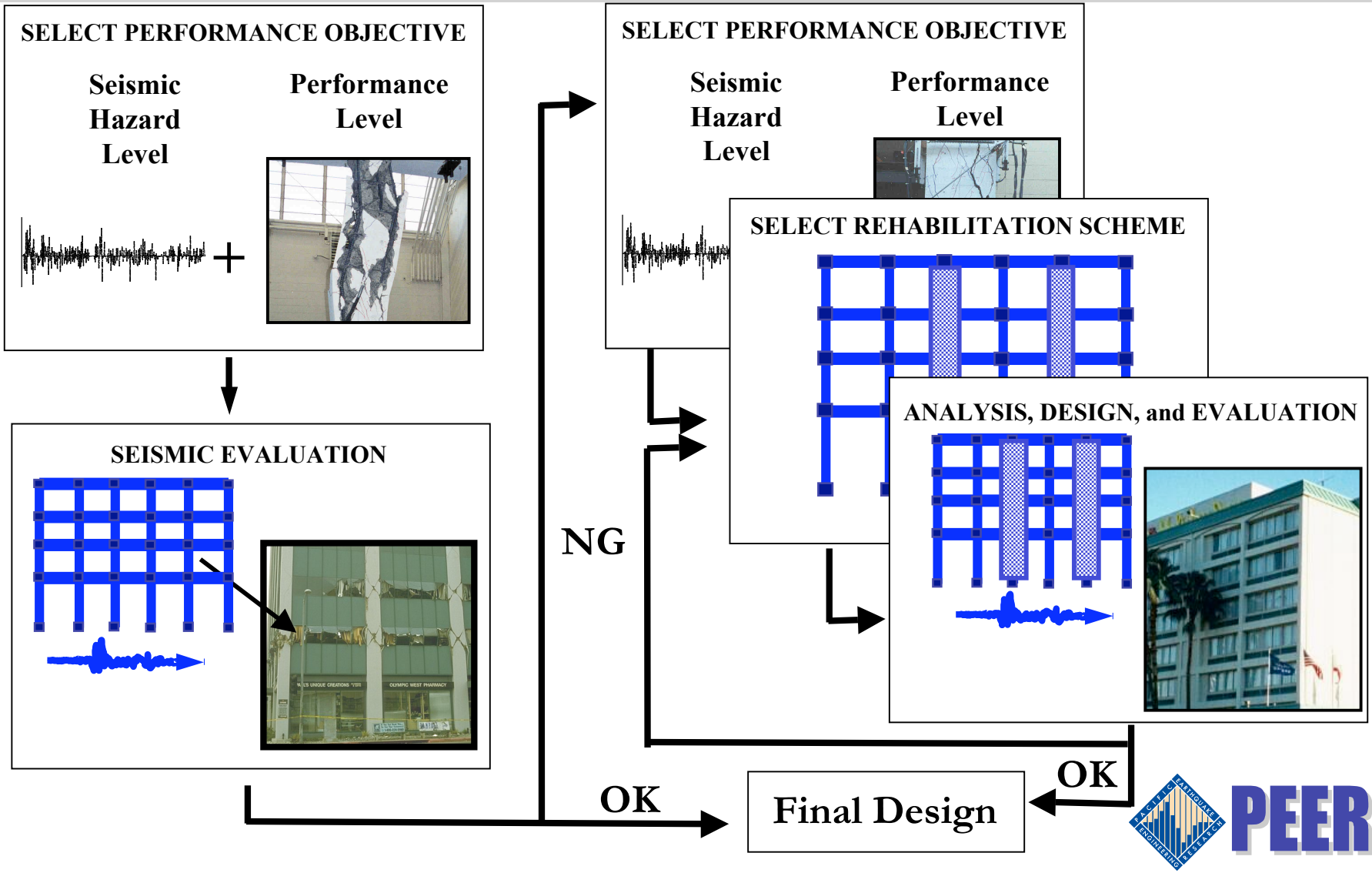
PBEE of Non-Ductile Reinforced Concrete Building Systems

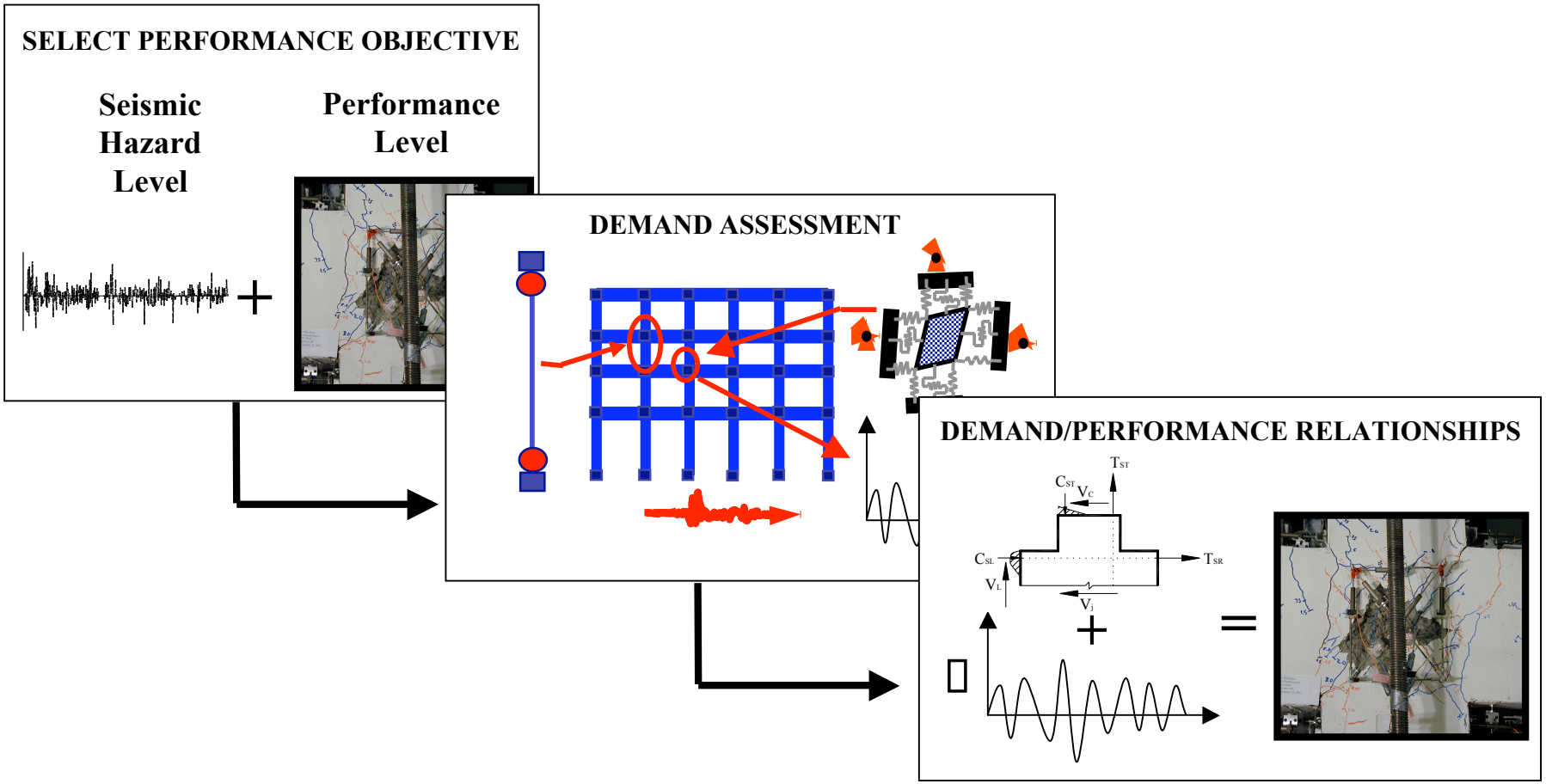
Dawn Lehman

University of Washington

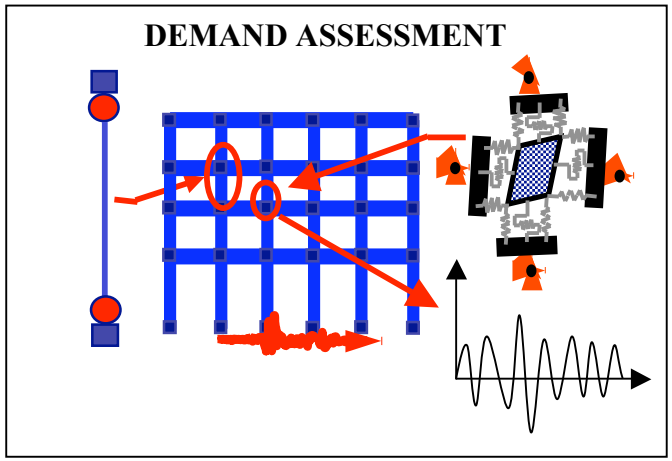
Seismic Rehabilitation Process

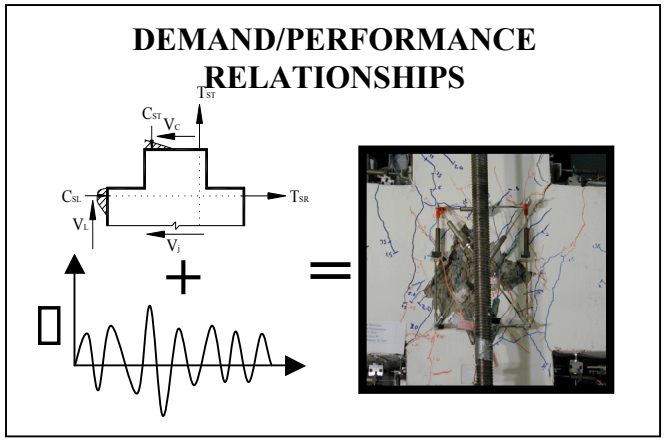


Seismic Evaluation Process



Tools for Seismic Evaluation





- Simulation Models
  - Component Models
  - System
- Performance Models
  - Component Performance (Damage/Repair)
  - System Performance
  - Demand-to-Damage (EDP to DM)

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PEER Research on Non-Ductile Buildings

- What have we done
  (Present state of knowledge)
- What are we doing
- What needs to be done
  (Future research needs and areas)

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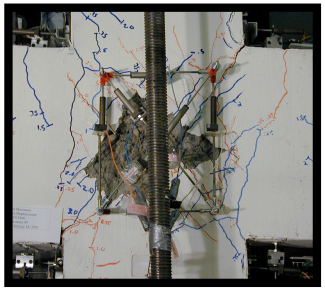
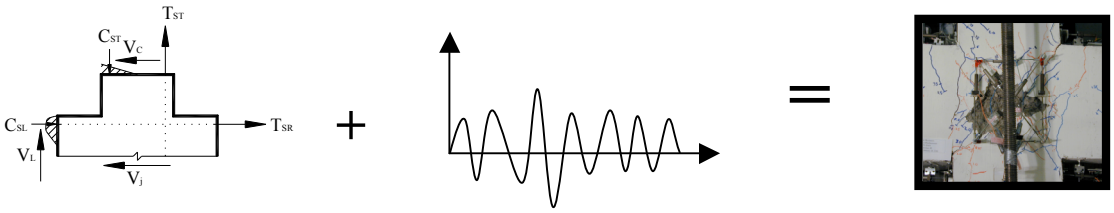
What Have We Done:
Experimental Research

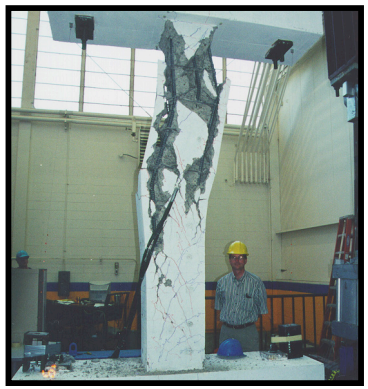
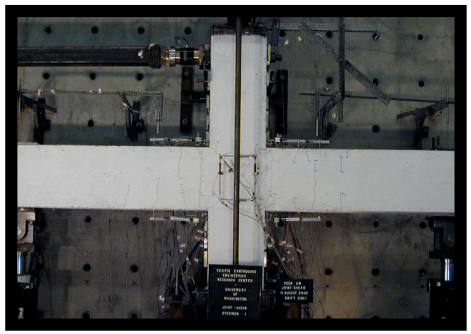
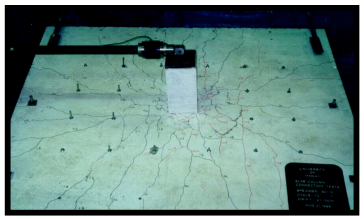
- Measure Component Response
  - "Typical" Geometries
  - Test Parameters: Shear and Axial Load, Displacement History
- Damage Assessment



- Demand-Performance Relationships



Experimental Research Program

	**Shear-Critical Columns** **Moehle, University of California, Berkeley**
	Columns with Splices **Wallace, UCLA**
	**Interior Beam-Column Joints** **Lehman and Stanton, UW**
	Exterior Beam-Column Joints **Pantelides, University of Utah**
	**Slab-Column Connections** **Robertson, University of Hawaii**

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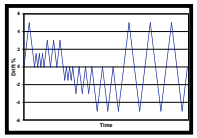
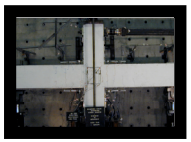
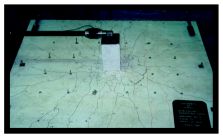
Study Parameters

	Test	v	$P/(A_g f'_c)$		f'_c	□
Columns		✓	✓	✓		
		✓	✓	✓		✓
B/C Joints		✓	✓			
		✓		✓	✓	
Slab Col.		✓				✓

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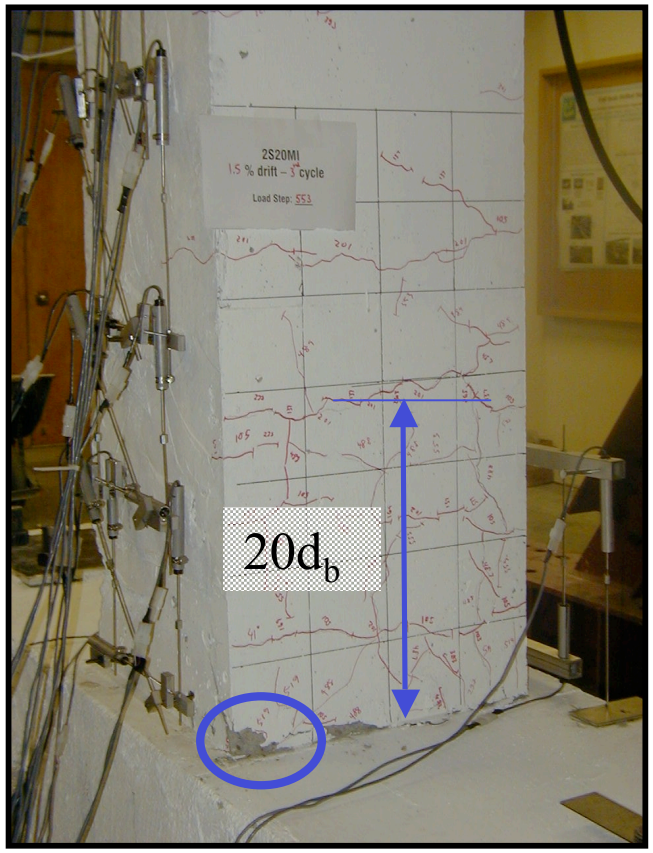
Damage Assessment



Initial Spalling **Severe Spalling** **Loss of Axial Load**

Melek and Wallace 2002

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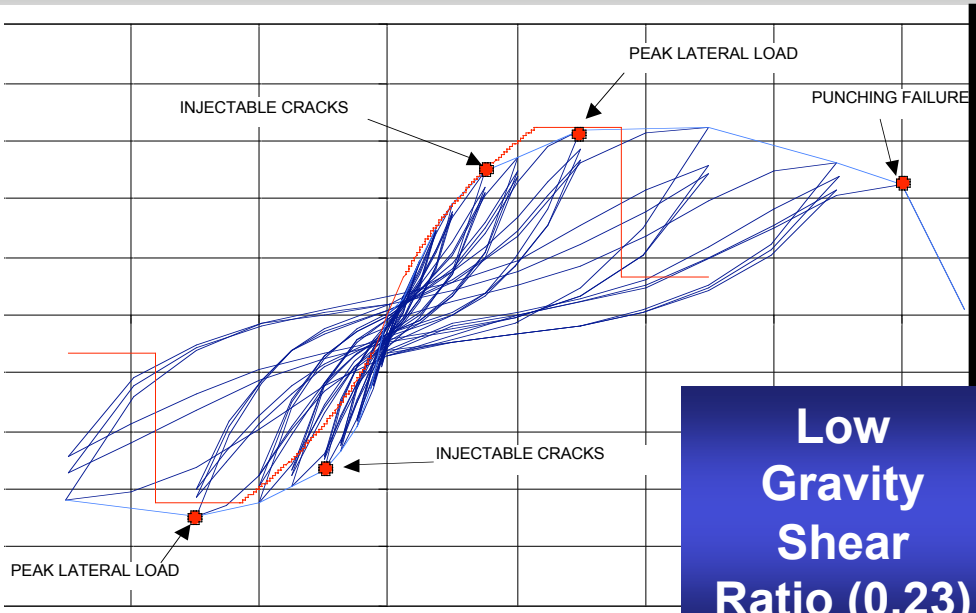
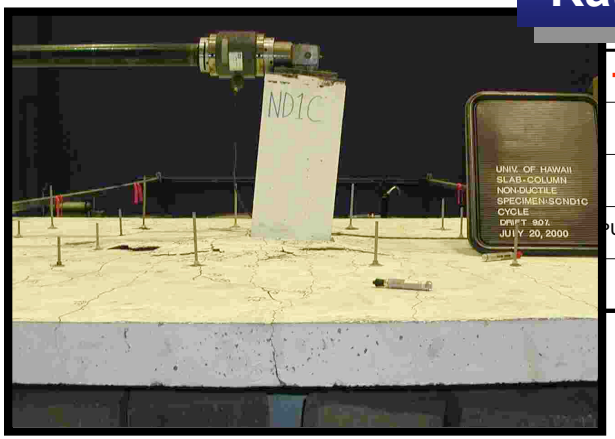
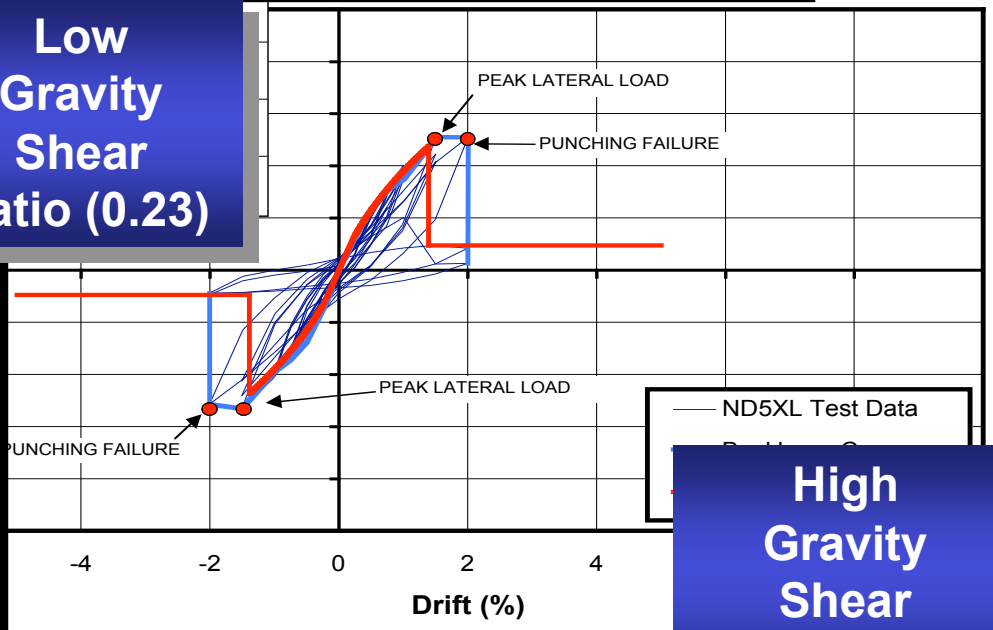
Influence of Salient Parameters: Gravity Shear Ratio



Low Gravity Shear Ratio (0.23)

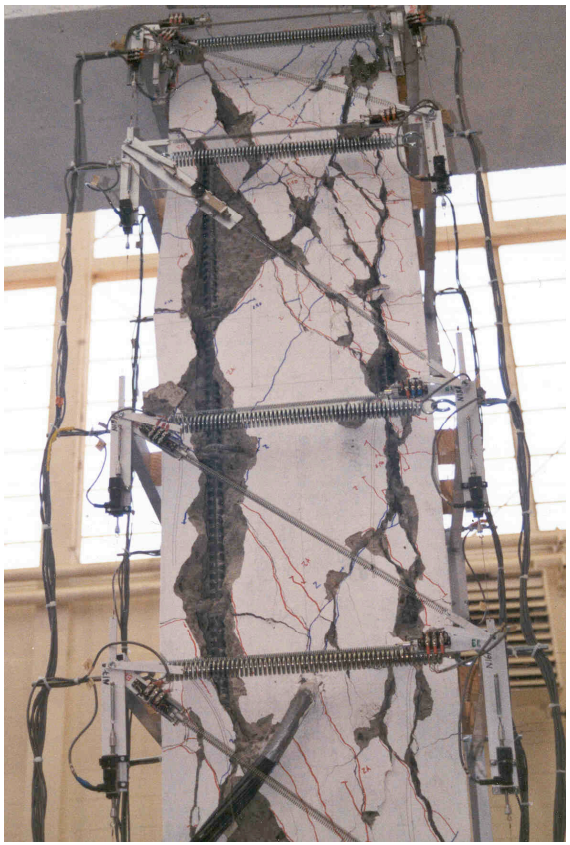




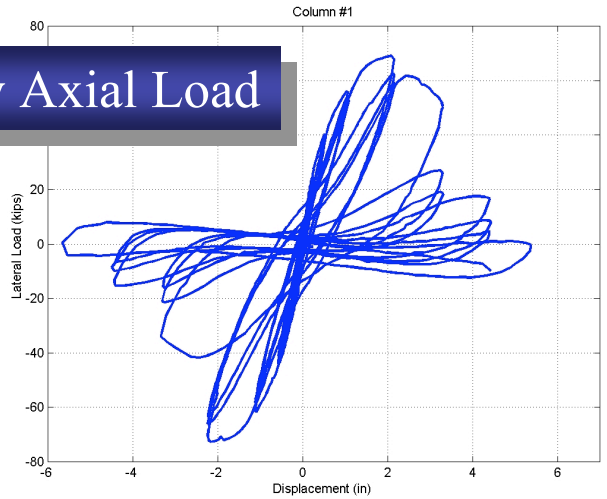
High Gravity Shear Ratio (0.47)

Robertson et al. 2001

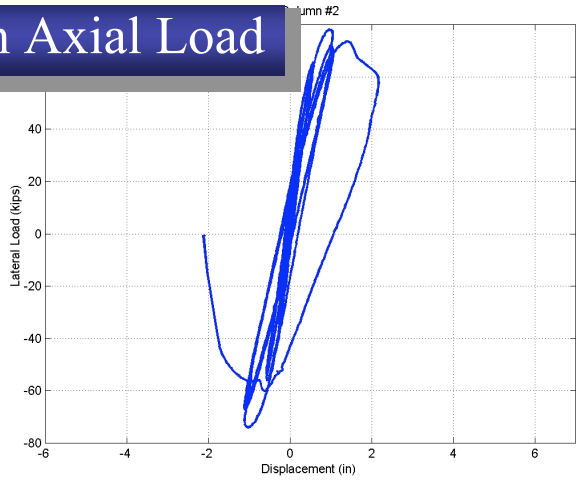
Influence of Salient Parameters: Axial Load Ratio



Low Axial Load



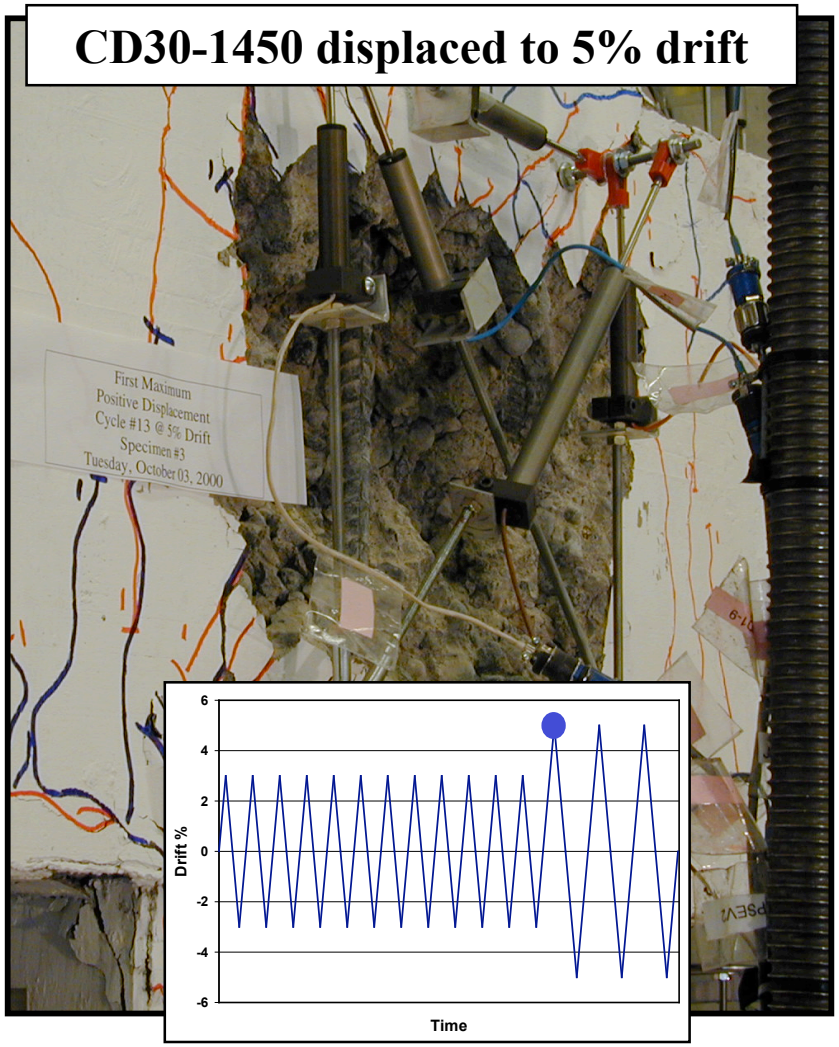
High Axial Load



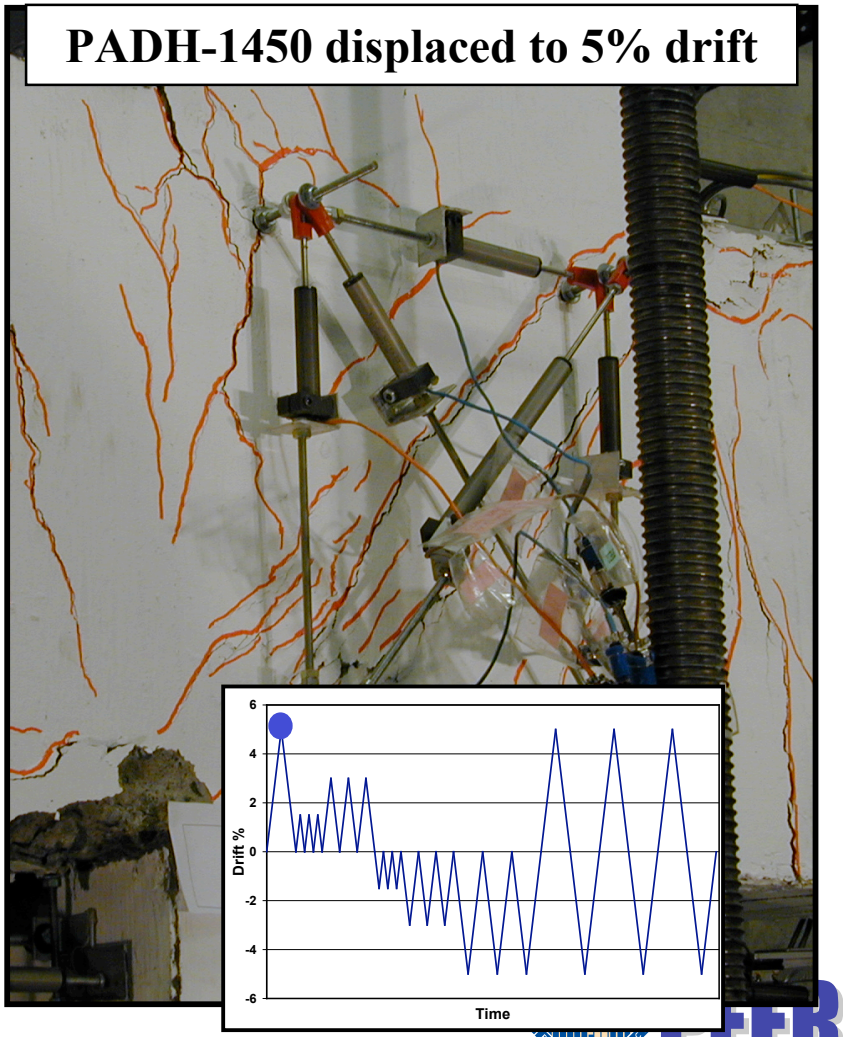
Moehle et al. 2001

Influence of Salient Parameters: Effect of Displacement History

CD30-1450 displaced to 5% drift

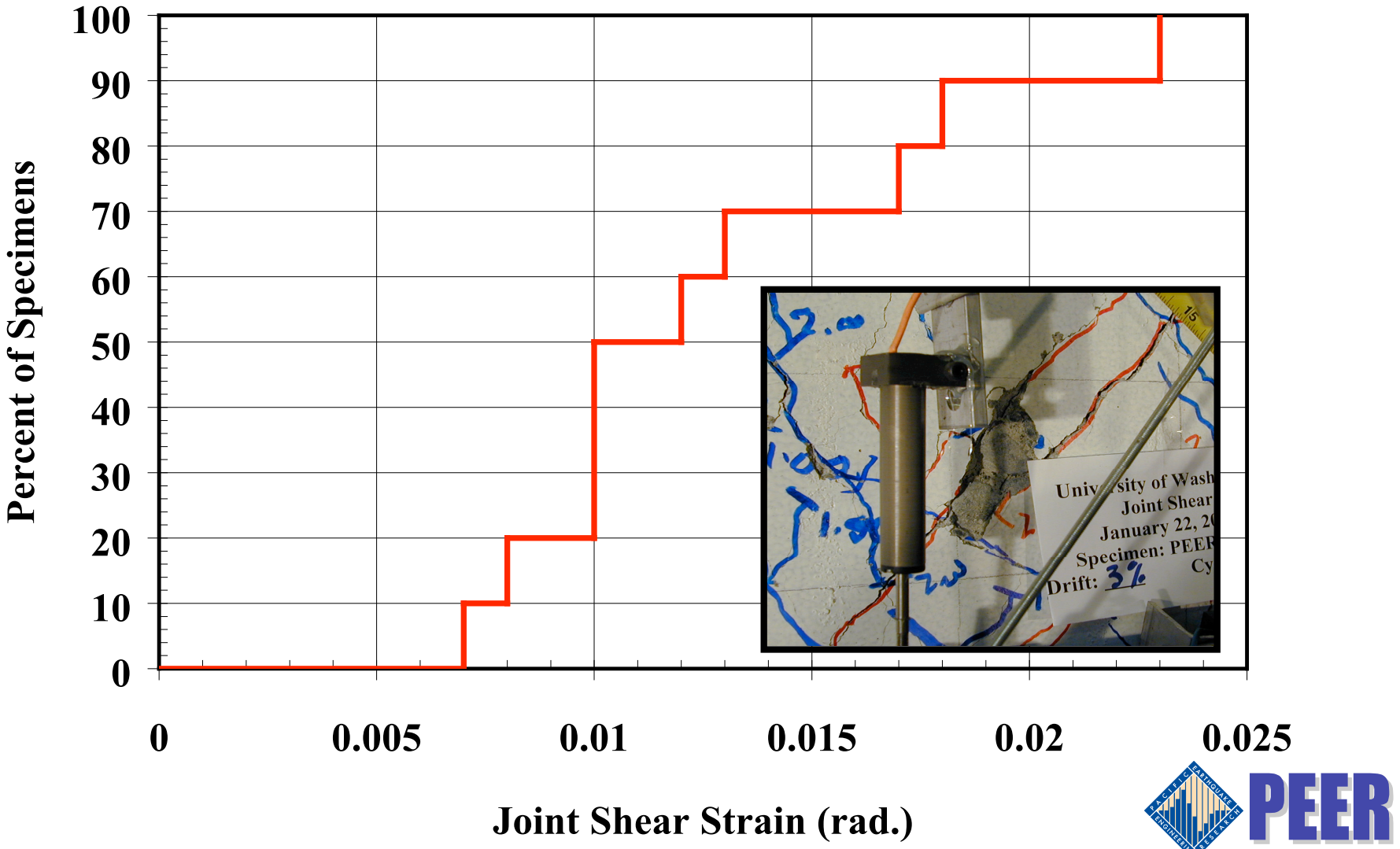


PADH-1450 displaced to 5% drift



Walker et al. 2001

Demand-Performance Relationships



What Are We Doing:
Seismic Evaluation of Building Test Bed

- Development and Validation of Simulation Models for Components
  - Beam-Columns, Joints, Slab-Column Connections
  - Lumped-Plasticity Models
  - Macro-Element Models
- Demand-Performance Relationships
  - Performance Related to Repair Costs
  - Fragility Curves
- Performance Evaluation
  - 2-D Model (3-D under development)
  - Multiple Performance Levels

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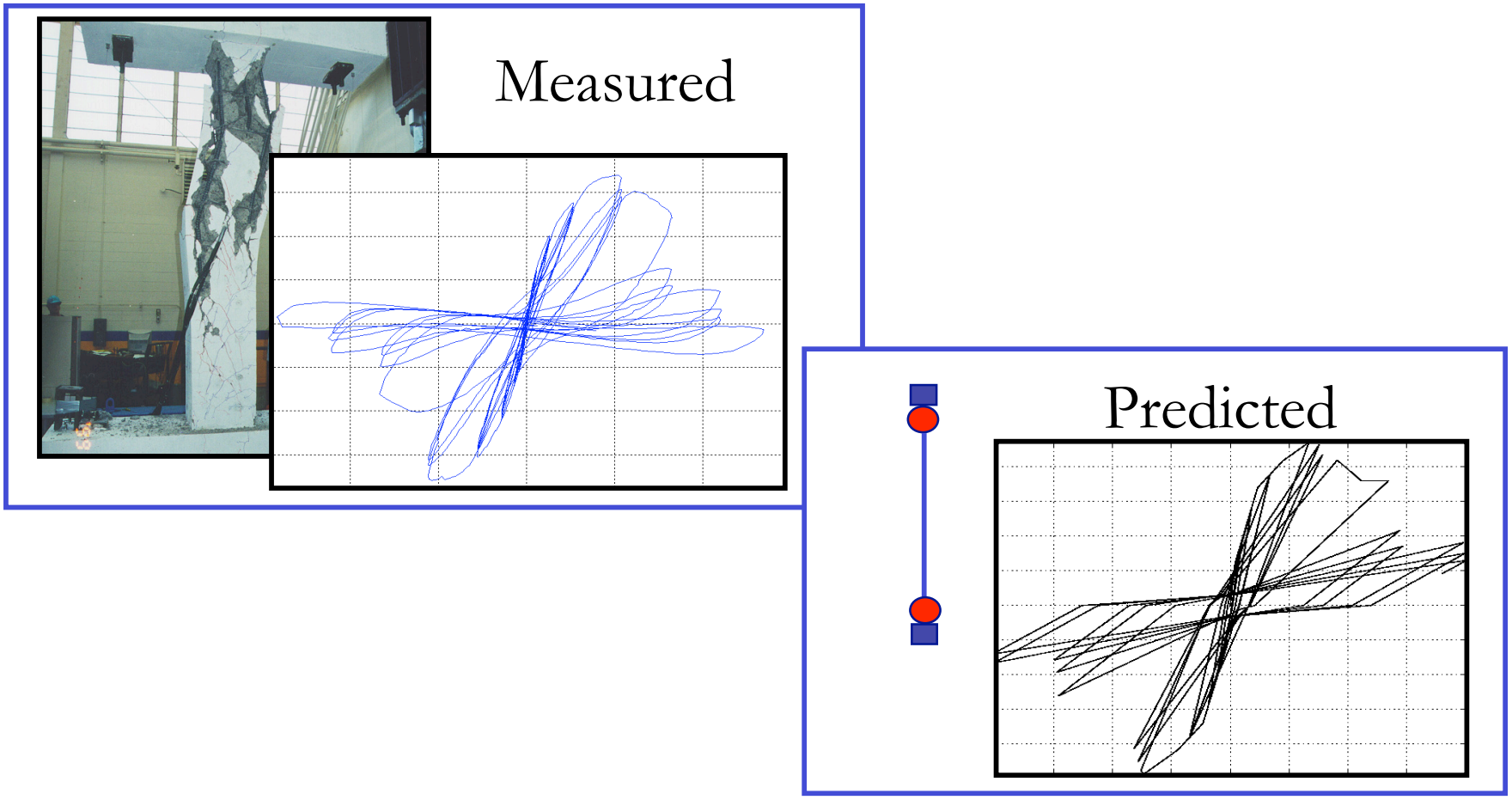
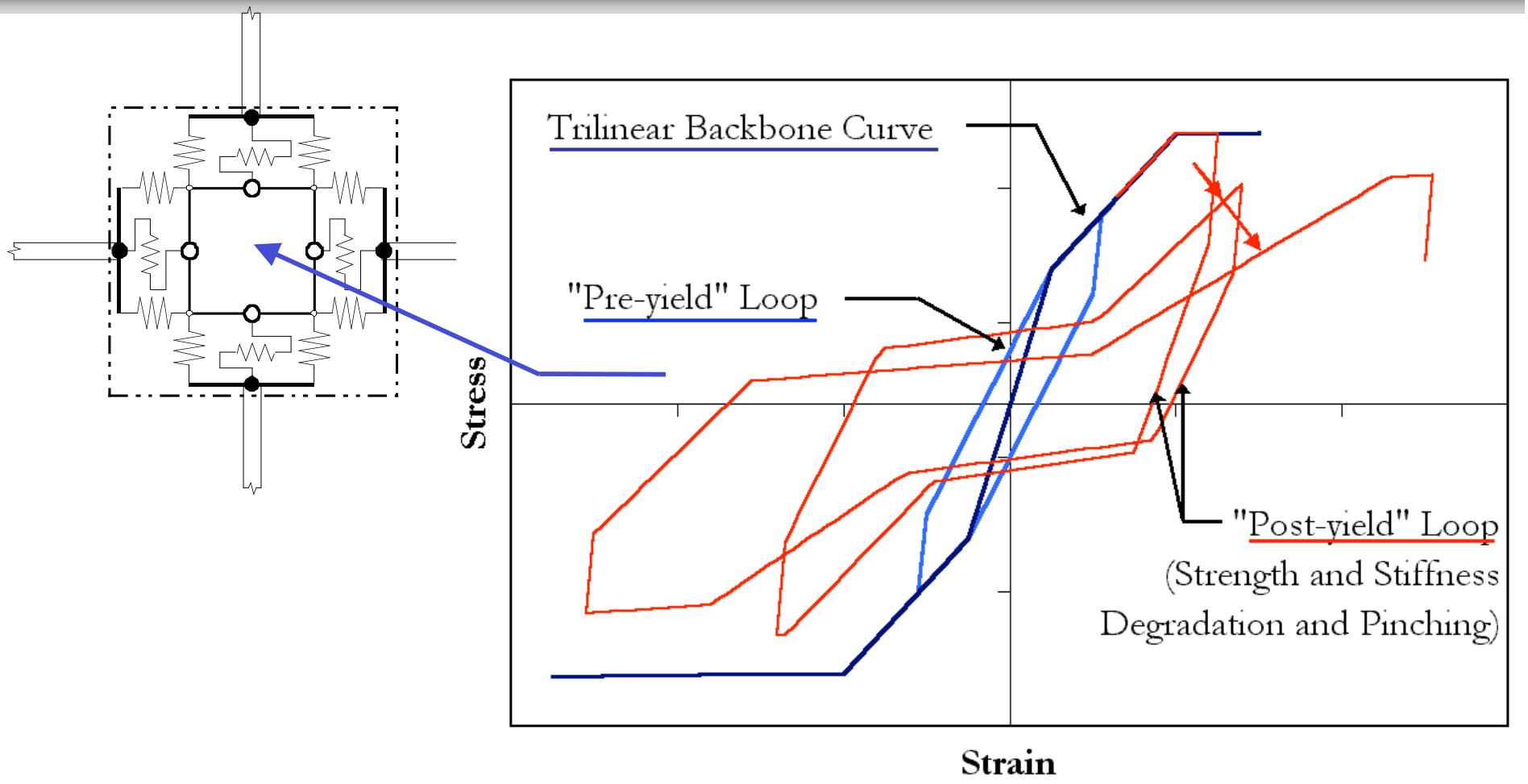
Simulation Models: Lumped Plasticity



Simulation Models: Macro-Element



Simulation Models for Building Components OpenSEES

- Beam-Column Elements
  - ➳ Lumped Plasticity
  - ➳ Shear-Critical (under development)
  - ➳ Splice (under development)
- Beam-Column Joint Elements
  - ➳ Rotational Spring
  - ➳ Macro-Element (under development)
- Slab-Column Elements (under development)

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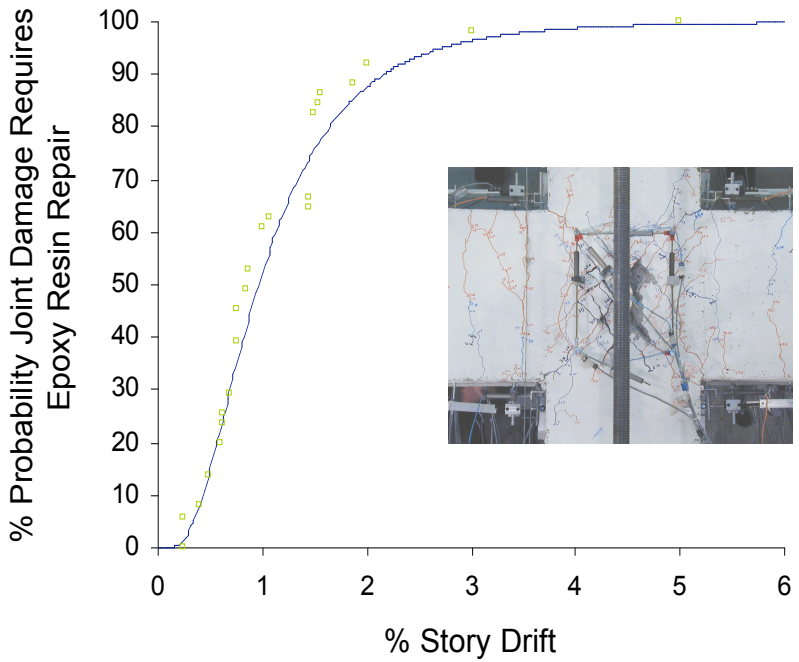
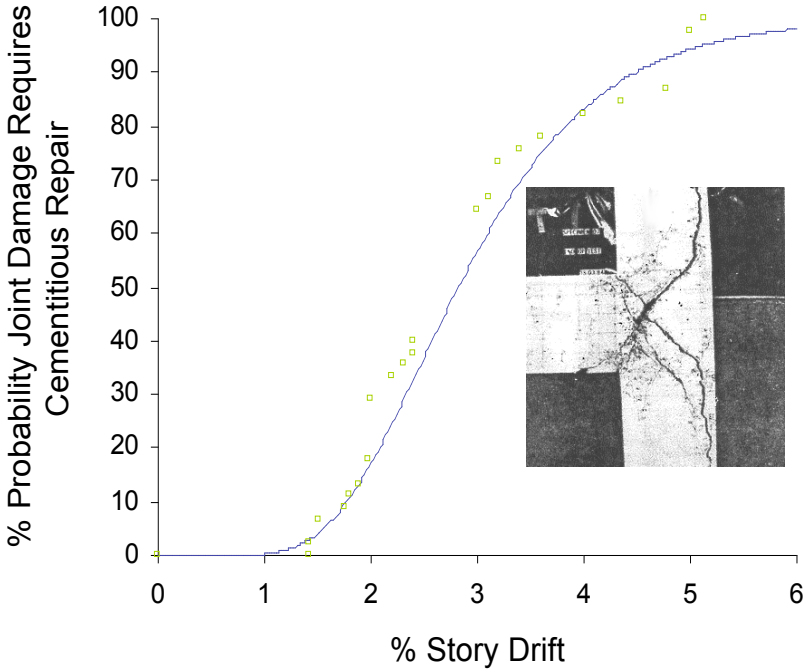
Demand-Performance Relationships
(from Pagni and Lowes 2003)

Damage Level 1: Epoxy Injection



Damage Level 2: Cementitious Material



Performance Evaluation of Test Bed
(Lowes et al. 2003)

- **2-D Model with one exterior and one interior frame**
- **Foundations are assumed rigid**
- **Columns, beams, slabs modeled using**
  - **Lumped-plasticity beam-column elements**
  - **Fiber-sections to computer M-curvature relationships**
  - **Column splice failure is modeled using reduced steel yield strength and reduced strain capacity**
  - **Column shear failure is modeled using a brittle-type shear spring that is not hysteretic**

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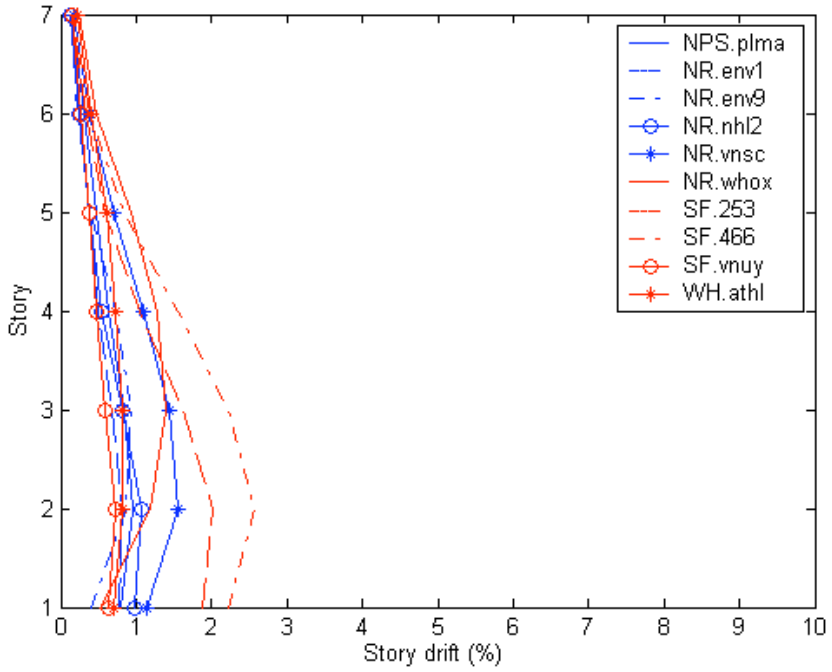
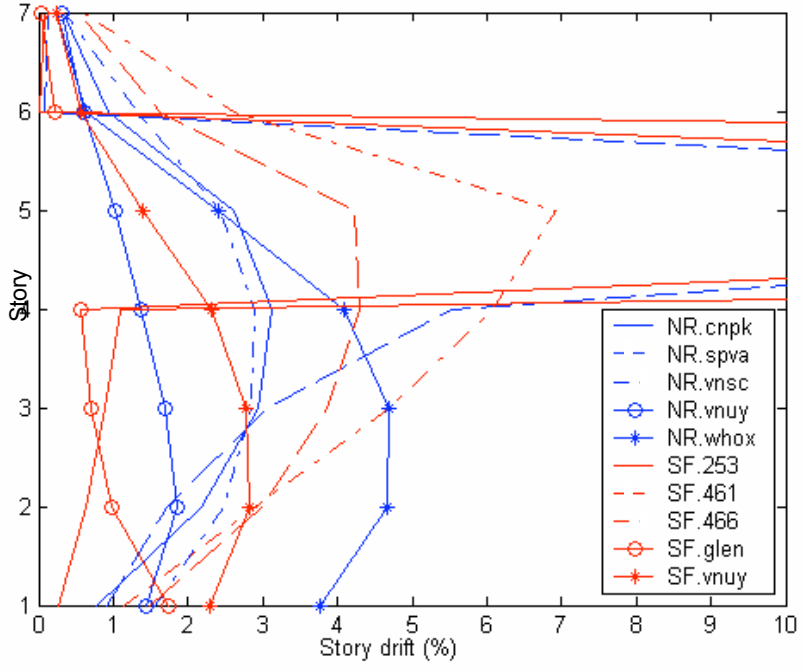
Performance Evaluation (Lowes et al. 2003)



Seismic Hazard Level:
50% Chance of Exceedence in 50 Years



Seismic Hazard Level:
10% Chance of Exceedence in 50 Years

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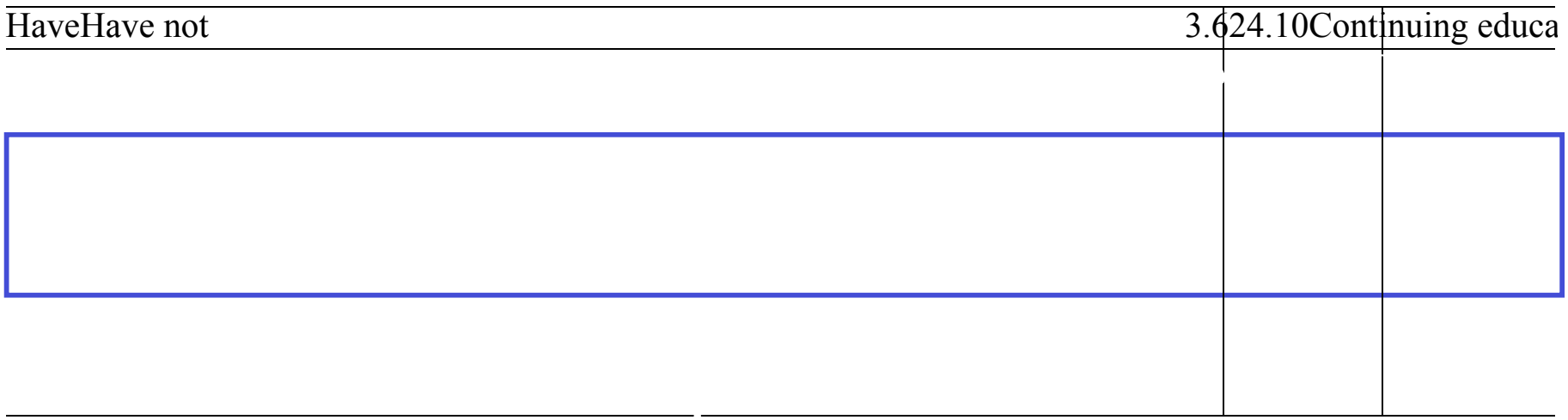
Future Research Needs

What Would Help You in Practicing PBEE?

(Those who HAVE practiced PBEE vs. Those who HAVE NOT)



Survey of SEAW Engineers on Use and Adoption of PBEE

Meszaros, Fransisco, and Lehman 2003

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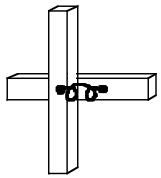
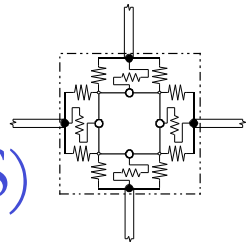
Simulation Models for Demand Evaluation

- Model of System
  - 2-Dimensional Models
  - 3-Dimensional Models
  - Verification Test(s)
- Component Models
  - Short-Term:
    Simplified tools in existing software
  - Long-Term:
    Advanced model formulation (OpenSEES)
  - Component Interaction





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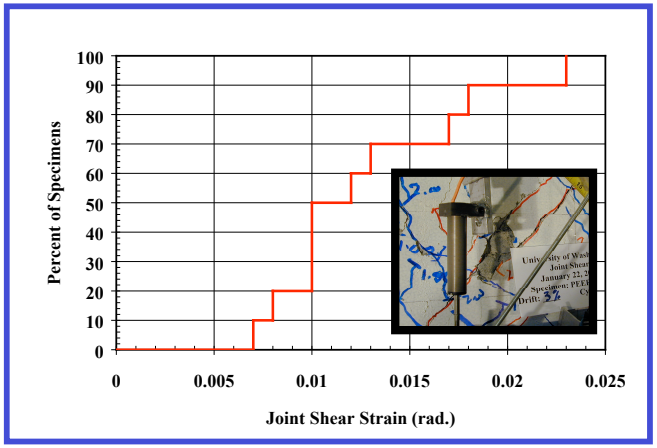
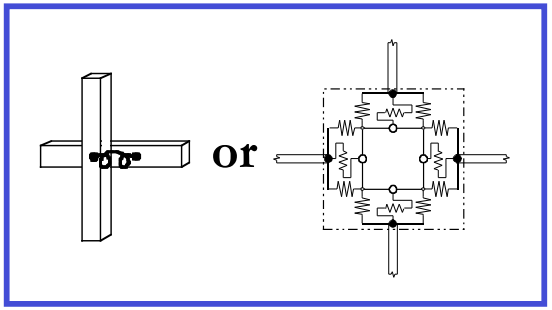
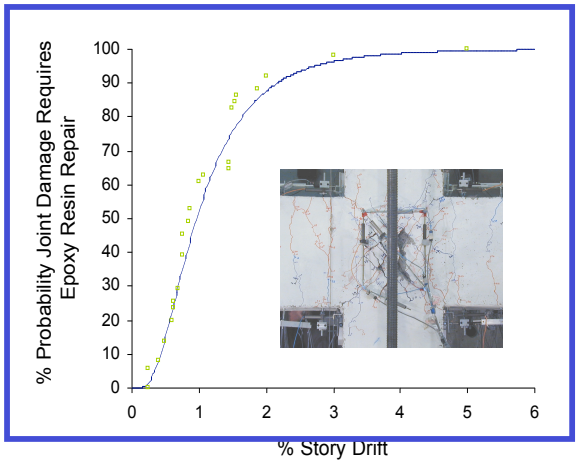
Performance Evaluation

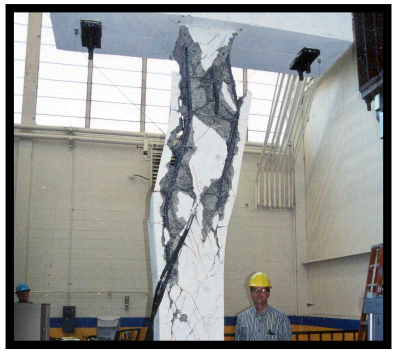
$EDP_{experiment}$ → EDP_{model} → $DM_{component}$







$DM_{component}$ → DM_{system}



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Component Evaluation

- Study Parameters
  - ✳ **Shear Demand**
  - ✳ **Axial Load Demand**
  - ✳ **Geometry (e.g., eccentric beams)**
  - ✳ **Reinforcement Details (bond, anchorage)**
  - ✳ **Displacement History (model validation, response)**
  - ✳ **Material (e.g., concrete strength)**
- Other Considerations
  - ✳ **Component Interaction**
  - ✳ **System Verification**

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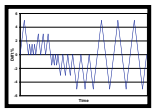
Evaluation of Component Response

Component	v	P	f'_c	□		Geometry
Joints 	✓	✓	✓	✓	✓	
Beams Columns 	✓	✓	✓	✓	✓	✓
Structural Walls 	✓	✓		✓		
Diaphragms (including Connections) 	✓			✓		
Foundations 	✓					

Component Models

Component	Experimental	Simulation	Performance
Joints 	✓	✓	✓
Beams Columns 	✓	✓	✓
Structural Walls 	✓		
Diaphragms (including Connections) 	✓		
Foundations 	✓		

Models for Repair and Retrofit

	Experimental	Simulation	Performance
RETROFIT 	✓	✓	
REPAIR 	✓		

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