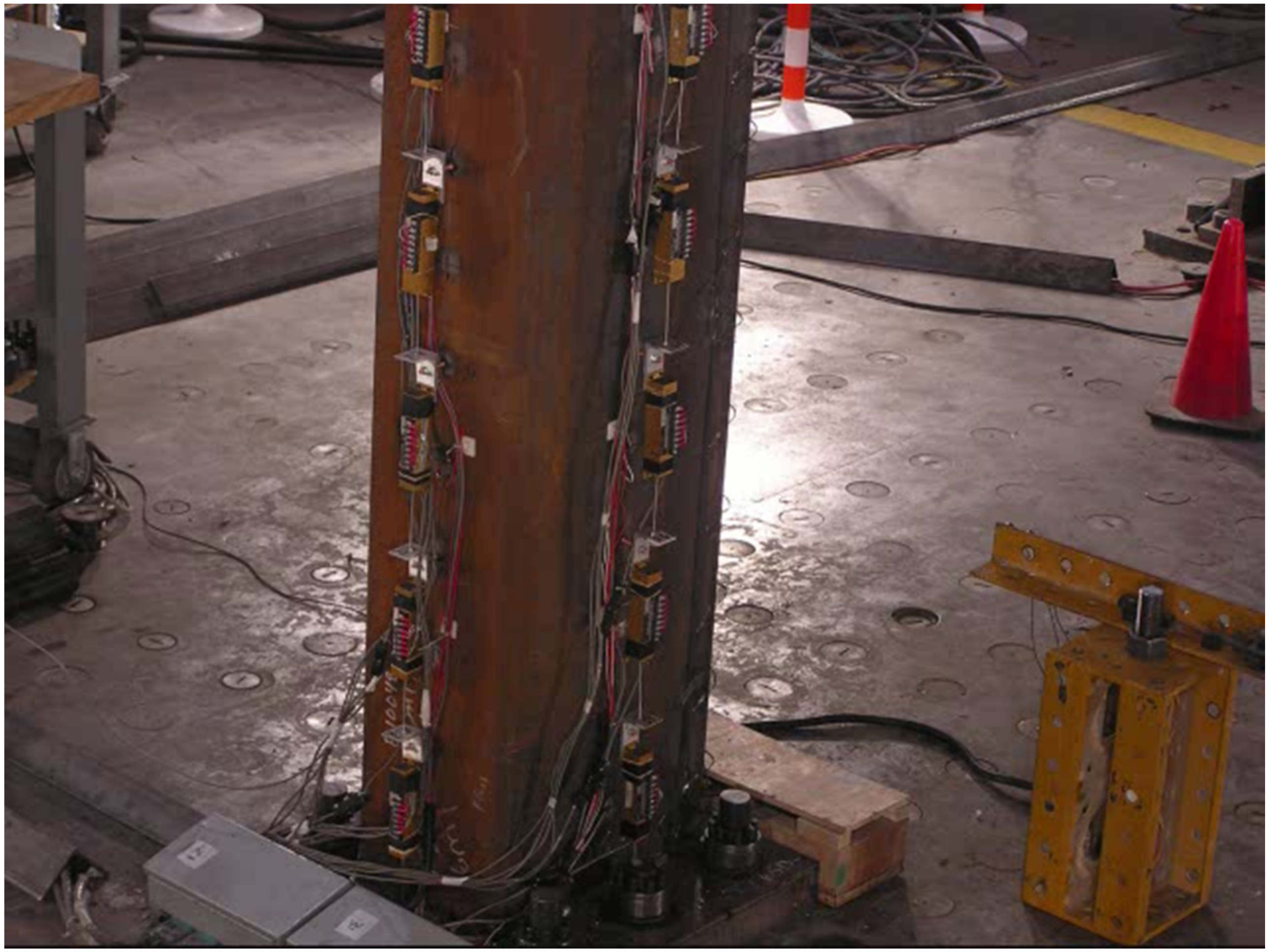
LC4: Torsion

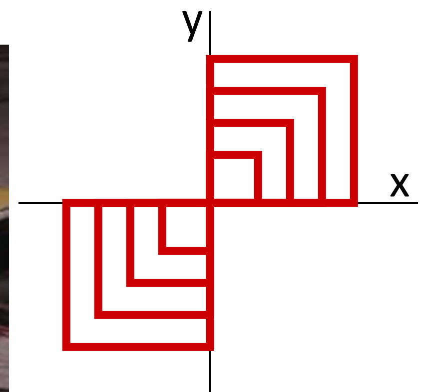
Specimen 8Rw-18-12



D = 508 mm
B = 305 mm
t = 7.15 mm
D/t = 71, 43
L = 5,553 mm
f'_c = 87.6 MPa
F_y = 365 MPa

Specimen 8Rw-18-12





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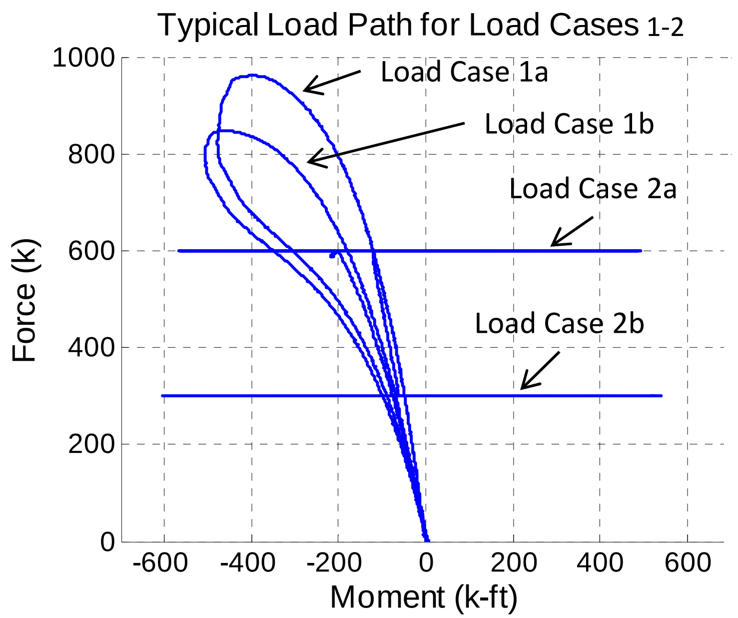
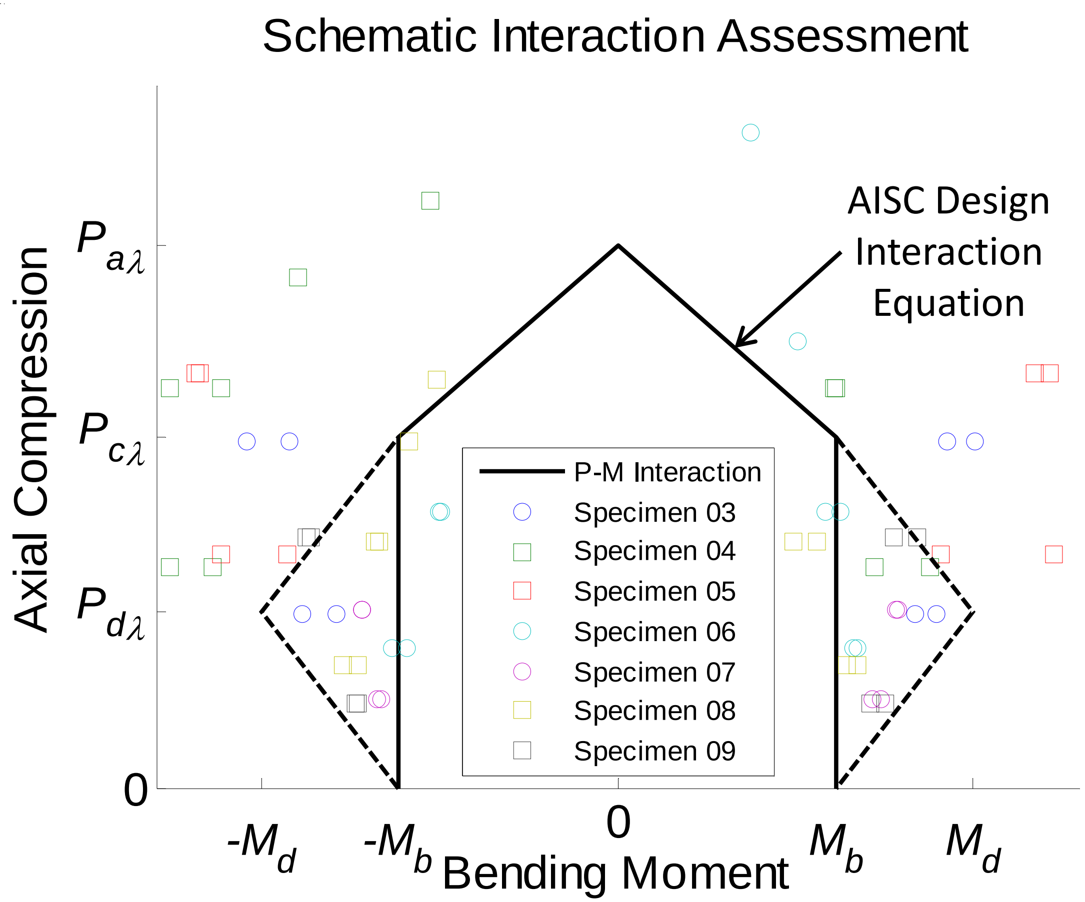
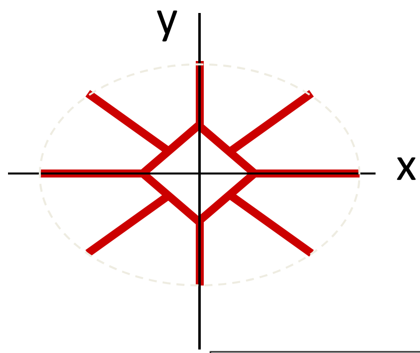
Experimental Interaction Surface
Load Cases 1-2

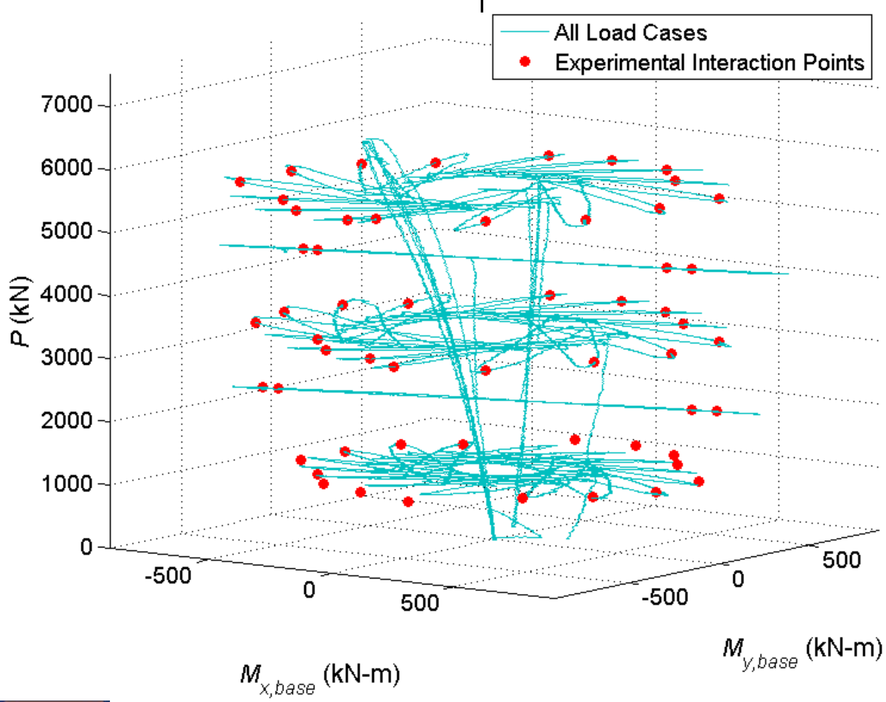


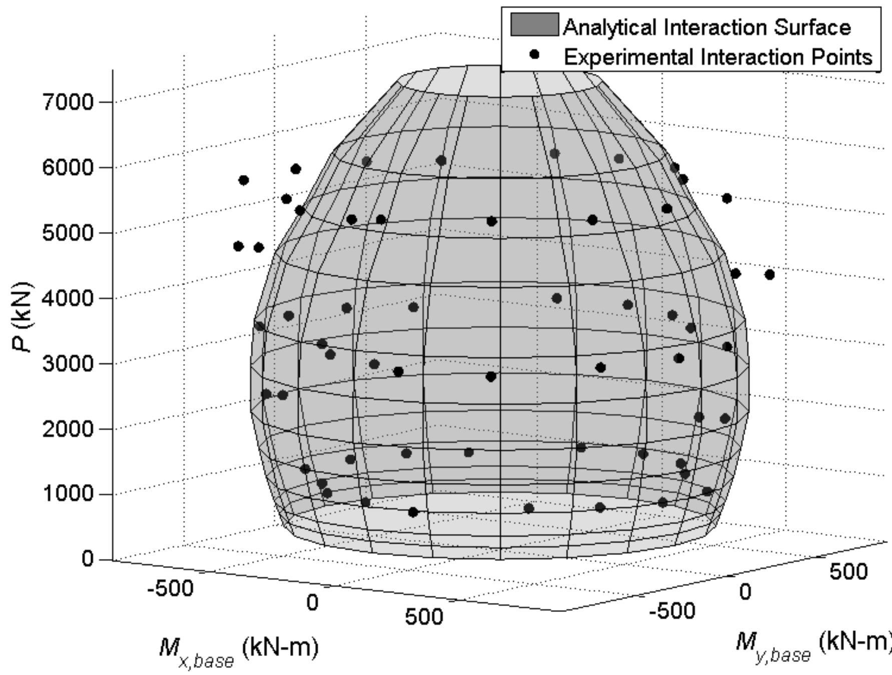


Specimen 3C20-18-5



D = 508 mm
t = 5.98 mm
D/t = 85
L = 5,525 mm
f'_c = 37.9 MPa
F_y = 328 MPa





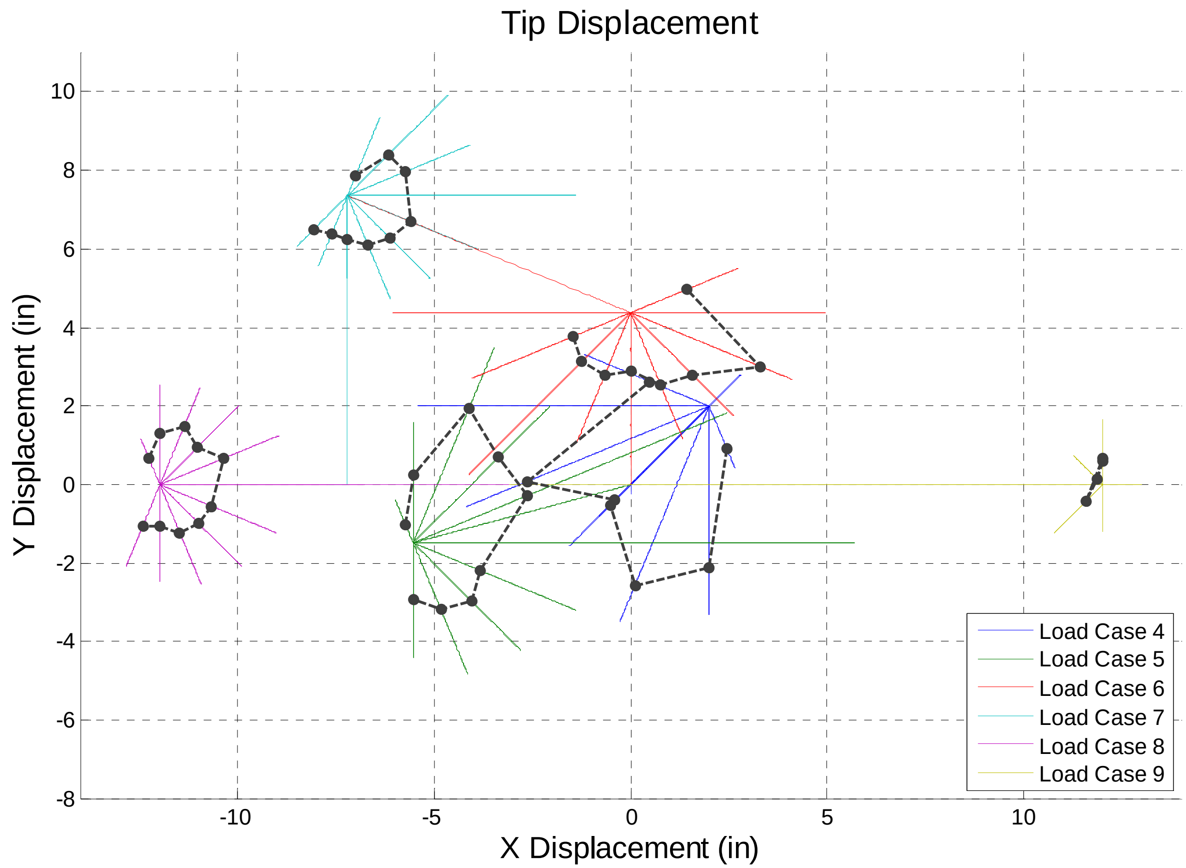
Experimental Assessment of Limit Surfaces

Evolution of Limit Surface

Specimen:
9Rs-18-12

RCFT20x12x0.3125
F_y = 53.0 ksi
f'_c = 13.3 ksi
L = 18 feet
KL = 36 feet

Axial Compression
800 kips



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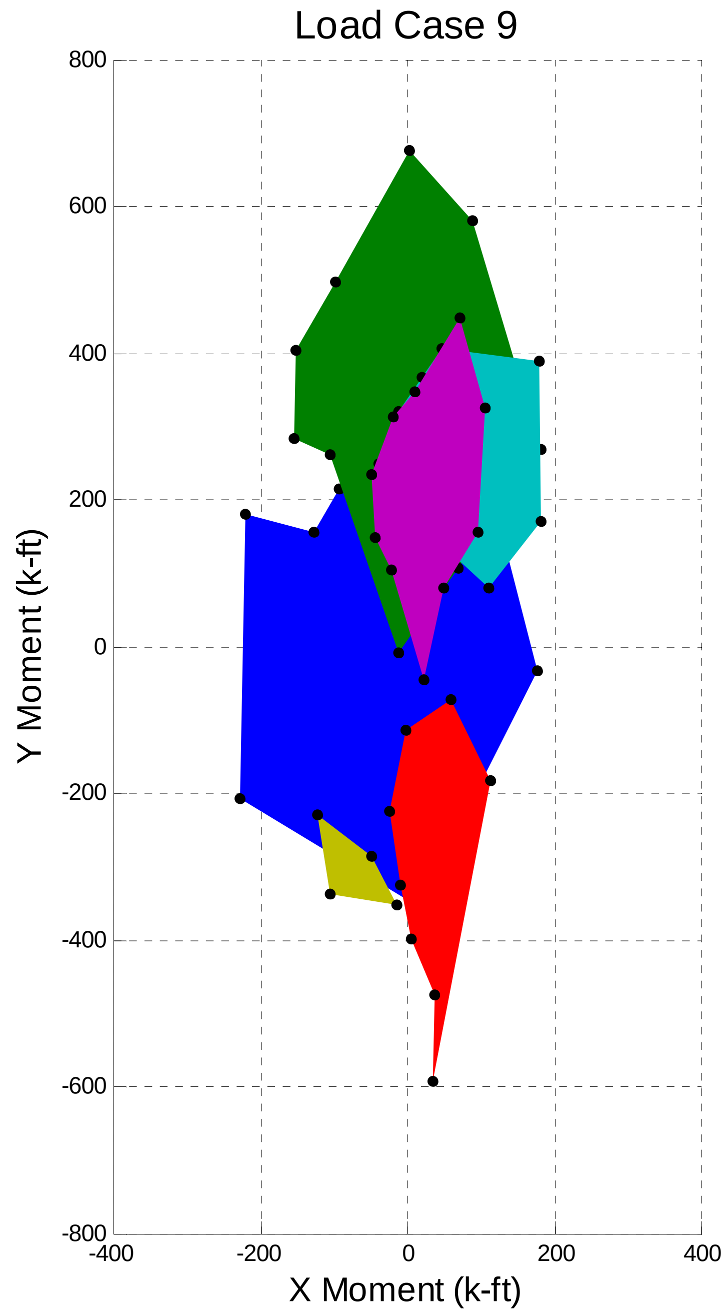
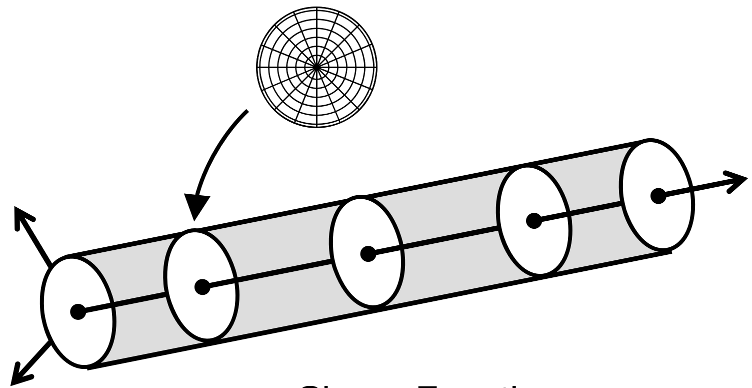
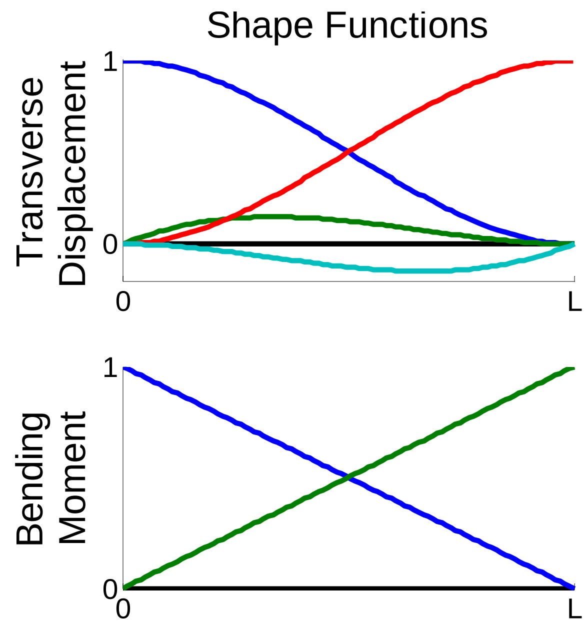


Mixed Beam-Column Element

- Mixed formulation with both displacement and force shape functions
- Total-Lagrangian corotational formulation
- Distributed plasticity fiber formulation: stress and strain modeled explicitly at each fiber of cross section
- Suitable for static and dynamic analysis
- Implemented in the OpenSees framework





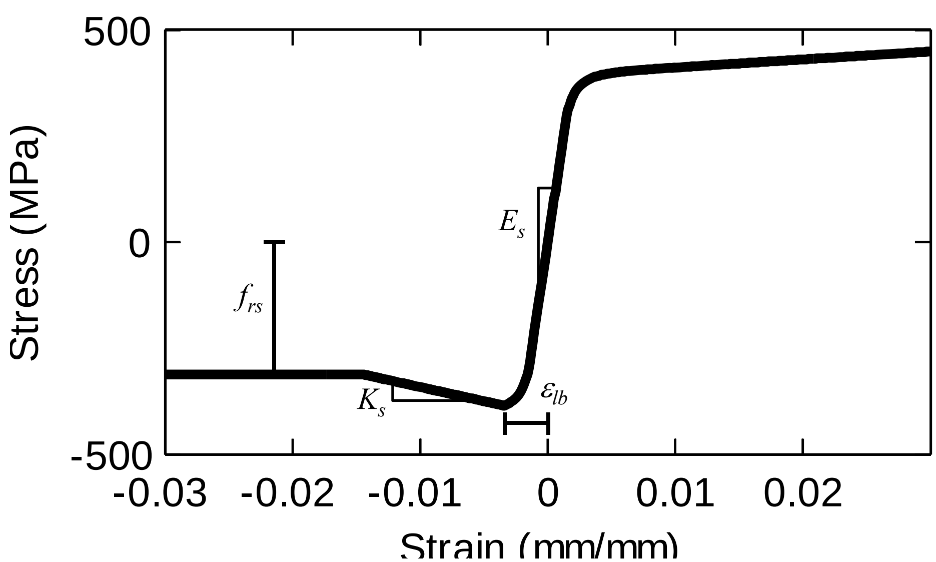
Uniaxial Cyclic Constitutive Relations

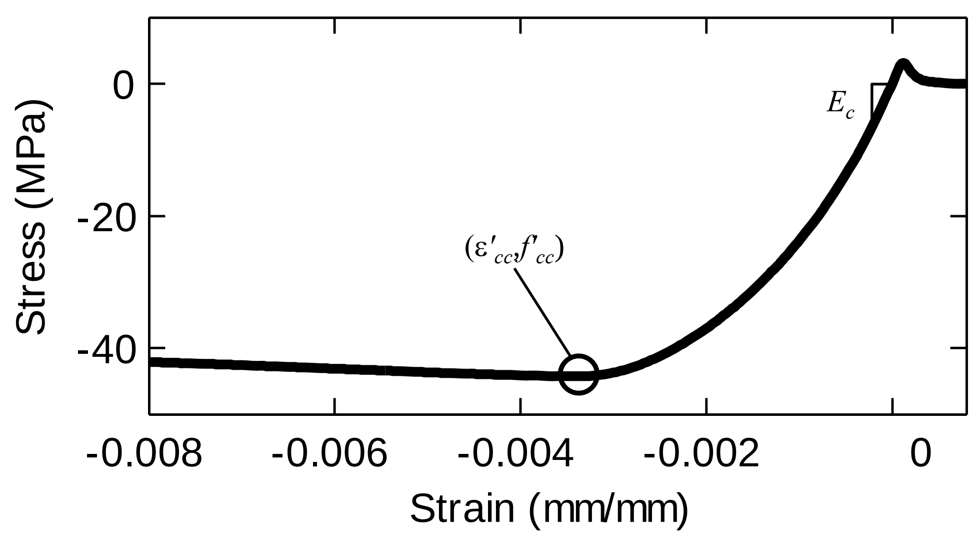
Steel

- Based on the bounding-surface plasticity model of Shen et al. (1995).
- Residual stresses modeled implicitly as an initial plastic strain
- No yield plateau, gradual transition to plasticity
- Modifications were made to model the effects of local buckling
  - Initiates with a strain limit
  - Linear degrading branch followed by constant stress branch

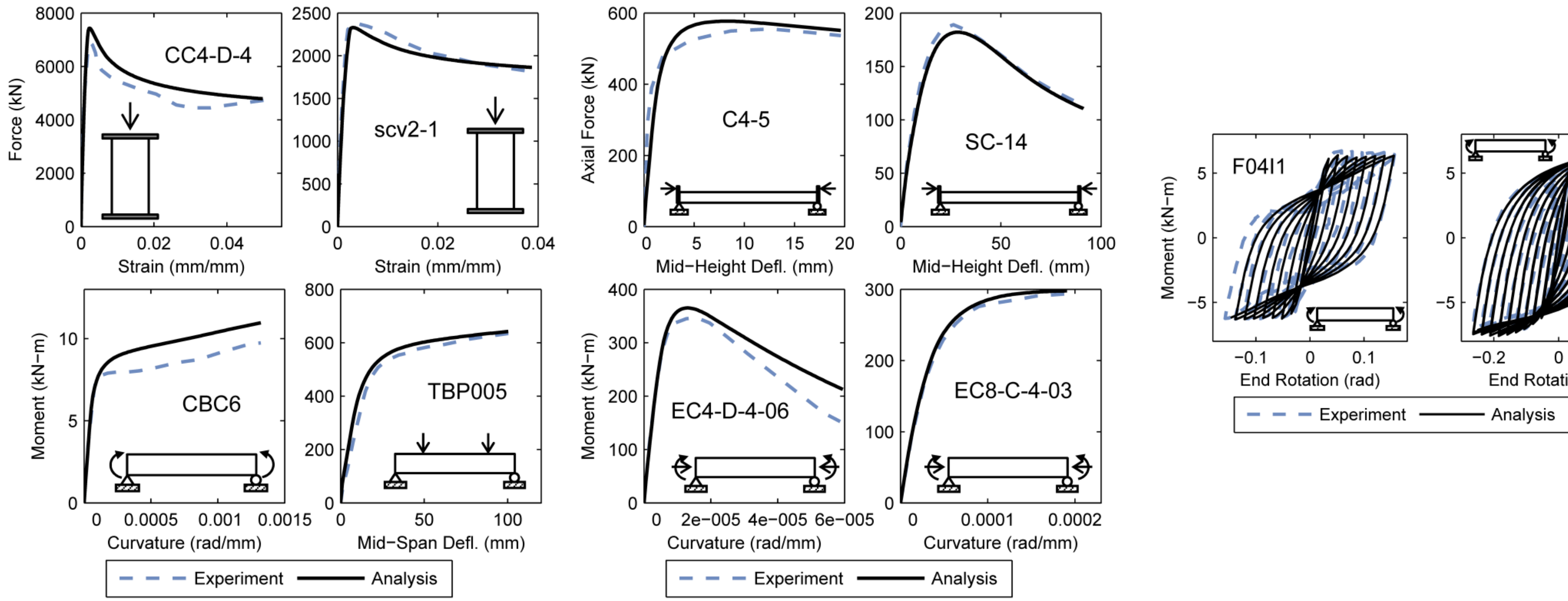
Concrete

- Based on the rule-based model of Chang and Mander (1994).
- Backbone stress-strain curve for the concrete is based on the model by Tsai, which is defined by:
  - Initial stiffness E_c
  - Peak coordinate $(\varepsilon'_{cc}, f'_{cc})$
  - r which acts as a shape factor.
- The confinement defined separately for each cross section



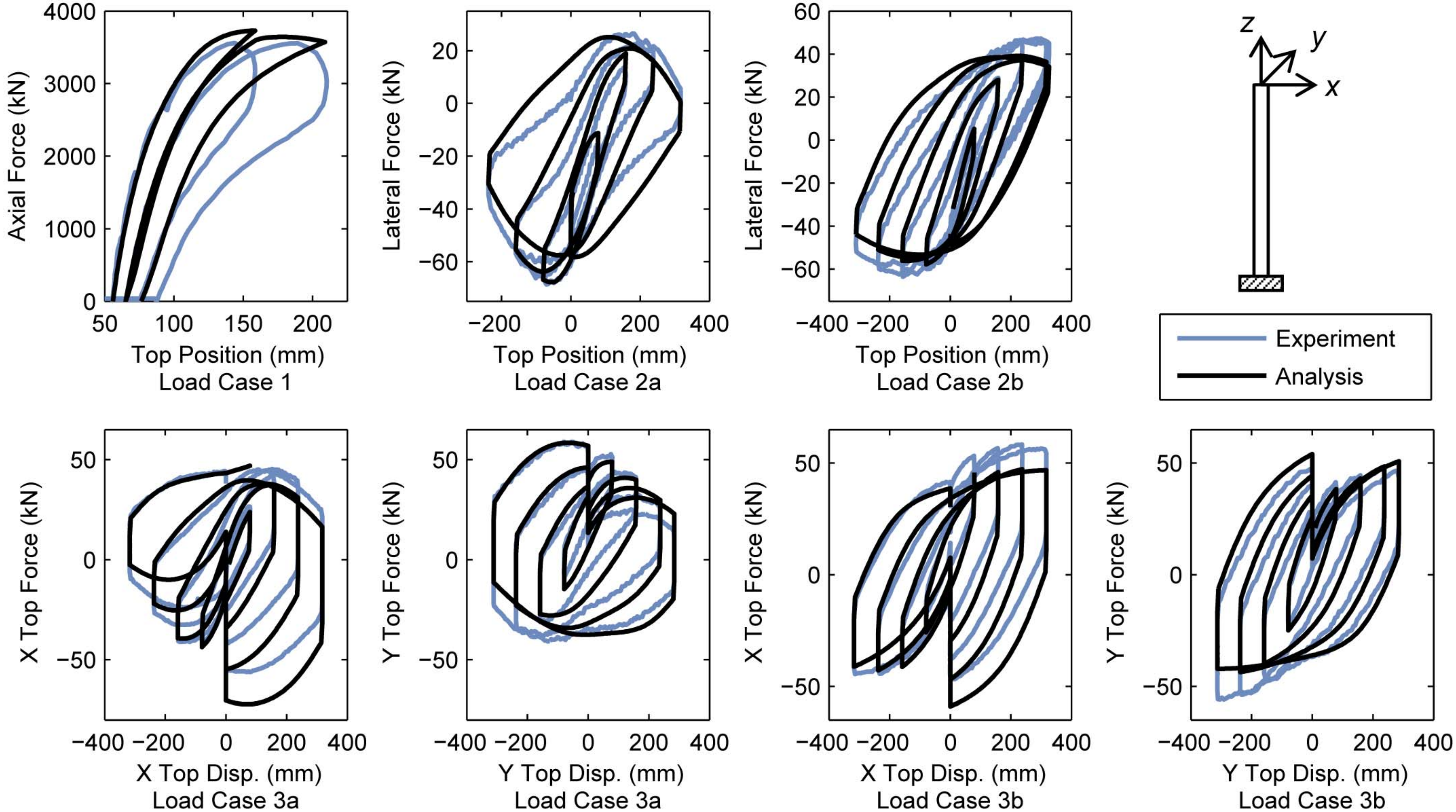


Validation of the Formulation



Specimen Name	Reference	Type	D (mm)	t (mm)	f'_c (MPa)	F_y (Mpa)	L (mm)	Other Details	# of FE
CC4-D-4	Yoshioka et al. 1995	SC	450	2.96	40.5	283	1,350	NA	**2**
scv2-1	Han and Yao 2004	SC	200	3.00	58.5	304	300	NA	**2**
CBC6	Elchalakani et al. 2001	BM	76.2	3.24	23.4	456	800	NA	**1**
TBP005	Wheeler and Bridge 2004	BM	456	6.40	48.0	351	3,800	NA	**4**
C4-5	Matsui and Tusda 1996	PBC	165	4.50	31.9	414	661	e = 103 mm	**4**
SC-14	Kilpatrick and Rangan 1999	PBC	102	2.40	58.0	410	1,947	e = 40 mm	**4**
EC4-D-4-06	Nishiyama et al. 2002	NBC	450	2.96	40.7	283	1,350	P = 4,488 kN	**1**
EC8-C-4-03	Nishiyama et al. 2002	NBC	222	6.47	40.7	834	666	P = 1,515 kN	**1**
F04I1	Elchalakani and Zhao 2008	CBM	110	1.25	23.1	430	800	NA	**2**
F14I3	Elchalakani and Zhao 2008	CBM	89.3	2.52	23.1	378	800	NA	**2**

Comparison with Slender Beam-Column Tests



Specimen: 11C20-26-5
CCFT 20x0.25

F_y = 44.3 ksi, f'_c = 8.1 ksi
L = 26 ft, KL = 52 ft

Direct Analysis Method

Required Strengths

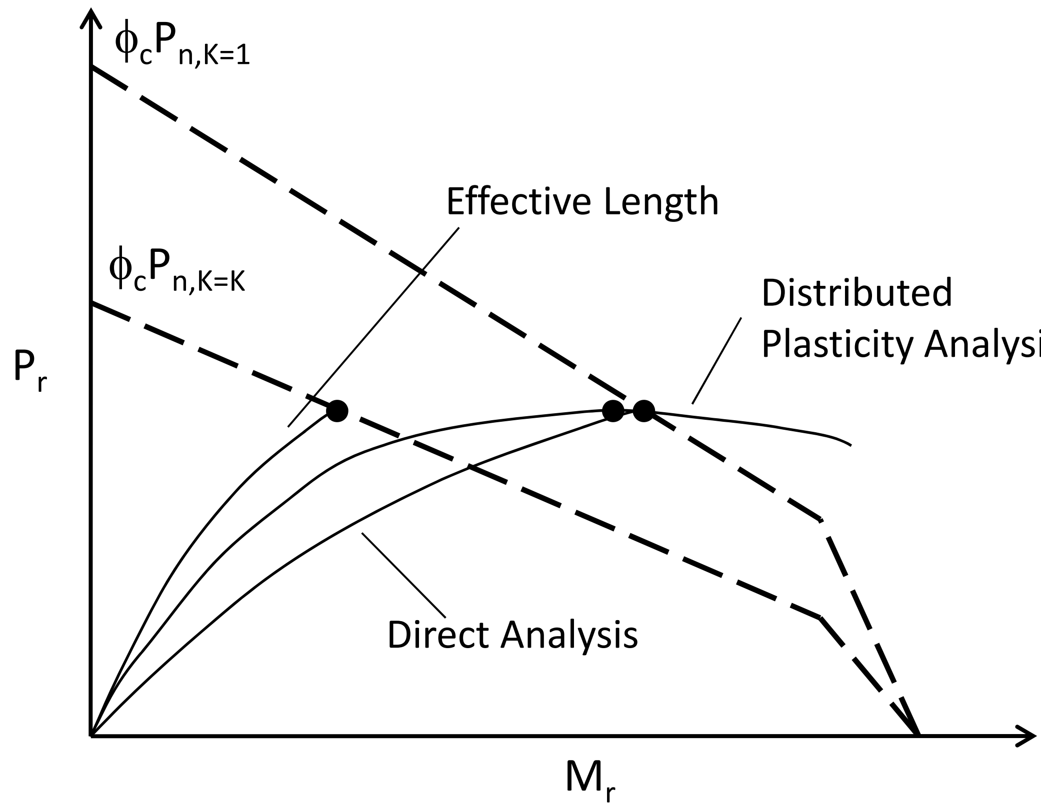
- Second-Order Elastic Analysis
- Consideration of Initial Imperfections

$$N_i = 0.002Y_i$$

- Stiffness Reductions

$$EI_{DA} = 0.8\tau_b EI_{elastic}$$

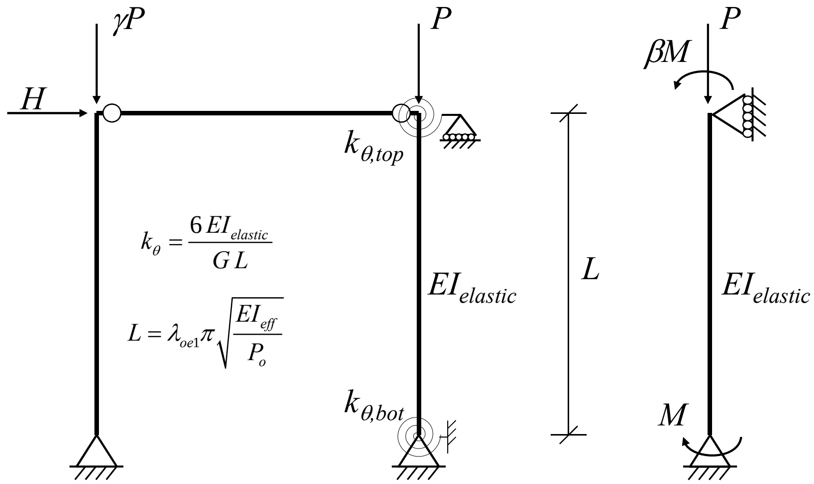
$$EA_{DA} = 0.8EA_{elastic}$$



Available Strengths

Use $K = 1$ to compute axial compressive strength

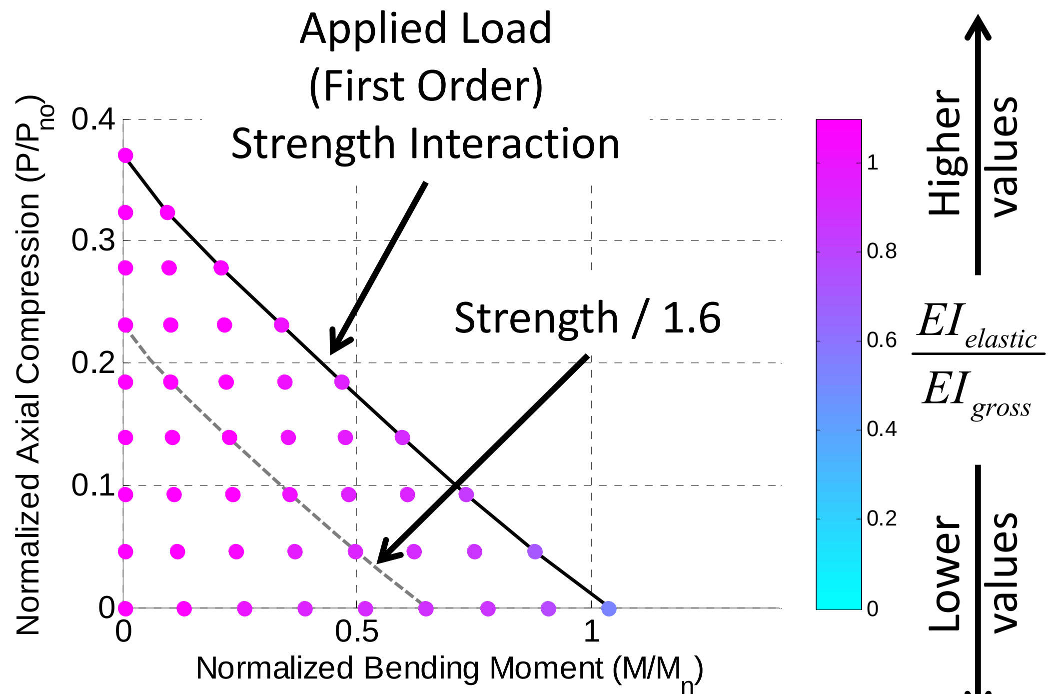
Direct Analysis Method for Composite Frames: New $EI_{elastic}$



Initial Imperfections:
Out-of-plumbness Δ_o = L/500;
Out-of-straightness δ_o = L/1000 (sinusoidal)

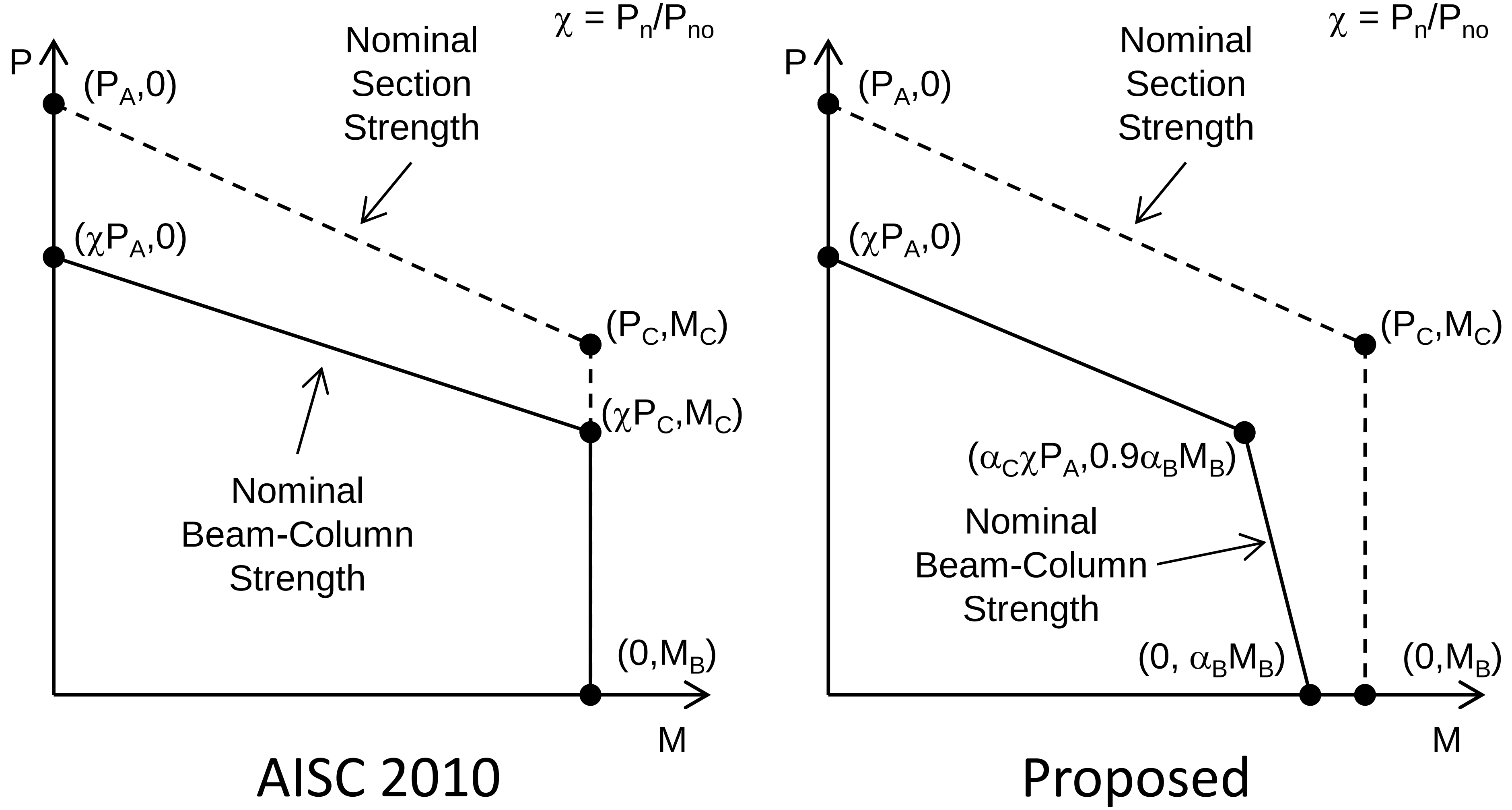
$$EI_{elastic} = E_s I_s + 0.75 C_3 E_c I_c$$

$$C_3 = 0.6 + 2\left(\frac{A_s}{A_c + A_s}\right) \le 0.9$$

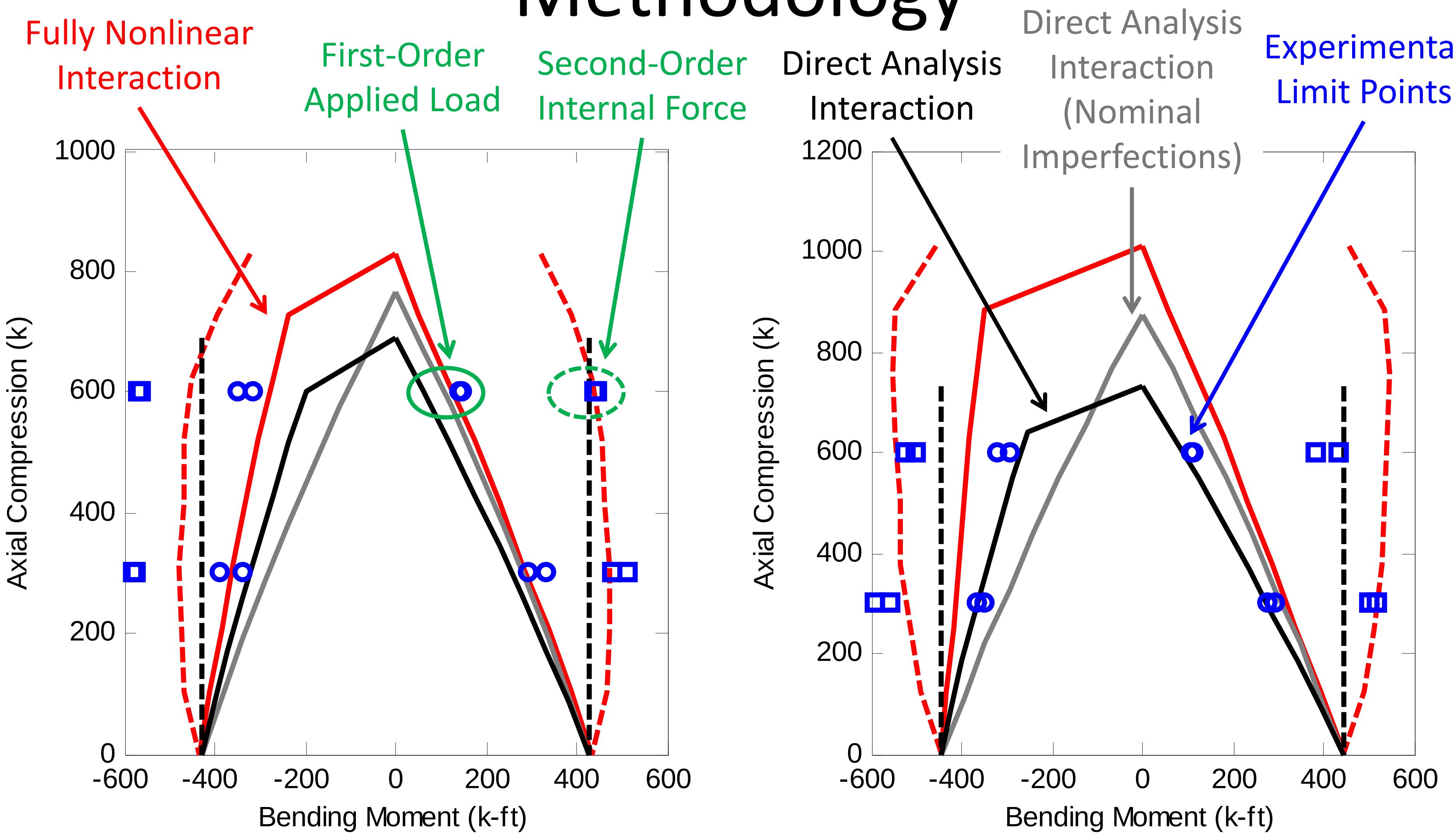


Section 7: RCFT-C-4, Frame 27: UC-45-g2

Direct Analysis Method for Composite Frames using $0.8\tau_b EI_{elastic}$



Experimental Validation of the Design Methodology



Specimen 4-Rw-18-5

($\Delta_o = 0.615L$)

Specimen 8-Rw-18-12

($\Delta_o = 0.828L$)

Conclusions

- 18 full-scale experiments conducted on slender concrete-filled steel tube beam-columns, including complex 3D cyclic loading
- New mixed finite element distributed plasticity formulation developed for composite systems (CFTs and SRCs)
- Parametric investigation underway to determine parameters needed to perform Direct Analysis (stability assessment with effective length factor K = 1) for composite systems
- New elastic flexural and axial rigidities, Direct Analysis reduction parameters, and interaction surface are proposed for design
- Future work: evaluation of seismic performance factors R, C_d, Ω_0

THANK YOU