Performance-Based Seismic Assessment and Design:

Recent Research Advances

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ACIES
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Bogota, Colombia
Nov 25, 2021

Performance-Based Seismic Design (PBSD)

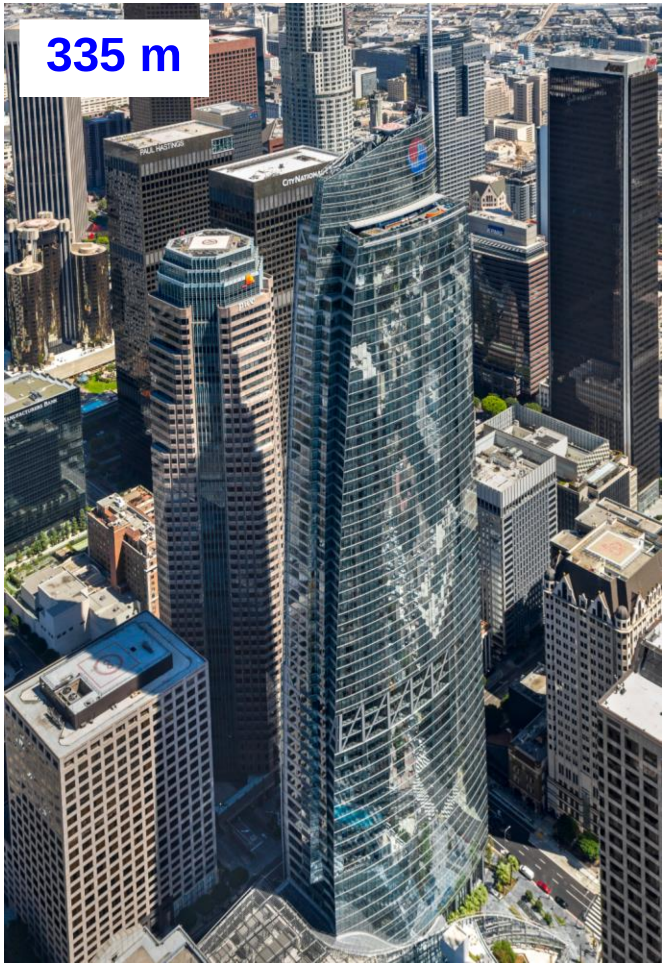
Prescriptive (Code)

Vs.

Non-Prescriptive (PBSD)

Performance-Based Seismic Design (PBSD)

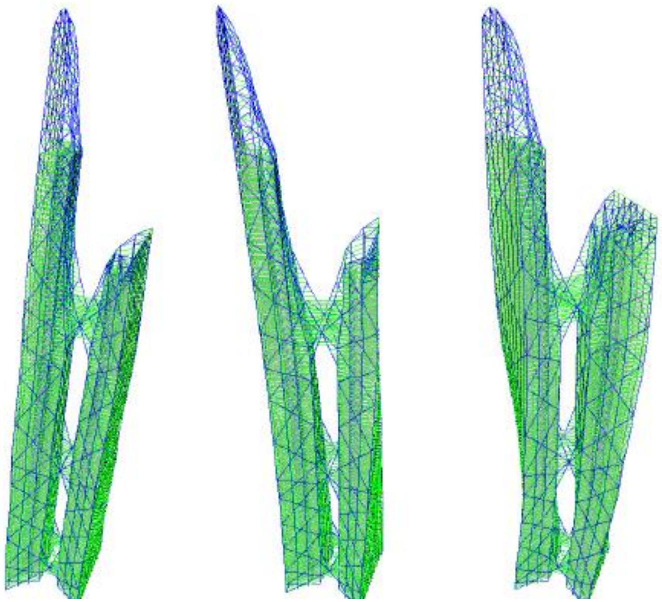
Prescriptive (Code) Vs. Non-Prescriptive (PBSD)

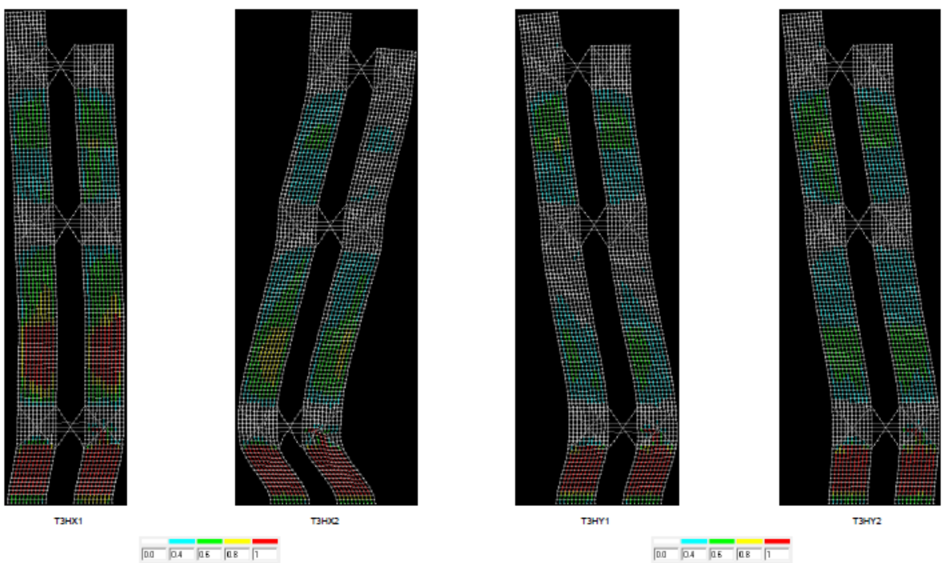


Performance-Based Seismic Design (PBSD)

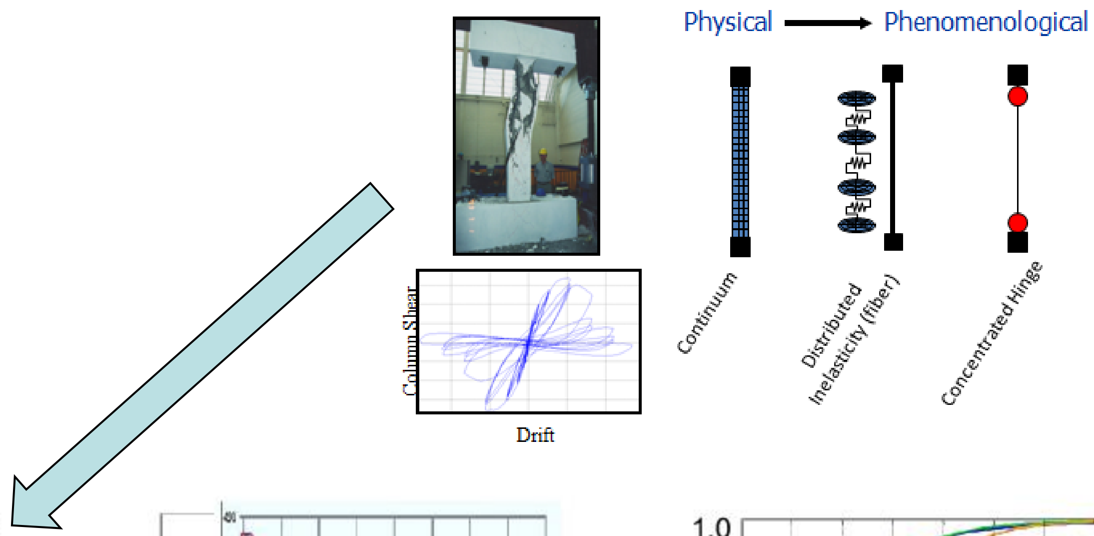
Prescriptive (Code) Vs. Non-Prescriptive (PBSD)

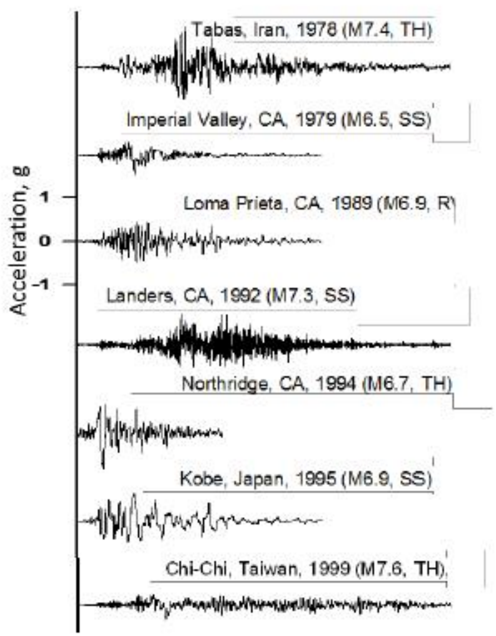
Courtesy: SOM



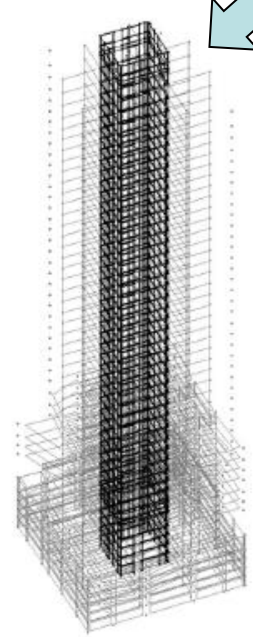


PBSD Procedure

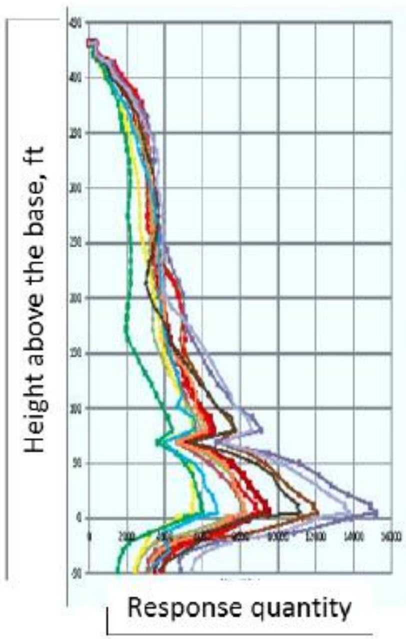




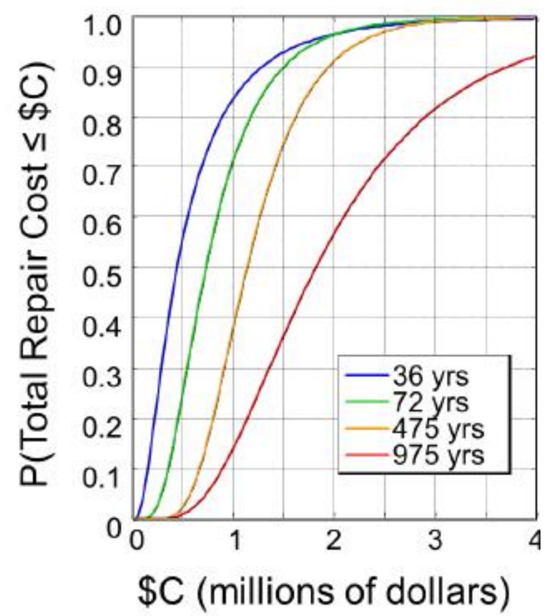
(a) Ground motions



(b) Structural analysis model



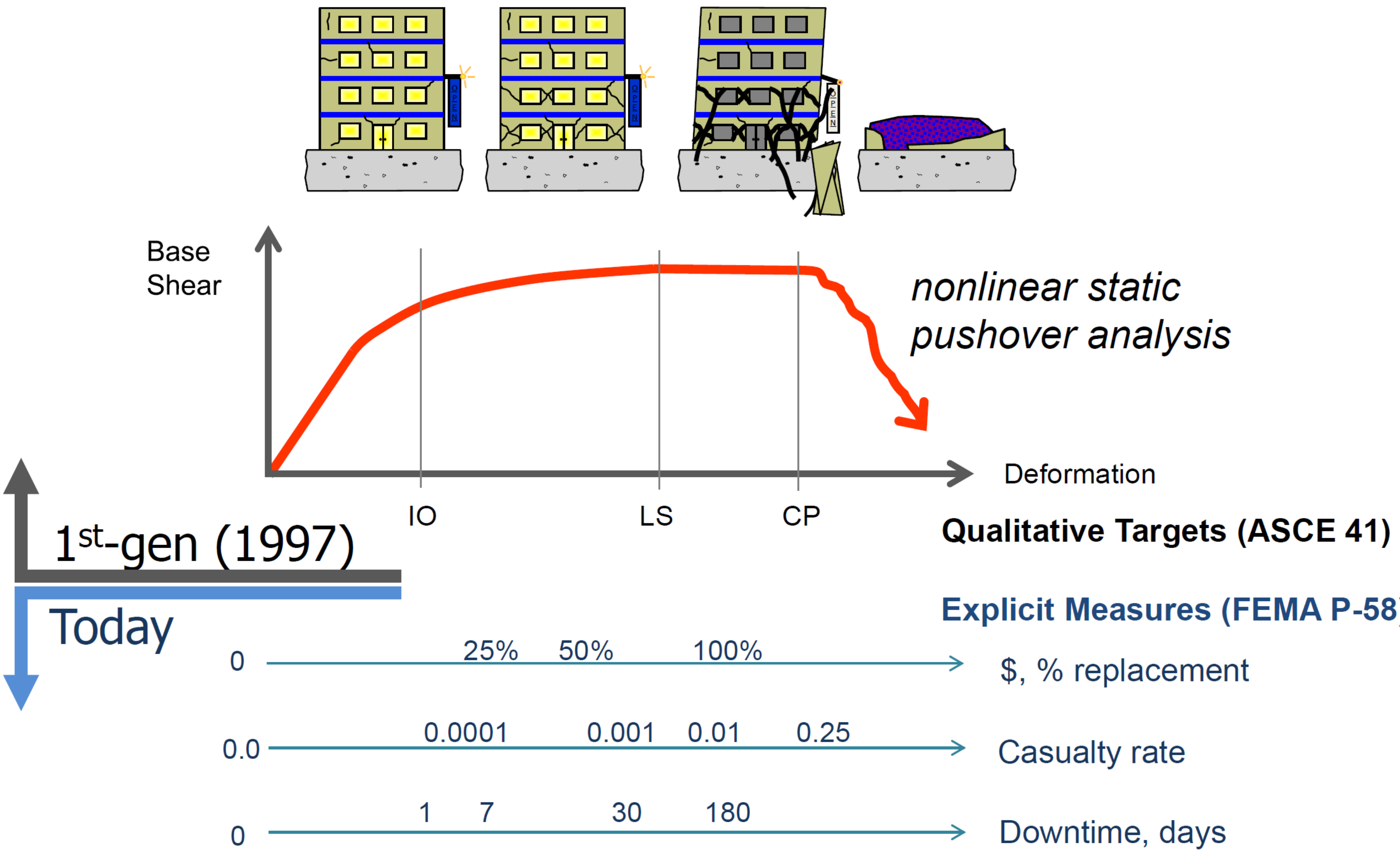
(c) Structural responses



(d) Performance

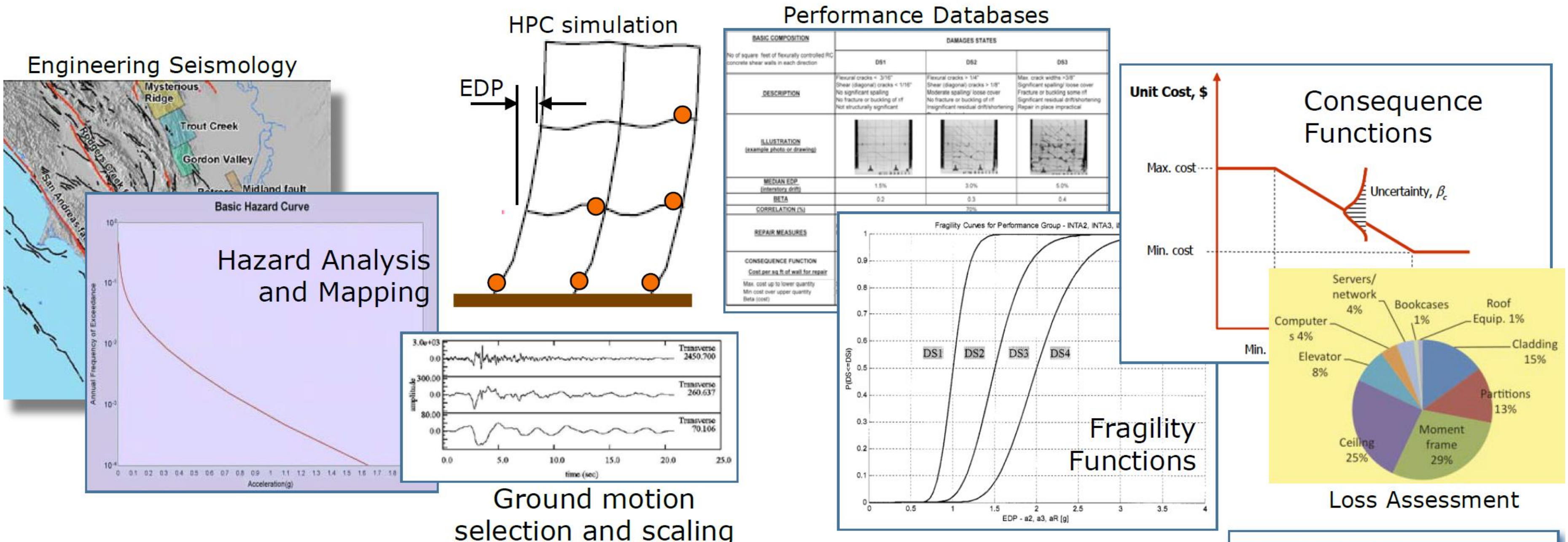
Slide Courtesy: Moehle

Performance-Based Earthquake Engineering



Slide Courtesy: Holmes and Deierlien

PEER PBEE Methodology



Seismic Hazard Analysis	→	**Response Analysis**	→	**Damage Analysis**	→	**Loss Analysis**
$\lambda(im)$		$G(edp \mid im)$		$G(dm \mid edp)$		$G(dv \mid dm)$
IM: intensity measure		**EDP**: Engineering Demand Parameter		**DM**: Damage Measure		**DV**: Decision Variable

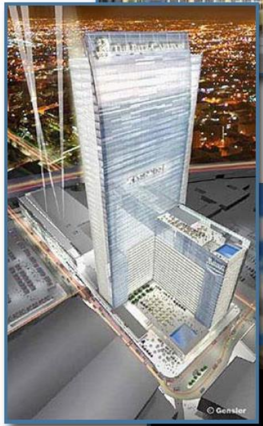
$$\lambda(DV > dv) = \int_{im}\int_{dm}\int_{edp} G(dv \mid dm)\, dG(dm \mid edp)\, dG(edp \mid im) \left| d\lambda(im) \right|$$

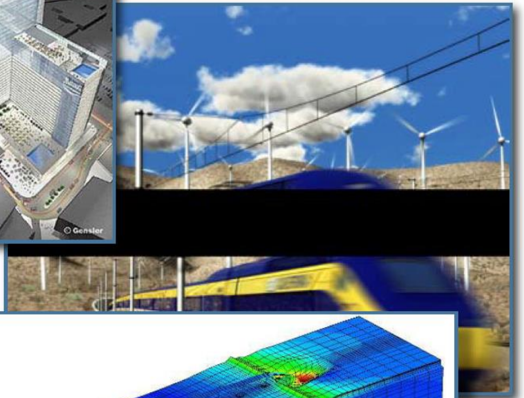
Probabilistic Assessment of:
- ✓ Cost of repair and loss of function
- ✓ Downtime
- ✓ Casualties
- ✓ *Embodied energy*

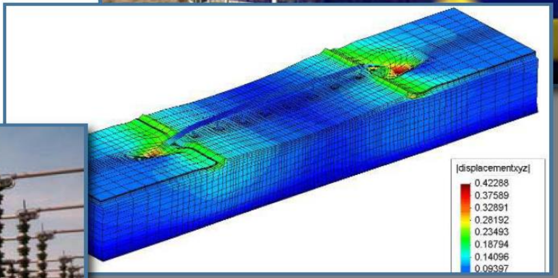
Slide Courtesy: Mahin

Applications of PBEE

- Buildings
  - Vulnerable existing buildings
  - New and existing tall buildings
  - Sustainable and resilient buildings
- Transportation Systems
  - Highway networks and bridges
  - High-speed rail systems
  - Ports and harbors
- Lifeline systems
  - Electrical power distribution systems
  - Nuclear power plants
  - LNG storage facilities







PEER

Slide Courtesy: Mahin

Performance-Based Seismic Design/Assessment

Common Performance Levels

- Operational (OP)
- Immediate Occupancy (IO)
- Life Safe (LS)
- Collapse Prevention (CP)

Service Level Design/Assessment (Frequent Earthquake, Return Period 43 years)

Performance Objective

Essentially elastic performance at the 50% probability of exceedance in 30 year (IO)

Acceptance Criteria

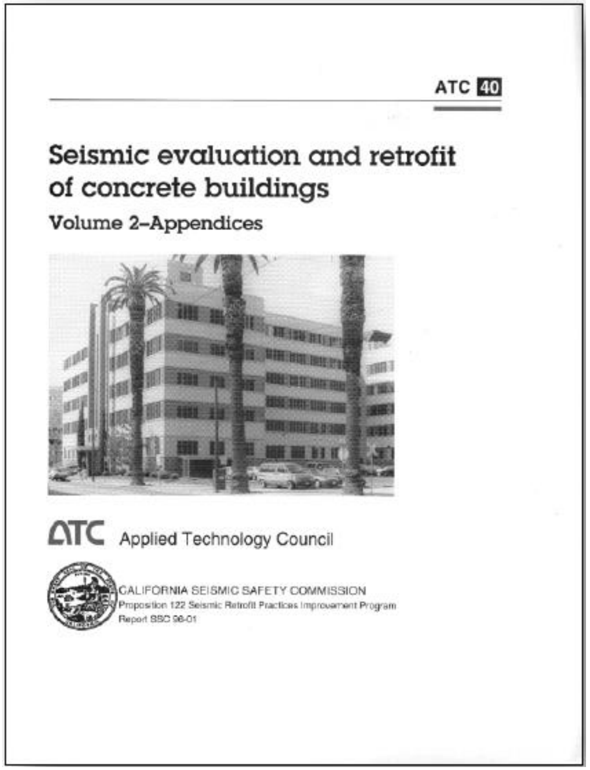
MCE Level Design/Assessment (Very Rare Earthquake, Return Period 2475 years)

Performance Objective

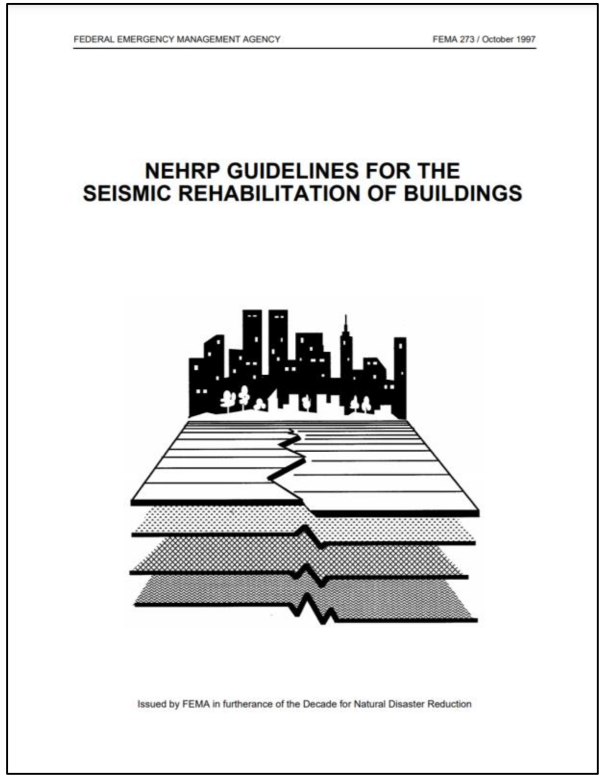
- Low probability of collapse under the MCE (2% prob. of exceedance in 50 year), (CP)
- No loss of gravity load carrying capacity
- No global instability
- No excessive permanent drifts
- No excessive inelastic straining to a level severely detrimental to strength

Acceptance Criteria

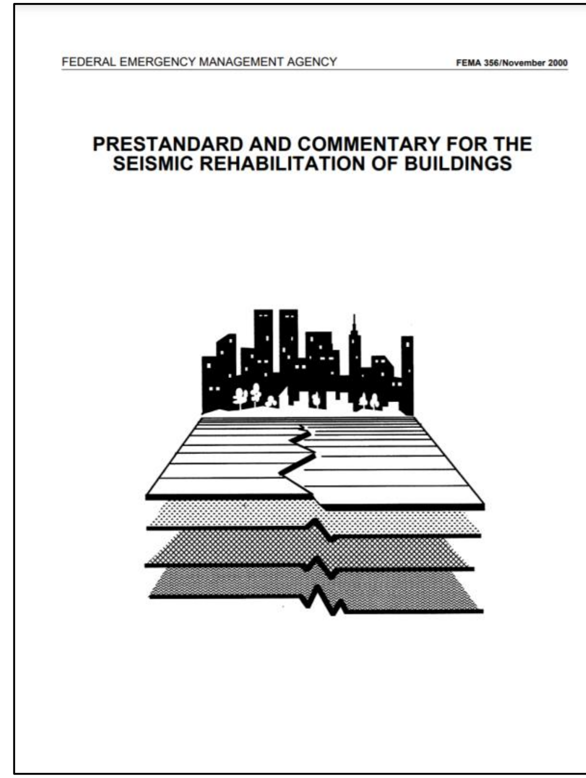
U.S. Performance-Based Seismic Design Guides



ATC 40
1996



FEMA 273
1997

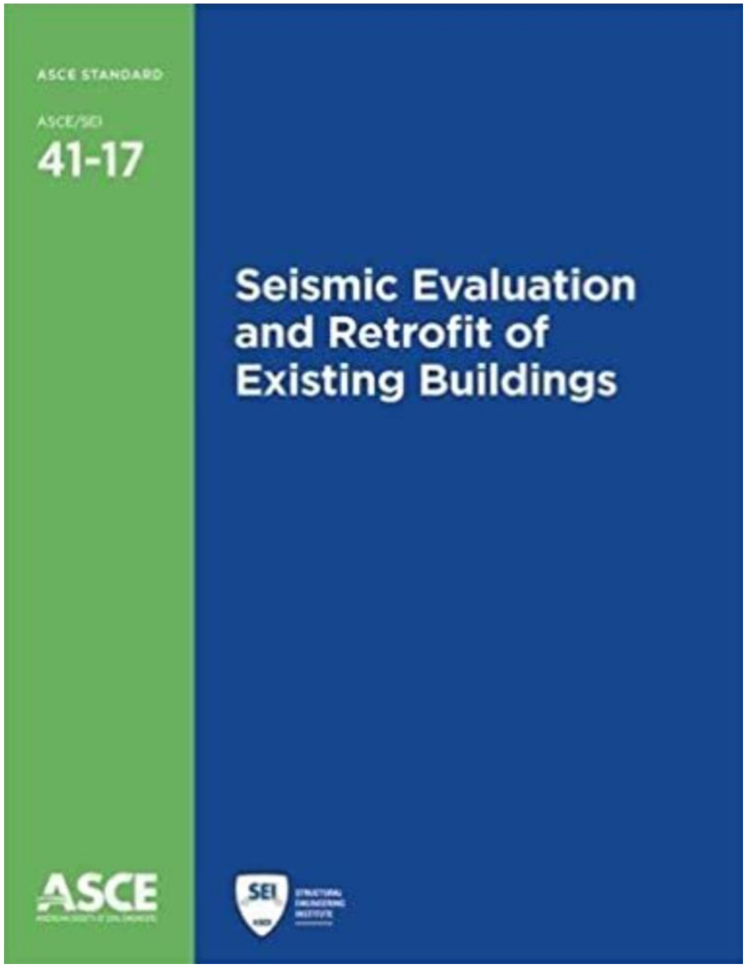


FEMA 356
2000

Vision 2000

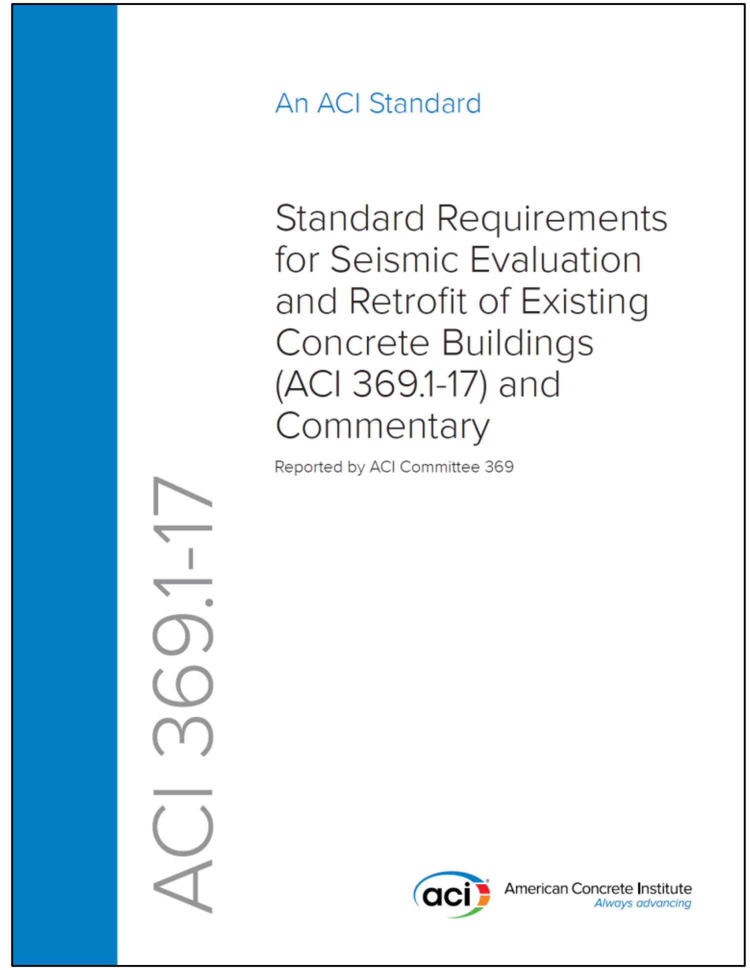
Earthquake Design Level	Earthquake Performance Level: Fully Operational	Operational	Life Safe	Near Collapse
Frequent (43 years)	Basic Objective	Unacceptable	Unacceptable	Unacceptable
Occasional (72 years)	Essential/Hazardous Objective	Basic Objective	Unacceptable	Unacceptable
Rare (475 years)	Safety Critical Objective	Essential/Hazardous Objective	Basic Objective	Unacceptable
Very Rare (975 years)	Not Feasible	Safety Critical Objective	Essential/Hazardous Objective	Basic Objective

U.S. Performance-Based Seismic Design Guides



ASCE 41 2017

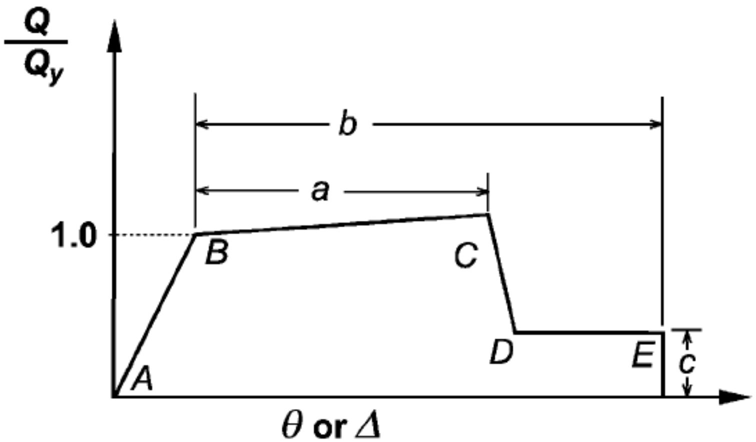
Not Just for Existing Buildings!

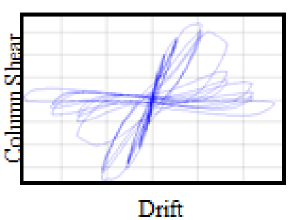


ACI 369 2017

Not Just for Existing Buildings!

Column Modeling





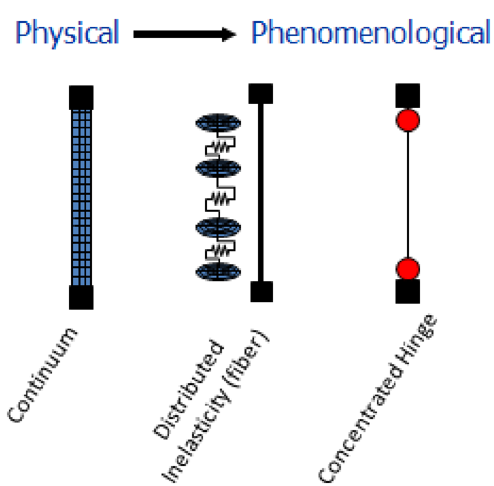
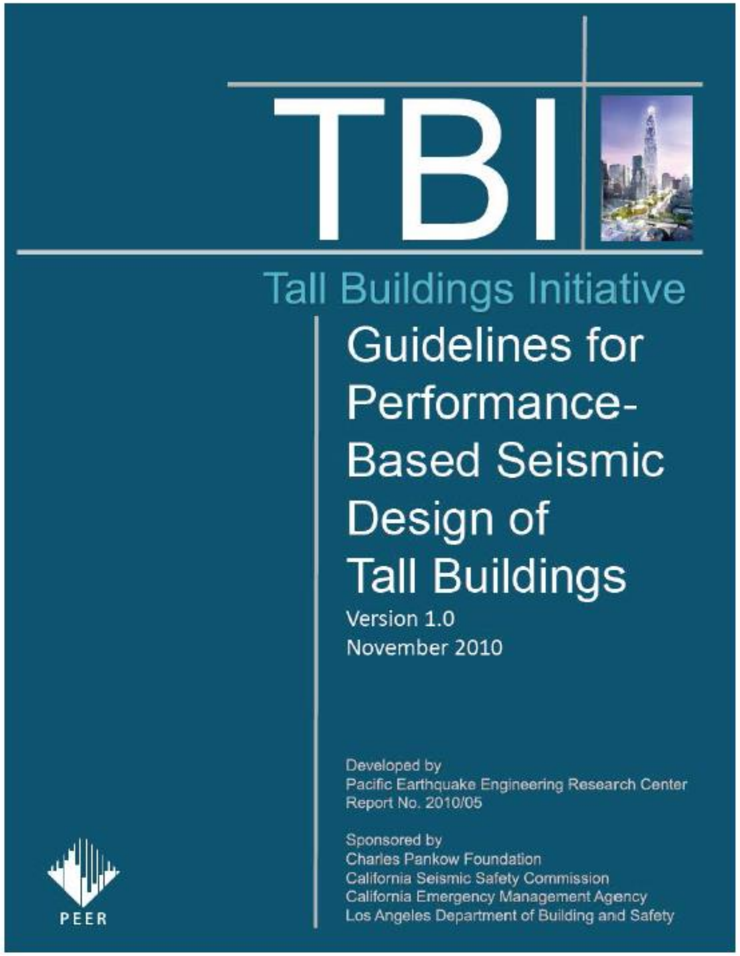


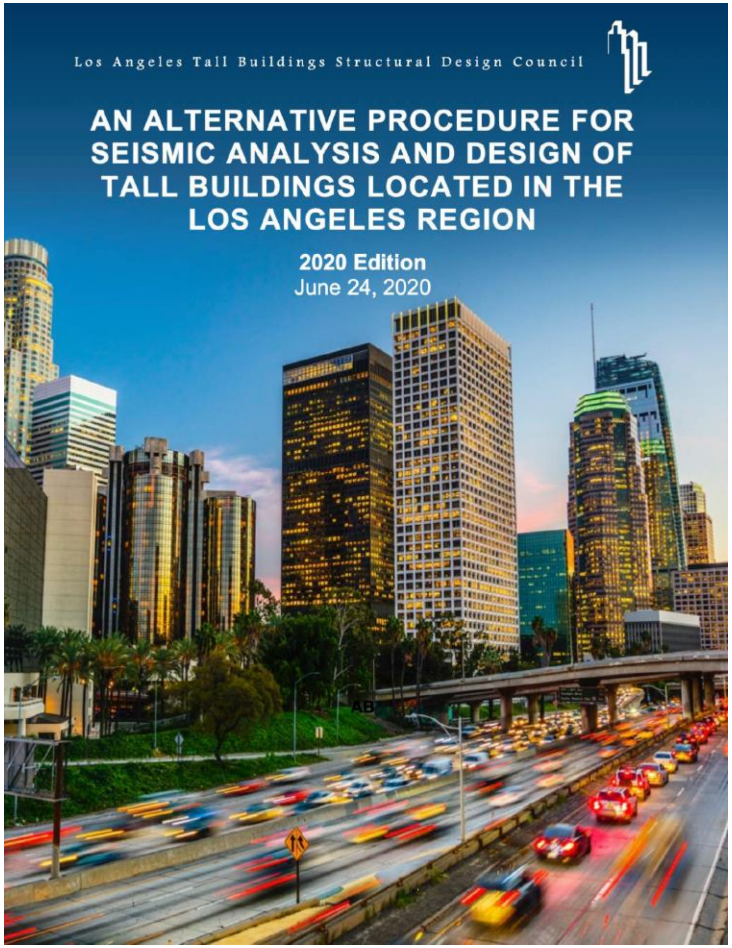
Table 6-8 Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures- Reinforced Concrete Columns

Conditions			Modeling Parameters[3]			Acceptance Criteria[3,4]				
			Plastic Rotations Angle, radians		Residual Strength Ratio	Plastic Rotations Angle, radians — Performance Level				
							Component Type			
							Primary		Secondary	
			a	b	c	IO	LS	CP	LS	CP
Condition i. [1]										
$\frac{P}{A_g f'_c}$ [2]	$\rho = \frac{A_v}{b_w s}$									
≤ 0.1	≥ 0.006		0.035	0.060	0.2	0.005	0.026	0.035	0.045	0.060
≥ 0.6	≥ 0.006		0.010	0.010	0.0	0.003	0.008	0.009	0.009	0.010
≤ 0.1	= 0.002		0.027	0.034	0.2	0.005	0.020	0.027	0.027	0.034
≥ 0.6	= 0.002		0.005	0.005	0.0	0.002	0.003	0.004	0.004	0.005
Condition ii. [1]										
$\frac{P}{A_g f'_c}$ [2]	$\rho = \frac{A_v}{b_w s}$	$\frac{V}{b_w d \sqrt{f'_c}}$								
≤ 0.1	≥ 0.006	≤ 3	0.032	0.060	0.2	0.005	0.024	0.032	0.045	0.060
≤ 0.1	≥ 0.006	≥ 6	0.025	0.060	0.2	0.005	0.019	0.025	0.045	0.060
≥ 0.6	≥ 0.006	≤ 3	0.010	0.010	0.0	0.003	0.008	0.009	0.009	0.010
≥ 0.6	≥ 0.006	≥ 6	0.008	0.008	0.0	0.003	0.006	0.007	0.007	0.008
≤ 0.1	≤ 0.0005	≤ 3	0.012	0.012	0.2	0.005	0.009	0.010	0.010	0.012
≤ 0.1	≤ 0.0005	≥ 6	0.006	0.006	0.2	0.004	0.005	0.005	0.005	0.006
≥ 0.6	≤ 0.0005	≤ 3	0.004	0.004	0.0	0.002	0.003	0.003	0.003	0.004
≥ 0.6	≤ 0.0005	≥ 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Condition iii. [1]										
$\frac{P}{A_g f'_c}$ [2]	$\rho = \frac{A_v}{b_w s}$									
≤ 0.1	≥ 0.006		0.0	0.060	0.0	0.0	0.0	0.0	0.045	0.060
≥ 0.6	≥ 0.006		0.0	0.008	0.0	0.0	0.0	0.0	0.007	0.008
≤ 0.1	≤ 0.0005		0.0	0.006	0.0	0.0	0.0	0.0	0.005	0.006
≥ 0.6	≤ 0.0005		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Condition iv. Columns controlled by inadequate development or splicing along the clear height[1]										
$\frac{P}{A_g f'_c}$ [2]	$\rho = \frac{A_v}{b_w s}$									
≤ 0.1	≥ 0.006		0.0	0.060	0.4	0.0	0.0	0.0	0.045	0.060
≥ 0.6	≥ 0.006		0.0	0.008	0.4	0.0	0.0	0.0	0.007	0.008
≤ 0.1	≤ 0.0005		0.0	0.006	0.2	0.0	0.0	0.0	0.005	0.006
≥ 0.6	≤ 0.0005		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ASCE 41 Modeling and Acceptance Criteria

U.S. Performance-Based Seismic Design Guides



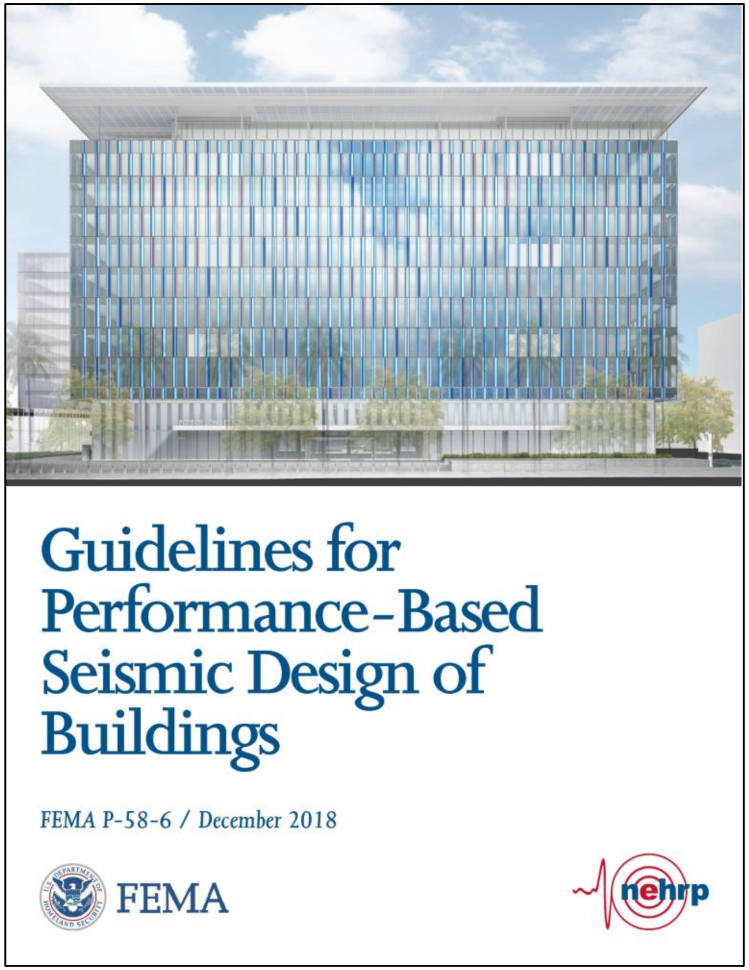


TBI 2017

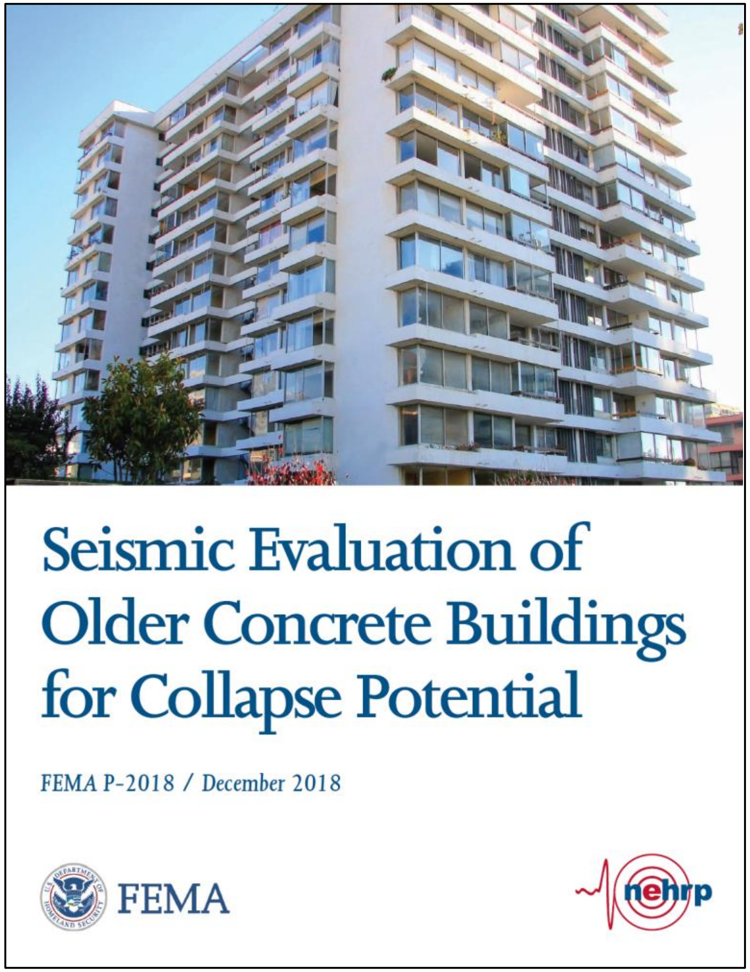
LATBSDC 2020

System assumptions, analysis procedures, performance levels, acceptance criteria

U.S. Performance-Based Seismic Design Guides

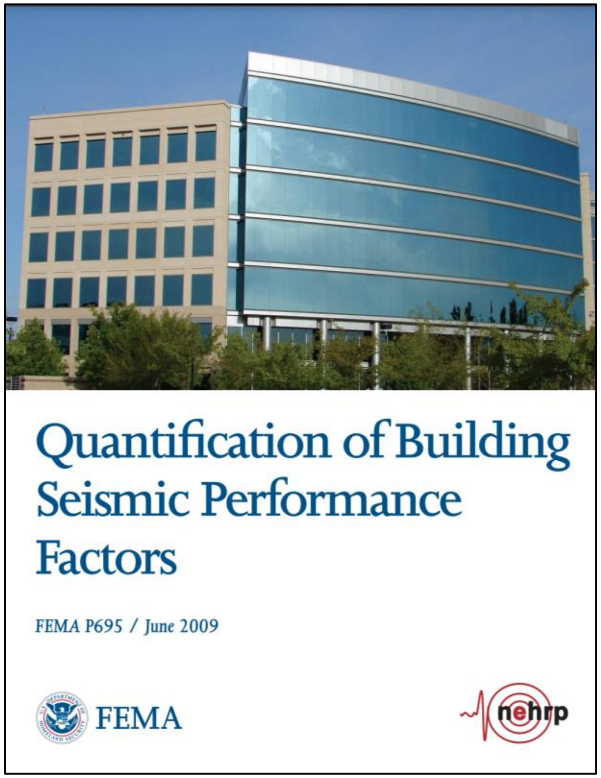


FEMA P-58-6 (ATC 58-2)
2018

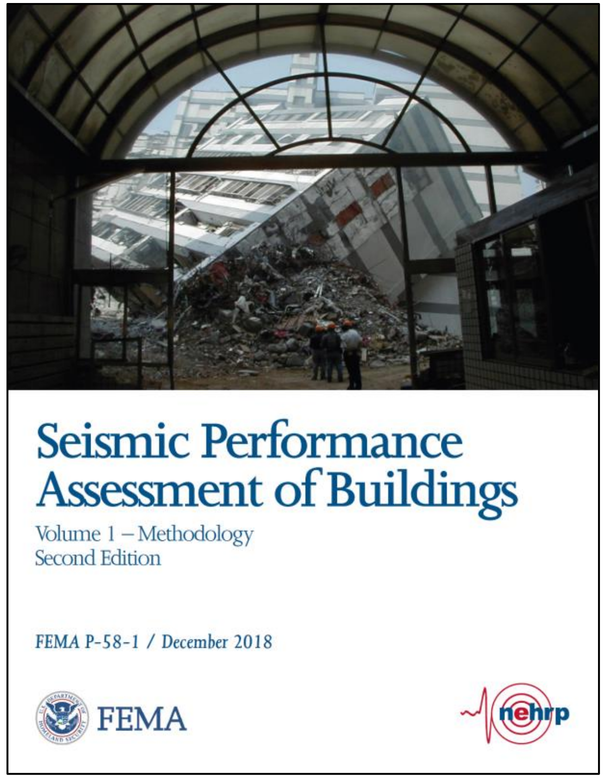


FEMA P-2018 (ATC 78)
2018

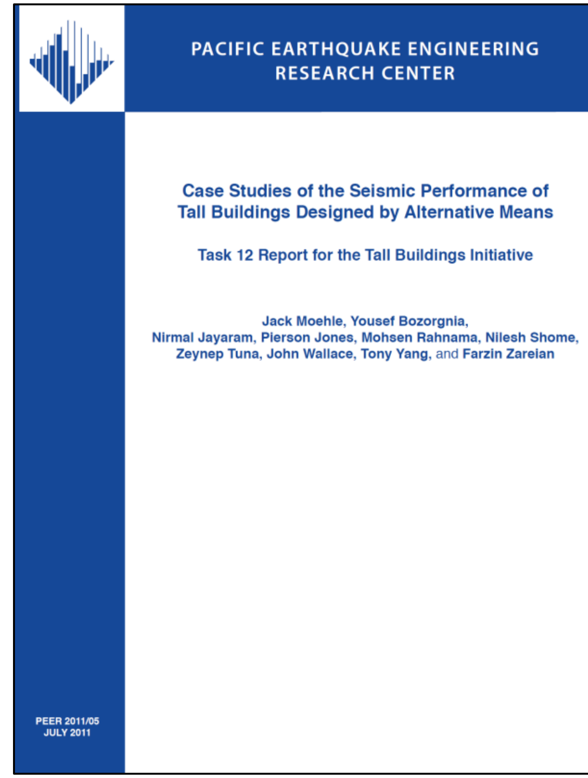
U.S. Performance-Based Seismic Design Guides



FEMA P-695
2009

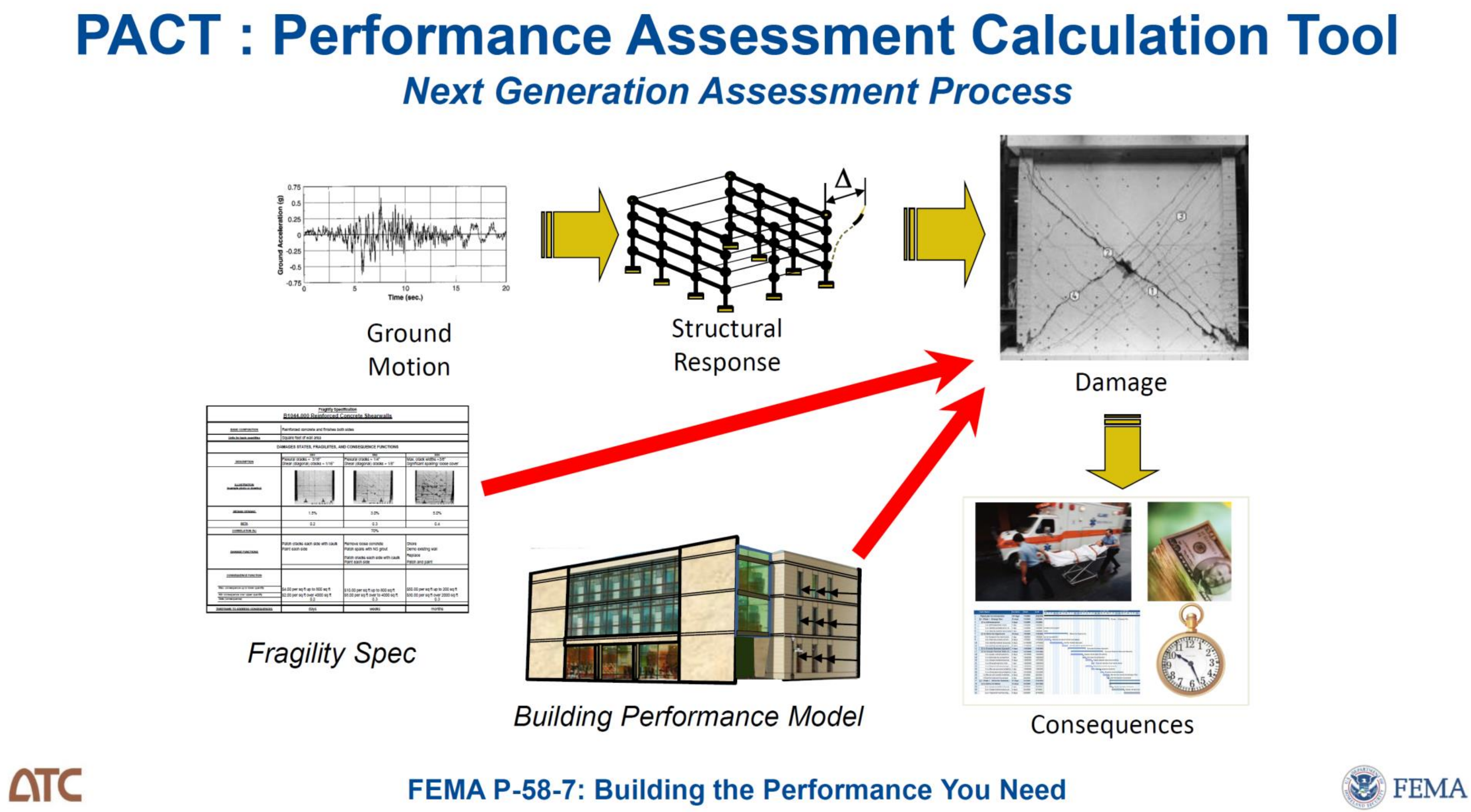


FEMA P-58-1
2012



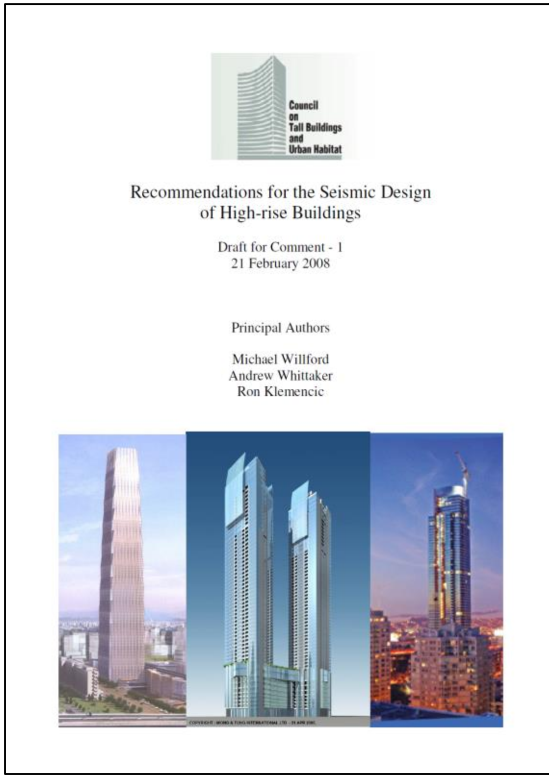
PEER TBI Case Studies
2011

PBEE PACT Tool



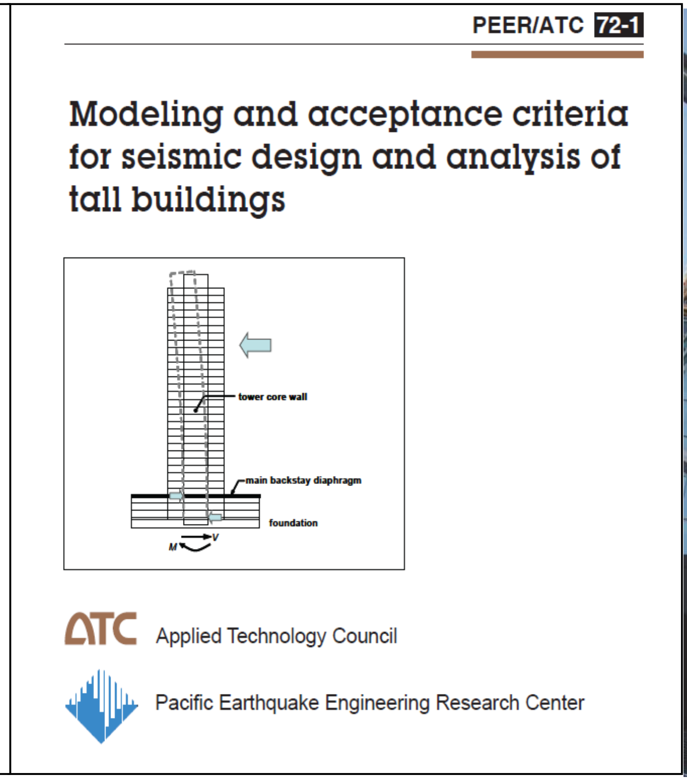
Slide Courtesy: FEMA

U.S. Performance-Based Seismic Design Guides



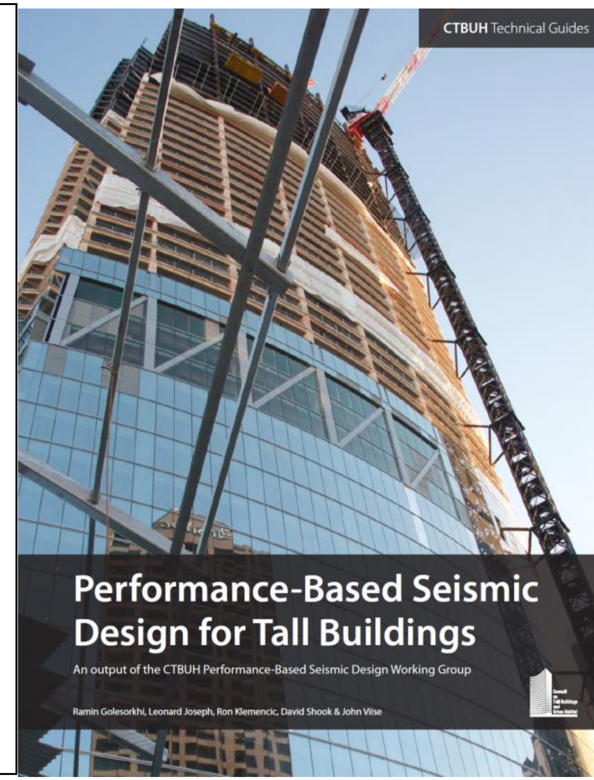
CTBUH

2008



PEER ATC 72

2011



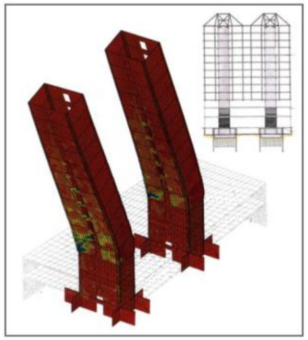
CTBUH

2017

U.S. Performance-Based Seismic Design Guides

24+ NIST Guides

NEHRP Seismic Design Technical Brief No. 4

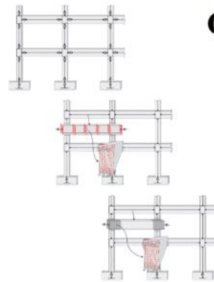


Nonlinear Structural Analysis For Seismic Design

A Guide for Practicing Engineers

Gregory G. Deierlein
Andrei M. Reinhorn
Michael R. Willford

NIST GCR 10-917-5



Guidelines for Nonlinear Structural Analysis for Design of Buildings

Part IIb – Reinforced Concrete Moment Frames

Applied Technology Council

This publication is available free of charge from:
https://doi.org/10.6028/NIST.GCR.17-917-46v3

NIST GCR 17-917-46v1

NEHRP Seismic Design Technical Brief No. 6

Seismic Design of Cast-in-Place Concrete Special Structural Walls and Coupling Beams

A Guide for Practicing Engineers

Jack P. Moehle
Tony Ghodsi
John D. Hooper
David C. Fields
Rajnikanth Gedhada

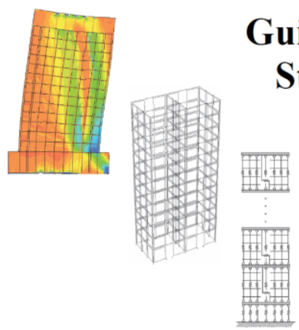
NIST GCR 17-917-45

Assessment of First Generation Performance-Based Seismic Design Methods for New Steel Buildings

Volume 3: Eccentrically Braced Frames

John L. Harris III
Matthew S. Speicher

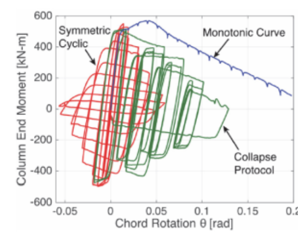
This publication is available free of charge from:
http://dx.doi.org/10.6028/NIST.TN.1863-3



Guidelines for Nonlinear Structural Analysis for Design of Buildings

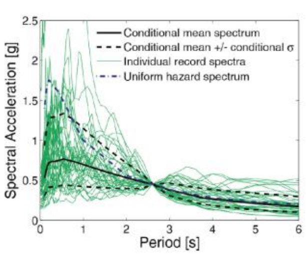
Part I – General

Applied Technology Council



Recommended Modeling Parameters and Acceptance Criteria for Nonlinear Analysis in Support of Seismic Evaluation, Retrofit, and Design

NIST GCR 11-917-15



Selecting and Scaling Earthquake Ground Motions for Performing Response-History Analyses

NEHRP Seismic Design Technical Brief No. 3

Seismic Design of Cast-in-Place Concrete Diaphragms, Chords, and Collectors

A Guide for Practicing Engineers

SECOND EDITION

Jack P. Moehle
John D. Hooper
Thomas R. Meyer

NEHRP Seismic Design Technical Brief No. 1

Seismic Design of Reinforced Concrete Special Moment Frames

A Guide for Practicing Engineers

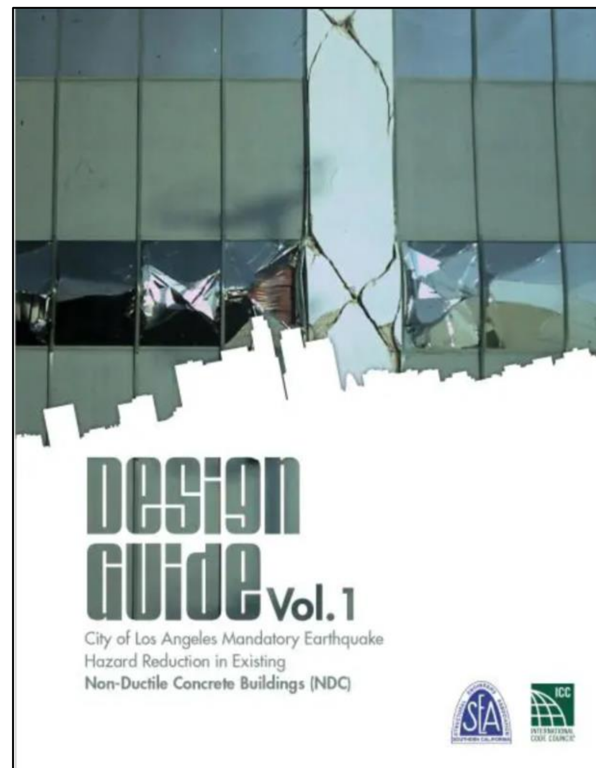
SECOND EDITION

Jack P. Moehle
John D. Hooper

U.S. Performance-Based Seismic Design Guides

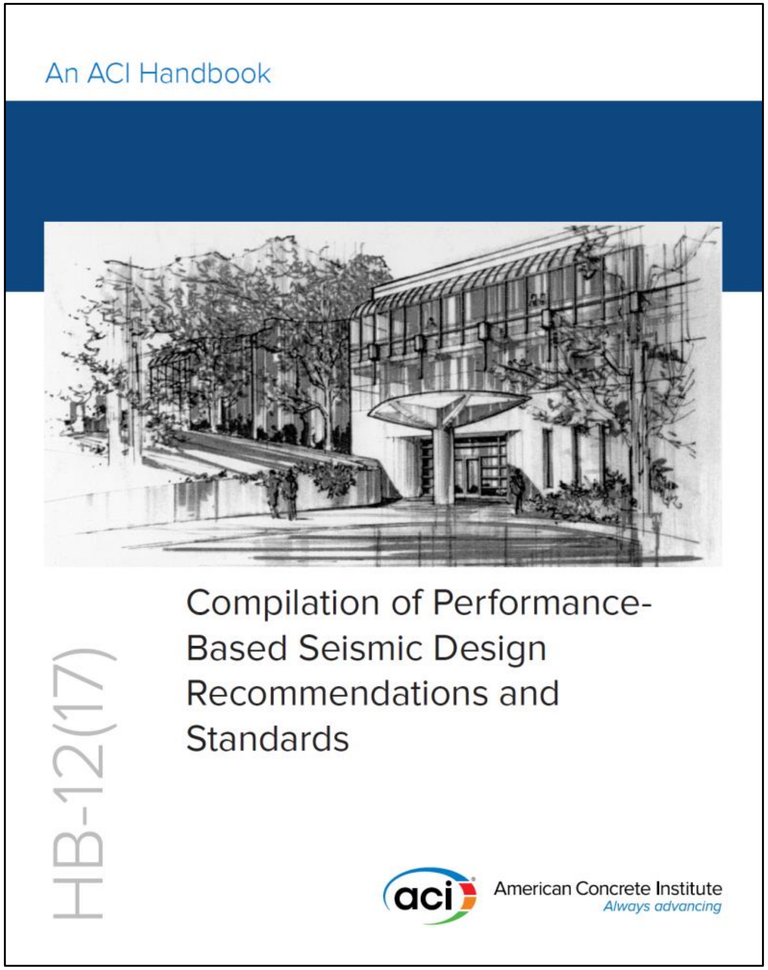
ACI Reports/Guides

SEAOC



U.S. Performance-Based Seismic Design Guides

A MAZE of Guidelines



ACI PBSD Handbook
2017

1. ASCE/SEI 41-13 "Seismic Evaluation and Retrofit of Existing Buildings"
2. SEI/ASCE 31-03 "Seismic Evaluation of Existing Buildings"
3. FEMA P-58-1 "Seismic Performance Assessment of Buildings"
4. FEMA P695 "Quantification of Building Seismic Performance Factors" (Project ATC-63)
5. FEMA 356 "Prestandard and Commentary for the Seismic Rehabilitation of Buildings"
6. PEER/ATC 72-1 "Modeling and Acceptance Criteria for Seismic Design and Analysis of Tall Buildings"
7. Recommendations for the Seismic Design of High-rise Buildings (CTBUH)
8. "An Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region," Los Angeles Tall Building Structural Design Council
9. ASCE 43-05 "Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities"
10. "Seismic Design of Cast-in-Place Concrete Special Structural Walls and Coupling Beams" NIST GCR 11-917-11REV-1
11. "Seismic Design of Reinforced Concrete Mat Foundations" NIST GCR 12-917-22
12. "Seismic Design of Cast-in-Place Concrete Diaphragms, Chords, and Collectors" NIST GCR 10-917-4
13. "Seismic Design of Reinforced Concrete Special Moment Frames" NIST GCR 8-917-1
14. "Case Studies of the Seismic Performance of Tall Buildings Designed by Alternative Means" Task 12 Report for the Tall Buildings Initiative, PEER
15. "Requirements and Guidelines for the Seismic Design of New Tall Buildings using Non-Prescriptive Seismic-Design Procedures," Administrative Bulletin: AB-083, SEAONC
16. "Guidelines for Performance-Based Seismic Design of Tall Buildings," PEER
17. FEMA 274 "NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings"

Summary #1

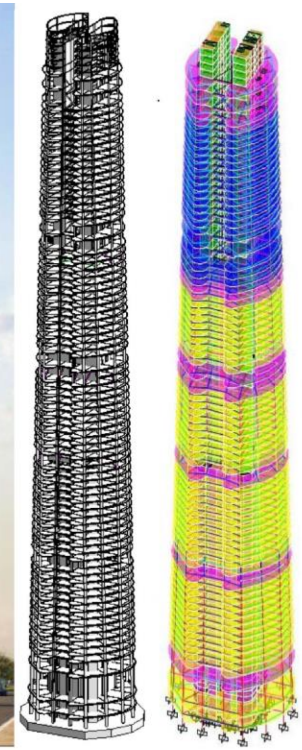
Document Title	Seismic Evaluation and Retrofit of Existing Buildings
Report Number	ASCE/SEI 41-13
Year	2014
Author(s)	American Society of Civil Engineers Committee 41
Organization	Structural Engineering Institute/American Society of Civil Engineering
URL as of March 2016	http://www.asce.org/templates/publications-book-detail.aspx?id=6728
Scope	Seismic Evaluation of Existing Buildings
Abstract	ASCE/SEI 41-13 is a combination of ASCE/SEI 31-03 and ASCE/SEI 41-06 into a single standard. This combined standard has eliminated any inconsistencies that existed between the two superseded standards. The Tier 1 checklists have been modified and reorganized, and the Tier 2 methodology has been expanded. While mostly an effort to combine ASCE/SEI 31-03 and ASCE/SEI 41-06 into a single document, a number of significant technical changes have been included including more emphasis on nonlinear response history analysis, provisions for buckling-restrained braces, expanded liquefaction provisions, rocking foundation analysis procedure, updated URM provisions, and a fully updated chapter on seismic isolation and energy dissipation. An effort has been made to align ASCE/SEI 41-13 with ASCE/SEI 7 with the addition of the Basic Performance Objective Equivalent to New Building Standards (BPON). The revised standard includes performance objectives for equivalence to the design of new buildings. This set of performance objectives is intended to provide a link between ASCE 7 and ASCE 41 when a seismic evaluation or upgrade is required to be equivalent to a new building. The nonstructural performance levels were significantly changed to reflect actual earthquake performance and to better align with the intent of ASCE/SEI 7.
Performance Levels	Immediate Occupancy (IO); Life Safety (LS); and Collapse Prevention (CP); Damage Control; Limited Safety.
Notes	A combination of ASCE/SEI 41-06 and ASCE/SEI 31-03
Comments	
Superseded documents	ASCE/SEI 41-13 replaced ASCE/SEI 41-06 "Seismic Rehabilitation of Existing Buildings (2005)" and ASCE 31-03 "Seismic Evaluation of Existing Buildings (2003)".
Update Frequency	3 years
Status	
Free of Charge?	$220.00 List / $165.00 ASCE Member
Keywords	Seismic evaluation, seismic rehabilitation, backbone curves, analytical component modeling, nonlinear response history analysis, capacity design, hysteretic modeling

U.S. Performance-Based Seismic Design Guides

A MAZE of Guidelines

PBSD Consulting: 30+ Guidelines

The "Iconic Tower" 400m, Tallest in Africa



List of Performance-Based Seismic Design Documents:

State of U.S. Practice 2018

Compiled By:

Dr. Wael Hassan, P.E., S.E.
Associate Professor, Structural Earthquake Engineering
Professional Structural Engineer, State of California

For

Seismic Design of The Iconic Tower, Egypt

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9. Recommendations for the Seismic Design of High-rise Buildings. Council of Tall Buildings and Urban Habitat (CTBUH). 2008.
10. NIST GCR 10-917-5. Nonlinear Structural Analysis for Seismic Design: A Guide for Practicing Engineers. National Institute of Standards and Technology. NEHRP Seismic Design Technical Brief No. 4. 2010.

U.S. Performance-Based Seismic Design Guides

NIST Research

Engineering Practice Paper

EERI EARTHQUAKE SPECTRA

Implementing the performance-based seismic design for new reinforced concrete structures: Comparison among ASCE/SEI 41, TBI, and LATBSDC

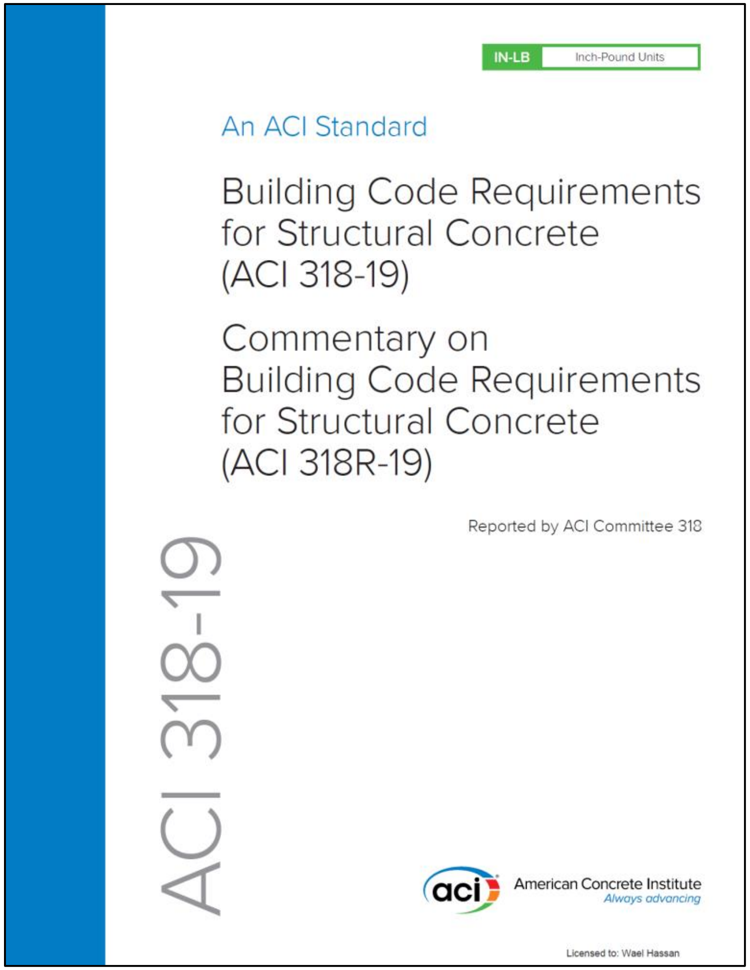
Earthquake Spectra
2021, Vol. 37(3) 2150–2173

DOI: 10.1177/8755293020981968
journals.sagepub.com/home/eqs
SAGE

Siamak Sattar, M.EERI[1], Anne Hulsey, M.EERI[2], Garrett Hagen[3], Farzad Naeim, M.EERI[4], and Steven McCabe, M.EERI[1]

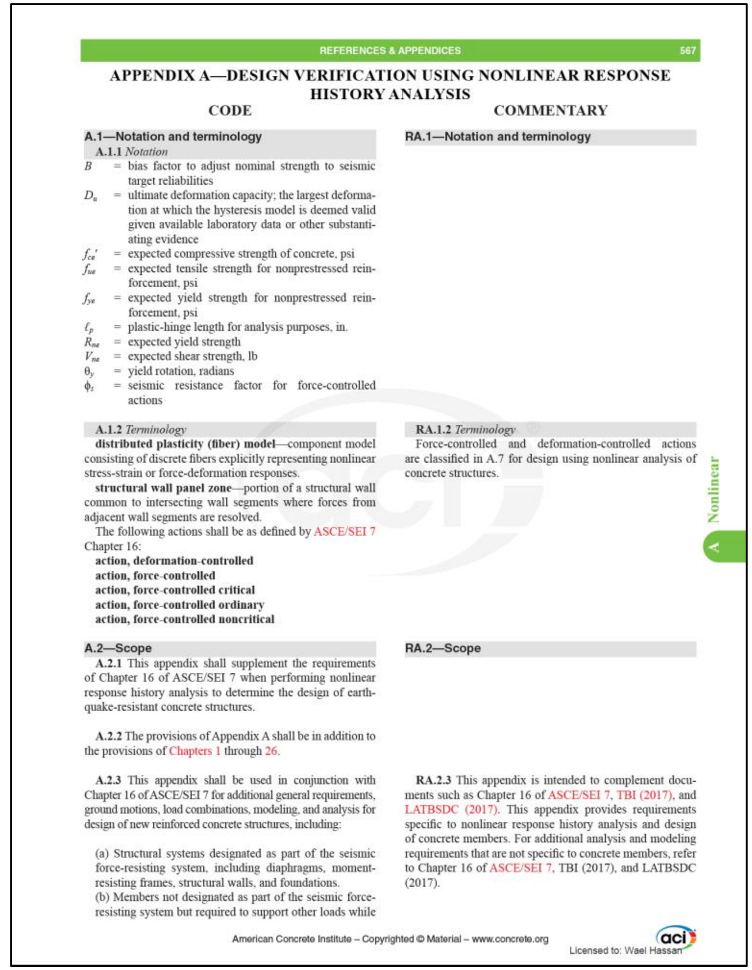
U.S. Performance-Based Seismic Design Guides

ACI Code



ACI 318-19

2019



REFERENCES & APPENDICES 567

APPENDIX A—DESIGN VERIFICATION USING NONLINEAR RESPONSE HISTORY ANALYSIS

CODE

A.1—Notation and terminology

A.1.1 *Notation*

B = bias factor to adjust nominal strength to seismic target reliabilities

D_u = ultimate deformation capacity; the largest deformation at which the hysteresis model is deemed valid given available laboratory data or other substantiating evidence

f_{ce}' = expected compressive strength of concrete, psi

f_{ue} = expected tensile strength for nonprestressed reinforcement, psi

f_{ye} = expected yield strength for nonprestressed reinforcement, psi

ℓ_p = plastic-hinge length for analysis purposes, in.

R_{ne} = expected yield strength

V_{ne} = expected shear strength, lb

θ_y = yield rotation, radians

ϕ_s = seismic resistance factor for force-controlled actions

A.1.2 *Terminology*

distributed plasticity (fiber) model—component model consisting of discrete fibers explicitly representing nonlinear stress-strain or force-deformation responses.

structural wall panel zone—portion of a structural wall common to intersecting wall segments where forces from adjacent wall segments are resolved.

The following actions shall be as defined by ASCE/SEI 7 Chapter 16:

action, deformation-controlled
action, force-controlled
action, force-controlled critical
action, force-controlled ordinary
action, force-controlled noncritical

A.2—Scope

A.2.1 This appendix shall supplement the requirements of Chapter 16 of ASCE/SEI 7 when performing nonlinear response history analysis to determine the design of earthquake-resistant concrete structures.

A.2.2 The provisions of Appendix A shall be in addition to the provisions of Chapters 1 through 26.

A.2.3 This appendix shall be used in conjunction with Chapter 16 of ASCE/SEI 7 for additional general requirements, ground motions, load combinations, modeling, and analysis for design of new reinforced concrete structures, including:

(a) Structural systems designated as part of the seismic force-resisting system, including diaphragms, moment-resisting frames, structural walls, and foundations.

(b) Members not designated as part of the seismic force-resisting system but required to support other loads while

COMMENTARY

RA.1—Notation and terminology

RA.1.2 *Terminology*

Force-controlled and deformation-controlled actions are classified in A.7 for design using nonlinear analysis of concrete structures.

RA.2—Scope

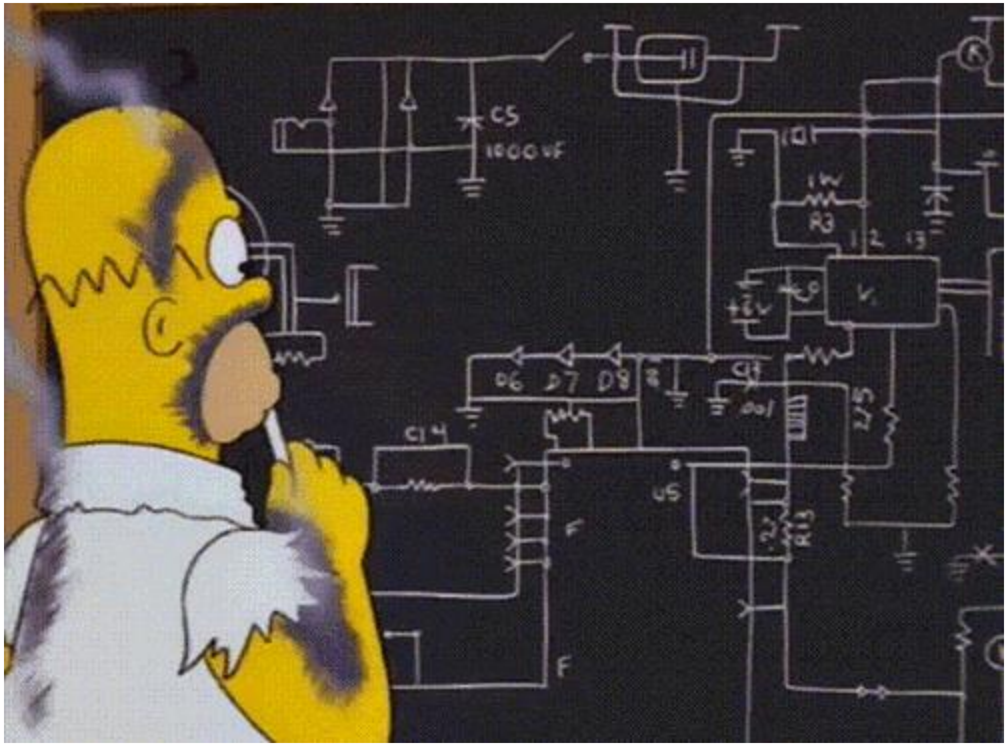
RA.2.3 This appendix is intended to complement documents such as Chapter 16 of ASCE/SEI 7, TBI (2017), and LATBSDC (2017). This appendix provides requirements specific to nonlinear response history analysis and design of concrete members. For additional analysis and modeling requirements that are not specific to concrete members, refer to Chapter 16 of ASCE/SEI 7, TBI (2017), and LATBSDC (2017).

Nonlinear A

Appendix A

Design with Nonlinear Analysis

U.S. PBSD still “Non-prescriptive”?



U.S. Performance-Based Seismic Design Research

Provide tools to stakeholders to conduct accurate and informed PBSD

- **Component Level** (experimental)**:**

  Strength, Deformation, Ductility

- **Component Level** (analytical)**:**

  Constitutive models, Backbones

  Strength models, Fragility, Acceptance Criteria

- **Isolated System Level** (experimental)**:**

  Model verification/calibration

- **Isolated System Level** (analytical)**:**

  System Fragility, Economic Vulnerability, Resilience/Functional Recovery

- **Distributed/Integrated Systems Level** (Regional Simulations)**:**

  Neighborhood, City, Regional Economic Vulnerability, Resilience/Functional Recovery

- Improving Analysis Procedures
- Ground Motions/Hazards
- New Materials
- Novel Retrofits
- High-power computing/simulation
- Big data. ML, AI
- New Technology
- New Construction Methods
- Testing Methods/Standards

U.S. PBSD Guidelines

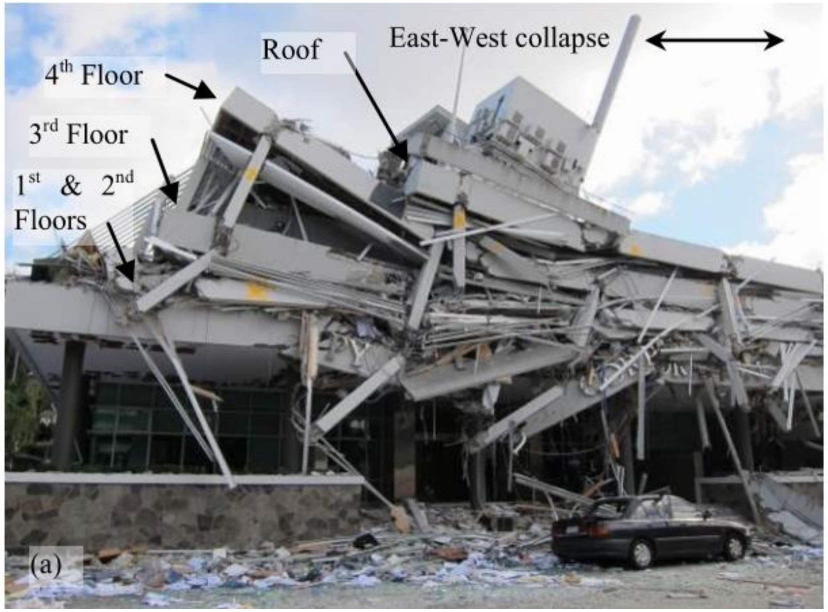
Example Background Research

A Walk-Through

Killer Buildings (Non-ductile Concrete Buildings)

Palu, Indonesia 2018

Christchurch, NZ 2011



PBSD Research Contribution

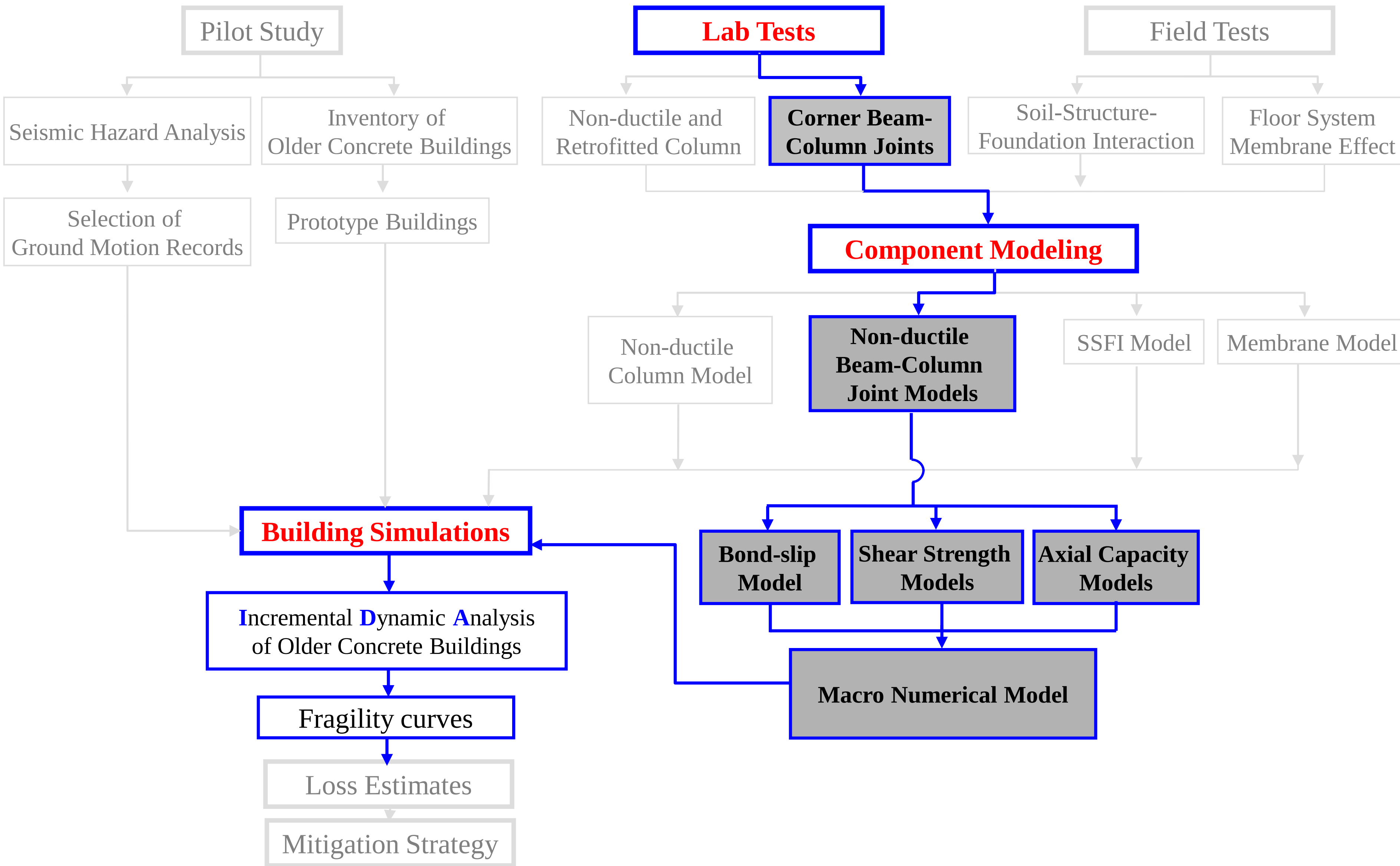
NEES GC Research: (2007- 2014) (NSF: $3.6 Million)

Mitigation of Collapse Risk of Older Concrete Buildings

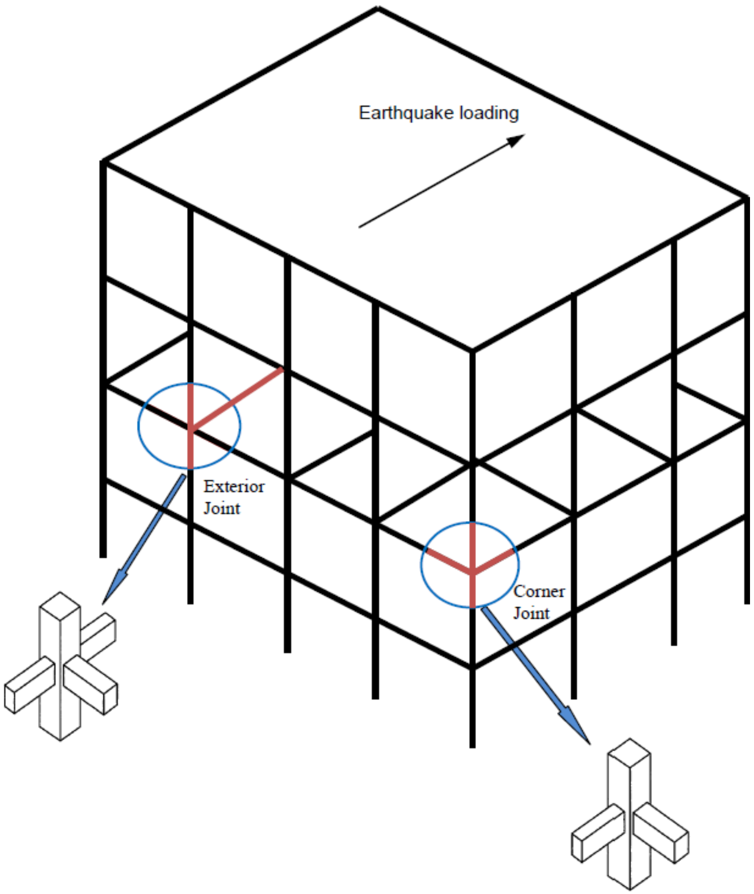
PI: Jack Moehle, UC Berkeley

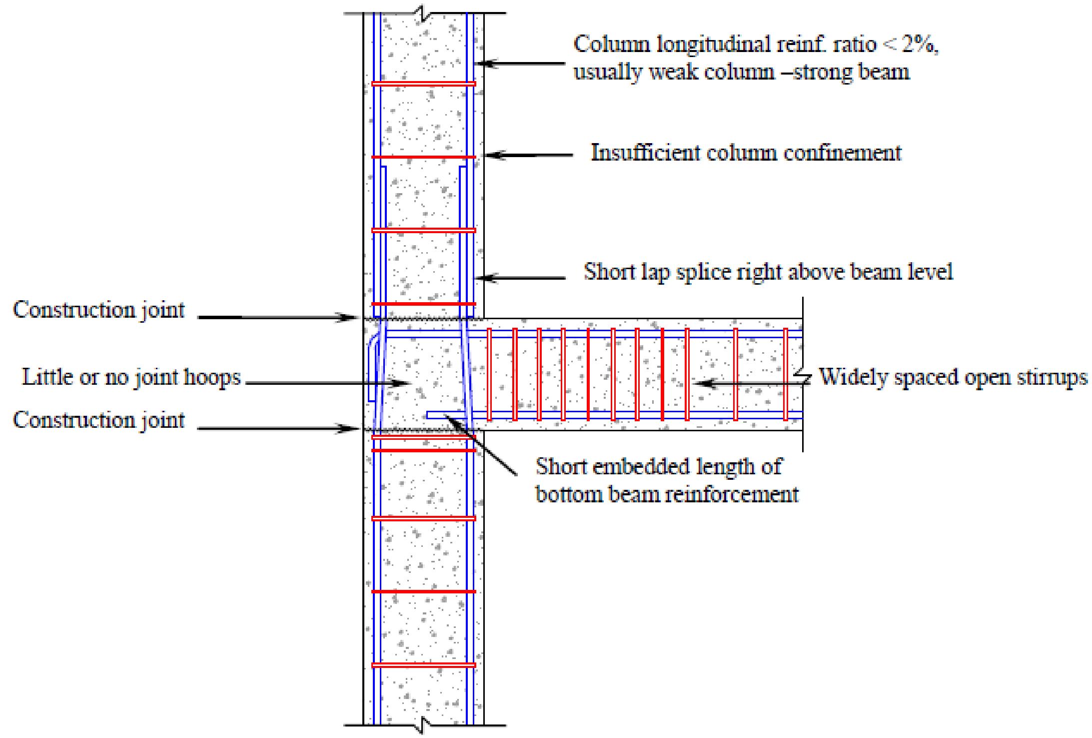
- UC Berkeley (Inventory, BC Joints tests & models, Fragility)
- UCSD (Floor membrane tests and models)
- UCLA (Field tests, SFSI)
- SJSU, U Washington (Inventory, Loss estimation)
- Purdue (Column tests and models)
- University of Kansas (Column tests and models)
- University of Puerto Rico (Joint shear models)

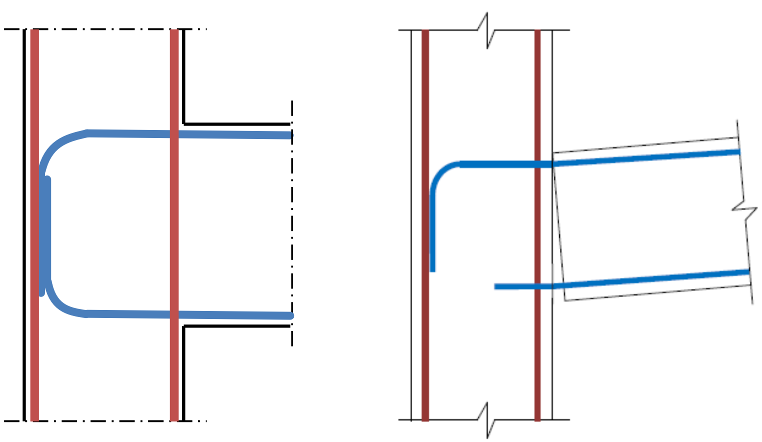
NEES GC Research: Mitigation of Collapse Risk of Older Concrete Buildings: Road Map



Deficient (Existing) (Non-Ductile) (Unreinforced) Joint Details







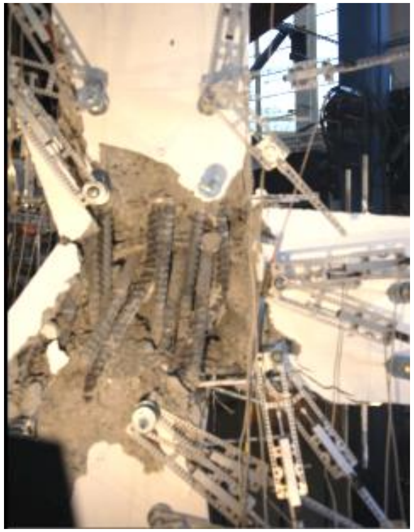
Seismic codes not enforced prior to 1970s

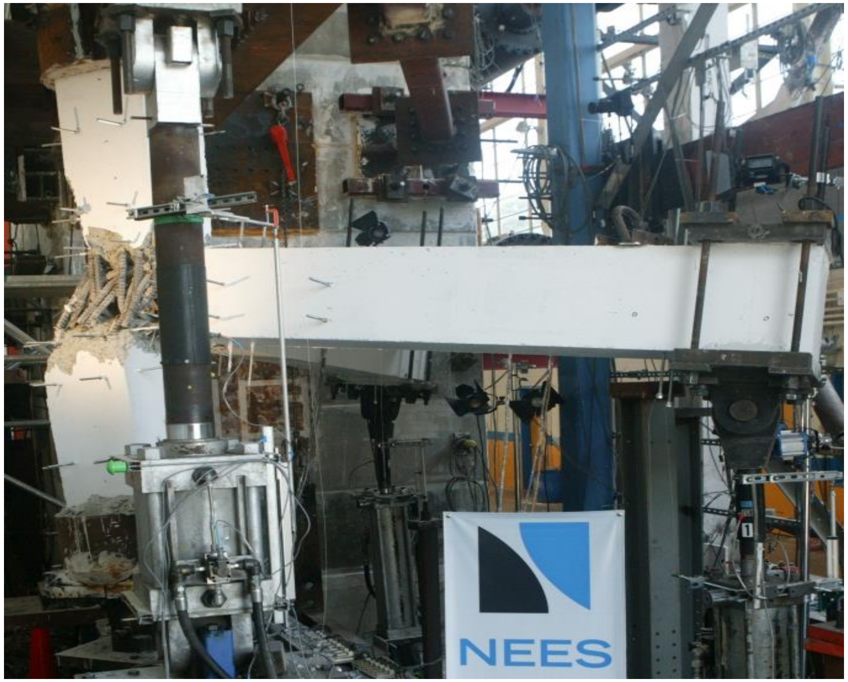
NO Joint Transverse Reinforcement

PBSD Research Contribution

NEES GC Research: (2007- 2014)

Seismic Vulnerability of Non-ductile Beam-Column Joints

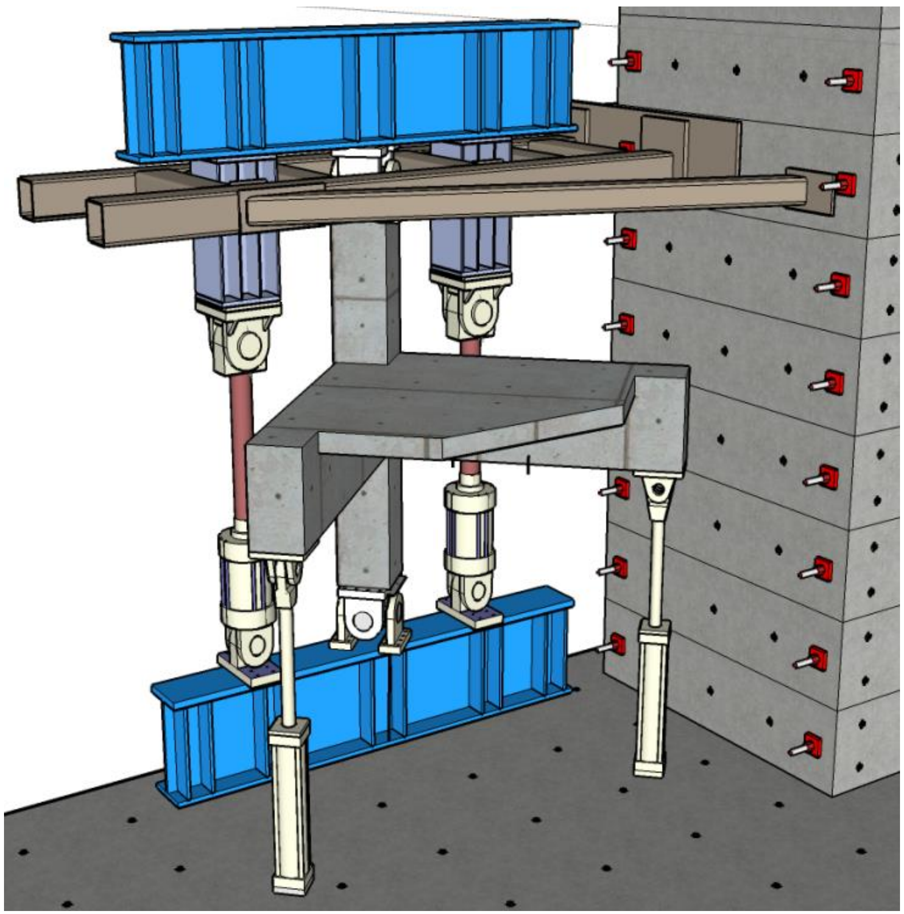




Research Contribution

Experimental Program

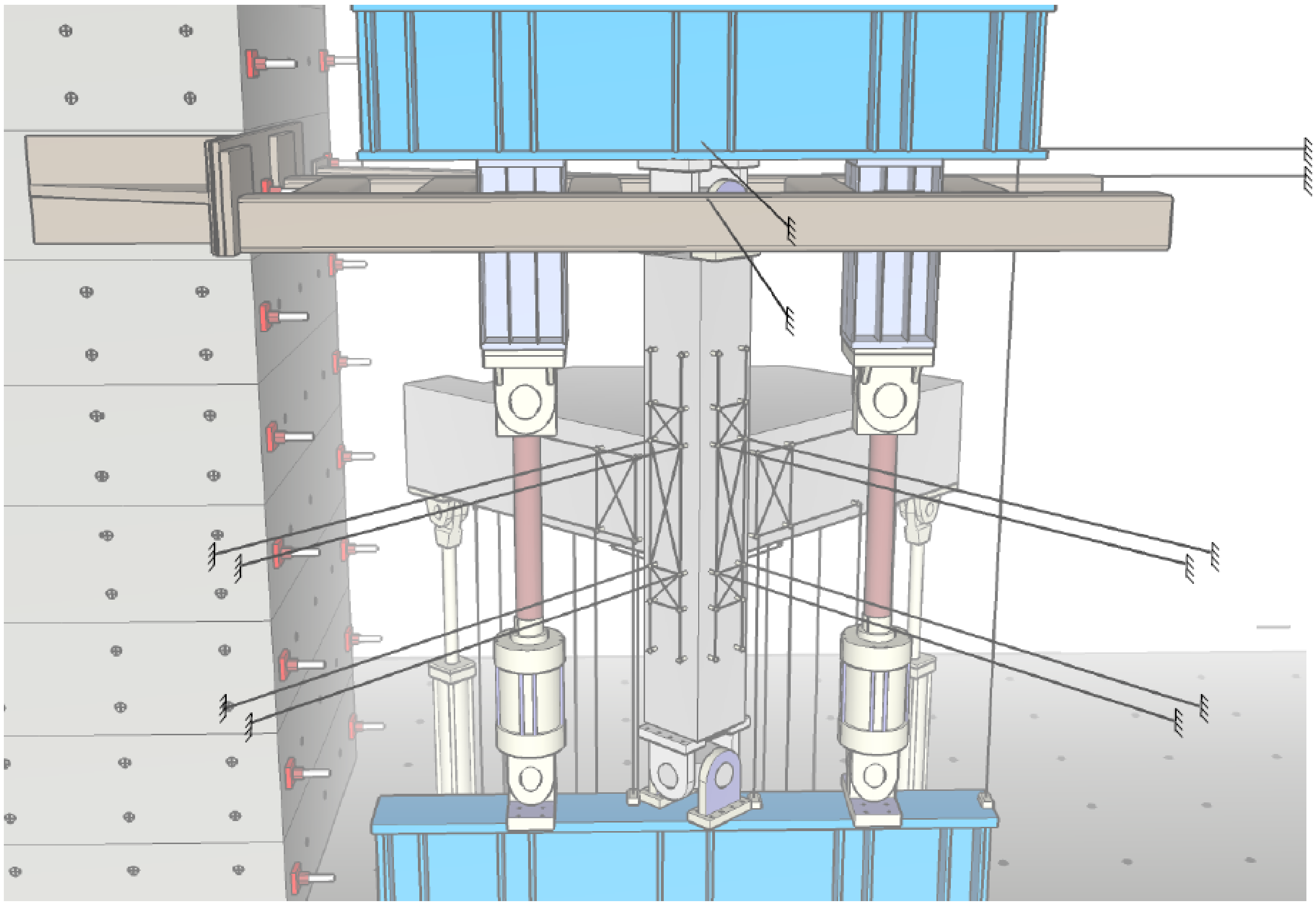
Test Setup



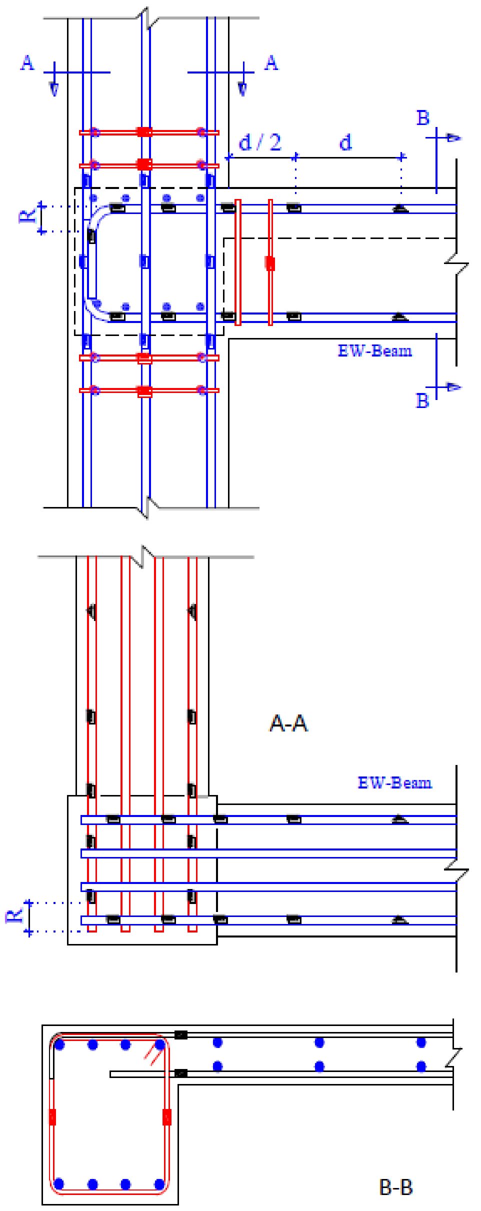
Experimental Program

Instrumentations

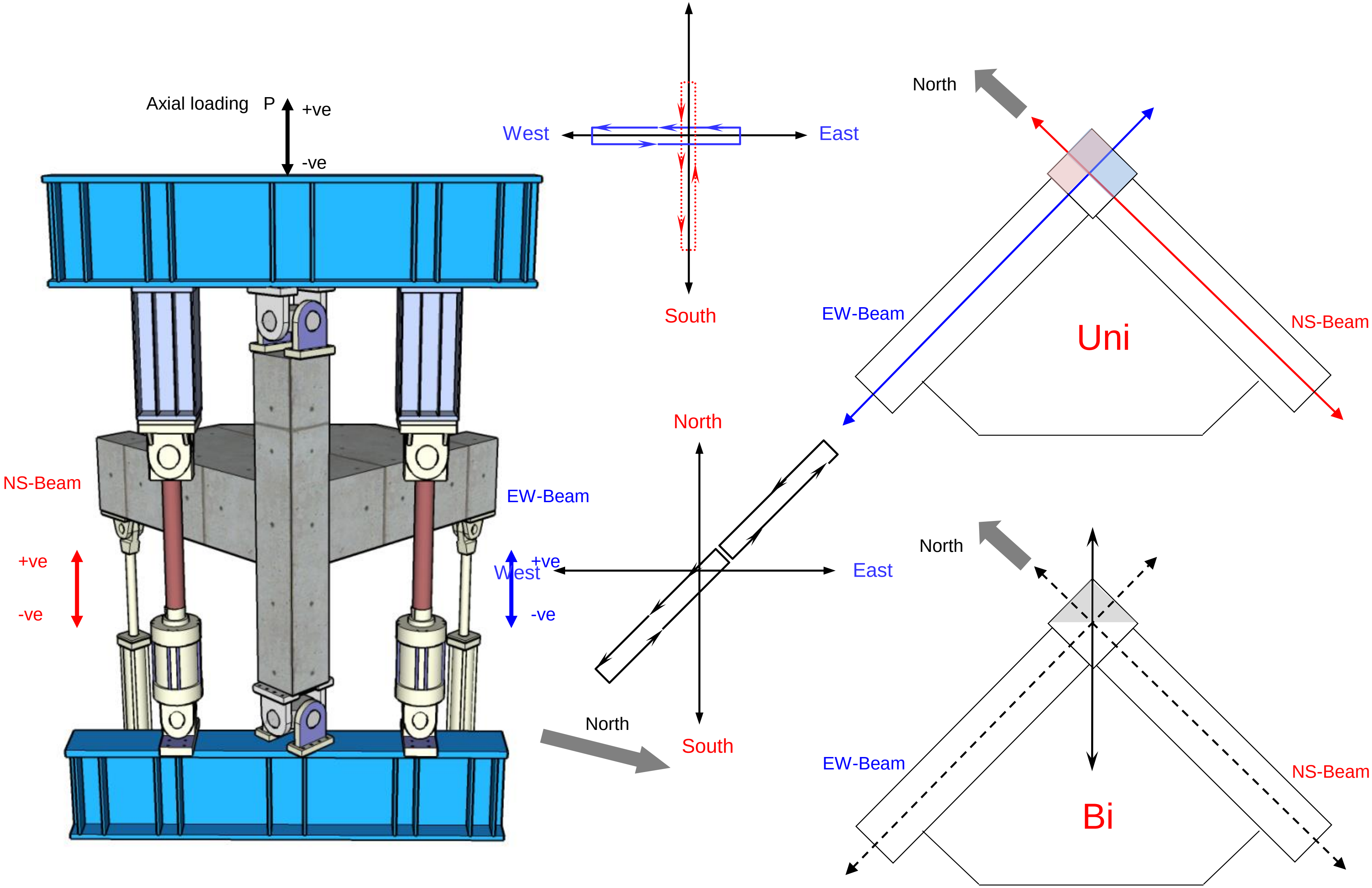
External Deformations



Steel Strains



Load Protocol



Proposed Analytical Strut-and-Tie Model (J-Failure)

- Strut Capacity D

$$D = f_{cu} A_{str} \qquad f_{cu} = 0.85\beta_s f_c^{'} \qquad \beta_s = 0.60$$

$$A_{str} = a_s b_j \qquad b_j : ACI-352$$

- Strut Dimensions

$$a_s = \sqrt{a_b^2 + a_c^2}$$

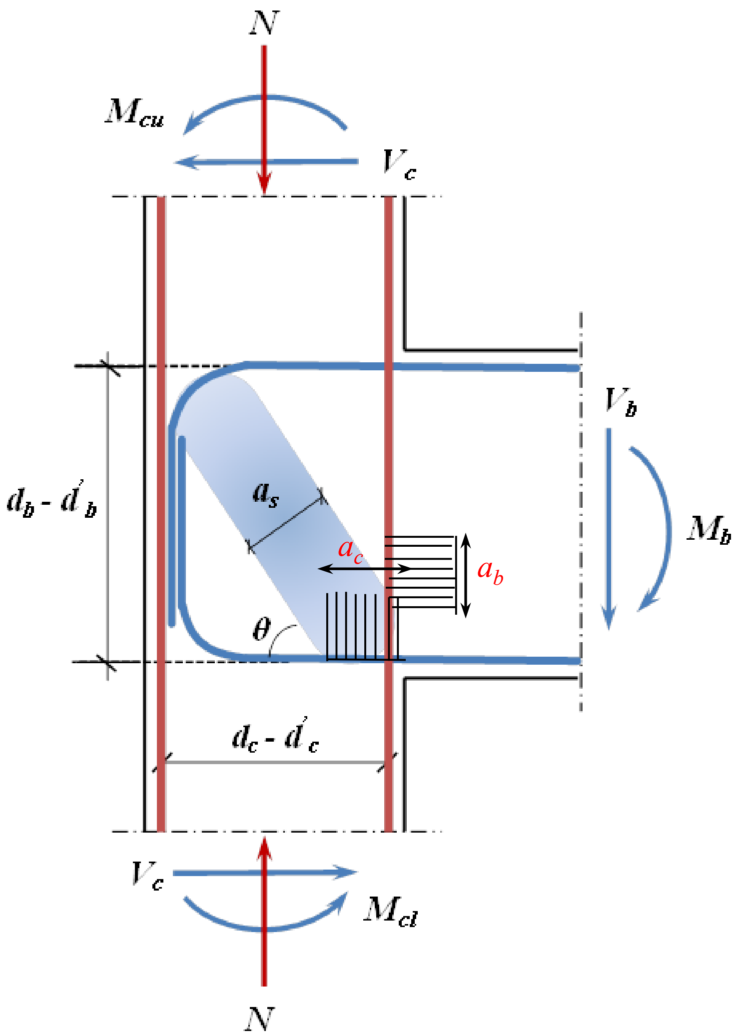
$$a_b = k d_b$$

$$k = [(\rho + \rho')^2 n^2 + 2(\rho + \rho' \frac{d_b^{'}}{d_b})n]^{1/2} - (\rho + \rho')n$$

$$a_c = (0.25 + 0.85 \frac{N}{f_c^{'} A_g}) h_c \qquad \leq 0.4 h_c$$

- Joint Capacity γ_j

$$V_j = D\cos\theta \qquad \theta = \tan^{-1}(\frac{d_b - d_b^{'}}{d_c - d_c^{'}}) \qquad \gamma_j = \frac{V_j}{h_c b_j \sqrt{f'_c}}$$



Proposed Empirical Shear Strength Model (J-Failure)

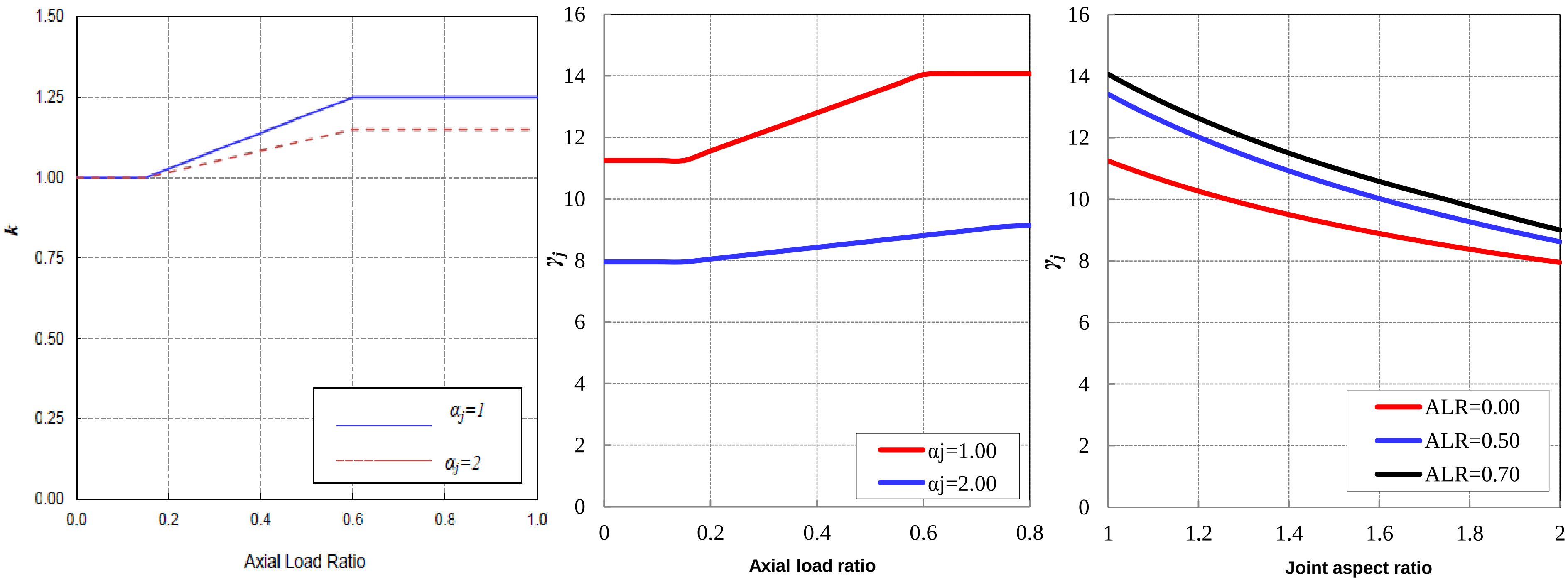
$$V_j = 11.25\alpha_j^{-0.50}\kappa b_j h_c \sqrt{f_c'}$$

Joint aspect ratio $\alpha_j = \dfrac{h_b}{h_c}$

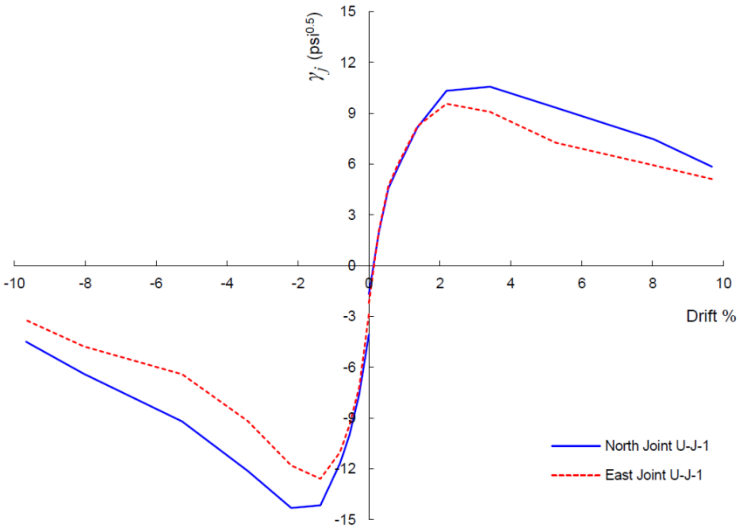
Axial load Enhancement Factor

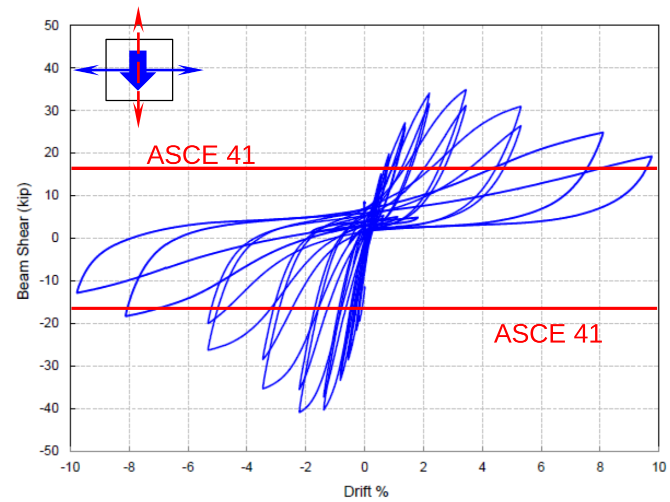
$$\kappa = 1 + (0.86 - 0.31\alpha_j)\left[\frac{P}{f_c' A_g} - 0.15\right] \quad 1 \le \kappa \le 1.35 - 0.10\alpha_j$$

Model is now in:
ACI 369
FEMA P-2018
NIST Design Guides
SEAOC Guidelines



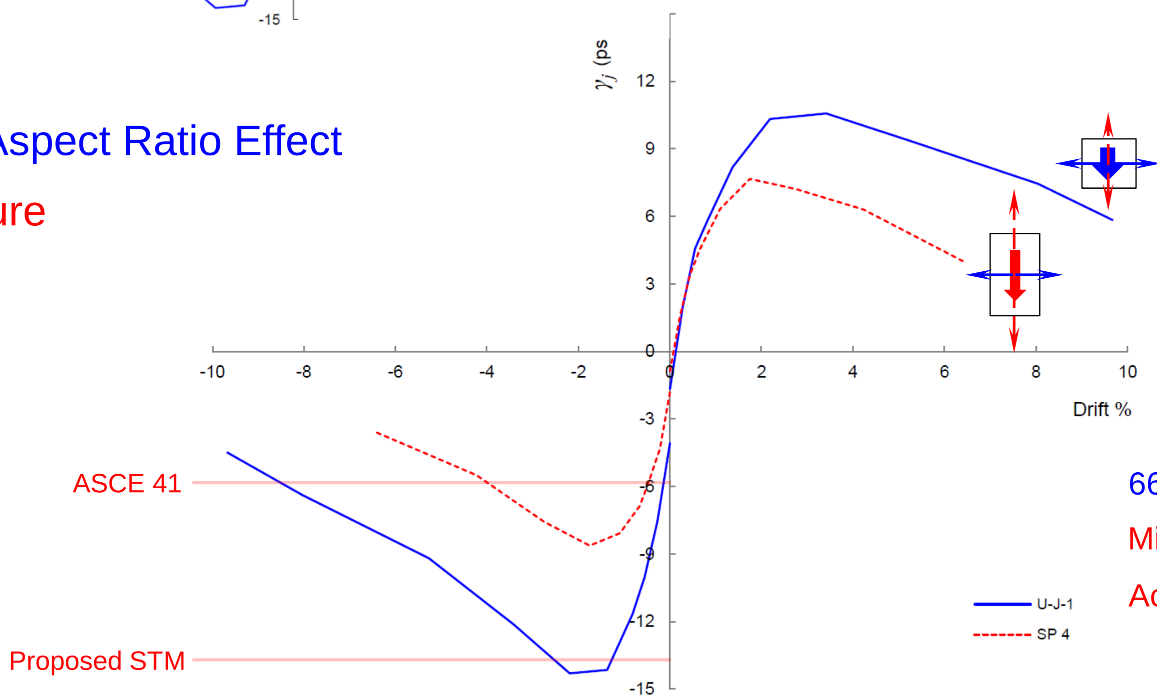
Sample Experimental Results





Joint Aspect Ratio Effect

J-Failure



66% shear strength enhancement

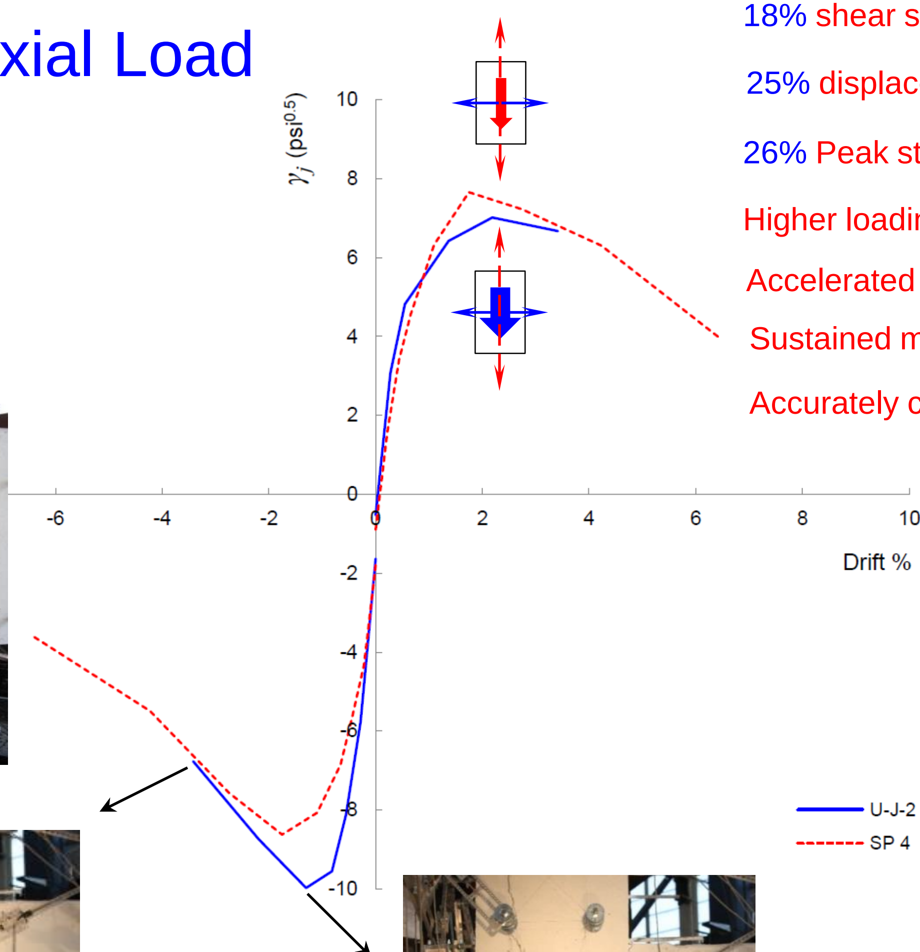
Minimal effect on displacement ductility

Accurately captured by STM

Sample Experimental Results

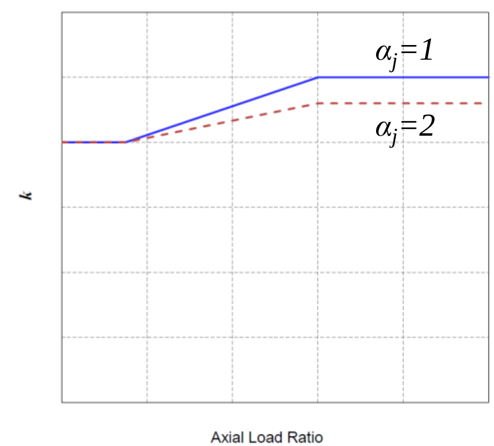
Effect of Axial Load

J-Failure



- 18% shear strength enhancement
- 25% displacement ductility reduction
- 26% Peak strength drift capacity reduction
- Higher loading stiffness
- Accelerated post-peak stiffness & strength degradation
- Sustained more than 3% drift before axial failure
- Accurately captured by STM

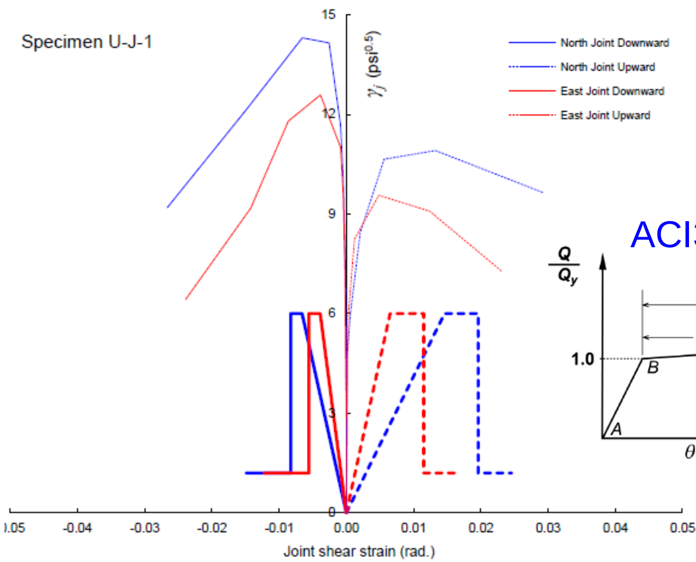
Axial Load Factor *k*



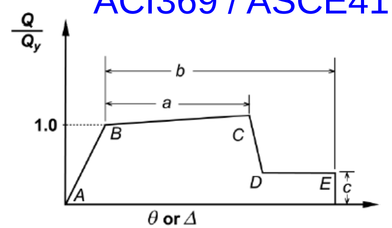
Joint Nonlinear Macro Model for FE Numerical Simulation

Model is now in:
FEMA P-2018
NIST, SEAOC
Soon in ASCE 41

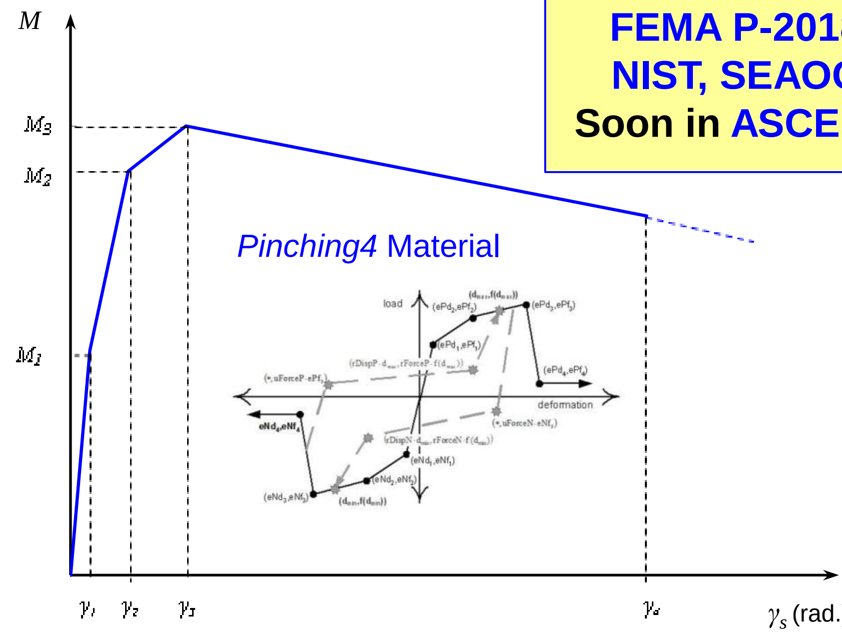
Experimental Backbone



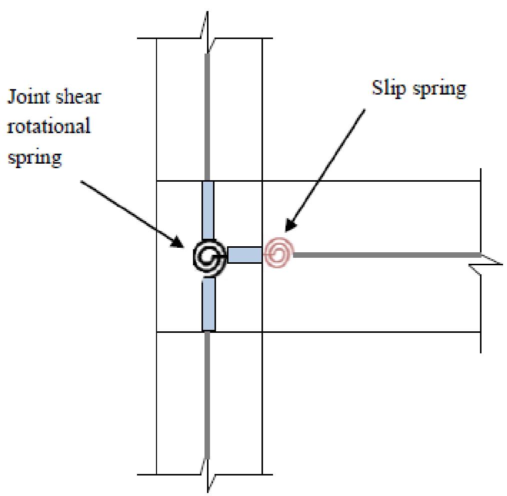
ACI369 / ASCE41

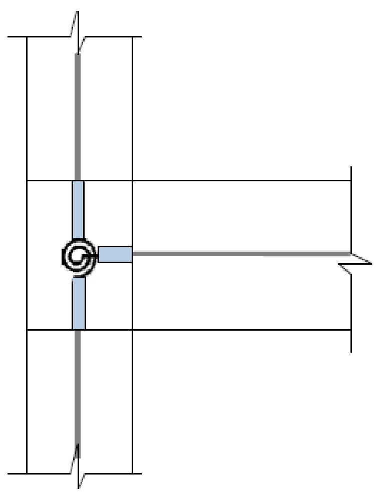


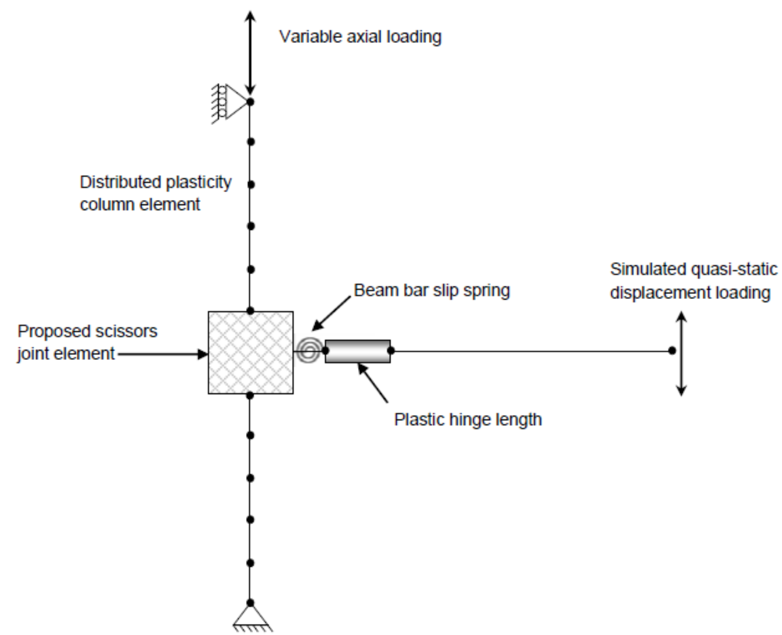
Proposed Backbone



Scissors Model







Joint Nonlinear Macro Model for FE Numerical Simulation

Proposed Backbone Model Parameters

1. Cracking

$$\begin{cases} \dfrac{\tau_{j-1}}{\sqrt{f_c'}} = 3.5\sqrt{1+0.002\dfrac{P}{A_j}} \qquad \le 0.6\dfrac{\tau_{j-3}}{\sqrt{f_c'}} \\ G_{01} = 0.5G_c \end{cases}$$

2. Pre-Peak

$$\begin{cases} G_{02} = 0.1G_c \\ \gamma_{s-2} = 0.002 \\ \tau_{j-2} = \gamma_{s-2}G_{02} \qquad \ge 0.9\tau_{j-3} \end{cases}$$

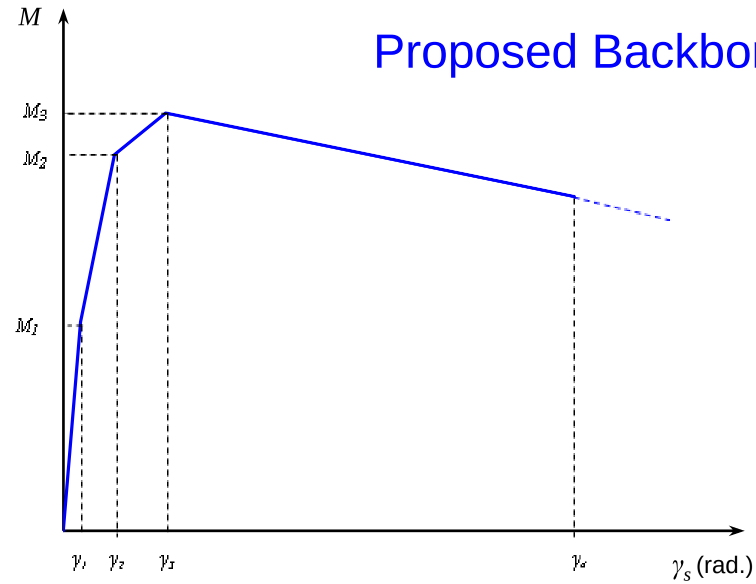
3. Peak

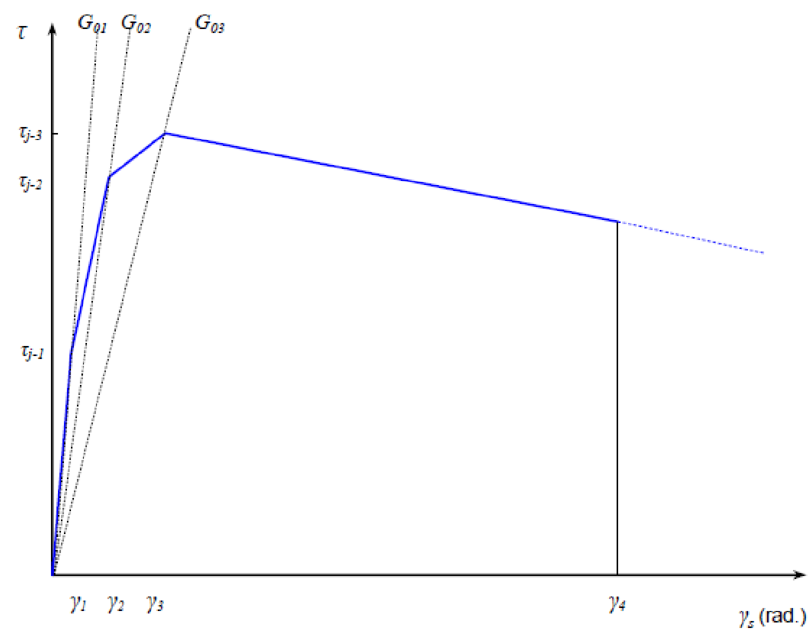
$$\begin{cases} \tau_{j-3} = \gamma_{STM}\sqrt{f_c'} \\ G_{03} = \left(0.14 - \dfrac{3}{80}\alpha_j\right)G_c \qquad \text{For} \qquad \dfrac{P}{f_c' A_j} \ge 0.3 \\ G_{03} = \left(0.175 - \dfrac{3}{40}\alpha_j\right)G_c \qquad \text{For} \qquad \dfrac{P}{f_c' A_j} < 0.3 \end{cases}$$

4. Post-Peak (Axial Failure)

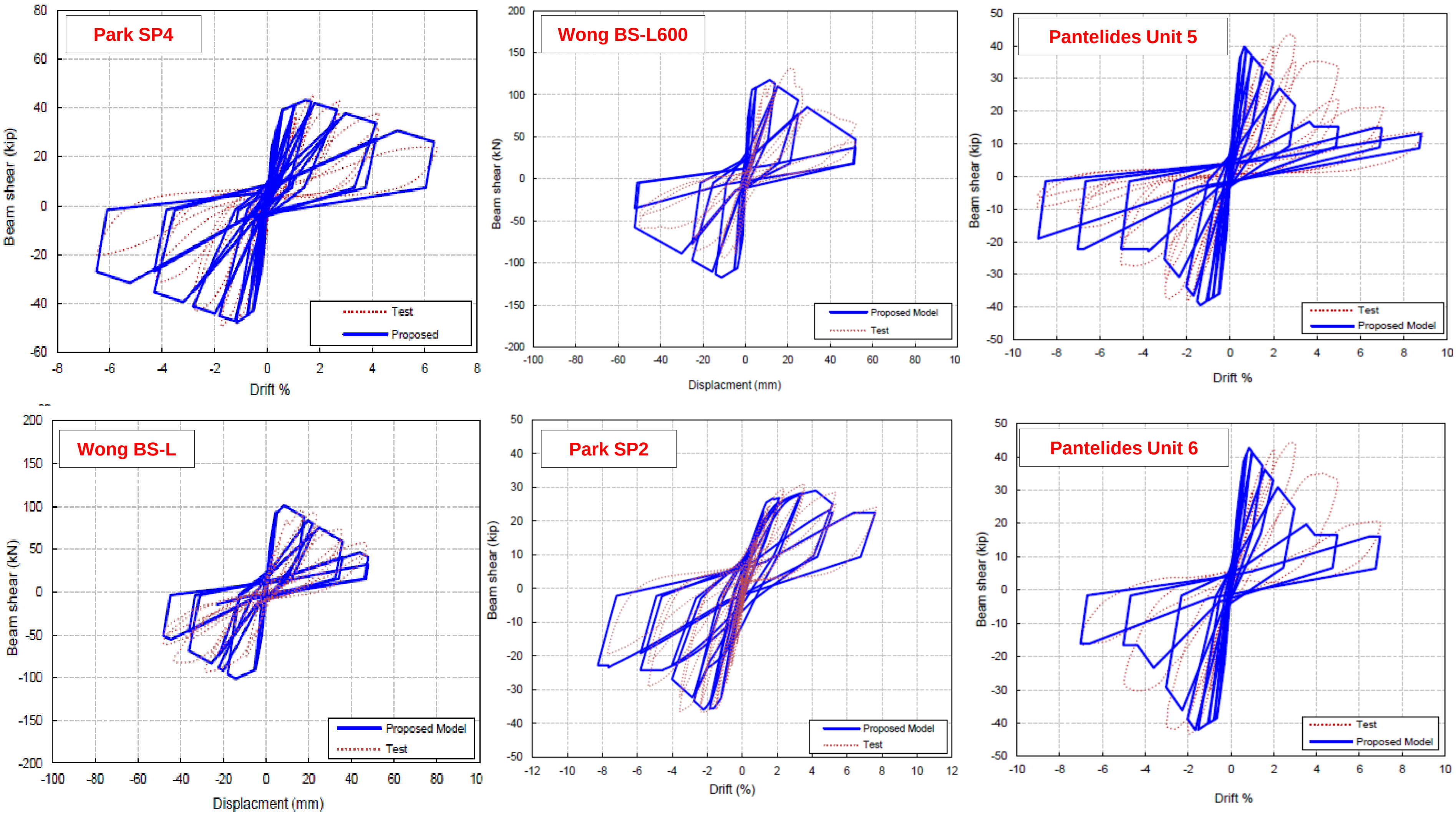
$$\begin{cases} \tau_{j-4} = 0.7\tau_{j-3} \\ \gamma_{s-4} = \gamma_{s-3} + 0.02 \qquad \text{For} \qquad \dfrac{P}{f_c' A_j} > 0.3 \\ \gamma_{s-4} = \gamma_{s-3} + 0.025 \qquad \text{For} \qquad \dfrac{P}{f_c' A_j} \le 0.3 \end{cases}$$

Proposed Backbone

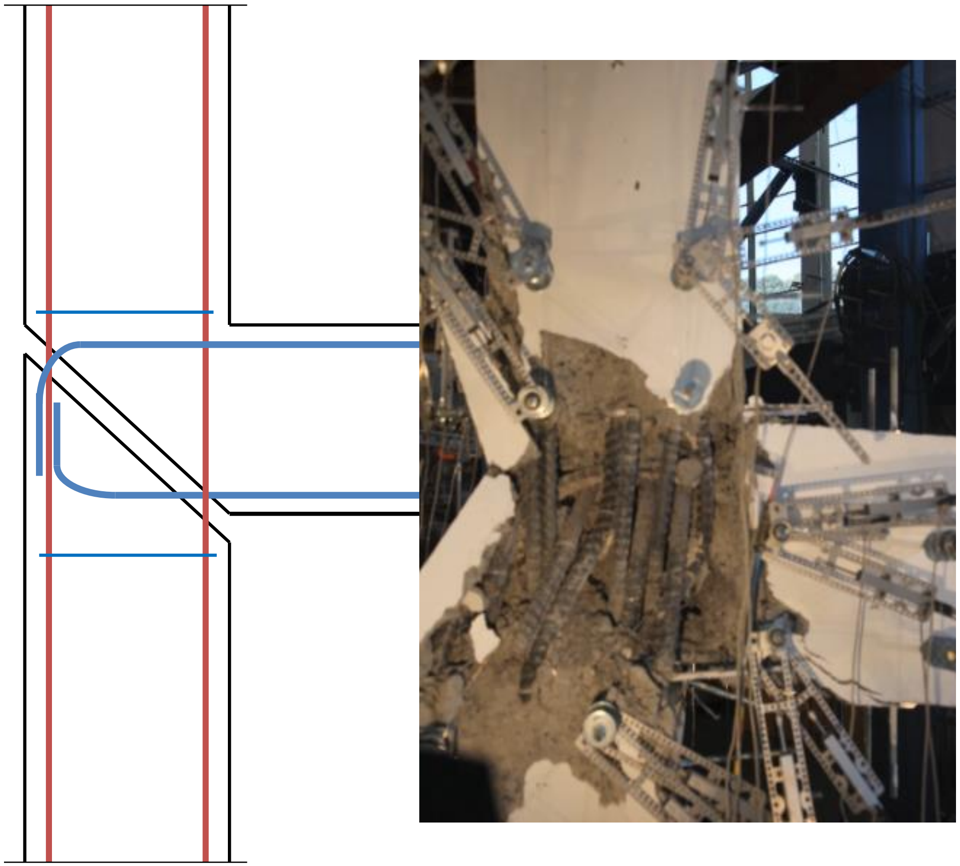


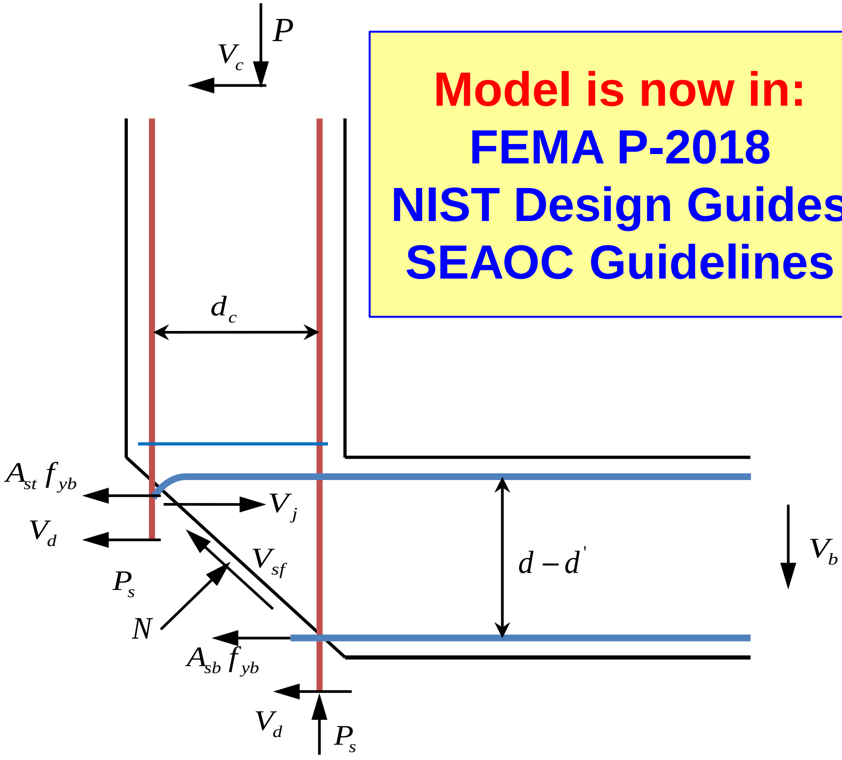


Proposed Nonlinear Macro Model Test Validation (OpenSees)



Proposed Axial Capacity Models for Beam-Column Joints





Model is now in:
FEMA P-2018
NIST Design Guides
SEAOC Guidelines

Analytical Shear Friction Model

$$\left(\frac{\Delta}{L}\right)_{axial} = 0.03\left\{\frac{(P+V_{b,a})\tan\theta + (V_{j,a} - A_{sb} f_{yb})}{(P+V_{b,a}) - (V_{j,a} - A_{sb} f_{yb})\tan\theta}\right\}^{-0.25}$$

Empirical Shear Friction Model

$$\left(\frac{\Delta}{L}\right)_{Axial} = 0.057\left(\frac{P.\tan\theta}{A_{sb} f_{yb}}\right)^{-0.50}$$

NEES GC Research Impact

L.A. Passed New Law October 2015 Enforcing Seismic Retrofit

1500 NDC Buildings

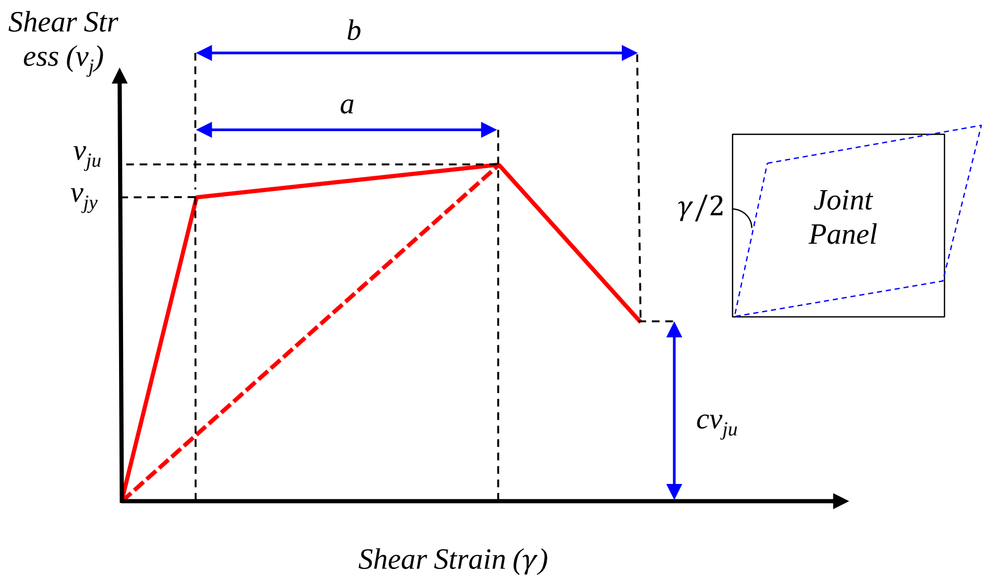
Los Angeles Times

Los Angeles will have the nation's toughest earthquake safety rules

PBSD Research at UAA

Probabilistic Nonlinear Cyclic Models for BCJ

(RA Elmorsy)

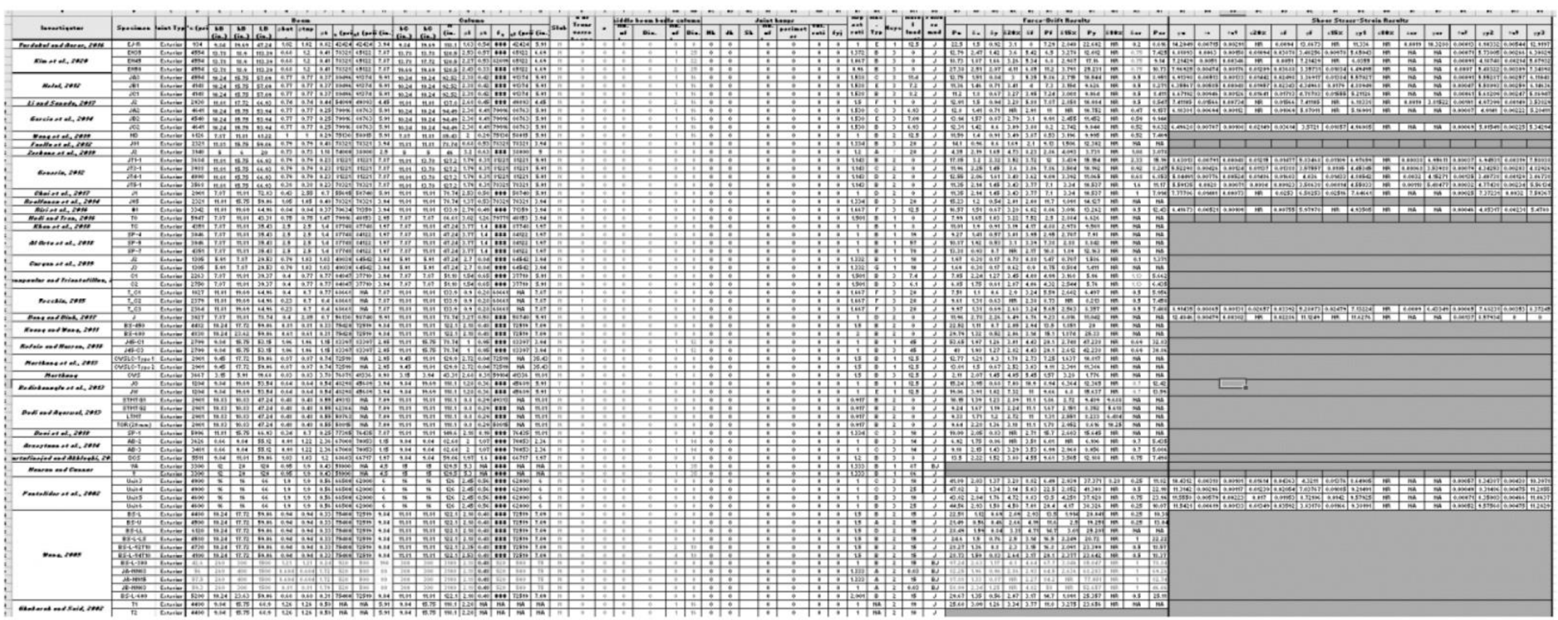


ASC 41/ACI 369

Proposal Oct 2021

Database (800 joint tests)

Period (1967-2020)



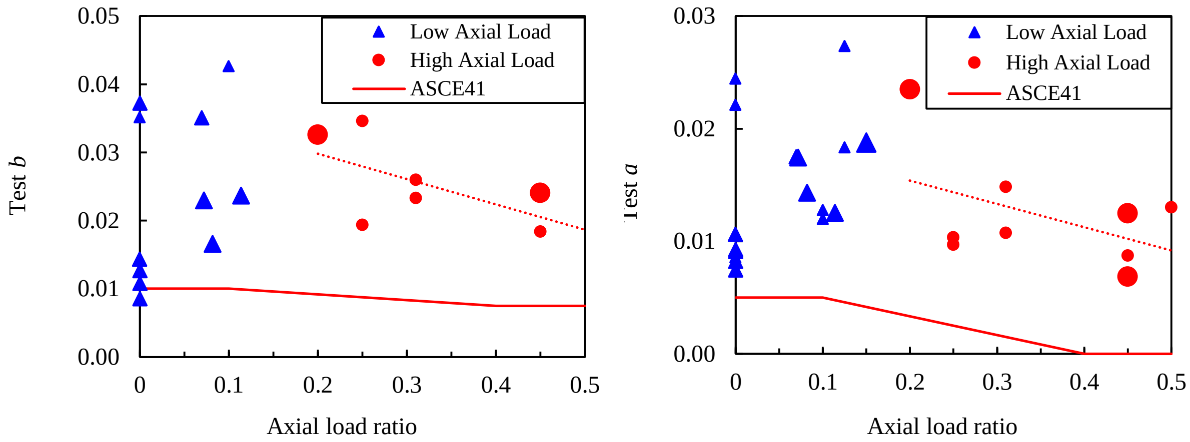
PBSD Research at UAA

Probabilistic Nonlinear Cyclic Models for BCJ

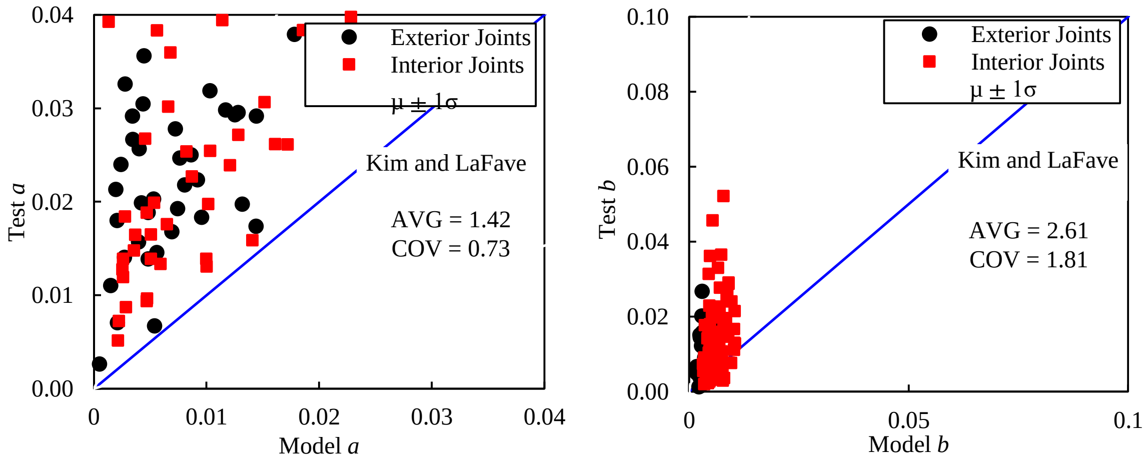
New probabilistic models for (EXTERIOR, INTERIOR, CORNER, KNEE)

Unreinforced	**Reinforced**
J-Failure	J-Failure
BJ-Failure	BJ-Failure
B-Failure	

Current ASCE



Literature Models Evaluation



PBSD Research at UAA

Probabilistic Nonlinear Cyclic Models for BCJ

Unreinforced Exterior and Corner (Parameter a & b)

J-Failure

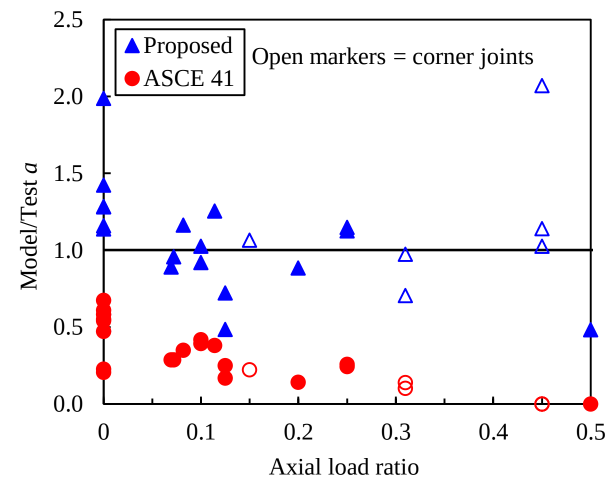
$$a = \frac{h_b}{63\ h_c} + \left(\frac{V_j}{513\ A_j f_c'} - \frac{1}{2808}\right)\sqrt{f_c'} - \frac{P}{52\ A_g\ f_c'} \geq 0$$

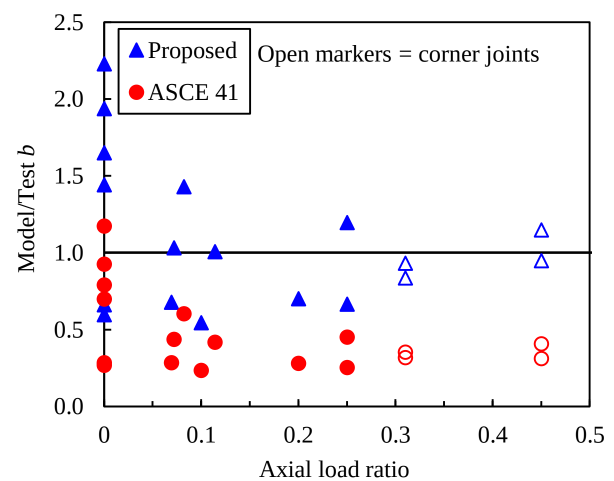
$$b = \frac{h_b}{102\ h_c} + \left(\frac{V_j}{600\ A_j f_c'} - \frac{1}{19{,}600}\right)\sqrt{f_c'} - \frac{P}{73\ A_g\ f_c'} \geq a$$

BJ-Failure

$$a = \left(\frac{1}{3384} - \frac{V_j}{1138 f_c' A_j}\right)\sqrt{f_c'} - \frac{P}{62\ A_g\ f_c'} \geq 0$$

$$b = \frac{\sqrt{f_c'}}{3626} + \frac{P}{82 A_g\ f_c'} - \frac{h_b}{211\ h_c} \geq a$$

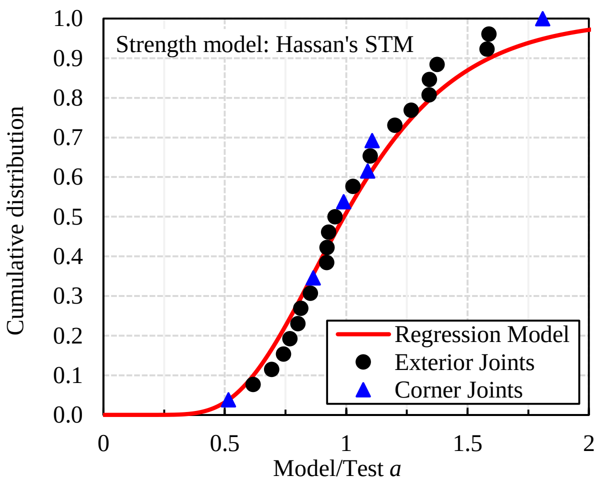


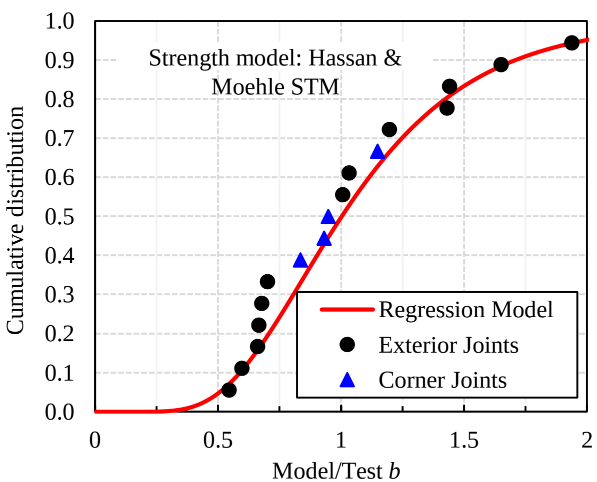


PBSD Research at UAA

Probabilistic Nonlinear Cyclic Models for BCJ

Unreinforced Joints (Fragility Curves and Performance Objective Coeff.)



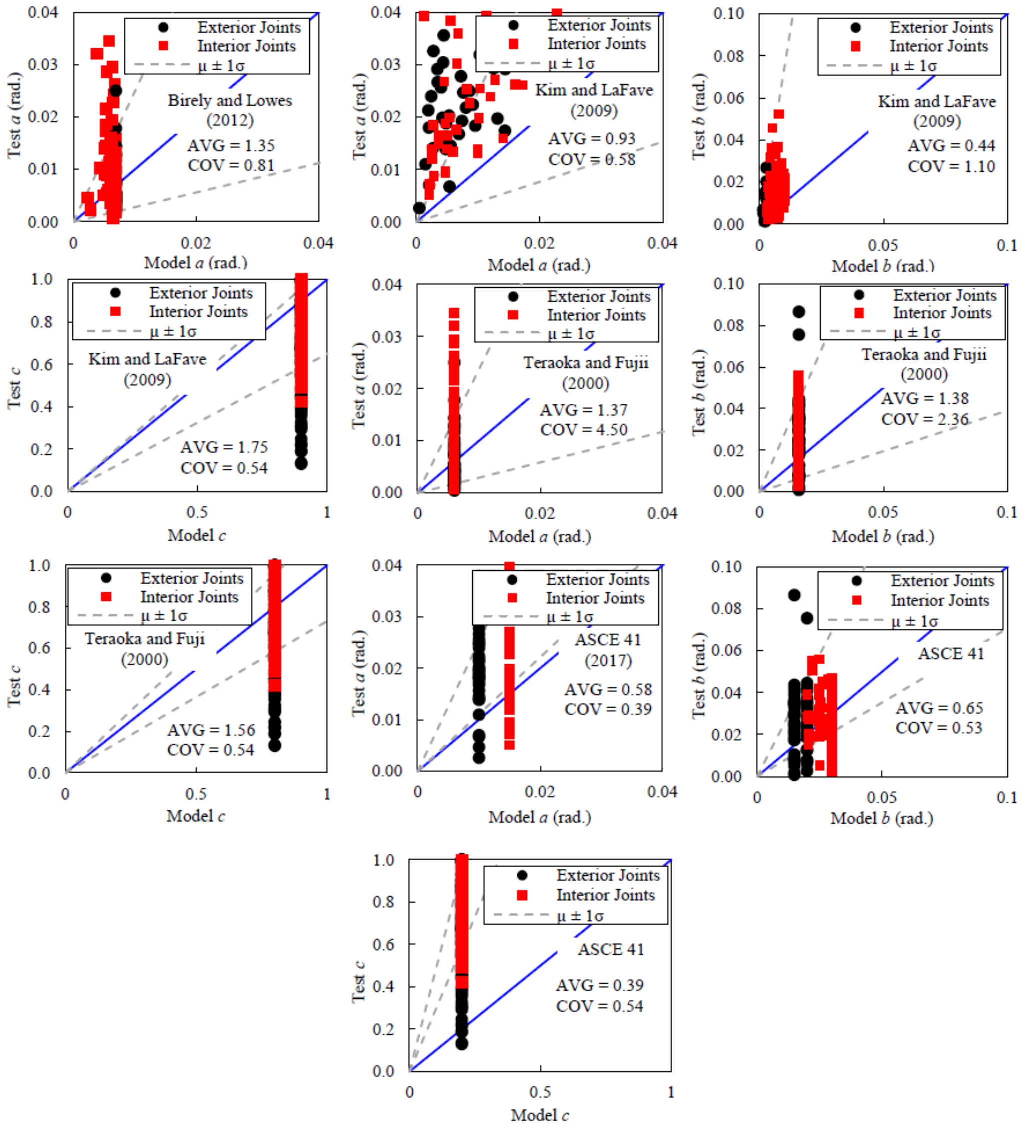


Joint Type	Model	Parameter	Multiplier to achieve POE					
			50% POE	40% POE	30% POE	20% POE	10% POE	5% POE
Exterior and Corner	Regression model	*a* (Hassan and Moehle STM)	1.00	0.90	0.82	0.73	0.62	0.54
		a (ACI 369-21)	1.00	0.91	0.83	0.74	0.63	0.56
		b (Hassan and Moehle STM)	1.00	0.90	0.81	0.71	0.59	0.51
		b (ACI 369-21)	1.00	0.89	0.78	0.67	0.54	0.46
		c	1.00	0.92	0.85	0.77	0.68	0.61
	Hassan's model	*a* (Hassan and Moehle STM)	0.74	0.66	0.59	0.52	0.43	0.37
		a (ACI 369-21)	1.33	1.19	1.06	0.93	0.77	0.66
		b (Hassan and Moehle STM)	0.86	0.77	0.68	0.57	0.48	0.40
		b (ACI 369-21)	0.86	0.77	0.68	0.57	0.48	0.40
	Modified ASCE 41	*a*	1.00	0.92	0.85	0.76	0.65	0.58
		b	1.00	0.90	0.81	0.71	0.59	0.51
Interior	Regression model	*a*	1.00	0.94	0.90	0.86	0.80	0.75
		b	1.00	0.95	0.90	0.85	0.78	0.72
		c	1.00	0.97	0.94	0.90	0.84	0.80

PBSD Research at UAA

Probabilistic Nonlinear Cyclic Models for BCJ

Evaluation of Existing Models (Reinforced Joints)



PBSD Research at UAA

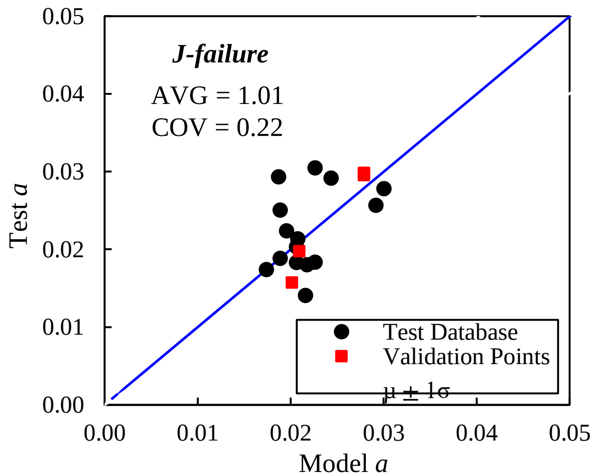
Probabilistic Nonlinear Cyclic Models for BCJ

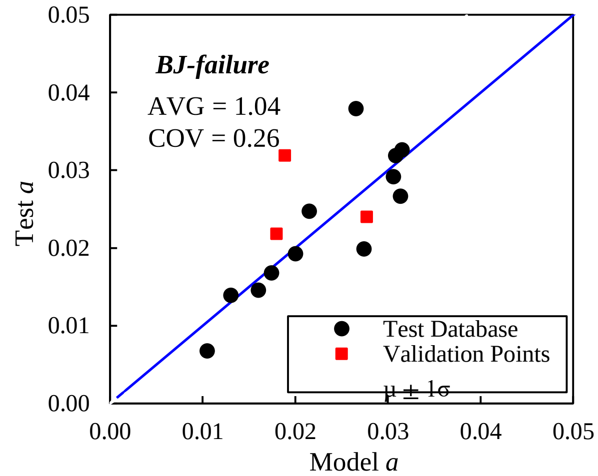
Reinforced Exterior (Parameter a & b)

J-Failure

$$a = \frac{1}{65}\frac{P}{f_c' A_g} + \frac{1}{324}\sqrt{f_c'} + \frac{\rho_j f_{yj}}{50 f_c'}$$

$$b = \frac{1}{8}\frac{P}{f_c' A_g} + \frac{1}{73}\sqrt{f_c'} + \frac{9\,\rho_j f_{yj}}{67 f_c'}$$

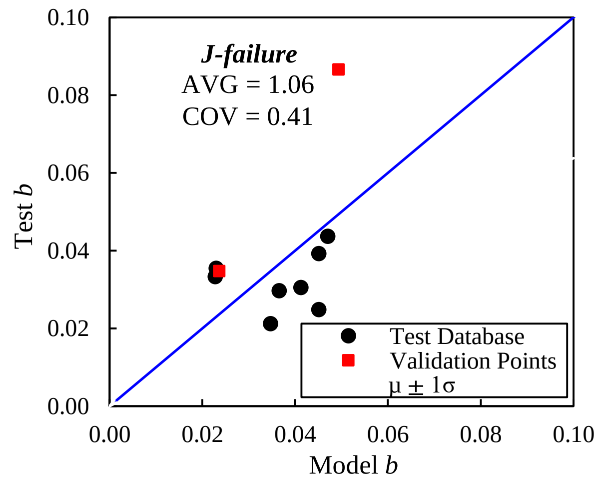


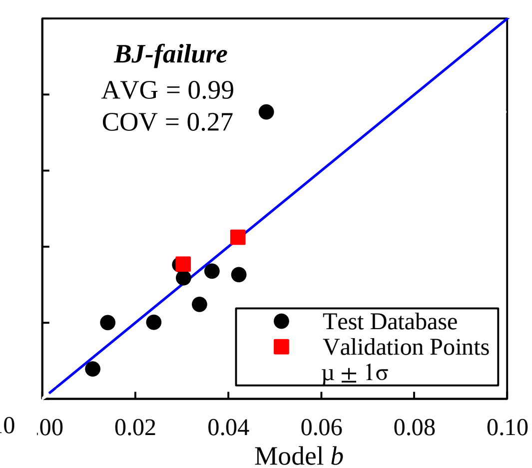


BJ-Failure

$$a = 0.2\,BI - \frac{\rho_j f_{yj}}{50 f_c'} - 0.11\,\frac{P}{f_c' A_g} \geq 0$$

$$b = 0.27\,BI - \frac{\rho_j f_{yj}}{15 f_c'} - \frac{1}{15}\frac{P}{f_c' A_g} \geq a$$

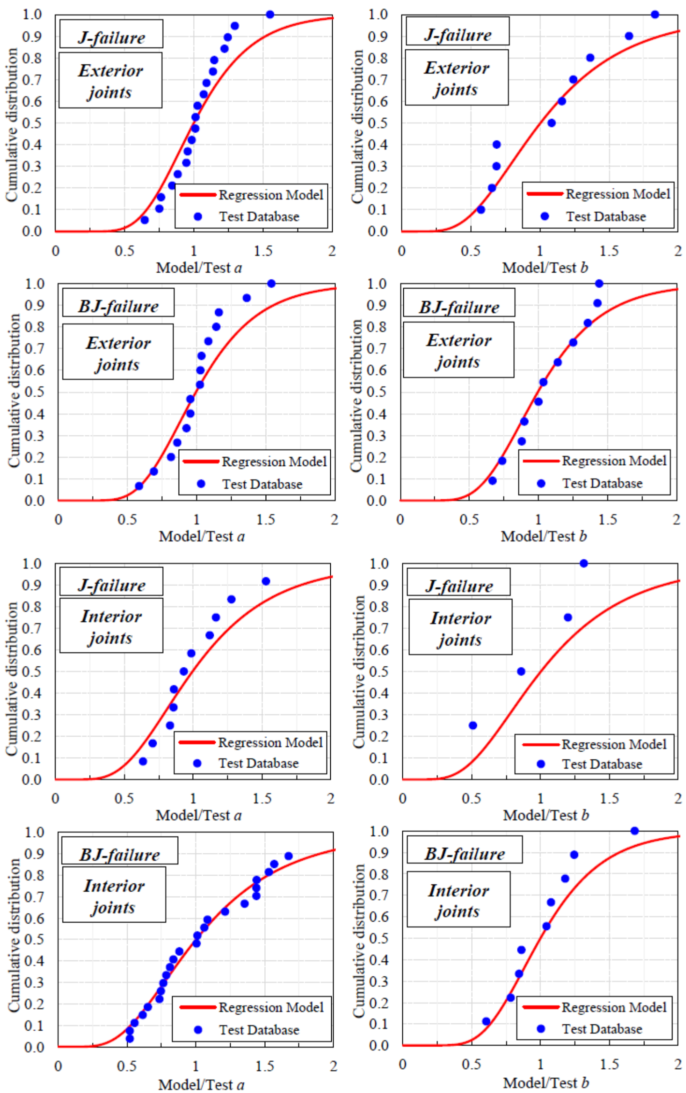




PBSD Research at UAA

Probabilistic Nonlinear Cyclic Models for BCJ

Reinforced Exterior Joints (Fragility Curves and Performance Objective Coeff.)

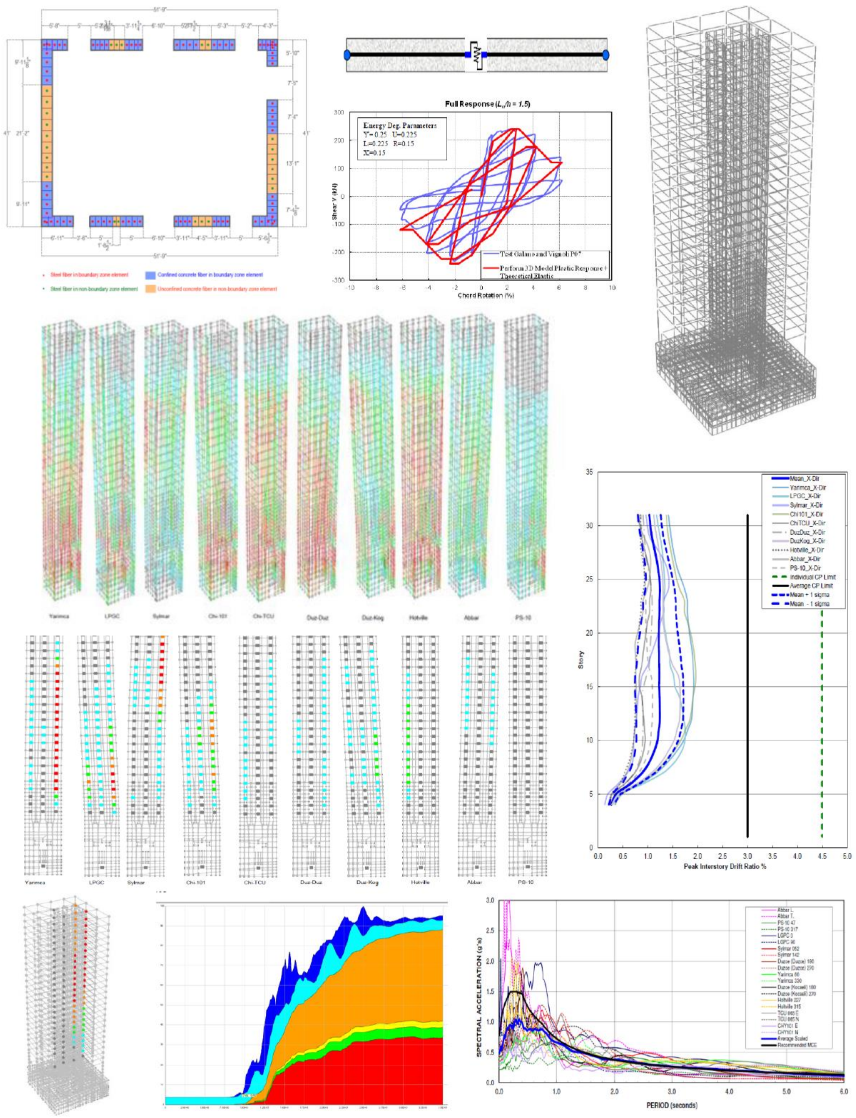


Joint Type	Parameter	Failure mode	Multiplier to achieve POE					
			50% POE	40% POE	30% POE	20% POE	10% POE	5% POE
Exterior	*a*	J	1.00	0.92	0.84	0.76	0.66	0.58
		BJ	1.00	0.91	0.83	0.74	0.64	0.56
	b	J	1.00	0.89	0.79	0.69	0.56	0.48
		BJ	1.00	0.91	0.82	0.73	0.63	0.55
Interior	*a*	J	1.00	0.89	0.78	0.68	0.56	0.47
		BJ	1.00	0.88	0.77	0.66	0.53	0.44
	b	J	1.00	0.89	0.77	0.66	0.53	0.45
		BJ	1.00	0.91	0.83	0.74	0.64	0.56

Professional Perspective (Some lack of Guidance?)

Skidmore, Owings & Merrill (SOM), San Francisco

- Lead of Tall Building Performance-Based Seismic Design



350 Mission

San Francisco

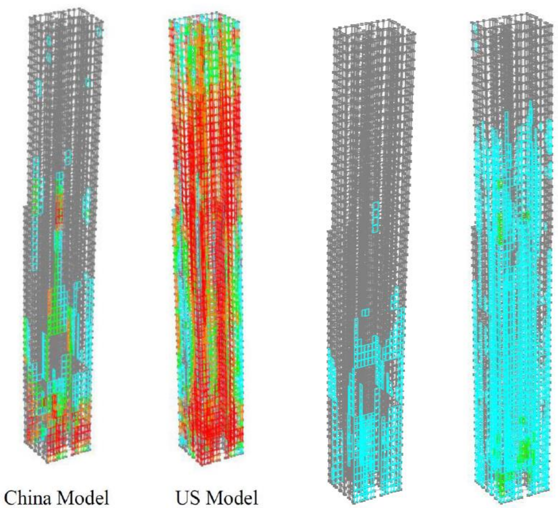
$250M
130 m

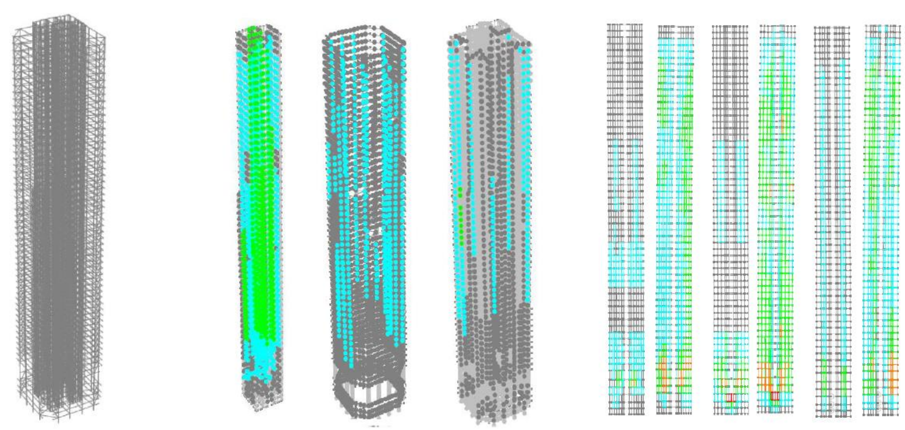
Professional Perspective (Some lack of Guidance?)

Skidmore, Owings & Merrill (SOM), San Francisco

Shenglong Fuzhou Global Center Tower, China

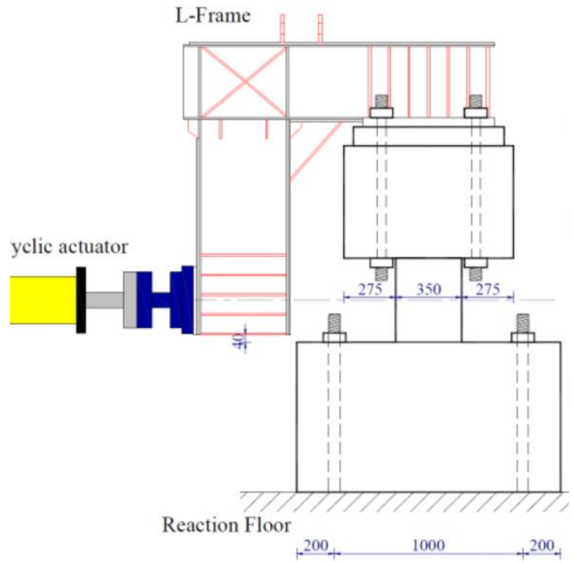
60-story-$750 Million
300 meters
140,000 m^2

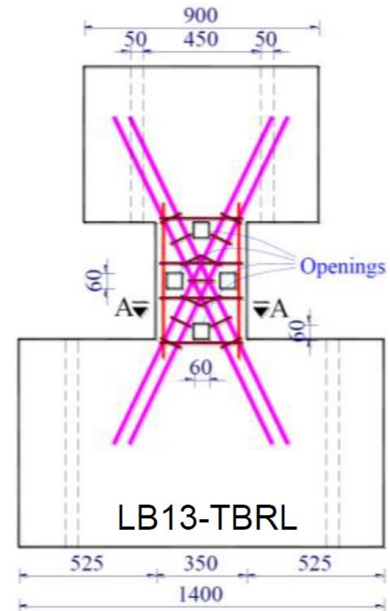


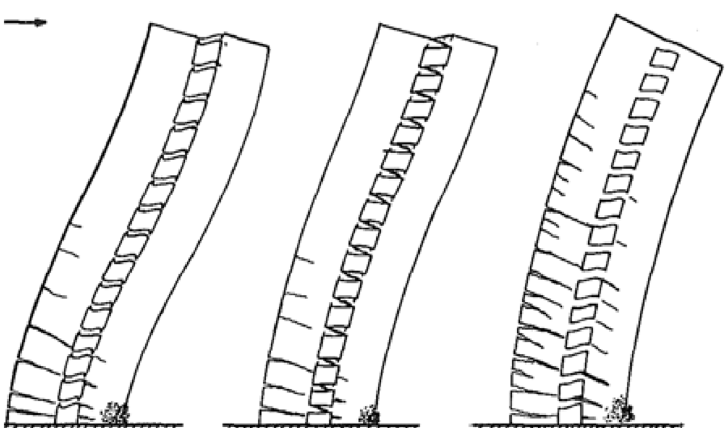


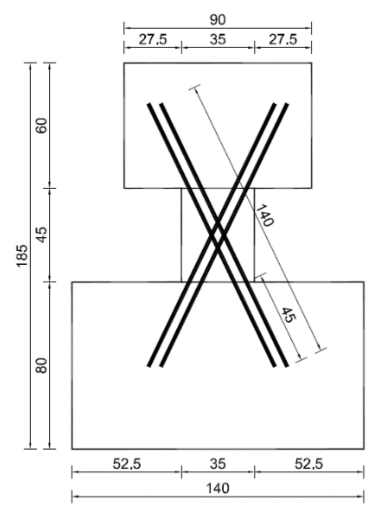
PBSD Research

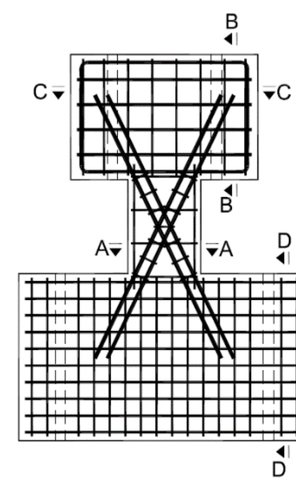
Seismic Behavior of Coupling Beams with Openings (RA Sayed)





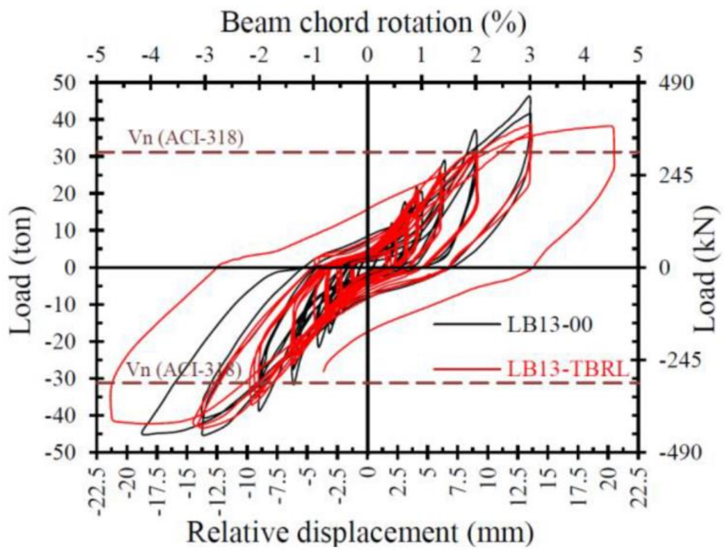


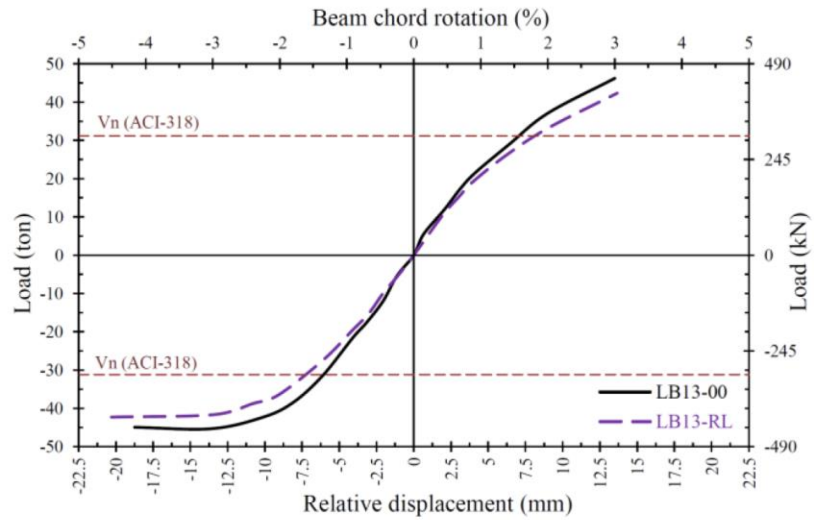


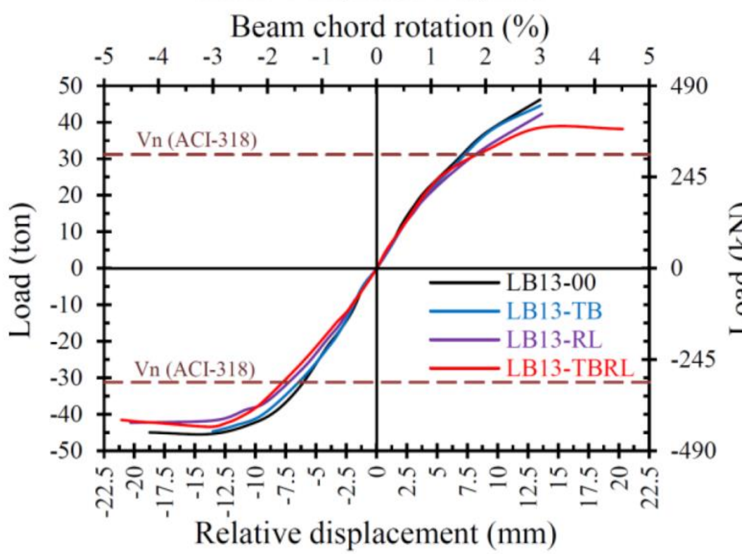


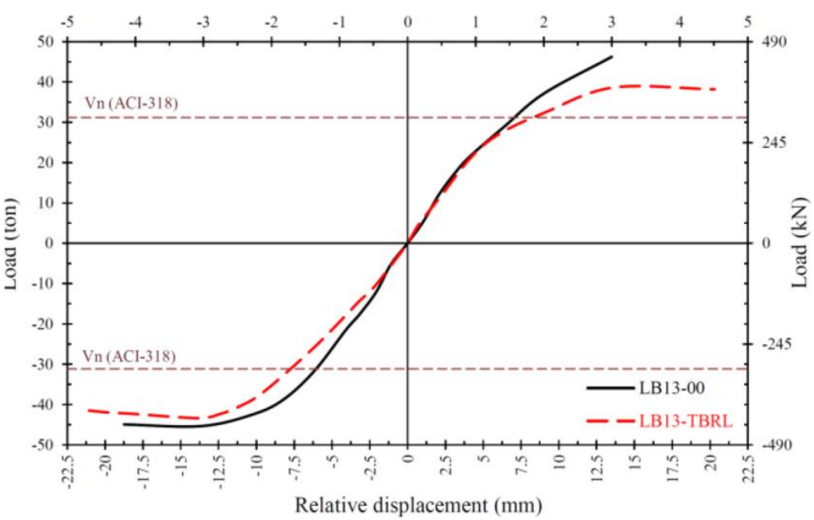
PBSD Research

Seismic Behavior of Coupling Beams with Openings









PBSD Research

Seismic Behavior of Coupling Beams with Openings

LB13-00

LB13-RL

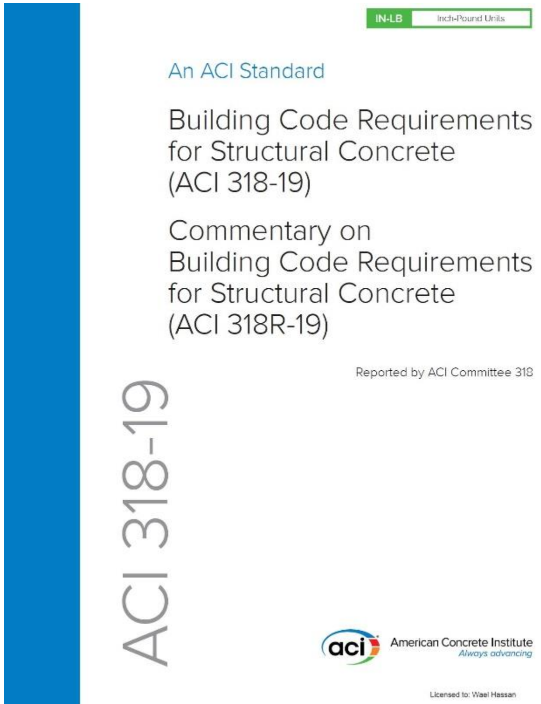
LB13-TB

LB13-TBRL

ACI 318-22

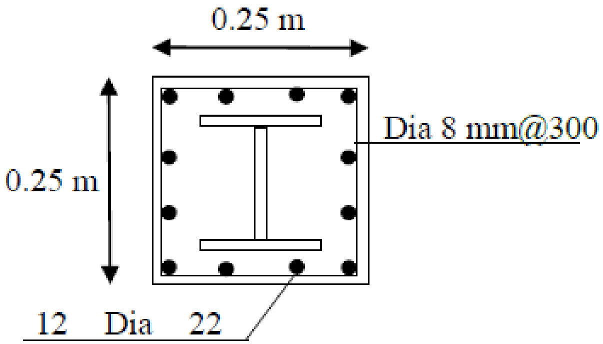
ACI 318-H Seismic Provisions

Code Change Proposal for Opening Size Limit



PBSD Parameters of SRC Columns (Existing/Modern)

Motivation



SRC Columns built < 1980

?

Almost no Info

Modern Columns

No Backbones!

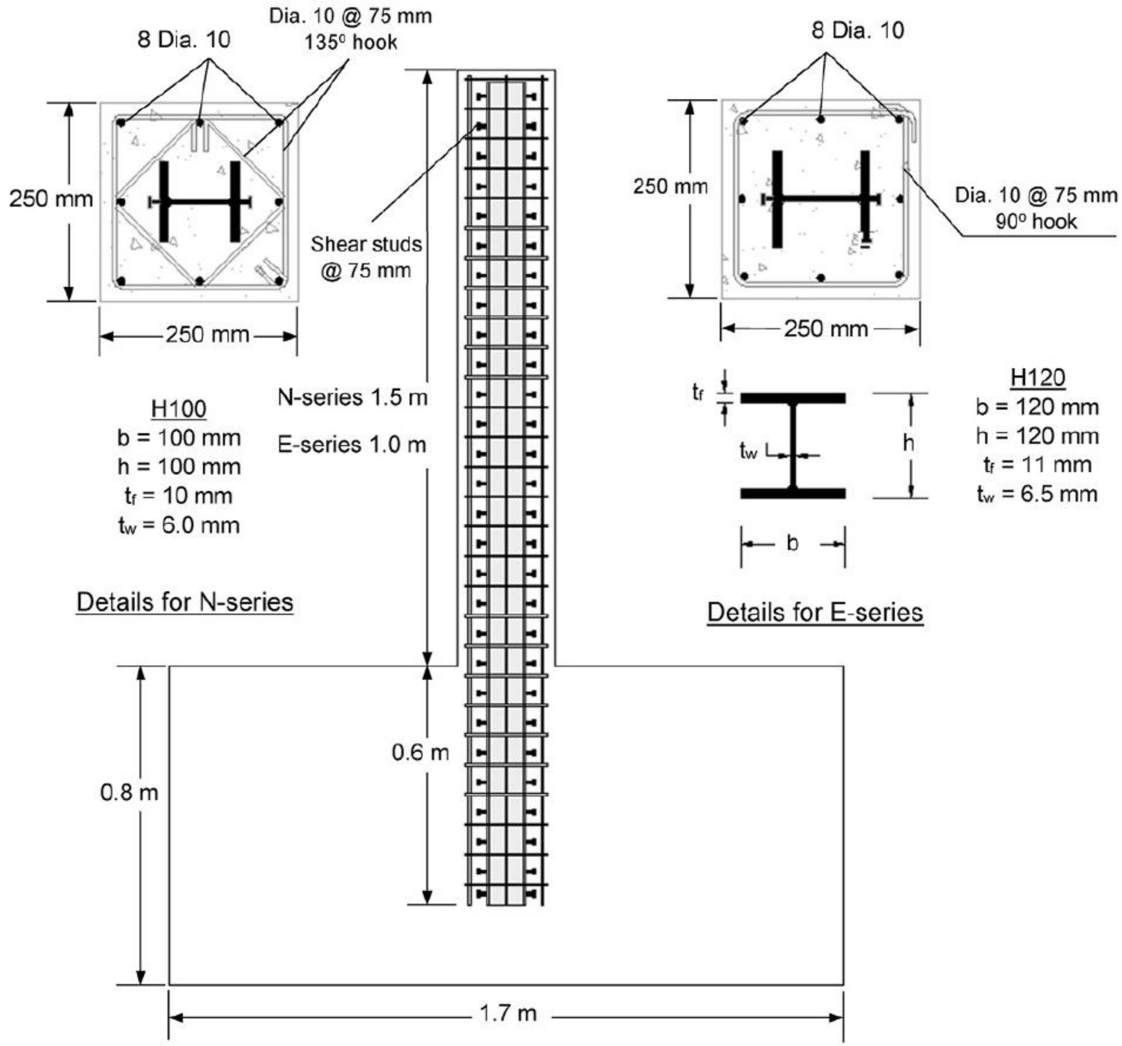
PBSD Parameters of SRC Columns (RA Farag)

Test Specimen Design

ACI 318-63 20 Story prototype (Existing)

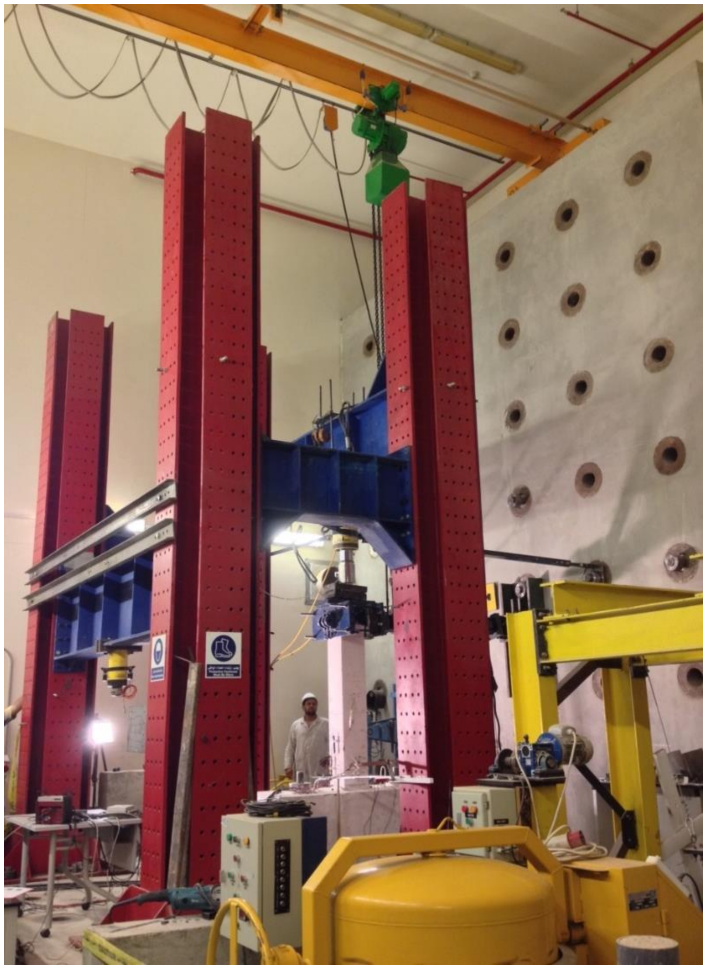
ACI 318-14 30 Story prototype (Modern)

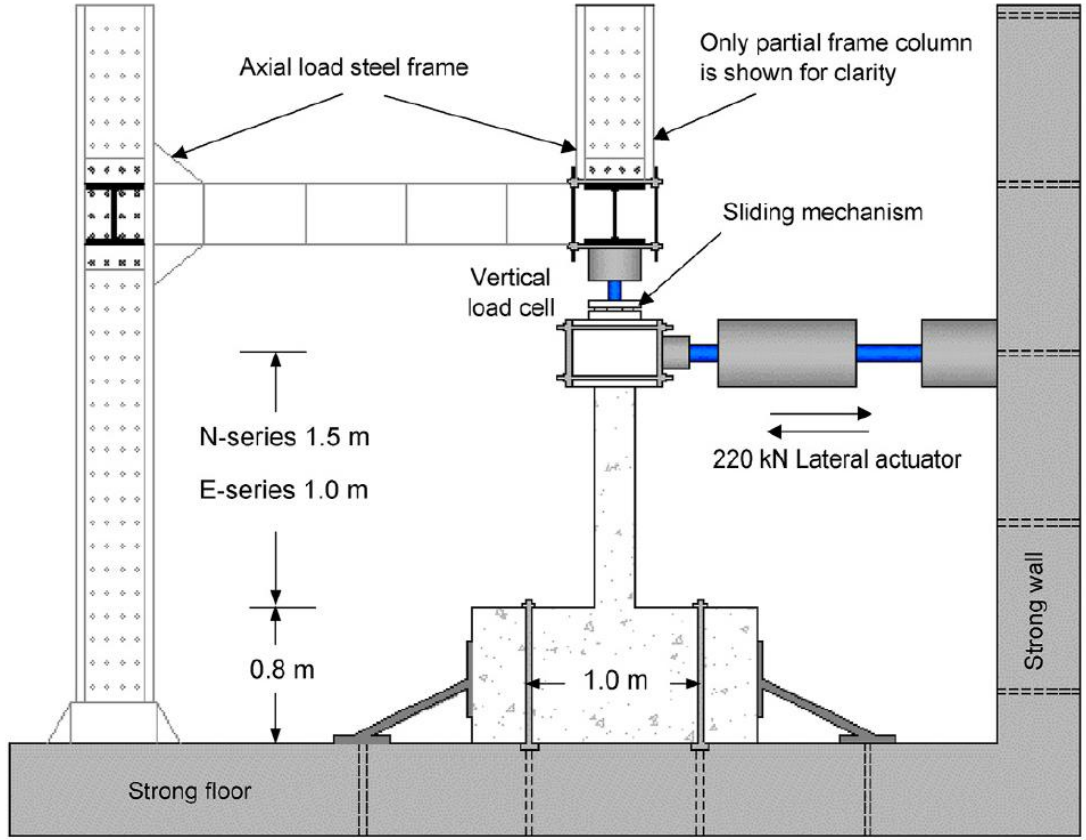
15 Test Columns

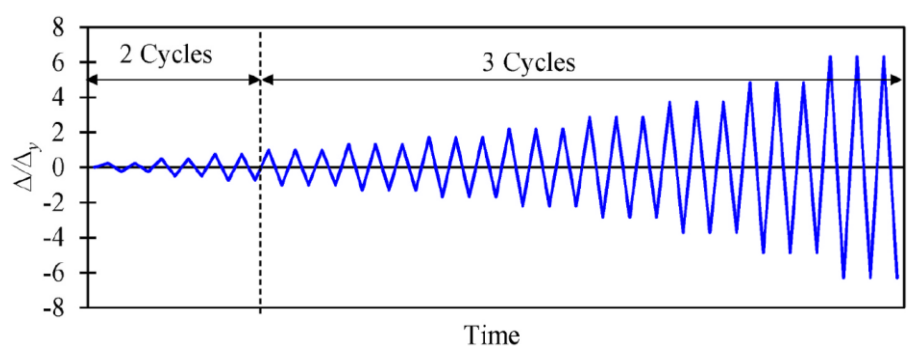


PBSD Parameters of SRC Columns (RA Farag)

Test Setup

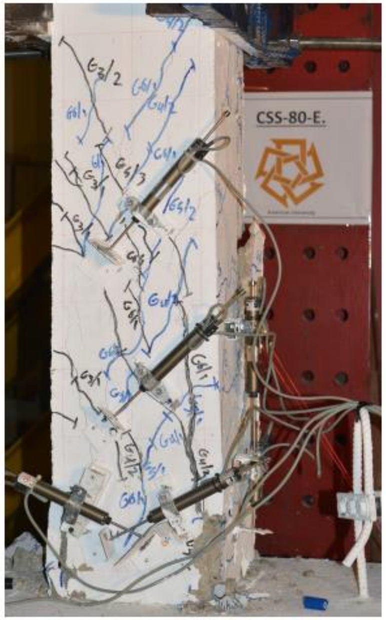




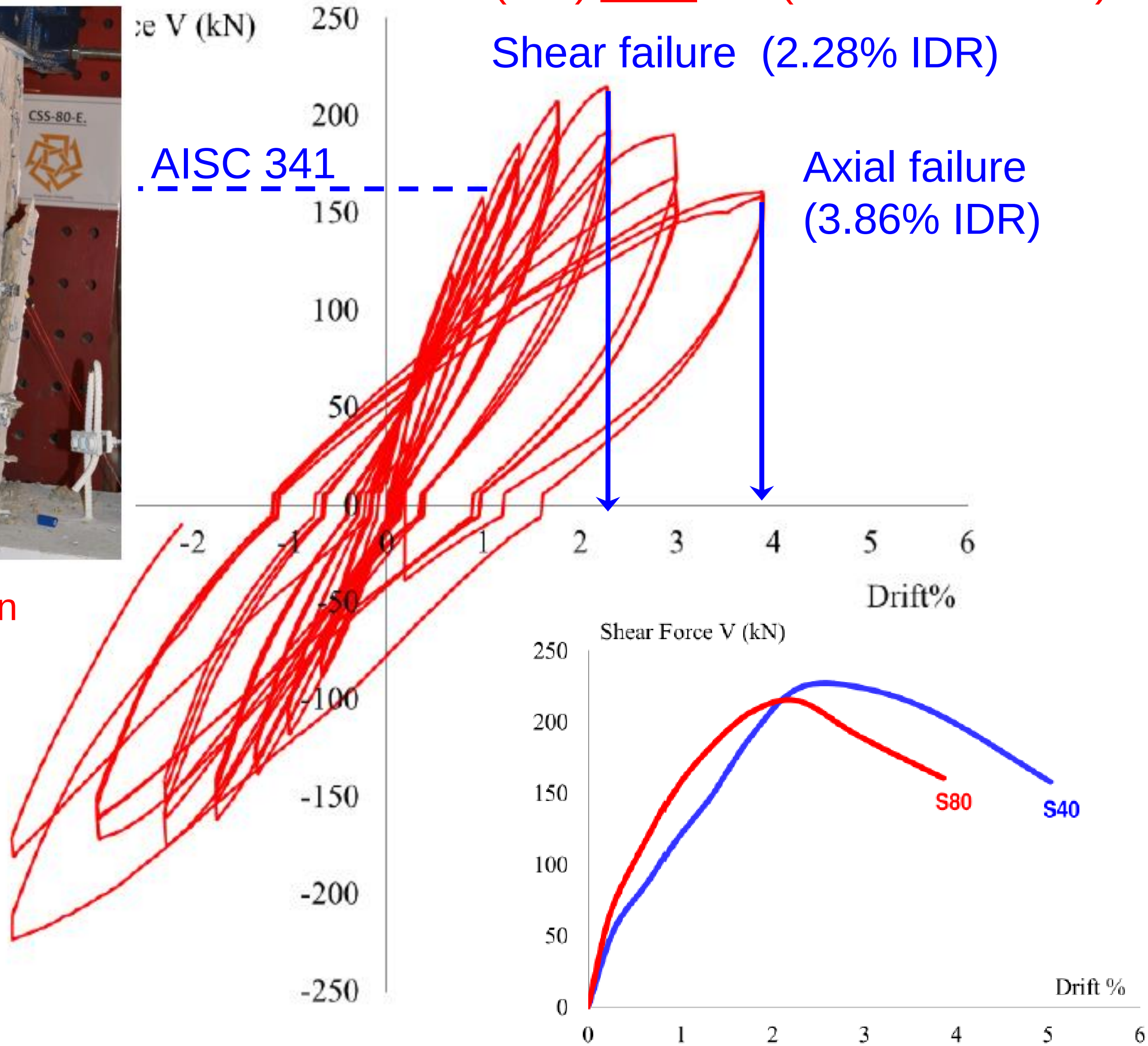


SRC Columns Experimental Results Shear Controlled Specimens

CSS80-E



(TBI) MCE AC (3% & 4.5% IDR)



21% Peak strength drift reduction

24% axial failure drift reduction

PBSD Parameters for SRC Columns

Test Database at UAA

Table 4

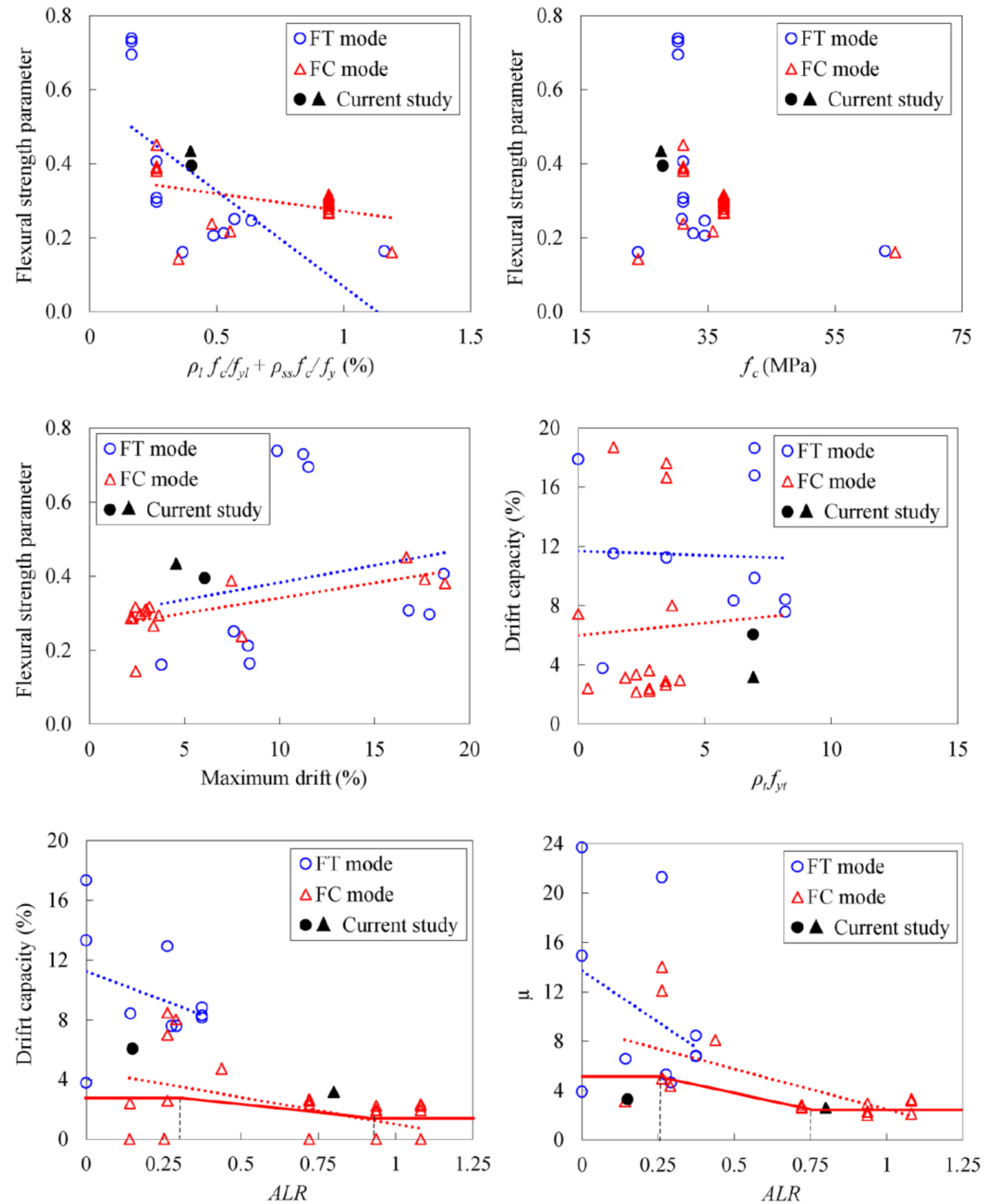
Database of literature cyclic tests of SRC composite columns with non-seismic details.

Investigator	Specimen ID	f'_c MPa	Specimen Dimensions			Steel Section			Longitudinal Steel		Transverse Steel			*ALR*	Shear Studs	Test Results						Failure Mode[c]
			b mm	*h* mm	*a* mm	ρ_{ss} %	f_{yw} MPa	f_{yf} MPa	ρ_l %	f_y MPa	ρ_t %	*s* mm	f_{yt} MPa			V_u kN	δ_y %	δ_u %	δ_{20}%	δ_f %	μ	
Suzuki et al., 1983	LH-020-CBS-00	31.1	210	210	800.0	2.94	348	348	0.00	0.00	2.04	20.0	341	0.000	N	122.7	0.89	9.13	13.3	16.8	14.9	FT
	LH-000-CBS-00	31.1	210	210	800.0	2.94	348	348	0.00	0.00	0.00	0.00	0.00	0.000	N	118.5	0.73	4.48	17.3	17.9	23.7	FT
	LH-020-CBS-20	31.1	210	210	800.0	2.94	348	348	0.00	0.00	2.04	20.0	341	0.262	N	162.2	0.61	1.33	12.9	18.6	21.3	FT
	LH-040-CBS-20	31.1	210	210	800.0	2.94	348	348	0.00	0.00	1.02	40.0	341	0.262	N	156.5	0.61	1.06	8.49	17.6	14.0	FC
	LH-100-CBS-20	31.1	210	210	800.0	2.94	348	348	0.00	0.00	0.41	100	341	0.262	N	152.2	0.58	1.87	7.00	18.7	12.1	FC
	LH-000-CBS-20	31.1	210	210	800.0	2.94	348	348	0.00	0.00	0.00	0.00	0.00	0.262	N	154.8	0.52	1.06	2.58	7.45	4.98	FC
	LH-040-CBS-33	31.1	210	210	800.0	2.94	348	348	0.00	0.00	1.02	40.0	341	0.437	N	180.3	0.58	1.77	4.72	16.7	8.08	FC
	LH-100-CBS-33	31.1	210	210	800.0	2.94	348	348	0.00	0.00	0.41	100	341	0.437	N	173.0	0.57	0.91	2.46	7.50	4.30	FS
	HT80-020-CBS-20	30.3	210	210	800.0	4.23	779	779	0.00	0.00	2.04	20.0	341	0.374	N	341.9	1.21	5.58	8.14	9.87	6.75	FT
	HT80-040-CBS-20	30.3	210	210	800.0	4.23	779	779	0.00	0.00	1.02	40.0	341	0.374	N	337.8	1.22	3.29	8.30	11.2	6.82	FT
	HT80-100-CBS-20	30.3	210	210	800.0	4.23	779	779	0.00	0.00	0.41	100	341	0.374	N	321.8	1.04	3.32	8.82	11.5	8.47	FT
	HT80-000-CBS-20	30.3	210	210	800.0	4.23	779	779	0.00	0.00	0.00	0.00	0.00	0.374	N	298.2	0.92	2.54	6.91	11.0	7.53	FS
Aoyama, 1984	Column	24.0	850	850	1850	3.38	265	265	0.47	265	0.14	200	265	0.141	N	1227	0.78	1.59	NR[a]	2.42	3.12	FC
	Girder	24.0	400	850	3250	3.36	265	265	0.67	265	0.36	120	265	0.000	N	382.5	0.97	3.78	NR	3.78	3.91	FT
Chen et al., 2014	SRC1-1-1	37.5	180	260	1100	5.81	285	285	1.68	357	1.02	53.0	276	0.721	N	139.5	NA[a]	NA	NA	NA	NA	FC
	SRC1-1-2	37.5	180	260	1100	5.81	285	285	1.68	357	1.02	53.0	276	0.721	N	147.7	0.91	1.55	2.57	3.63	2.84	FC
	SRC1-2-1	37.5	180	260	1100	5.81	285	285	1.68	357	0.83	65.0	276	0.721	N	135.3	NA	NA	NA	NA	NA	FC
	SRC1-2-2	37.5	180	260	1100	5.81	285	285	1.68	357	0.83	65.0	276	0.721	N	133.3	1.00	1.43	2.67	3.36	2.66	FC
	SRC1-3-1	37.5	180	260	1100	5.81	285	285	1.68	357	0.67	80.0	276	0.721	N	NA	NA	NA	NA	NA	NA	FC
	SRC1-3-2	37.5	180	260	1100	5.81	285	285	1.68	357	0.67	80.0	276	0.721	N	158.8	0.89	1.24	2.33	3.15	2.61	FC
	SRC2-1-1	37.5	180	260	1100	5.81	285	285	1.68	357	1.25	43.0	276	0.937	N	153.6	1.11	1.44	2.23	2.91	2.02	FC
	SRC2-1-2	37.5	180	260	1100	5.81	285	285	1.68	357	1.25	43.0	276	0.937	N	NA	NA	NA	NA	NA	NA	FC
	SRC2-2-1	37.5	180	260	1100	5.81	285	285	1.68	357	1.02	53.0	276	0.937	N	143.1	0.67	1.41	1.97	2.25	2.95	FC
	SRC2-2-2	37.5	180	260	1100	5.81	285	285	1.68	357	1.02	53.0	276	0.937	N	NA	NA	NA	NA	NA	NA	FC
	SRC2-3-1	37.5	180	260	1100	5.81	285	285	1.68	357	0.83	65.0	276	0.937	N	143.6	0.79	1.21	1.81	2.16	2.30	FC
	SRC2-3-2	37.5	180	260	1100	5.81	285	285	1.68	357	0.83	65.0	276	0.937	N	NA	NA	NA	NA	NA	NA	FC
	SRC3-1-1	37.5	180	260	1100	5.81	285	285	1.68	357	1.46	37.0	276	1.081	N	156.1	0.71	1.15	2.35	2.97	3.30	FC
	SRC3-1-2	37.5	180	260	1100	5.81	285	285	1.68	357	1.46	37.0	276	1.081	N	NA	NA	NA	NA	NA	NA	FC
	SRC3-2-1	37.5	180	260	1100	5.81	285	285	1.68	357	1.25	43.0	276	1.081	N	149.6	0.70	1.54	2.22	2.66	3.17	FC
	SRC3-2-2	37.5	180	260	1100	5.81	285	285	1.68	357	1.25	43.0	276	1.081	N	150.4	NA	NA	NA	NA	NA	FC
	SRC3-3-1	37.5	180	260	1100	5.81	285	285	1.68	357	1.02	53.0	276	1.081	N	158.6	0.92	1.33	1.94	2.40	2.12	FC
	SRC3-3-2	37.5	180	260	1100	5.81	285	285	1.68	357	1.02	53.0	276	1.081	N	147.1	NA	NA	NA	NA	NA	FC
Ricles and Paboojian, 1994	1	32.7	406	406	2489	4.46	372	374	1.89	455	1.10	127	559	0.276	N	248.1	1.43	2.76	7.59	8.34	5.30	FT
	2	34.5	406	406	2489	4.46	372	374	0.94	434	1.00	63.5	559	0.261	N	238.2	NA	NA	NA	NA	NA	FT
	3	30.9	406	406	1930	4.46	372	374	2.82	434	1.47	95.3	559	0.292	N	378.6	1.63	3.85	NR	7.59	4.66	FT
	4	31.1	406	406	1930	4.46	372	374	1.56	448	0.66	95.3	559	0.290	N	339.6	1.83	3.08	NR	8.01	4.37	FC
	5	34.5	406	406	1930	4.46	372	374	2.82	434	1.47	95.3	559	0.262	Y	402.1	NA	NA	NA	NA	NA	FT
	6	35.8	406	406	1930	4.46	372	374	1.56	448	0.66	95.3	559	0.252	Y	345.6	NA	NA	NA	NA	NA	FC
	7	62.9	406	406	1930	4.46	372	374	2.82	434	1.47	95.3	559	0.143	N	428.6	1.28	2.06	NR	8.42	6.56	FT
	8	64.5	406	406	1930	4.46	372	374	2.82	434	1.47	95.3	559	0.140	Y	431.1	NA	NA	NA	NA	NA	FC

[a] NR denotes that 20% drop is not reached.

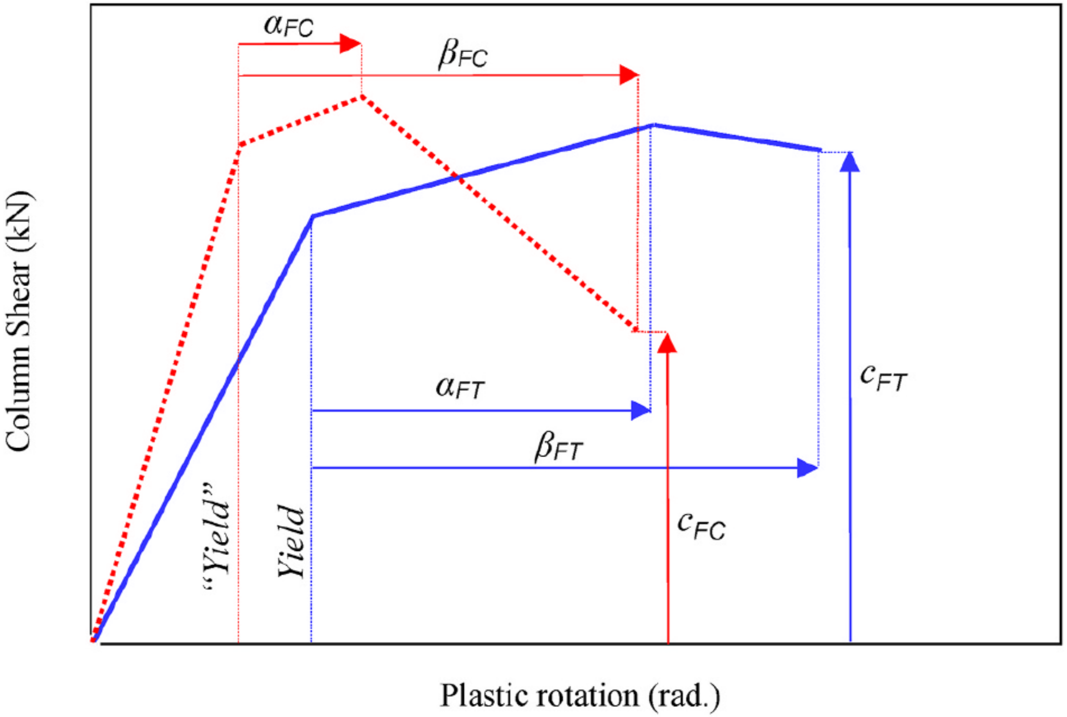
PBSD Parameters for SRC Columns

Analytical Models at UAA



PBSD Parameters for SRC Columns

Analytical Models at UAA **(Ready to use for ASCE 41)**



$$IDR = 0.034 - 0.015ALR$$

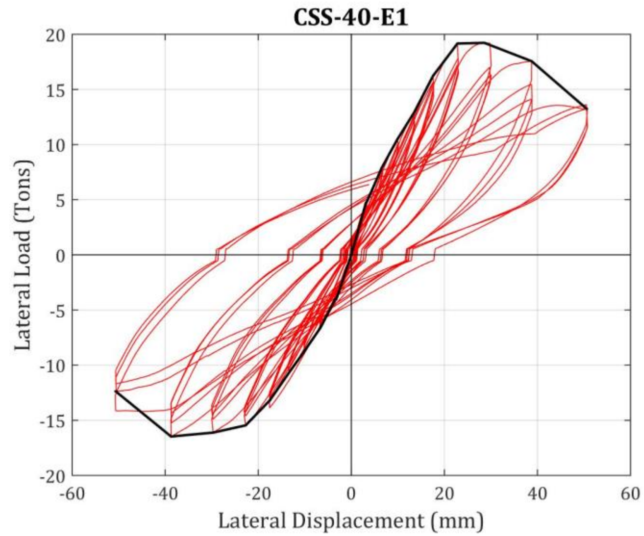
$$\mu = 4 - \frac{5}{3} ALR$$

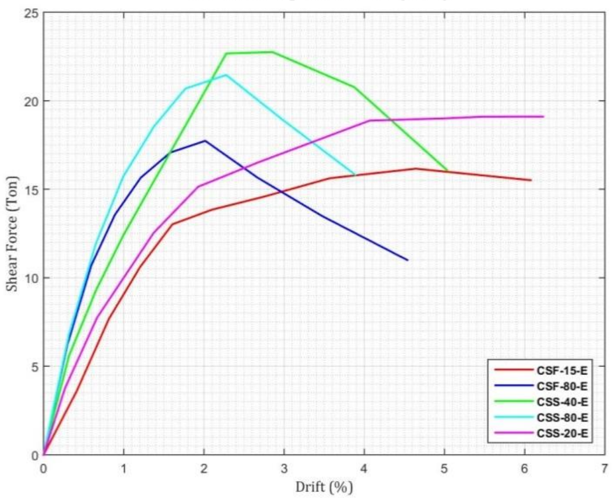
$$\alpha_{FC} = 0.017 - 0.01ALR \quad where \quad 0.01 \leq \alpha_{FC} \leq 0.015$$

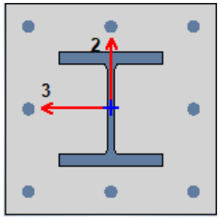
$$\beta_{FC} = 0.023 - 0.013ALR \quad where \quad 0.01 \leq \beta_{FC} \leq 0.018$$

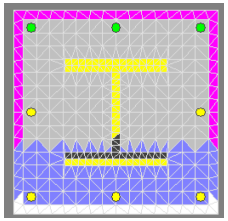
PBSD SRC Columns Fragility

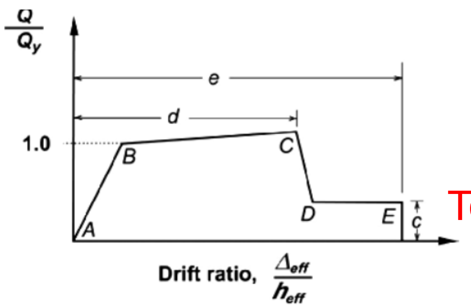
Fragility & Resilience: Existing Buildings (RA Gonzales)







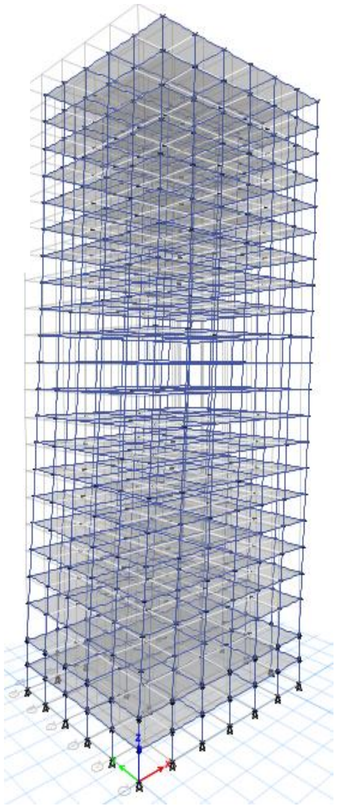


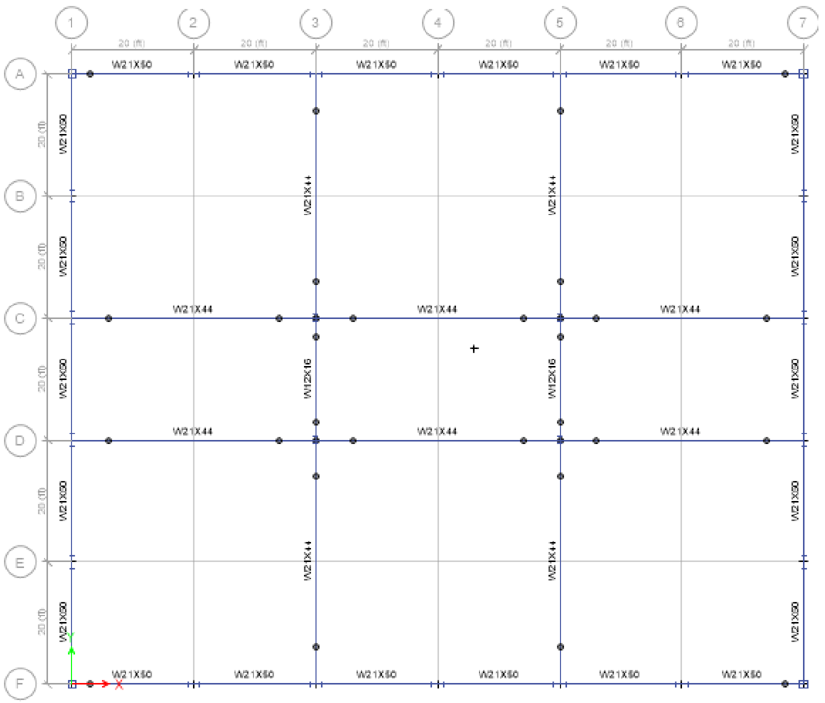


ASCE 41

Vs.

Test Backbones

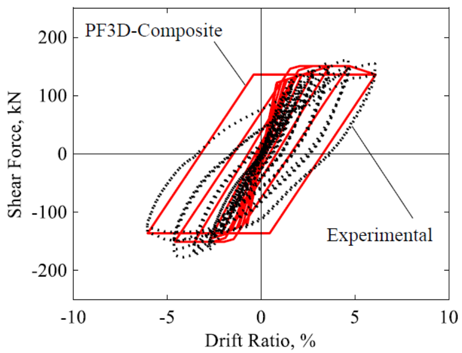


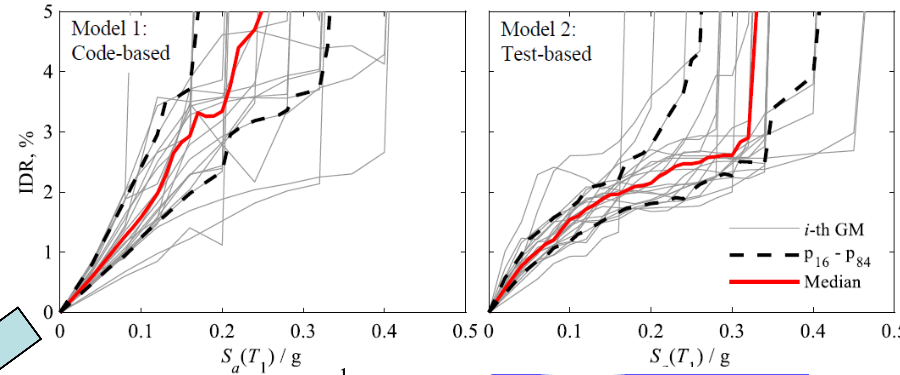


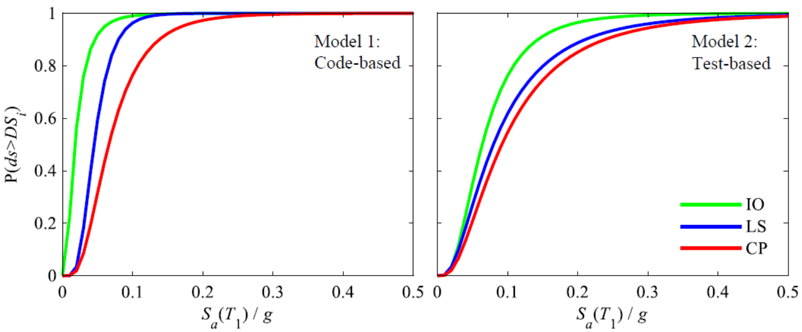
Two Buildings: SRC vs. ASCE 41 Method

PBSD SRC Columns Fragility

Fragility & Resilience of Existing Buildings (RA Gonzales)

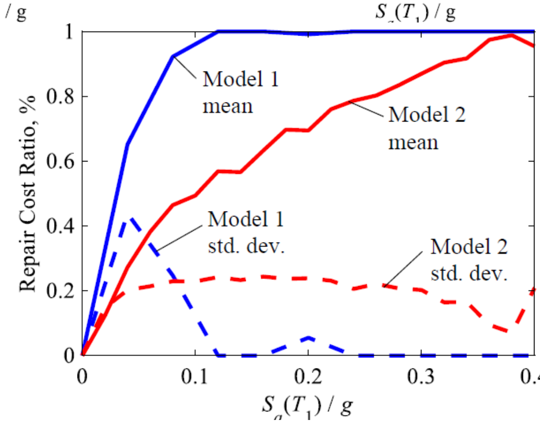


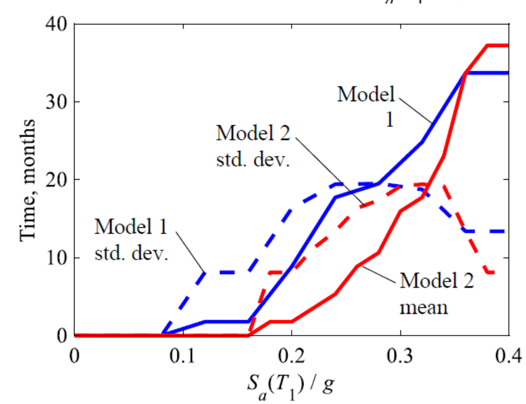




Fragility

Econ. Loss





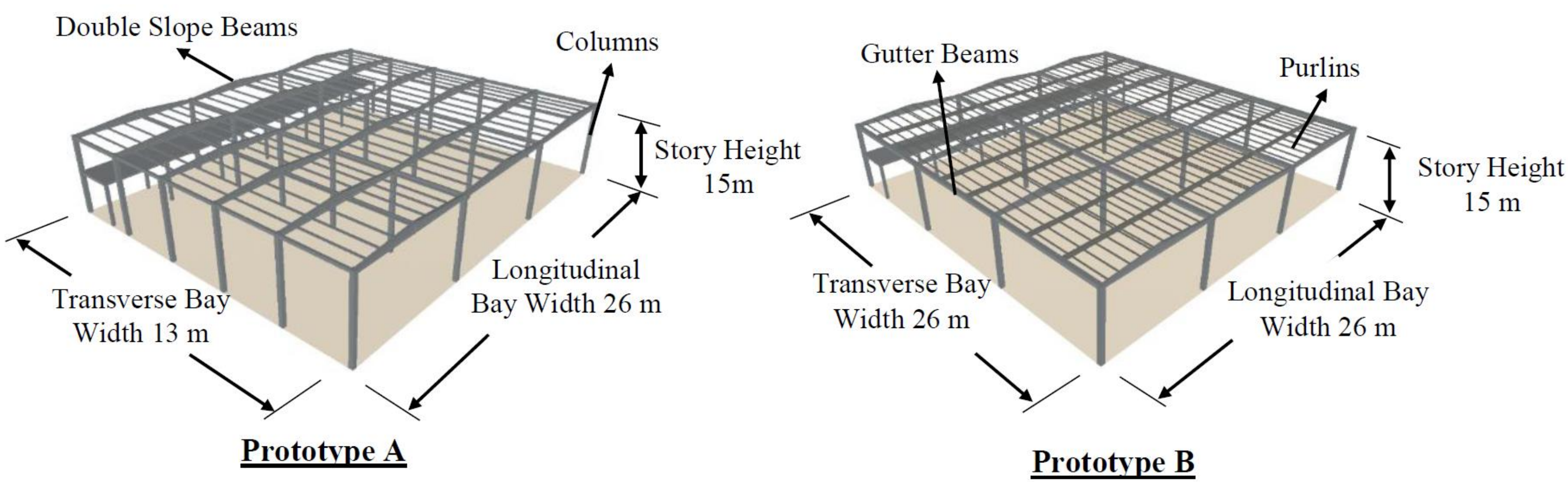
Resilience Function

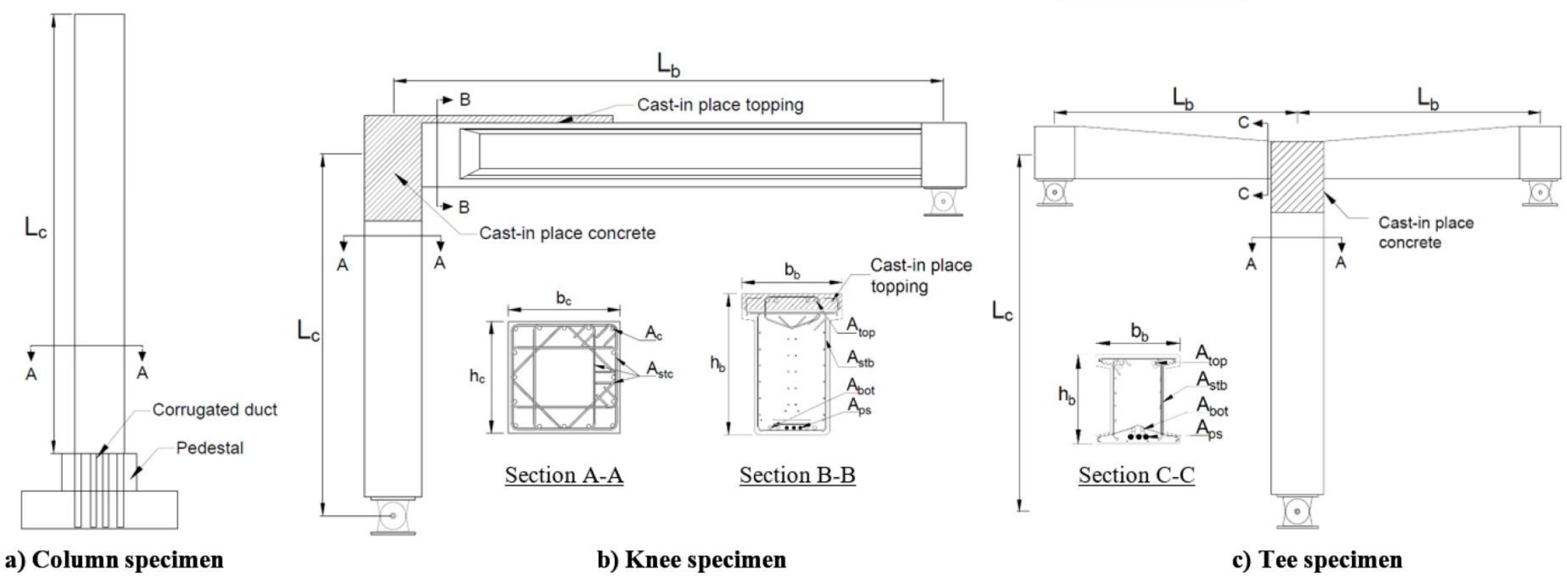
System-level

- Fragility
- Economic Vulnerability
- Resilience

PBSD/Fragility of Industrial Facilities

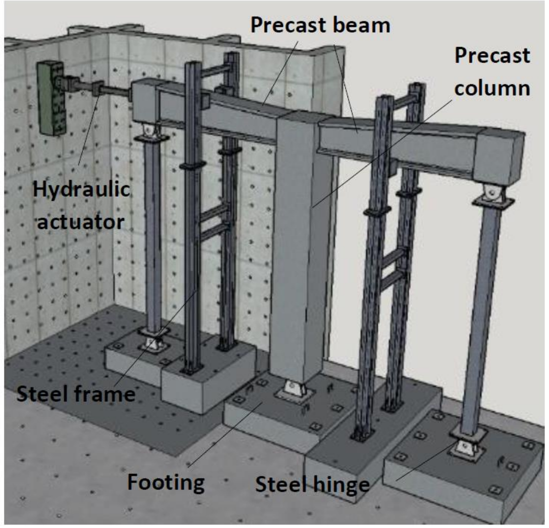
Seismic Behavior of Industrial Precast Facilities Ph1 (RA Bernal)

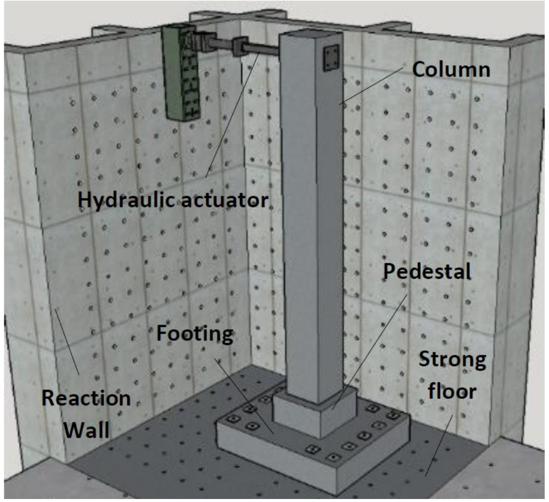


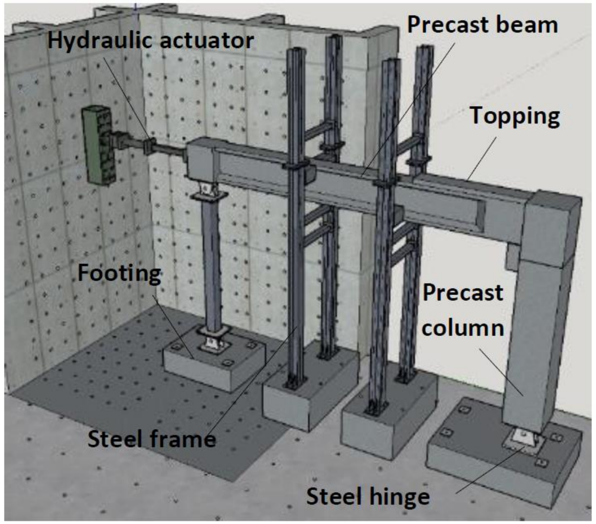


PBSD/Fragility of Industrial Facilities

Seismic Behavior of Industrial Precast Facilities Ph1 (RA Bernal)

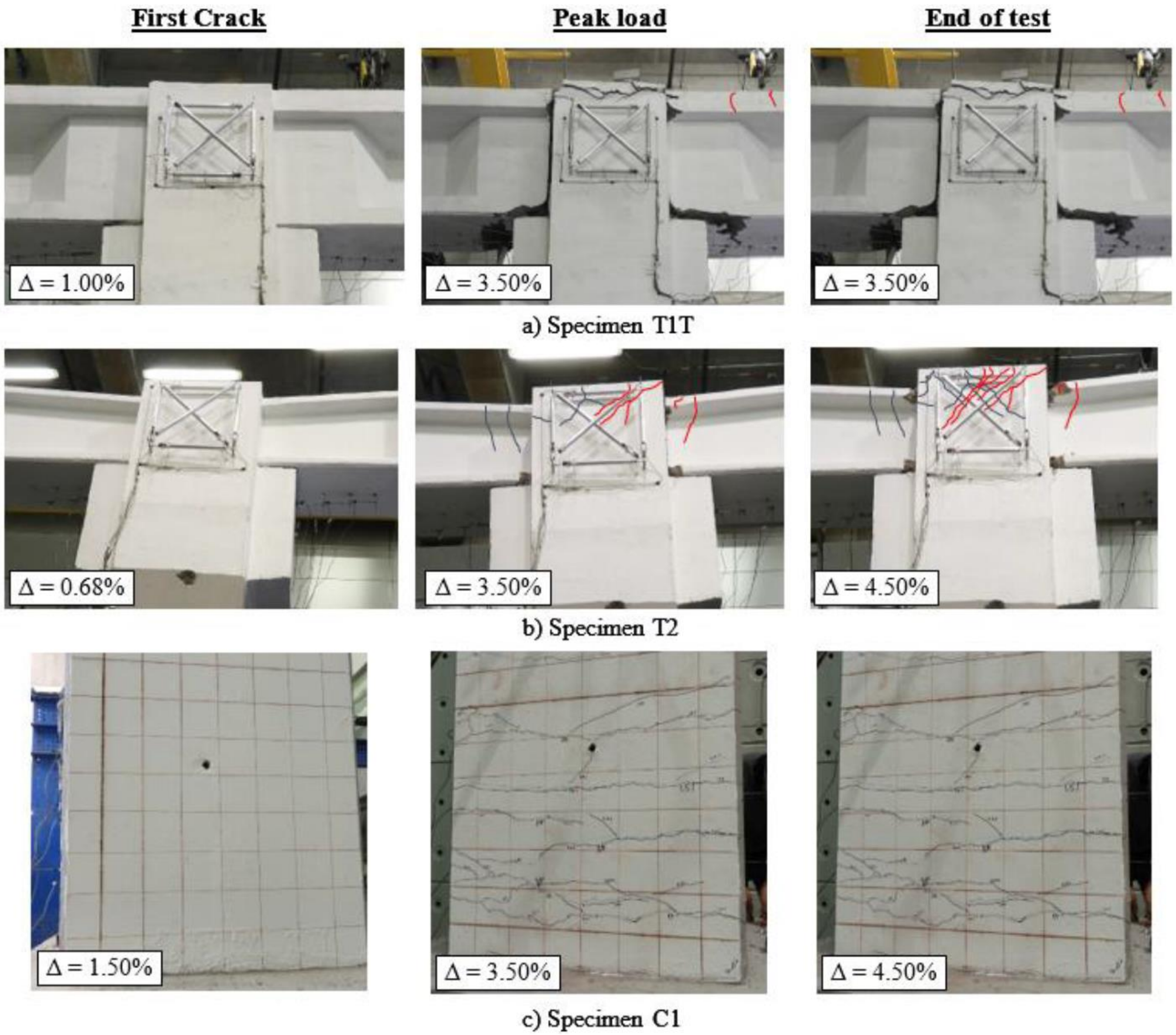






PBSD/Fragility of Industrial Facilities

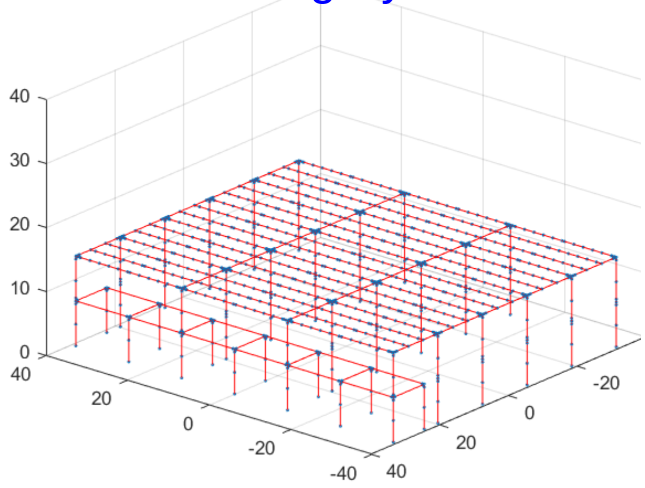
Seismic Behavior of Industrial Precast Facilities Ph1 (RA Bernal)



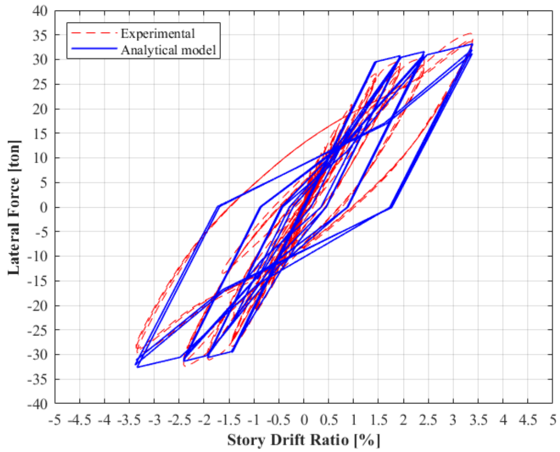
PBSD/Fragility of Industrial Facilities

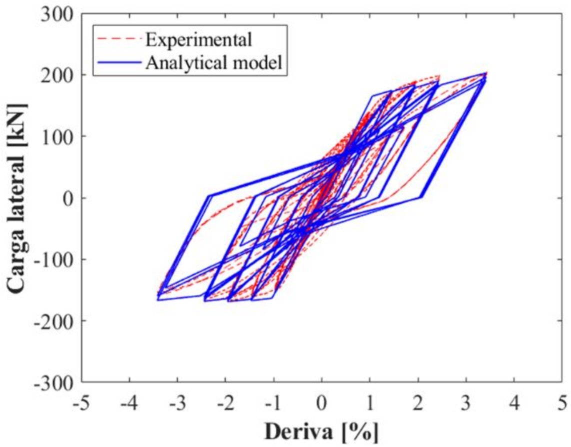
Seismic Fragility of Industrial Precast Facilities Ph2 (RA Soto)

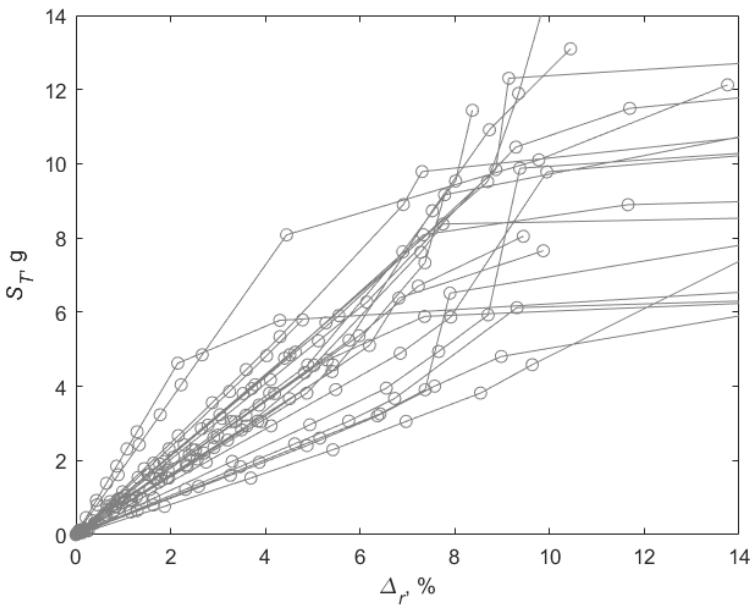
System-level Fragility

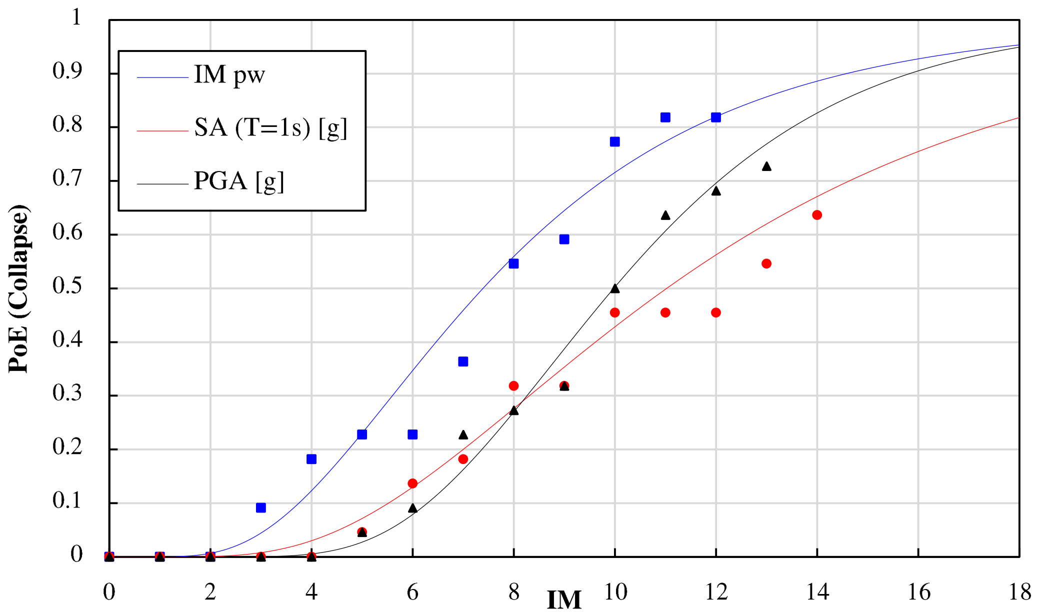


OpenSees Component Calibration





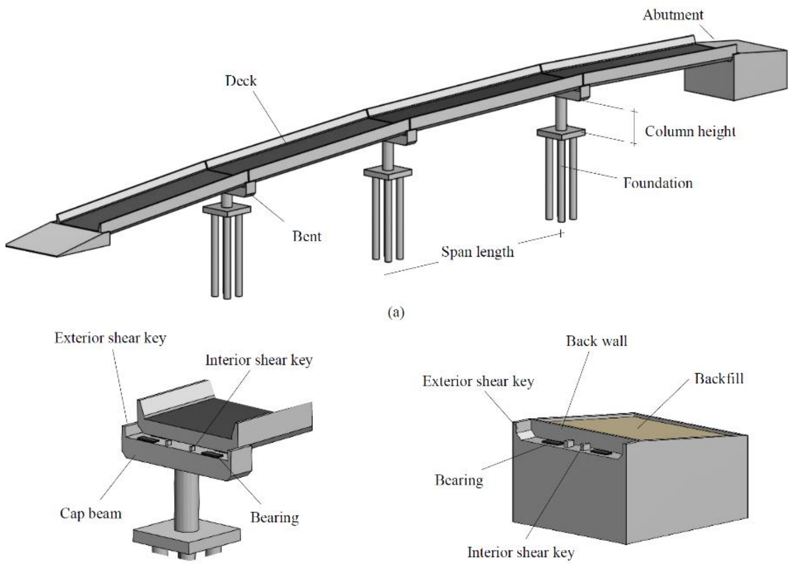




PBSD/Fragility of Existing and Code-conforming Bridges

Long Duration Effects (RA: Restrepo)

10 Bridge Typologies



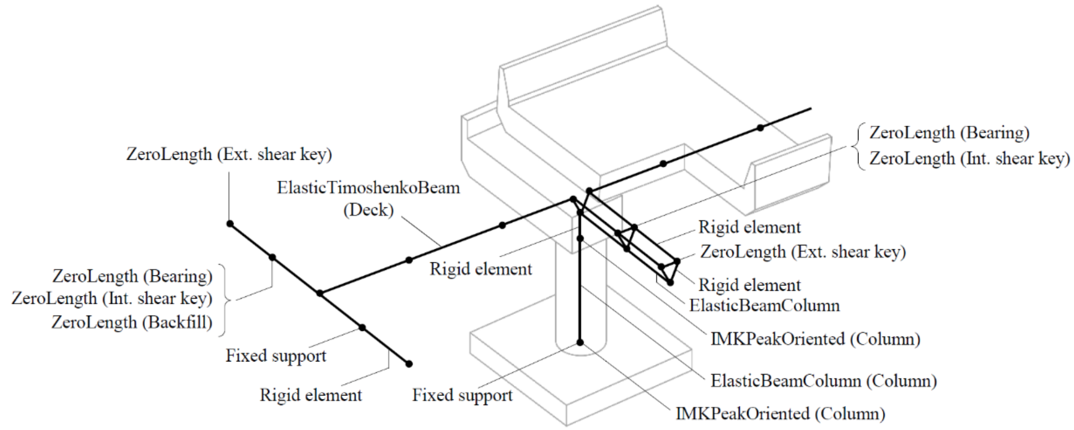
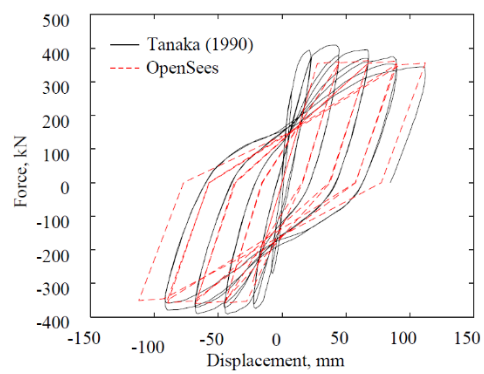
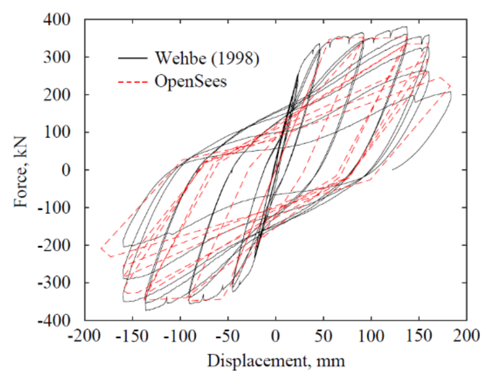
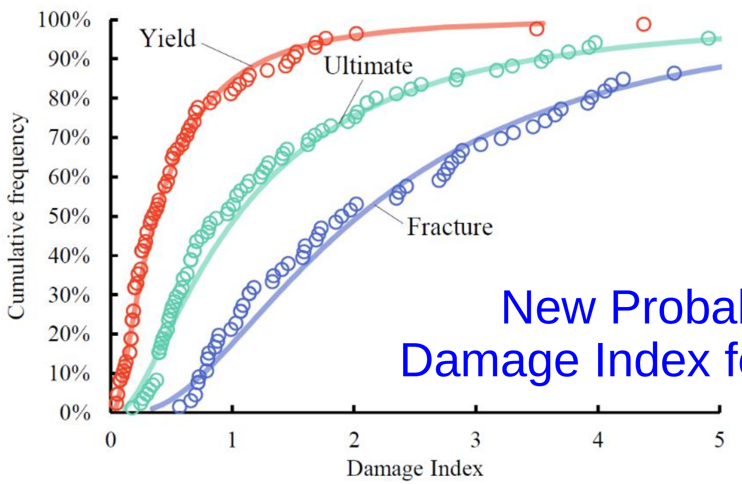


Figure 6 Details of an idealized bridge model.





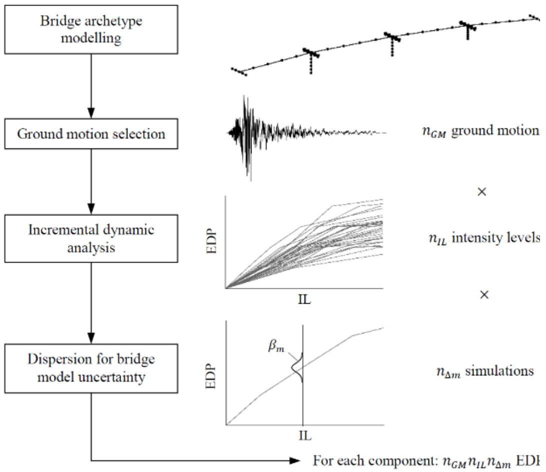


New Probabilistic Damage Index for Columns

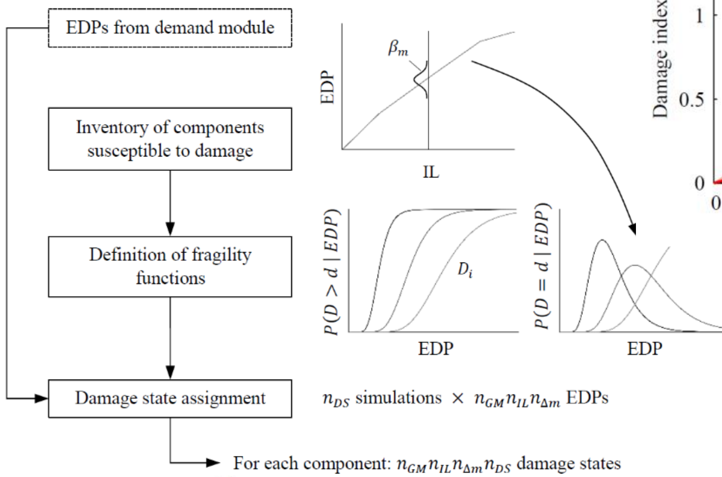
PBSD/Fragility of Existing and Code-conforming Bridges

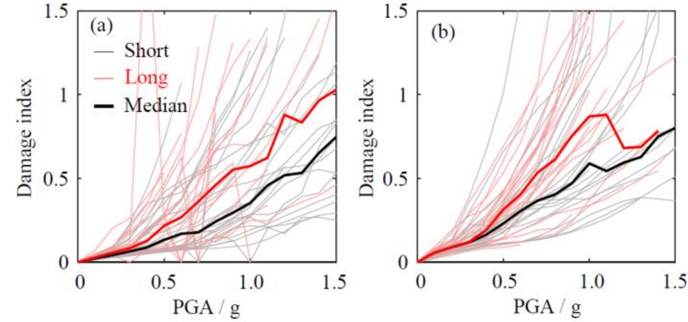
Long Duration Effects (RA: Restrepo)

Demand Module

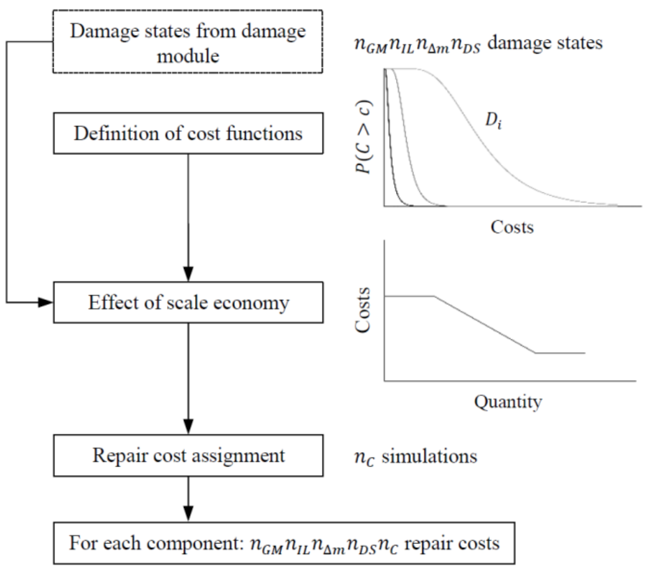


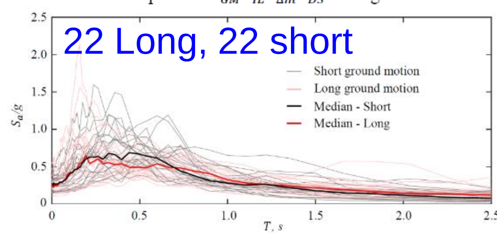
Damage Module

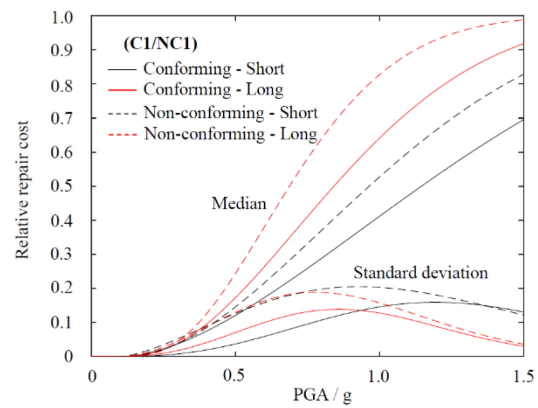


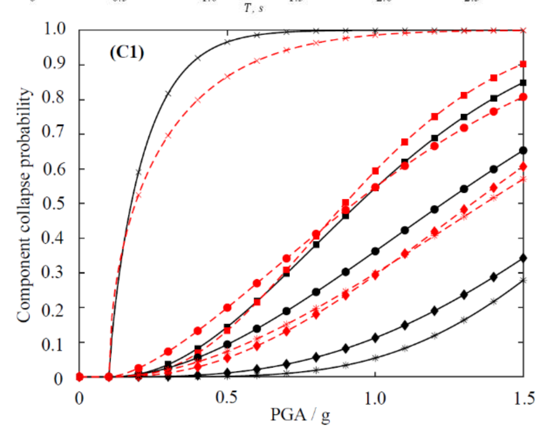


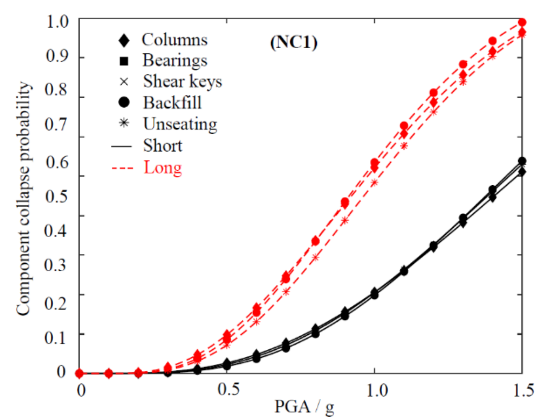
Cost Module





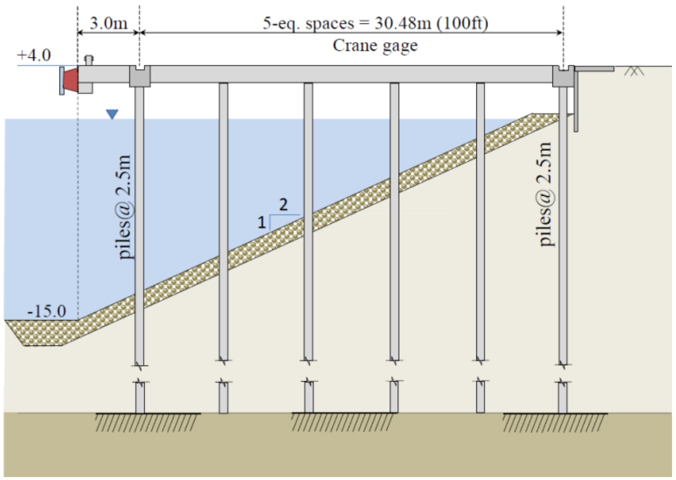


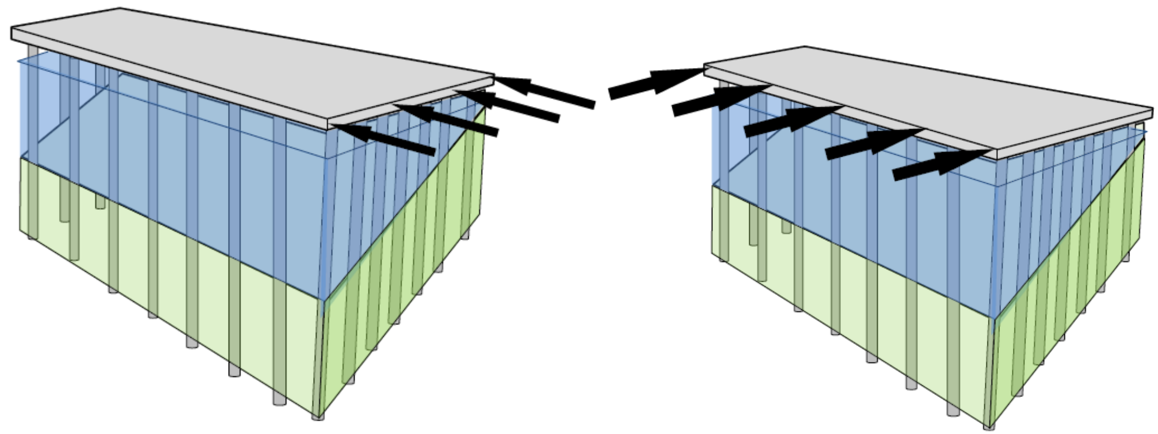


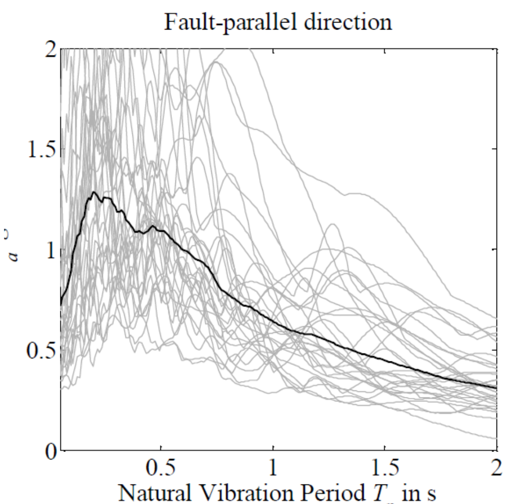


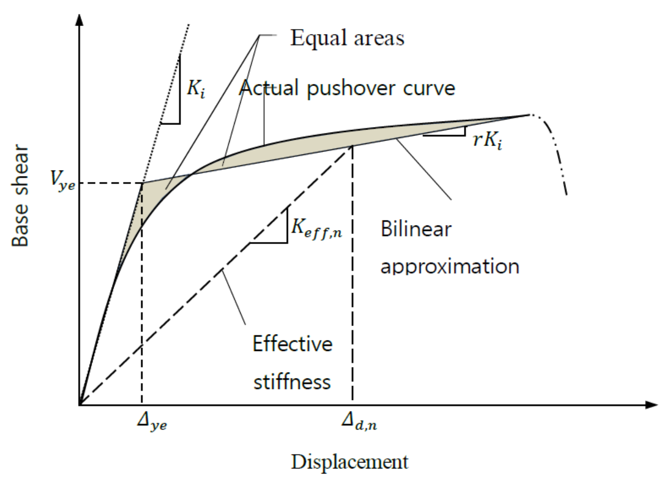
Sample PBSD Lifelines Research (Port Piers)

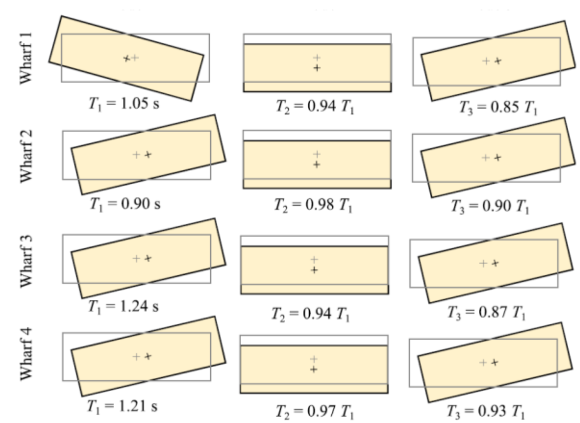
Assess. of ASCE-61 Pushover Nonlinear Analysis Method for Wharves











- SSM conservative for excitations in the longitudinal direction
- Moment, shear, and axial load demand +/- 20%
- Displacements & curvature demands within the 25 to 75 percentile

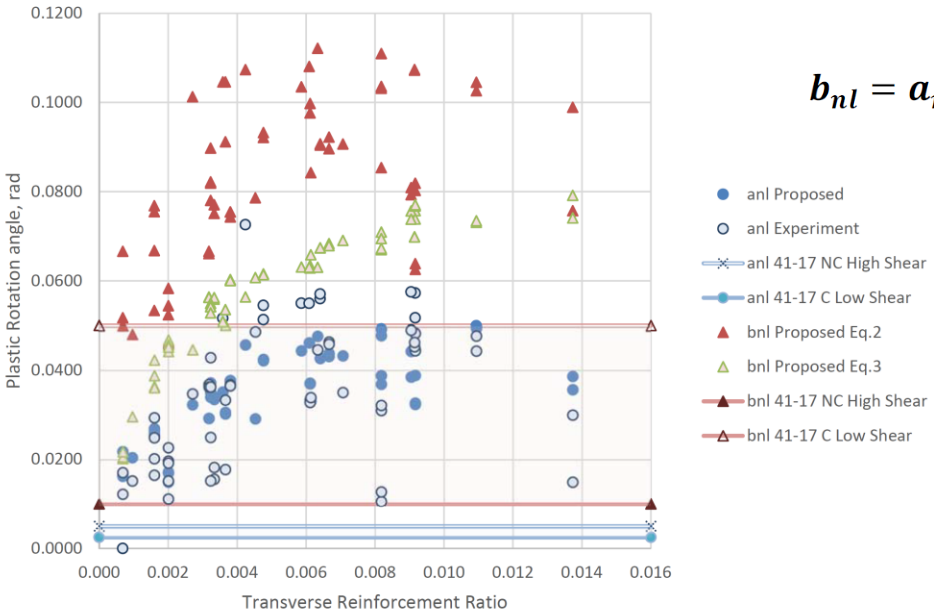
Recommendations to improve ASCE-61

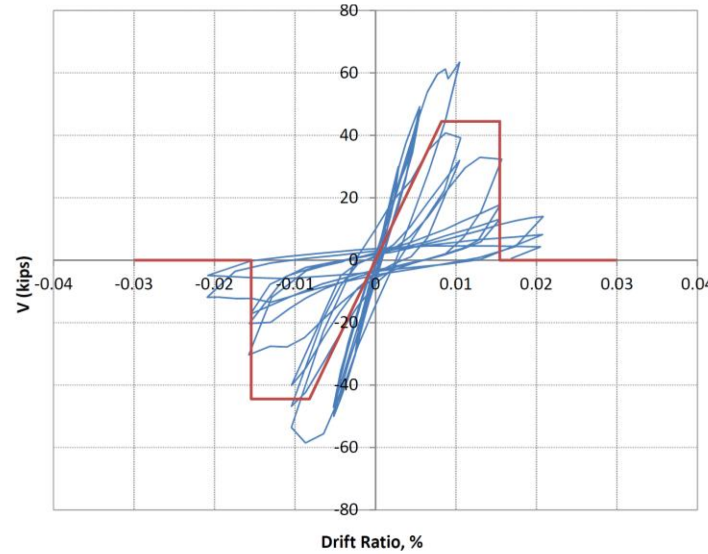
PBSD Parameters RC Beams (U of Texas, SA)

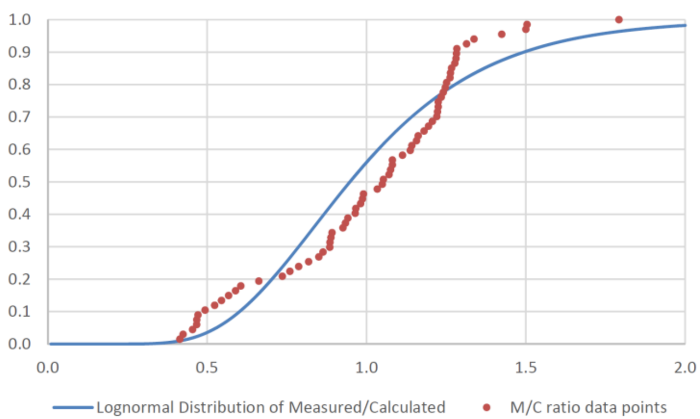
$$a_{nl} = k_{sc}\left(0.006\frac{M_{yE}}{V_{yE}\,d} + 0.0065\frac{V_{yE}}{b_w\,d\sqrt{f'_{cE}}} + 0.15\rho_t\frac{f_{ytE}}{f'_{cE}} - 0.0007\frac{s}{d_b}\right) - \theta_y \geq 0.0$$

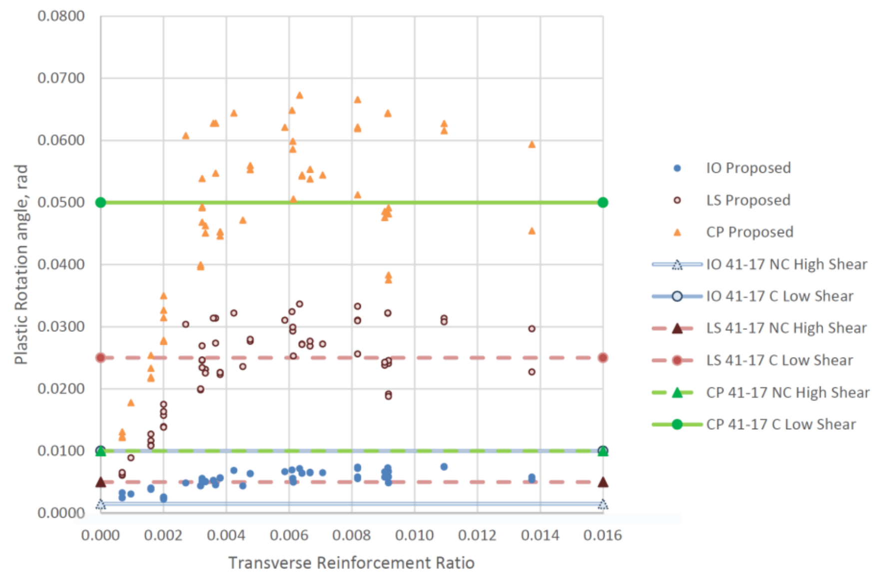
ACI 369/ASCE 41

$$b_{nl} = a_{nl} + 4\theta_y$$



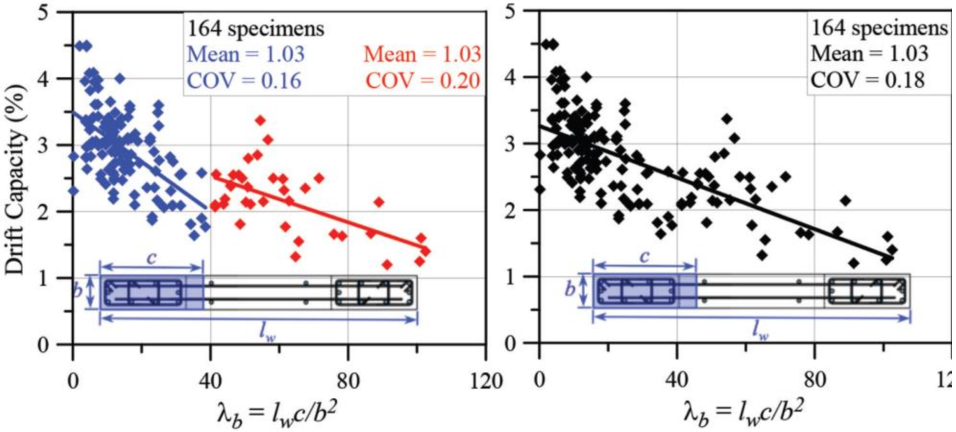




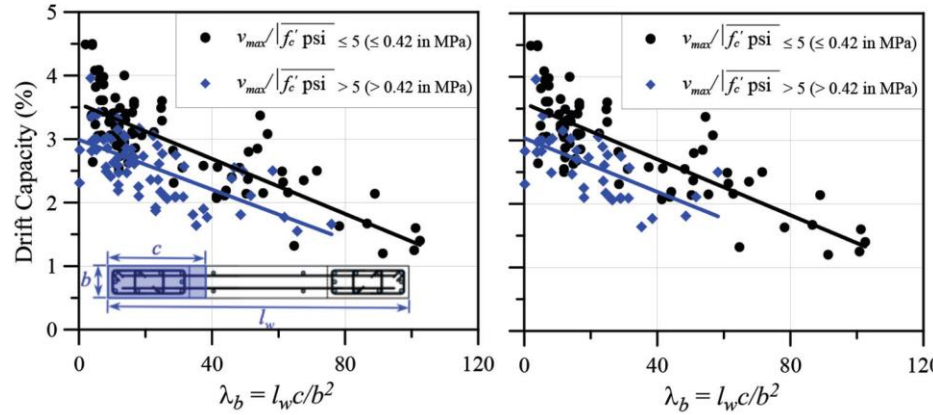


Slide Courtesy: Matamoros

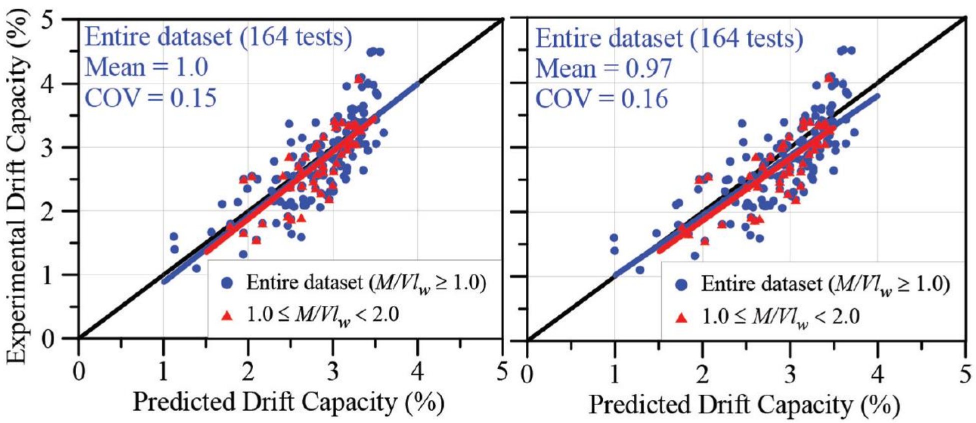
PBSD Parameters for RC Walls (UCLA)



(a) $0 \leq \lambda_b \leq 40$ and $40 < \lambda_b$ (b) $0 \leq \lambda_b$



(a) Entire dataset ($M/Vl_w \geq 1.0$) (b) $M/Vl_w \geq 2.0$



a) **Eq. 1** b) **Eq. 2**

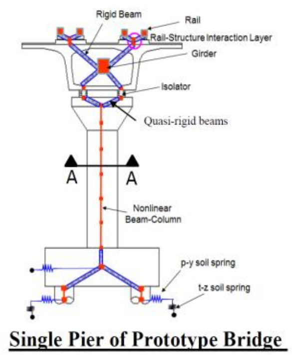
$$\frac{\delta_c}{h_w}(\%) = 3.85 - \frac{\lambda_b}{\alpha} - \frac{v_{max}}{10\sqrt{f_c' \text{psi}}}$$

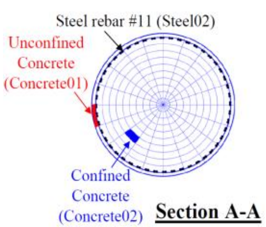
$$\frac{\delta_c}{h_w}(\%) = 4.0 - \frac{\lambda_b}{\alpha} - \frac{v_{max}}{10\sqrt{f_c' \text{psi}}}$$

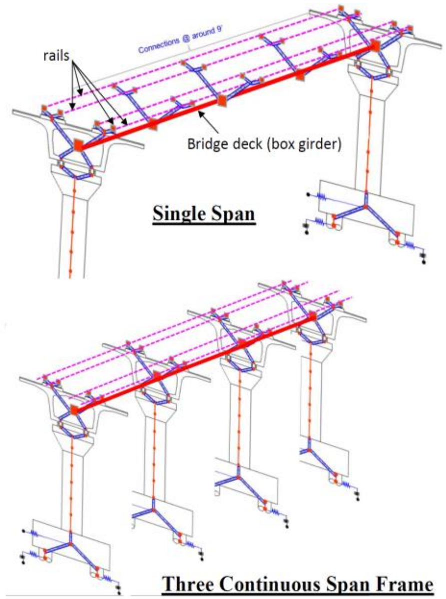
ACI 369/ASCE 41 & ACI 374

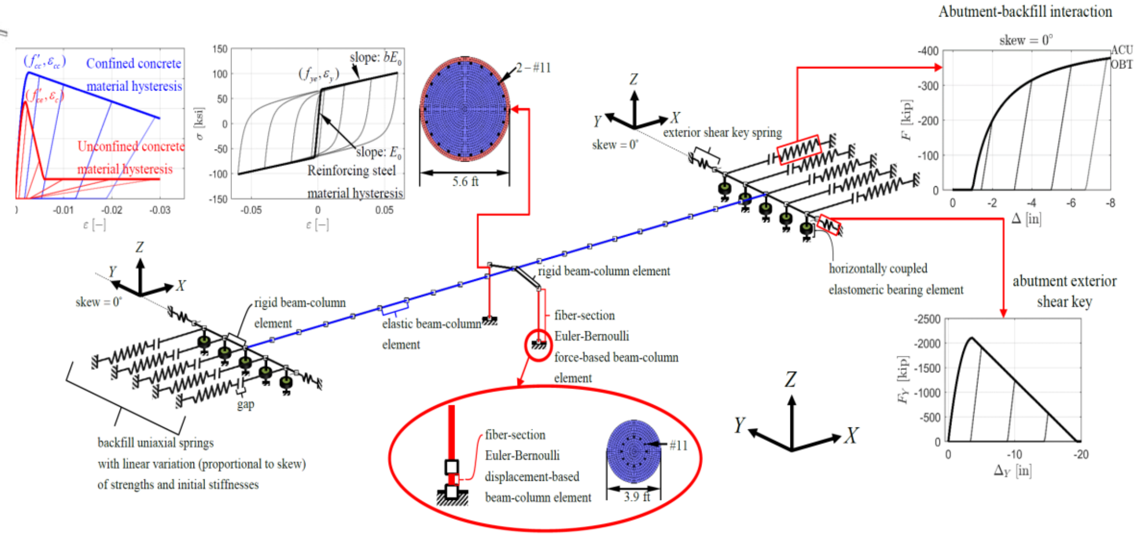
Slide Courtesy: Abdullah, Wallace

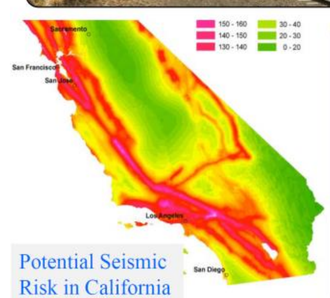
PBEE of Bridges/ CA High-Speed Rail (UCSD)

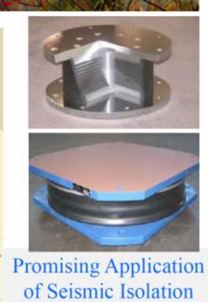




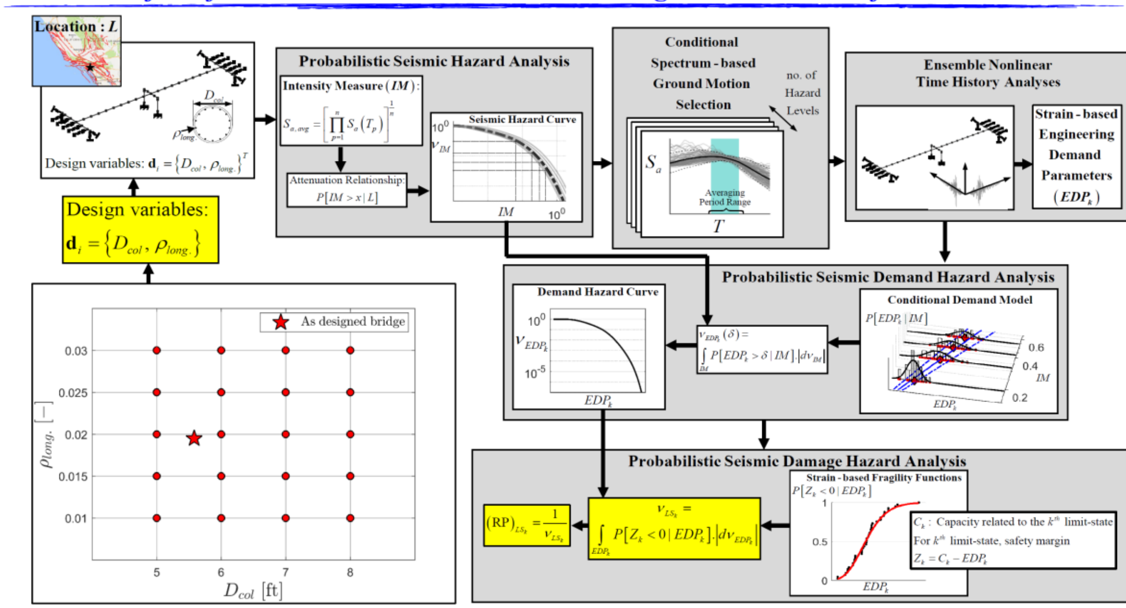








Overall Workflow for Full-blown Parametric Risk-Targeted Seismic Performance Assessment

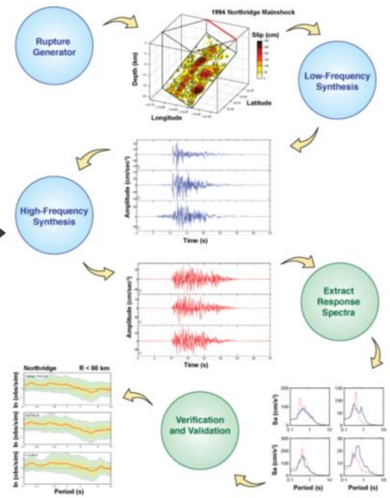


Slide Courtesy: Conte

PBEE of Bridges (UCI)

Generating simulated ground motions

- Site-based models
  - Stochastic
- Source-based models
  - Deterministic
  - Stochastic
  - Hybrid



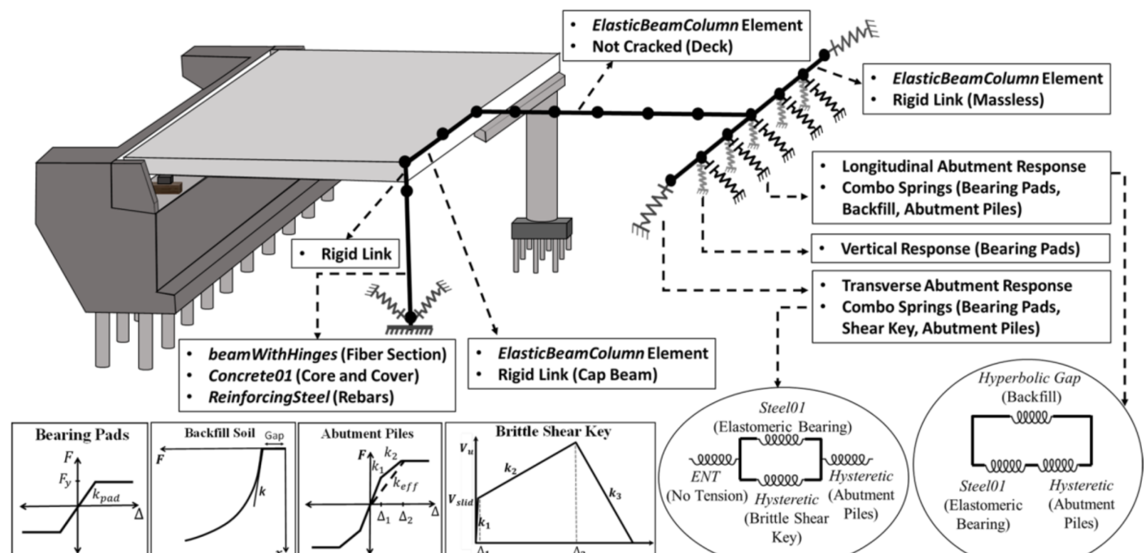
SIMQKE
(Gasparini and **Vanmarke**, 1976)

Stochastic Modeling and Simulation of Ground Motions for Performance-Based Earthquake Engineering

Sanaz Rezaeian
and
Armen Der Kiureghian
University of California, Berkeley

Stochastic Modeling and Simulation of Near-Fault Ground Motions for Performance-Based Earthquake Engineering

Mayssa Dabaghi
Armen Der Kiureghian
Department of Civil and Environmental Engineering
University of California, Berkeley

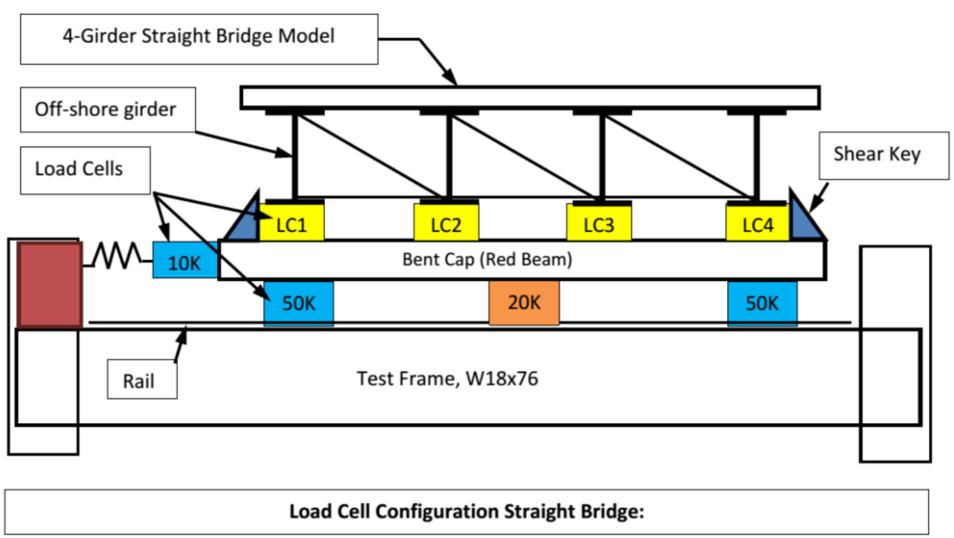


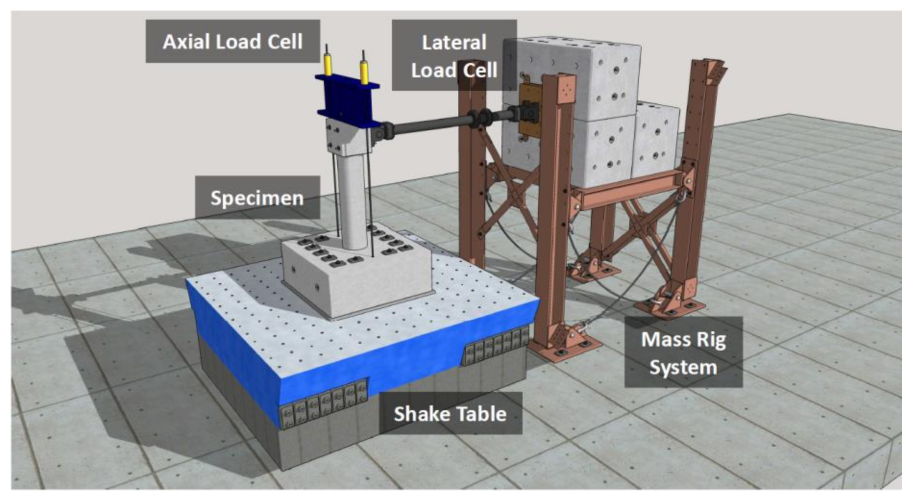
Slide Courtesy: Zarian

PBEE of Bridges (UNR)

Tsunami Effects

Long Dur. Effects





Slide Courtesy: Buckle, Moustafa

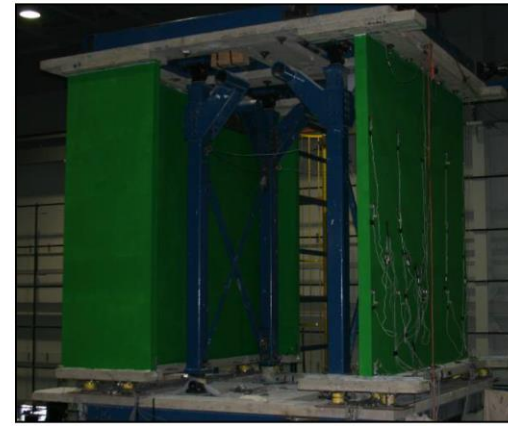
PBSD Non-structural Components (UCSD, UB, UNR)

NEESR GC: Simulation of the Seismic Performance of Nonstructural Systems

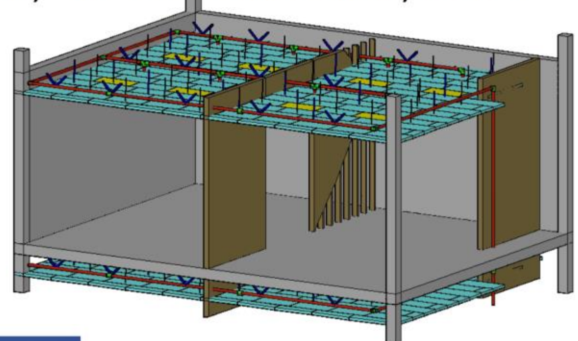
PI: Manos Maragakis, University of Nevada, Reno

Co-PI's: Tara Hutchinson, UCSD, Andre Filiatrault, U Buffalo,

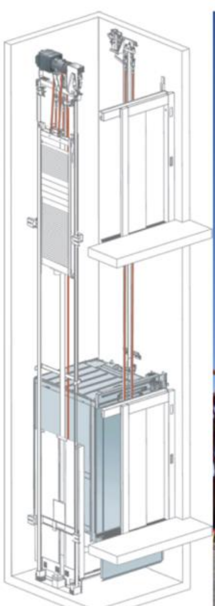
Steve French, Georgia Tech, Robert Reitherman, CUREE

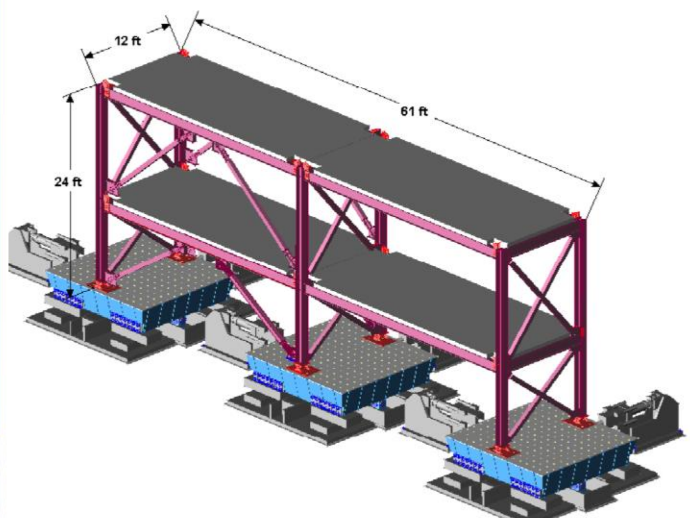


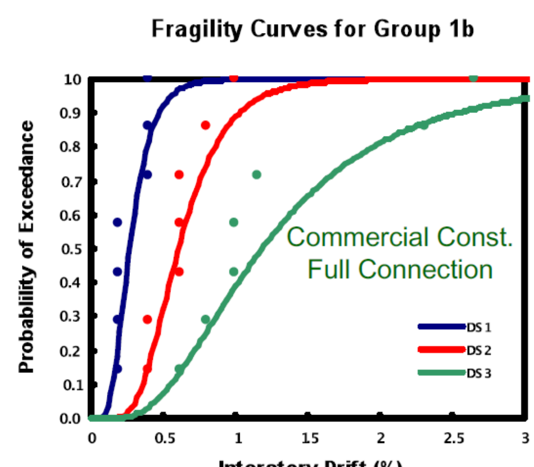
- Focus on seismic response of ceiling-piping-partition subsytems and their interactions



Ceiling Subsystem
Piping Subsystem
Partition Subsystem

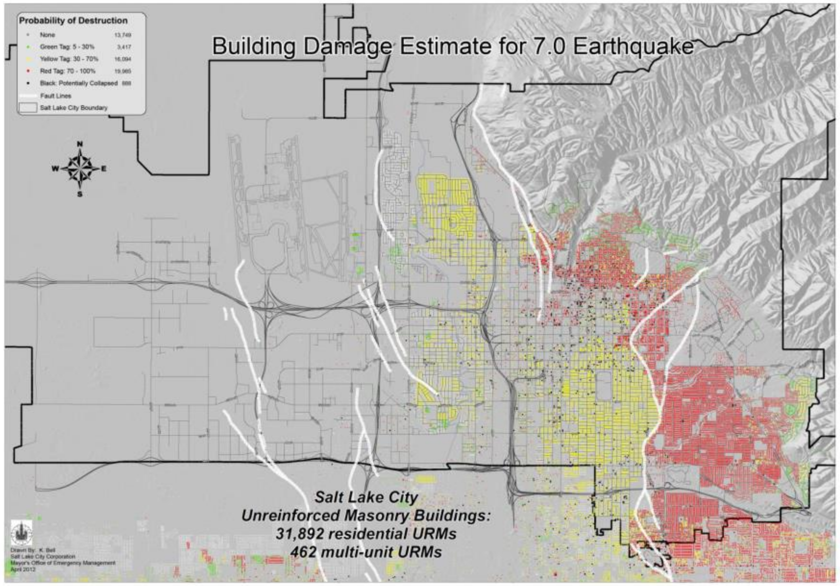






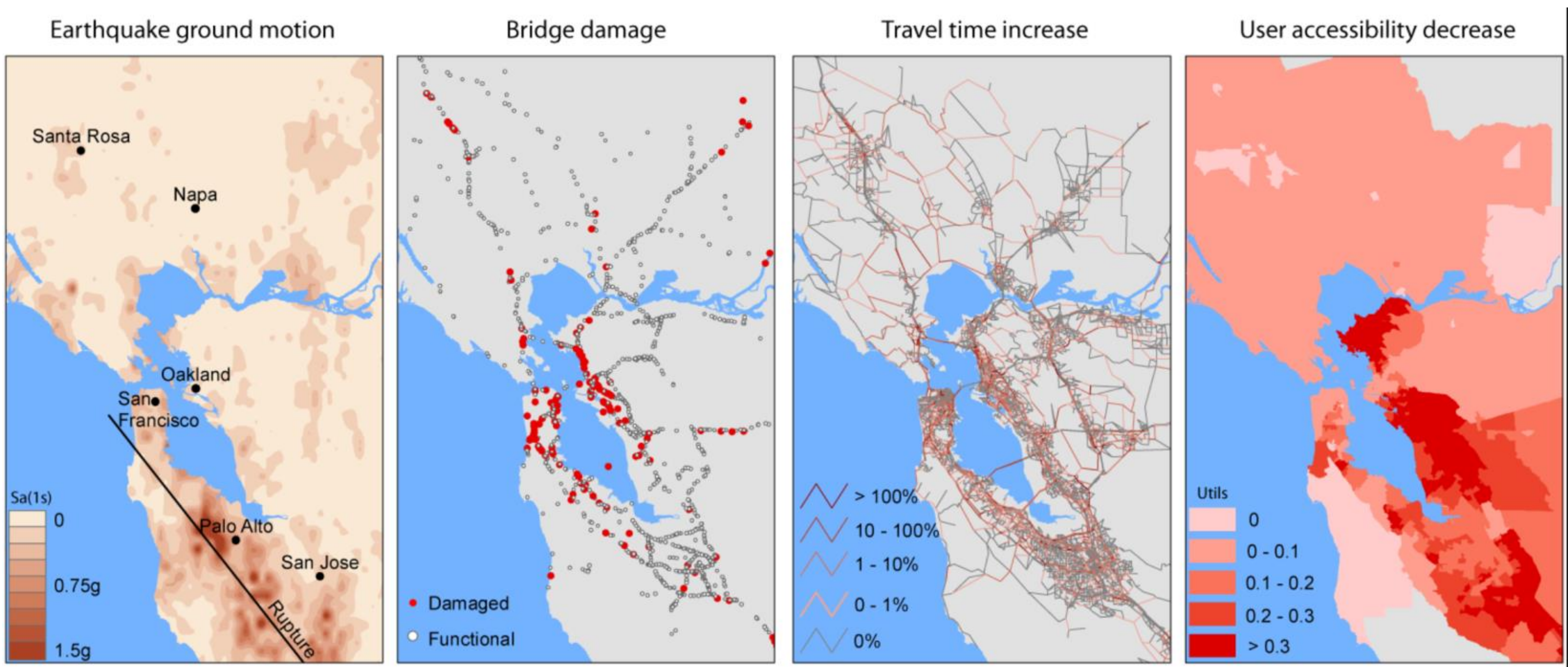
Slide Courtesy: Mosqueda

PBEE Regional Simulations (From Simple Hazus→ HPC)

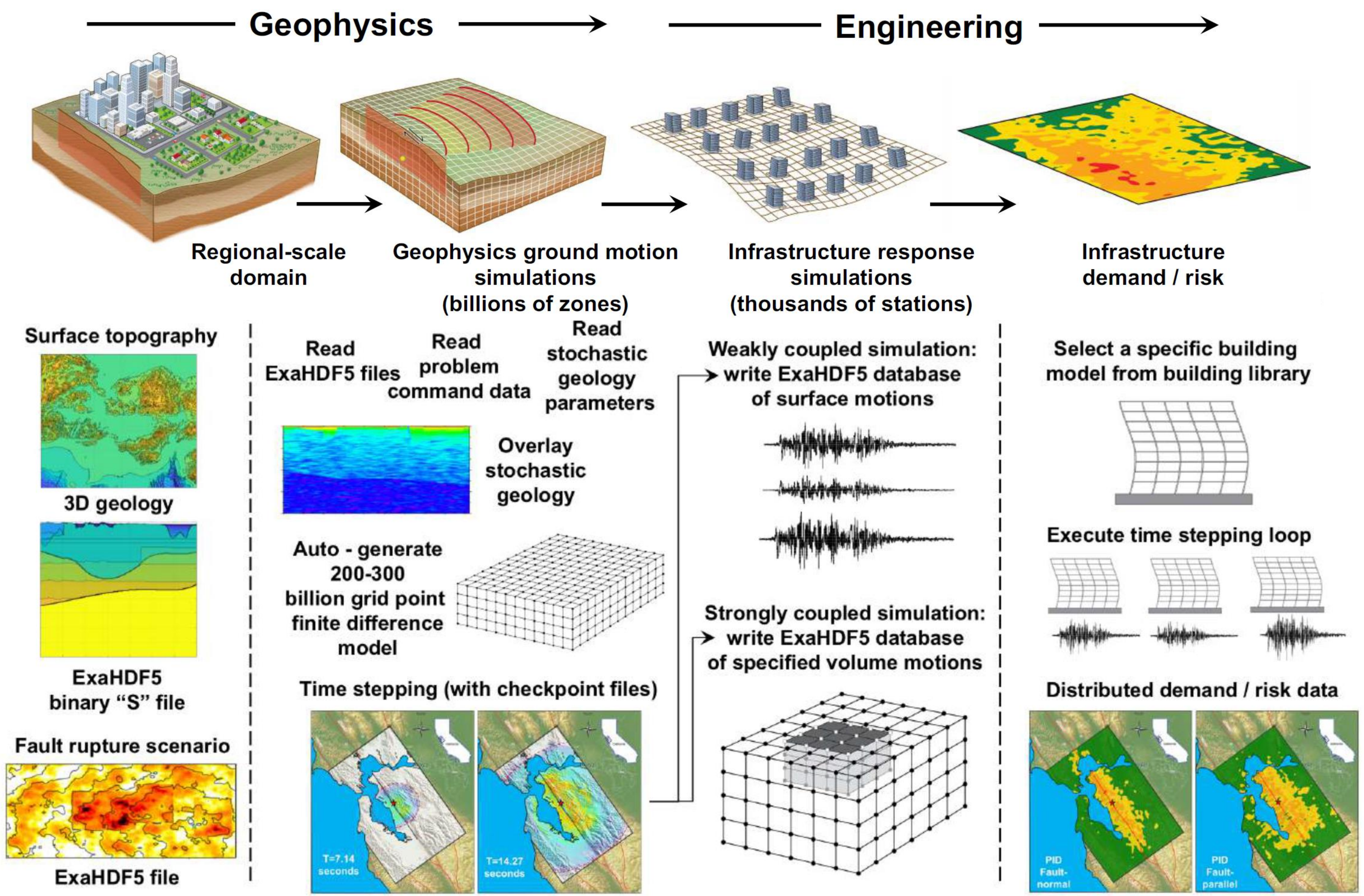


SLC URM DAMAGE M7.0

SF Bay Area Transp. Network, Baker

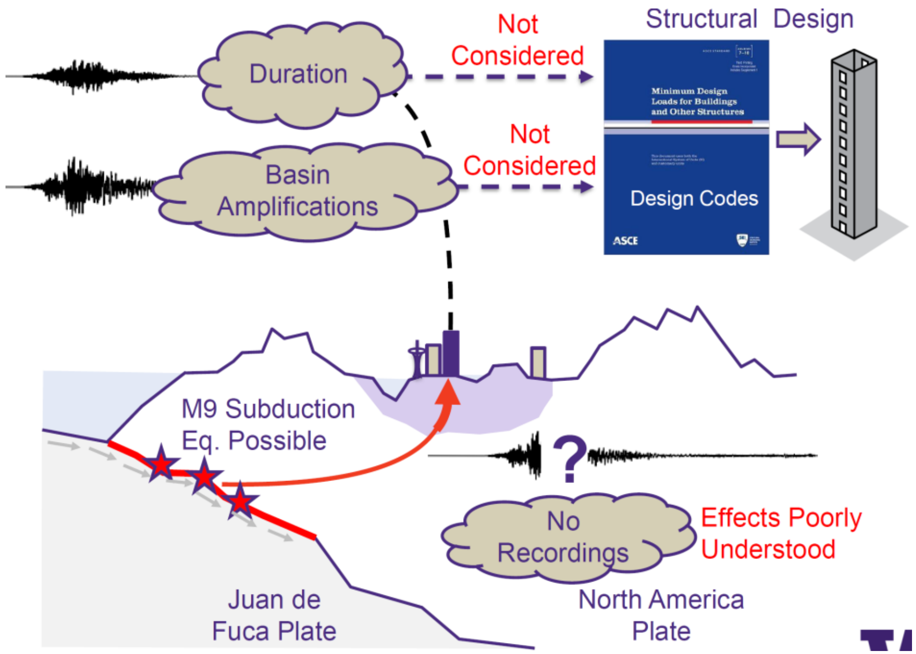


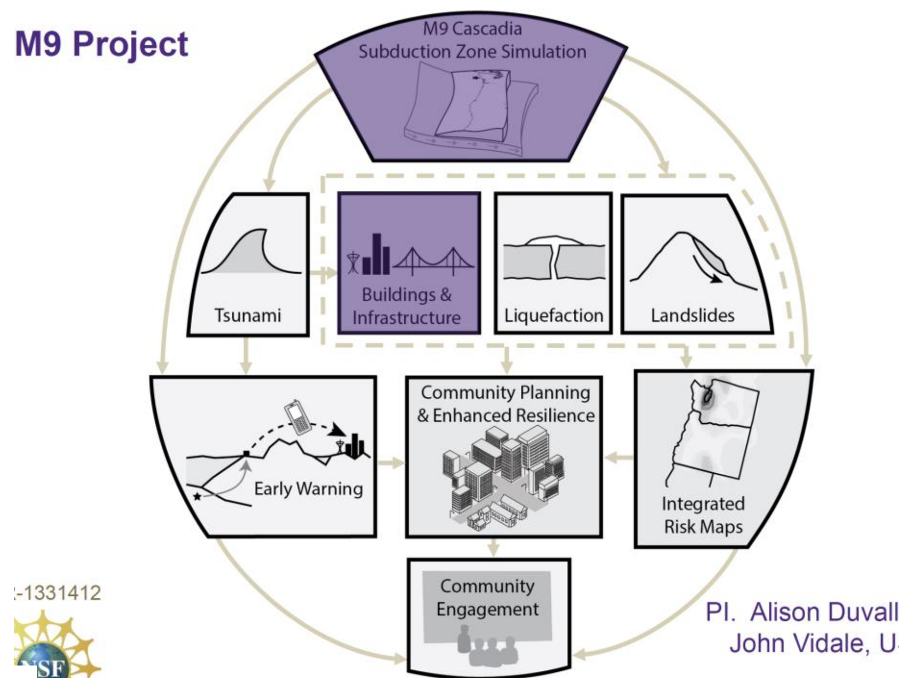
PBEE Regional Simulations (LBL, UNR)

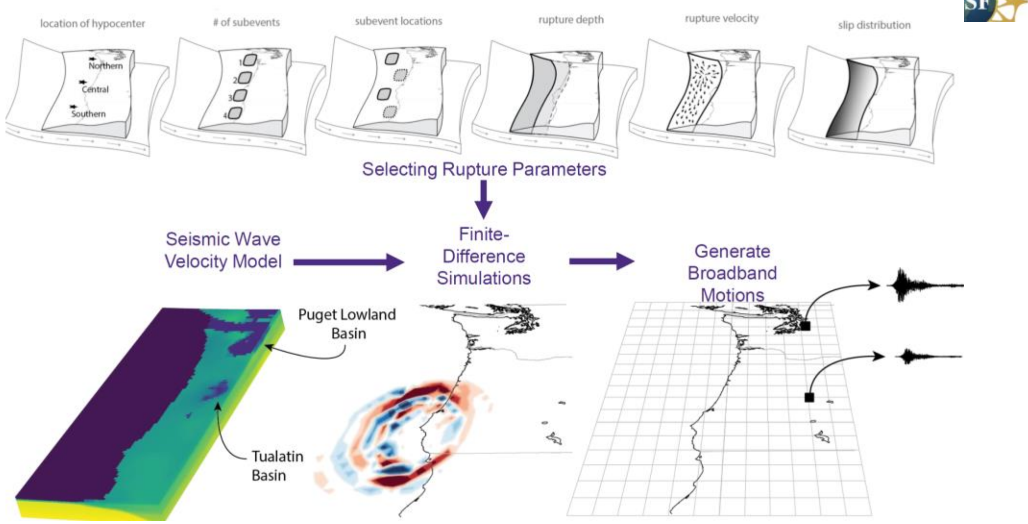


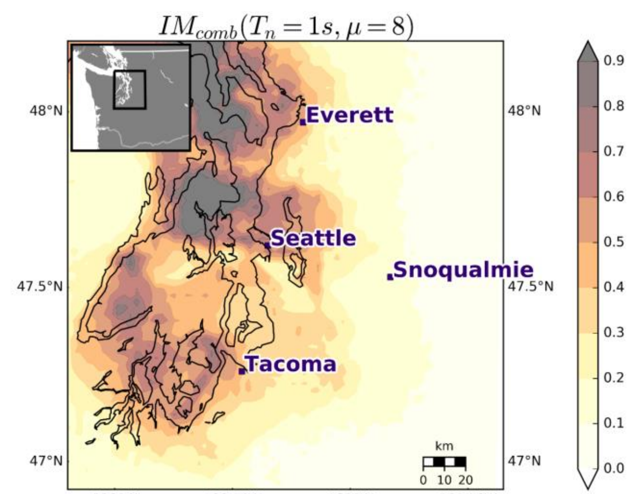
Slide Courtesy: McCallen

PBEE Regional Simulations (UW, The M9 Project)



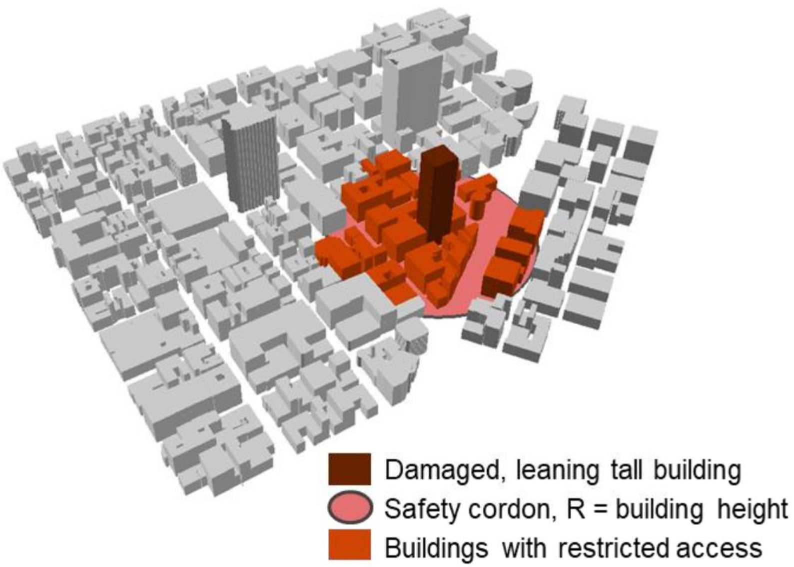


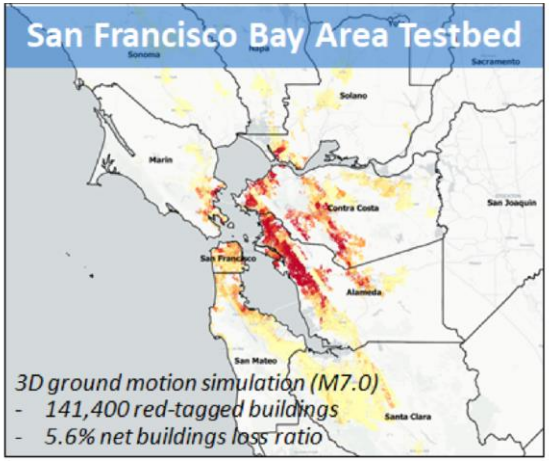


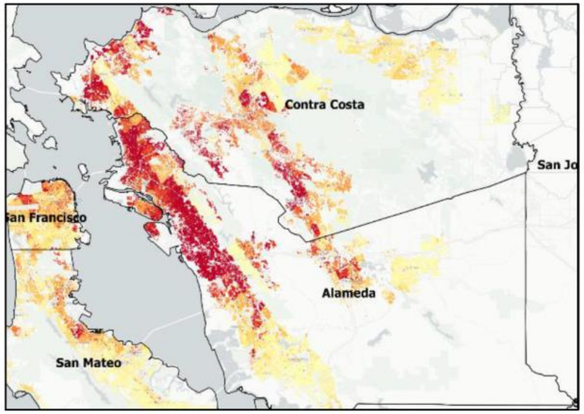


Slide Courtesy: Berman et al.

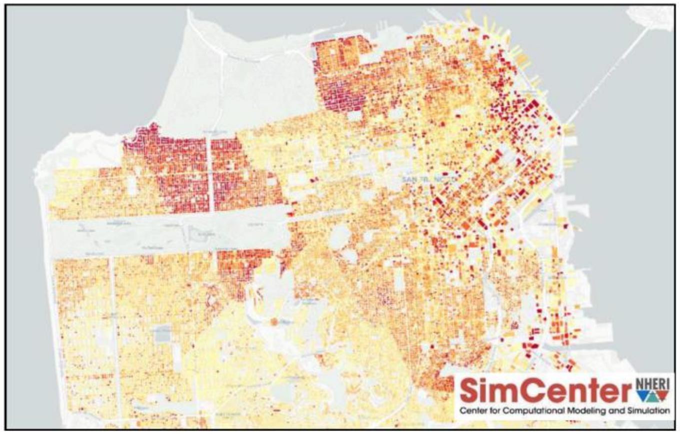
PBEE Regional Simulations (SF Tall Building Study)







Regional Simulation



San Francisco Parcels

Slide Courtesy: Ayse Hortacsu, SimCenter

Thank You

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