Cast-in-Place RC Coupled Shear Walls:
Unbonded Post-Tensioned Coupling Beams & Debonded Starter Bars at Wall Base

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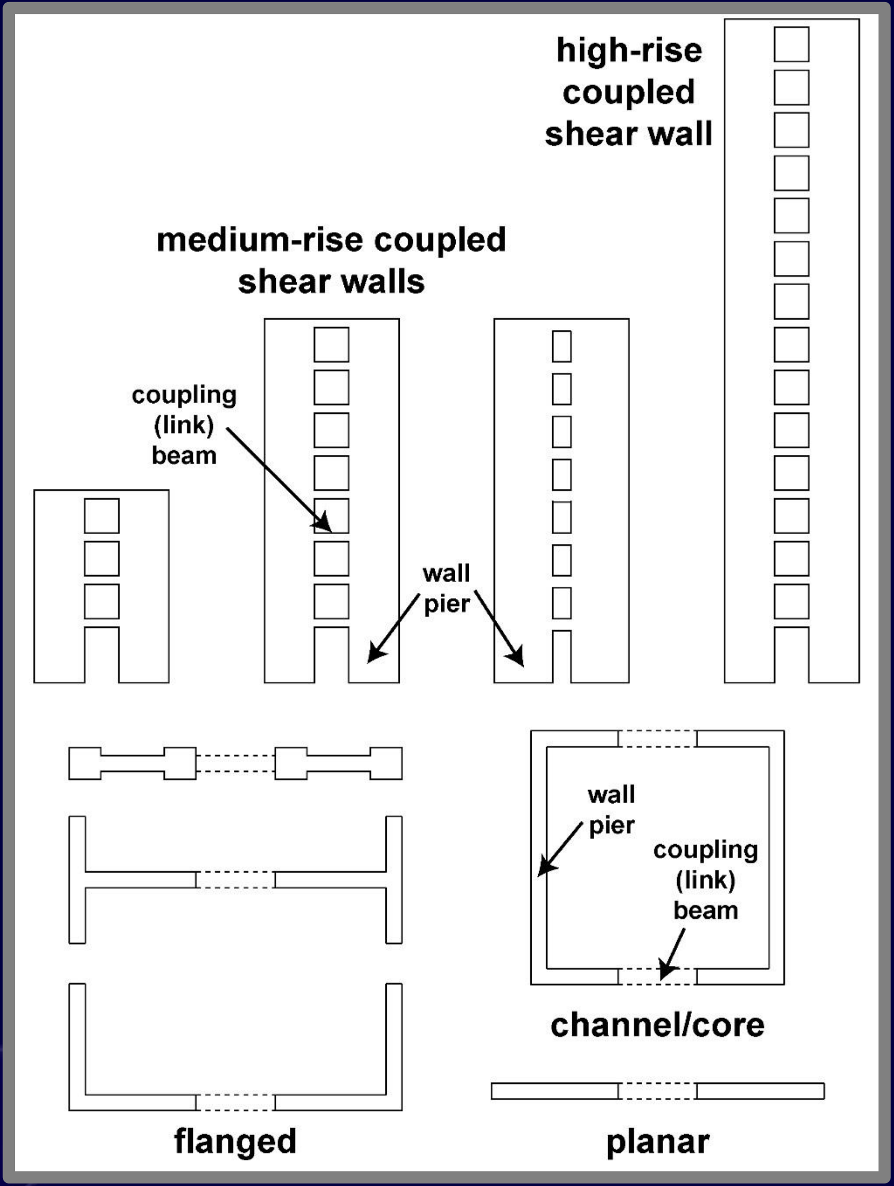
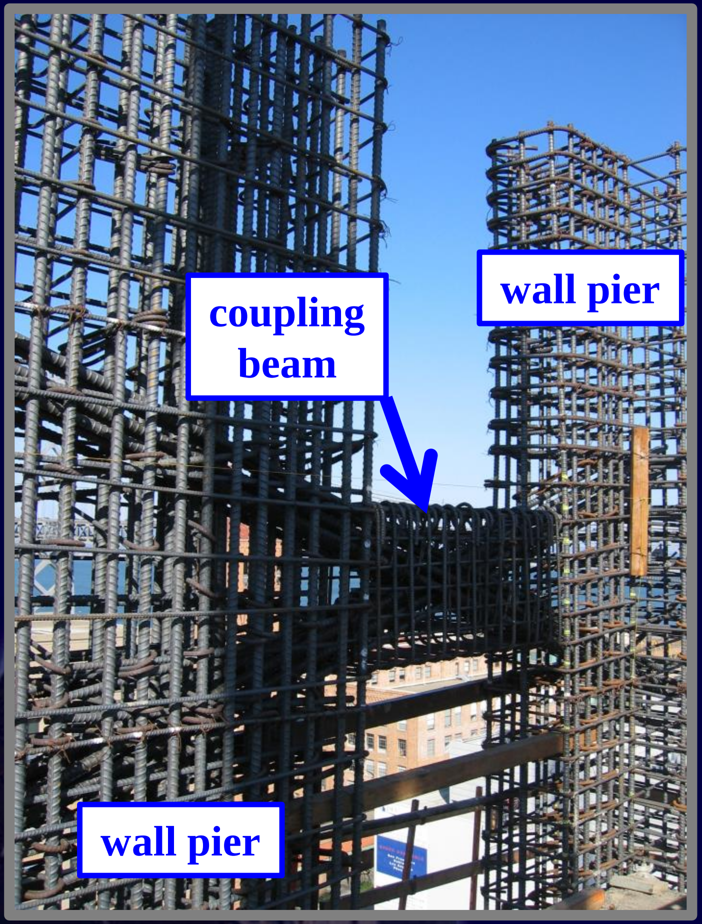
Coupled Shear Wall Systems

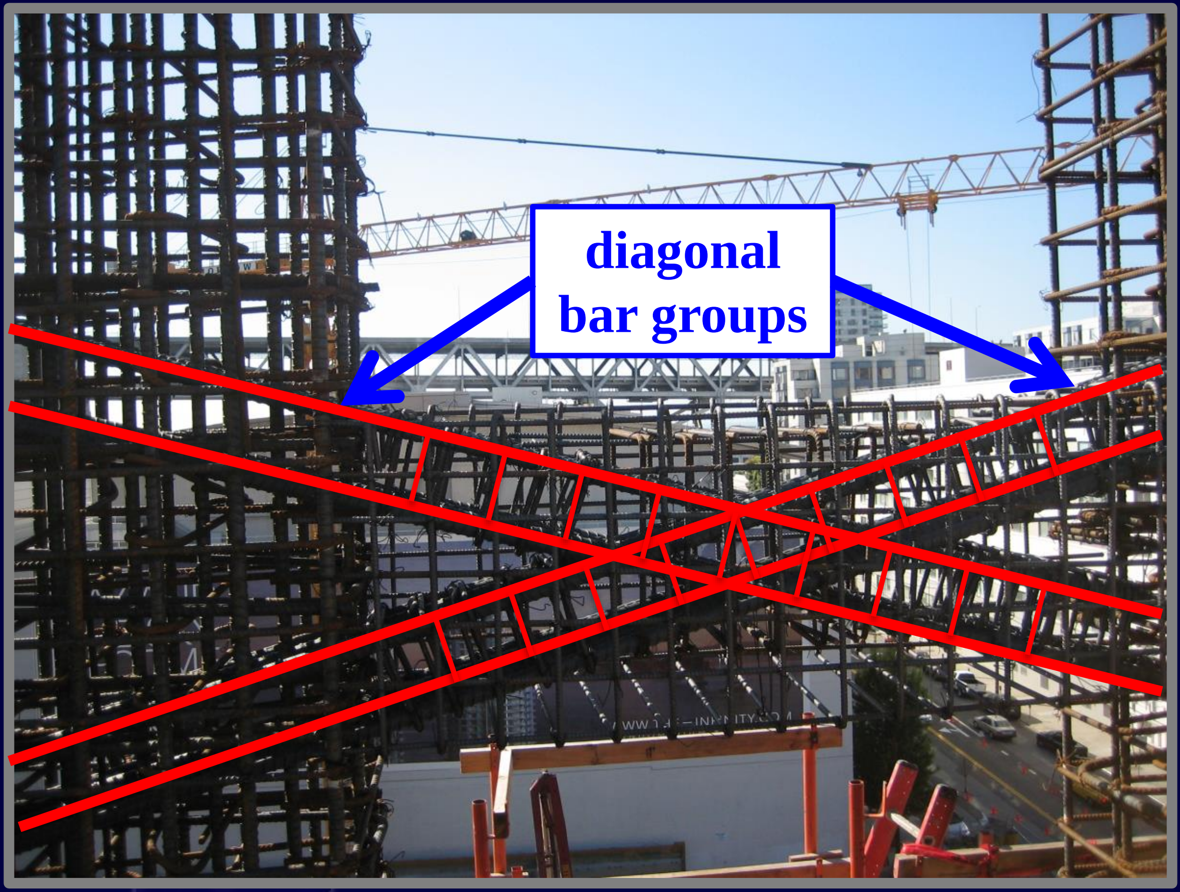
- RC coupled shear wall structures are a commonly used primary lateral load resisting system
- Two or more shear wall piers connected by coupling (or link) beams
- Provide large lateral strength, stiffness, and energy dissipation



Conventional Coupling Beams

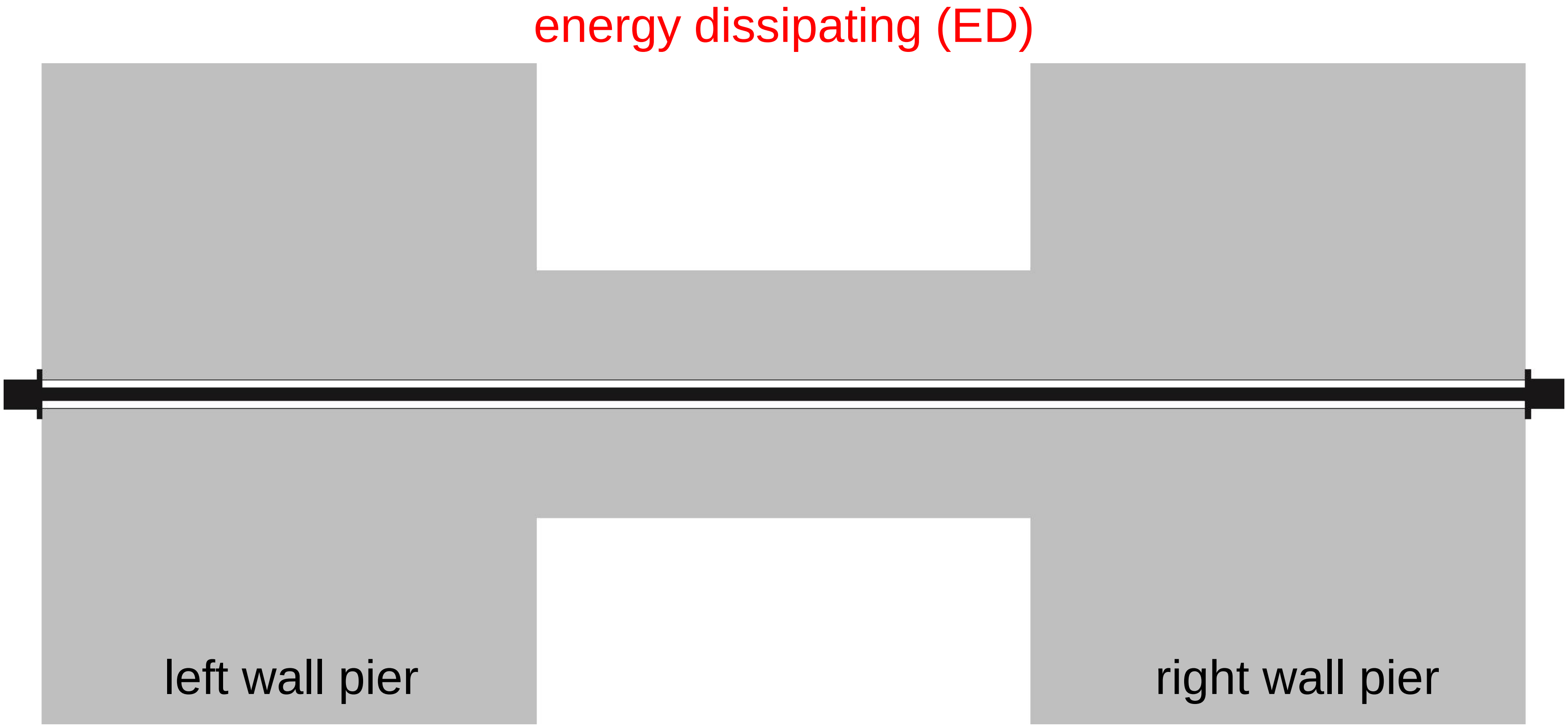
- Typical coupling beams are short
- Large shear force demands under large reversed-cyclic rotations





courtesy, Magnusson Klemencic Associates

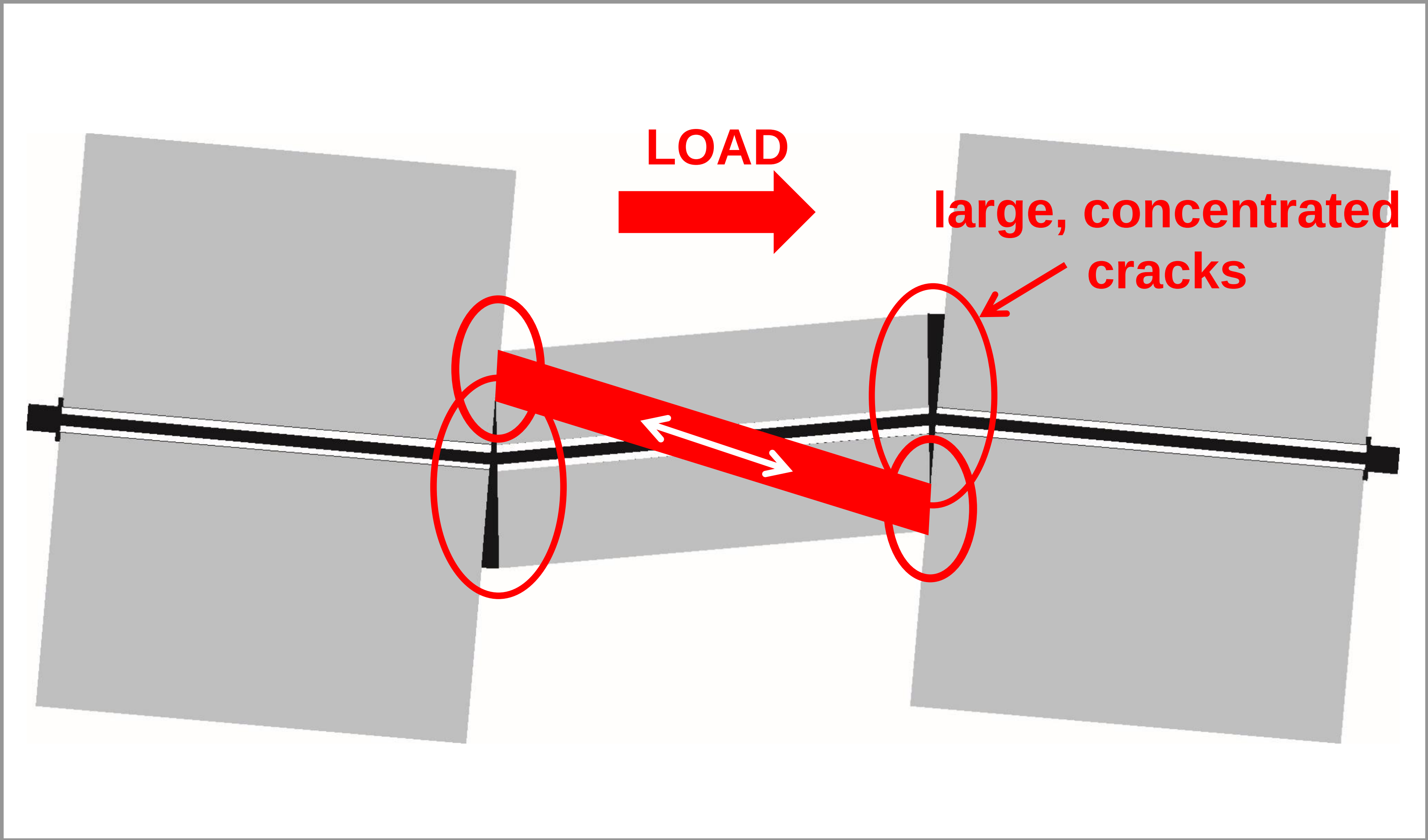
Post-Tensioned Coupling Beams



Partially Post-Tensioned RC Coupling Beam

(Specimen 1)

Post-Tensioned Coupling Beams



Validation & Design Process

- **ACI 318:**

  "...the proposed system shall have strength and toughness equal to or exceeding those provided by a comparable monolithic reinforced concrete structure satisfying this chapter."

- **Validation and Design Documents**
  - **ACI ITG-5.1** – ***Acceptance Criteria for Special Unbonded Post-Tensioned Structural Walls Base on Validation Testing and Commentary***
  - **ACI ITG-5.2** – ***Requirements for Design of a Special Unbonded Post-Tensioned Shear Wall Satisfying ACI ITG-5.1 and Commentary***
  - **ACI 318** – ***Building Code Requirements for Structural Concrete and Commentary***

Research Objectives

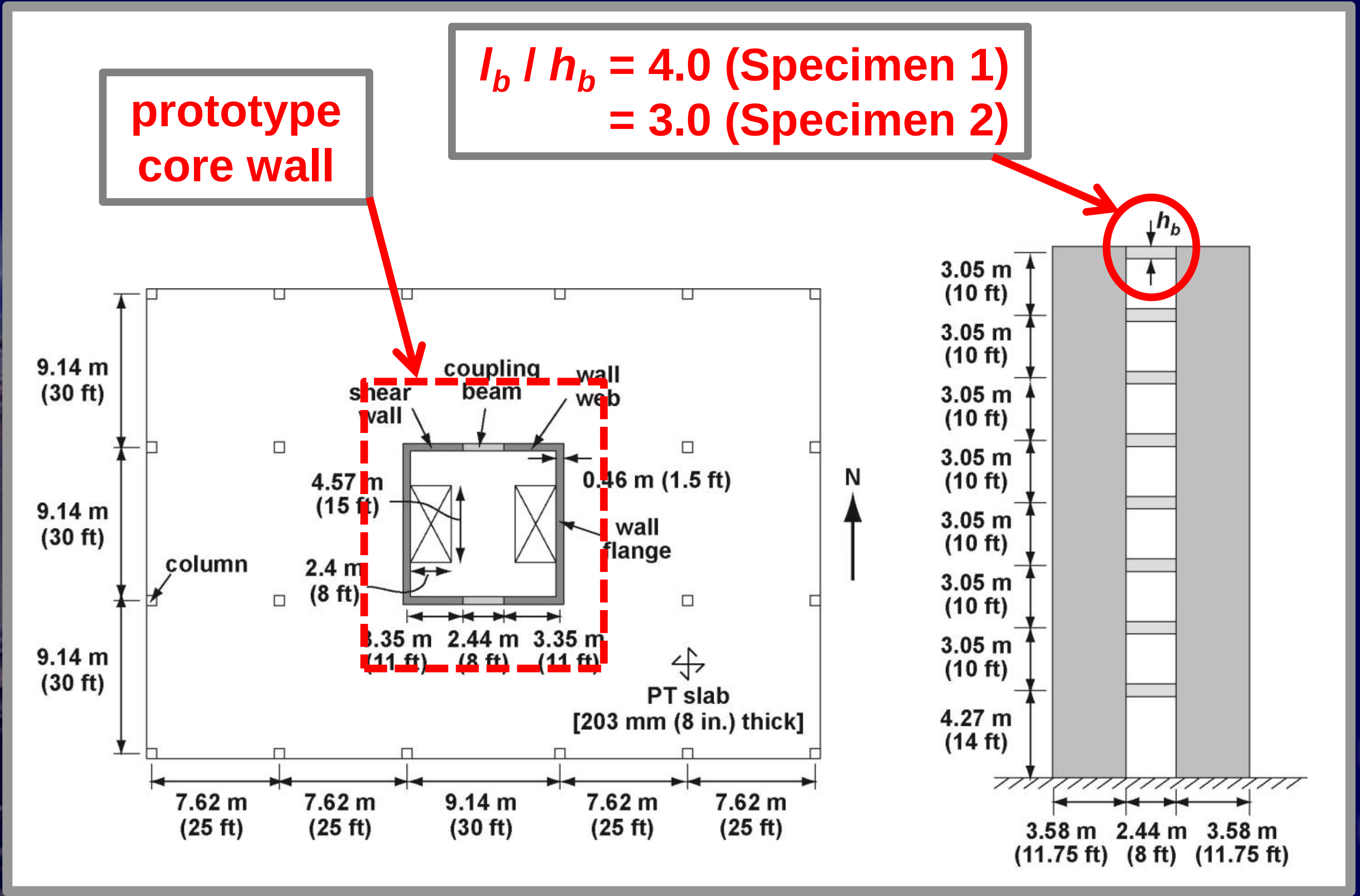
1. To develop a validated seismic design procedure
2. To conduct system-level experimental evaluations
3. To validate analytical models and simulation tools that predict system behavior
4. To create a Design Procedure Document

Presentation Outline

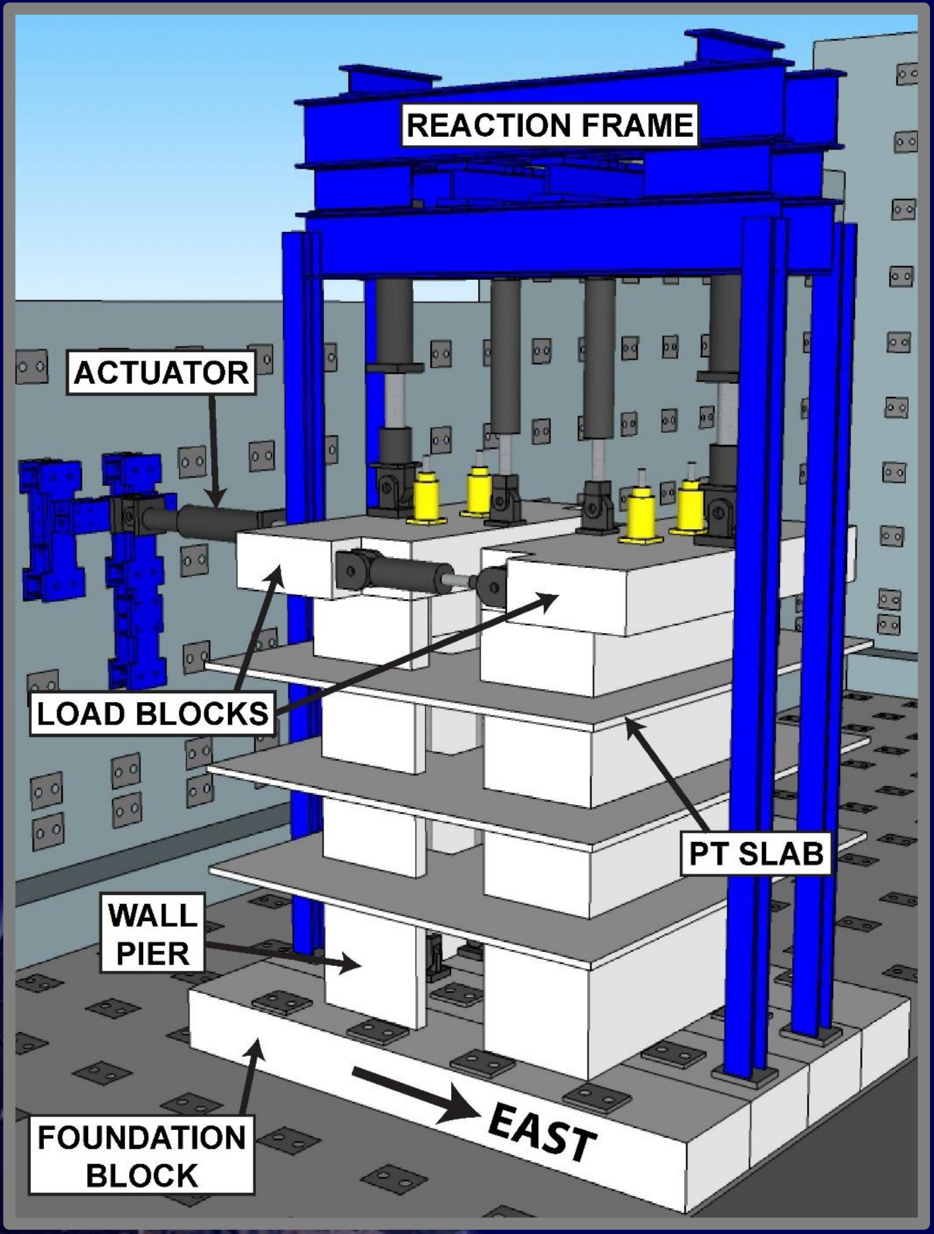
- Introduction and Objectives
- Experimental Program
- Specimen 1 Details and Behavior
- Specimen 2 Behavior and Comparisons
- Conclusions

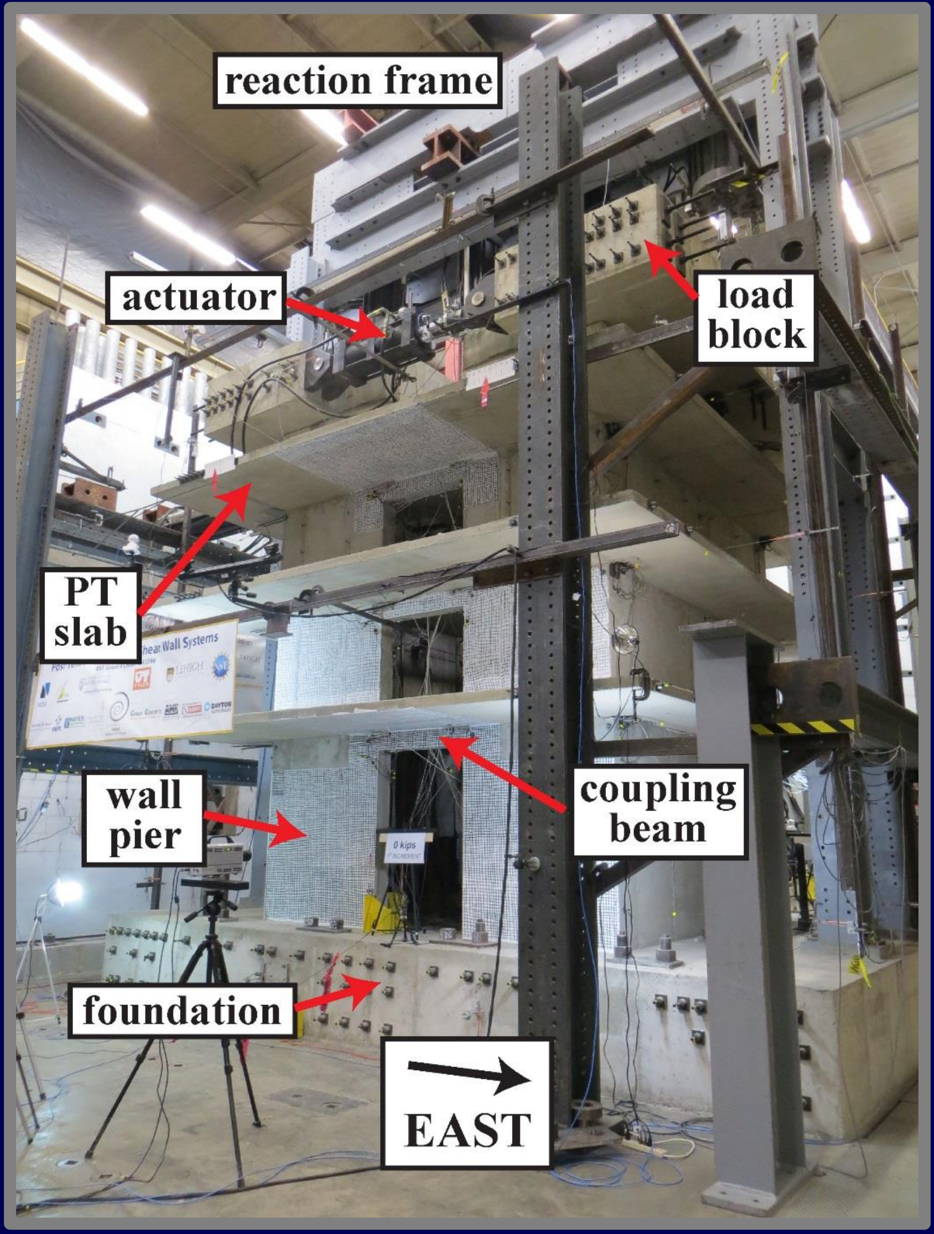
Prototype Structure

- Eight-Story Office Building (coupling degree=30%)
- Designed for Seismic Category D in Los Angeles, CA
  - S_S = 1.50; S_1 = 0.60; C_S = 0.136-0.154; R = 6.0; C_D = 5.0
- Base Moment for Full-Scale Core Wall ~134,000-151,000 kip-ft



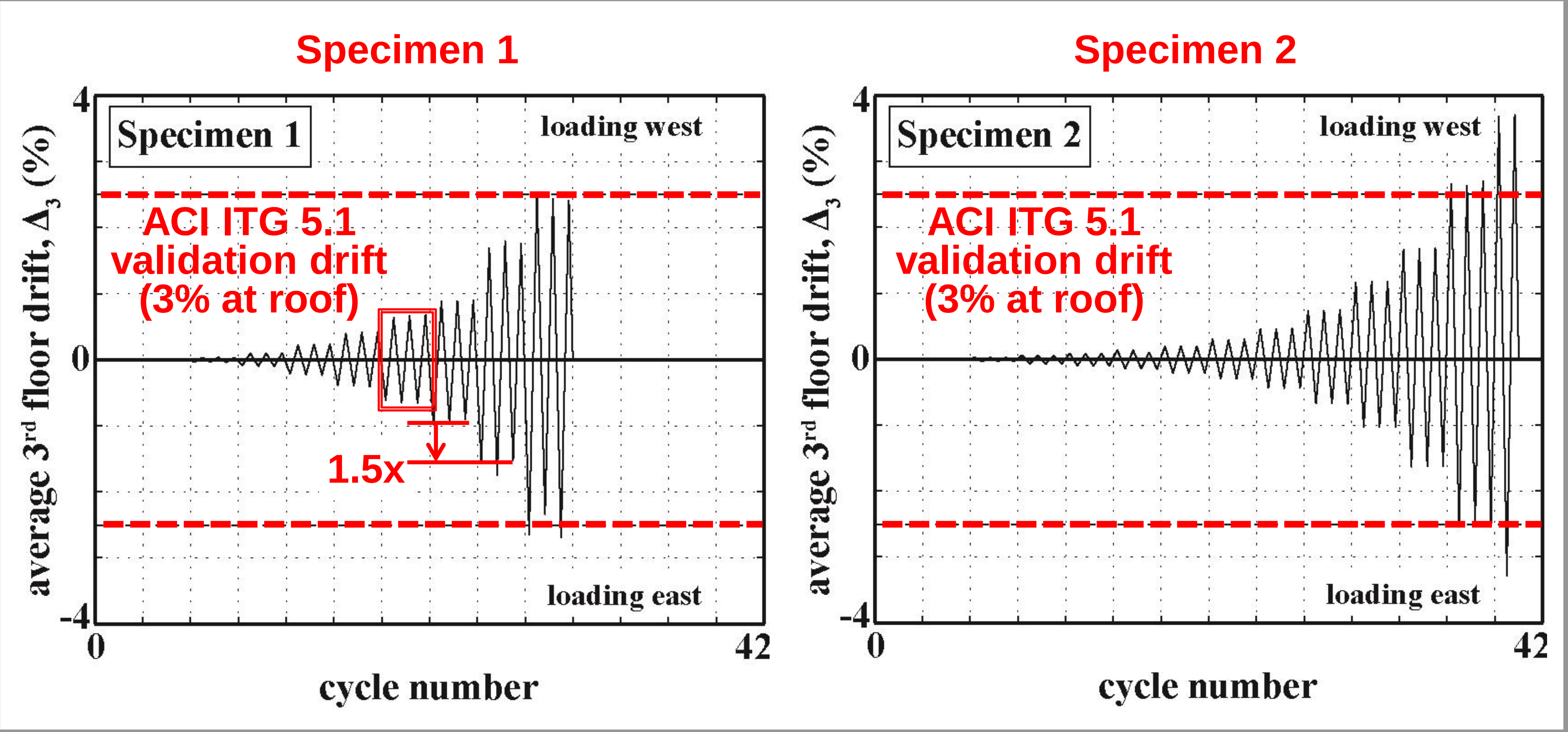
NEES Test Setup at Lehigh Univ. (40%-scale)





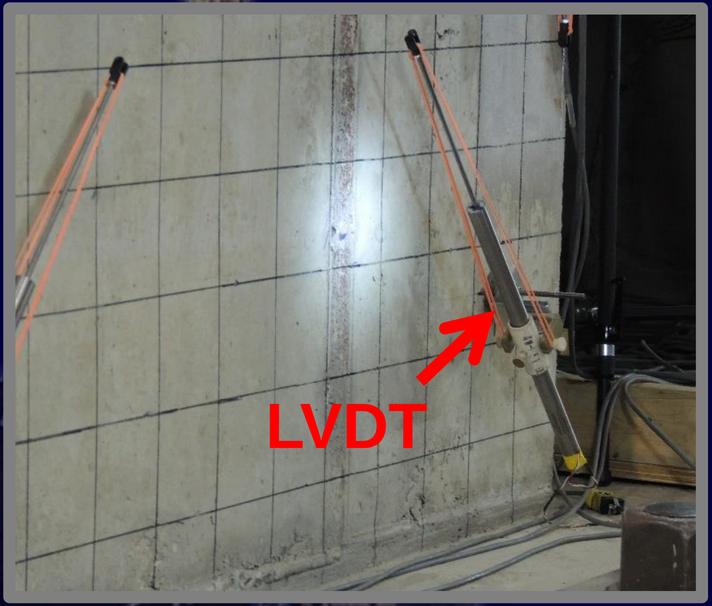
Applied 3rd Floor Drift History

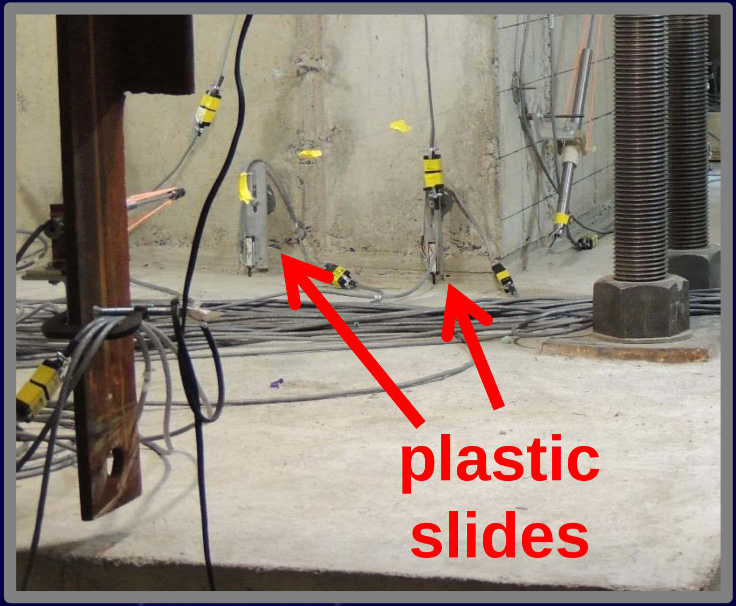
ACI ITG 5.1 loading protocol

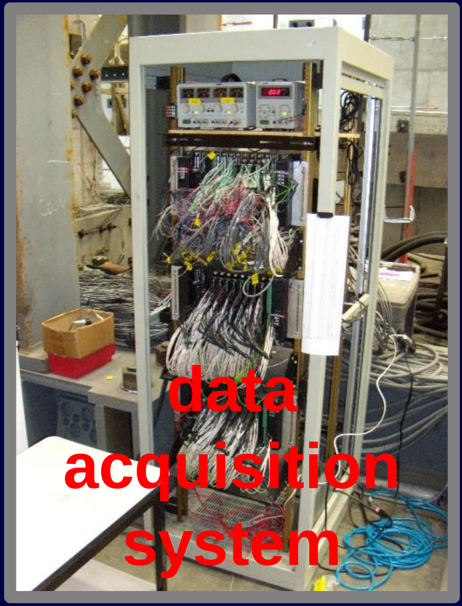


Instrumentation

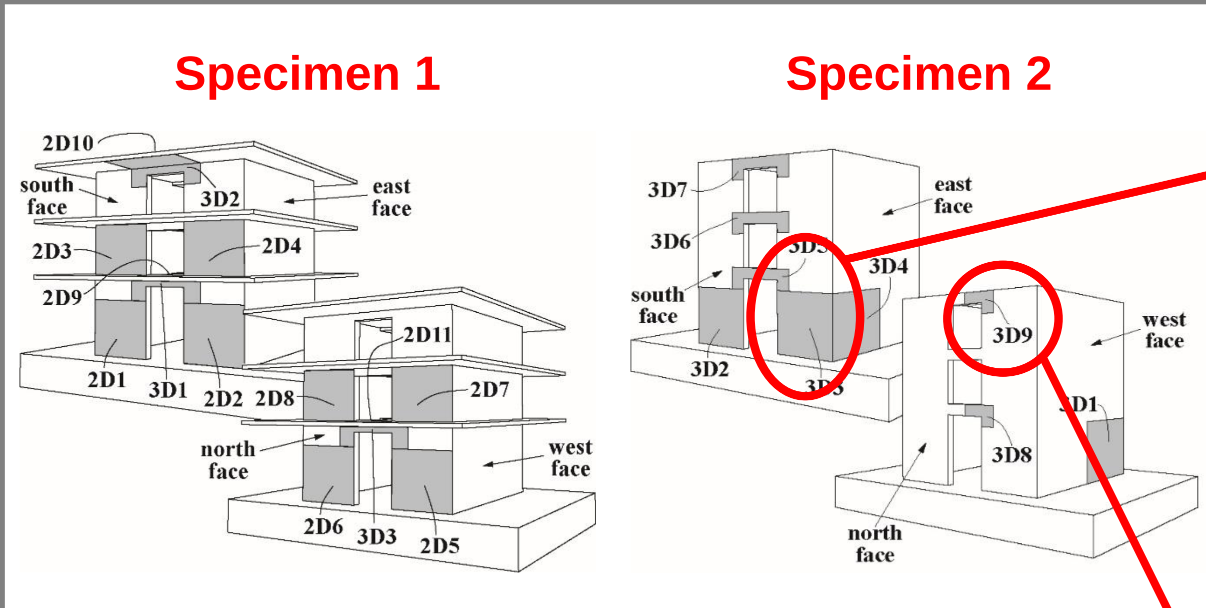
Type	Specimen 1	Specimen 2
load cells	29	29
displacement	123	156
rotation	46	46
strain gauges	214	250
TOTAL	**412**	**481**

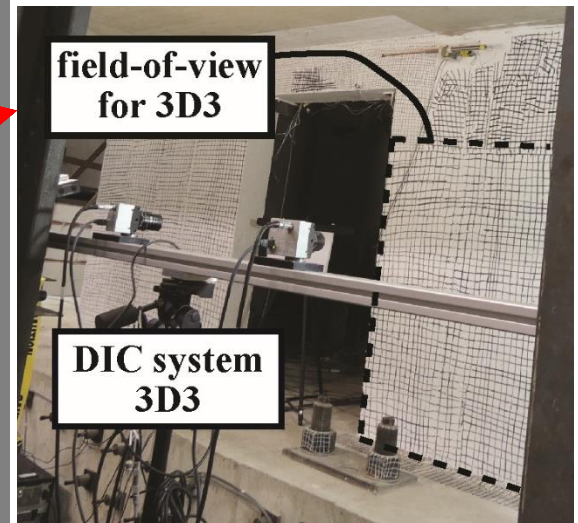


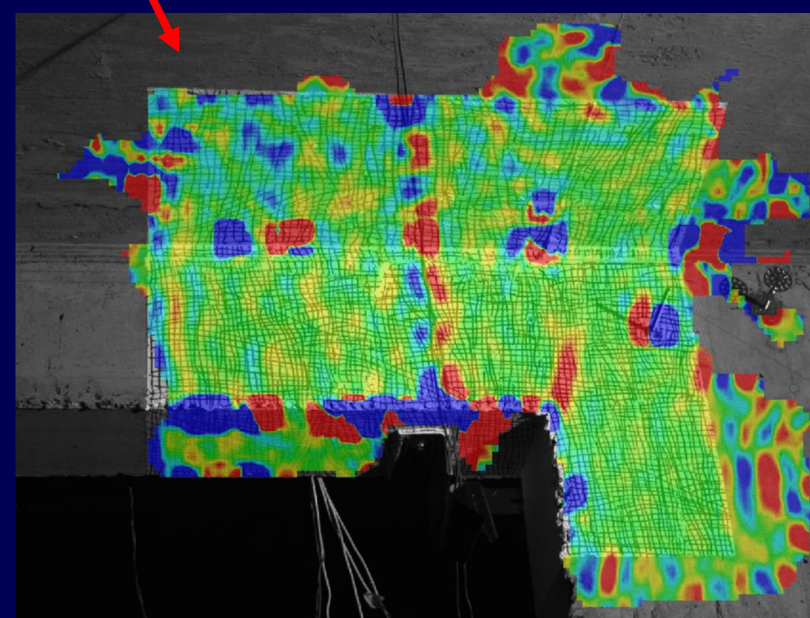




Digital Image Correlation (DIC)







Type	Specimen 1	Specimen 2
2D systems	11	0
3D systems	3	9
TOTAL	**14**	**9**

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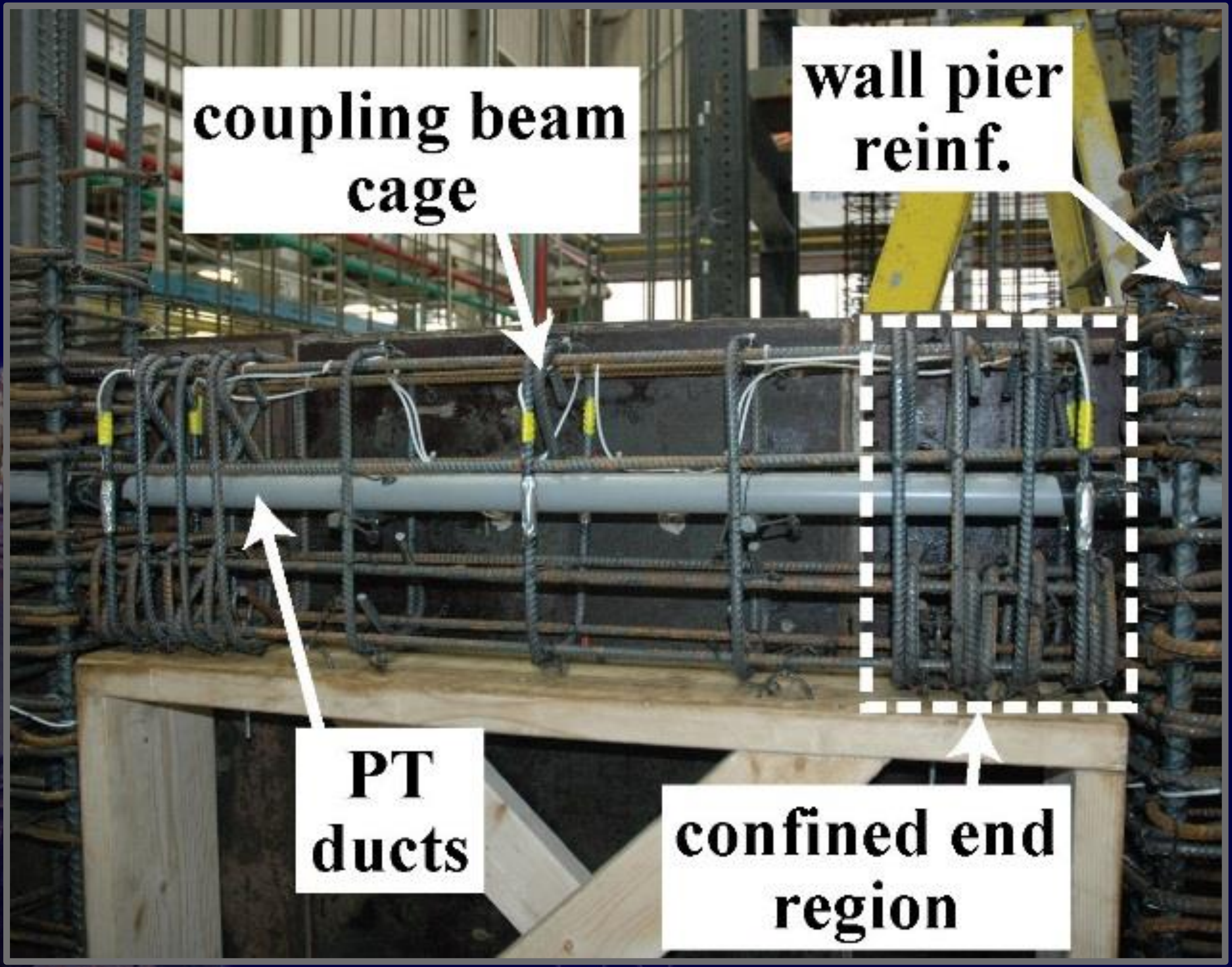
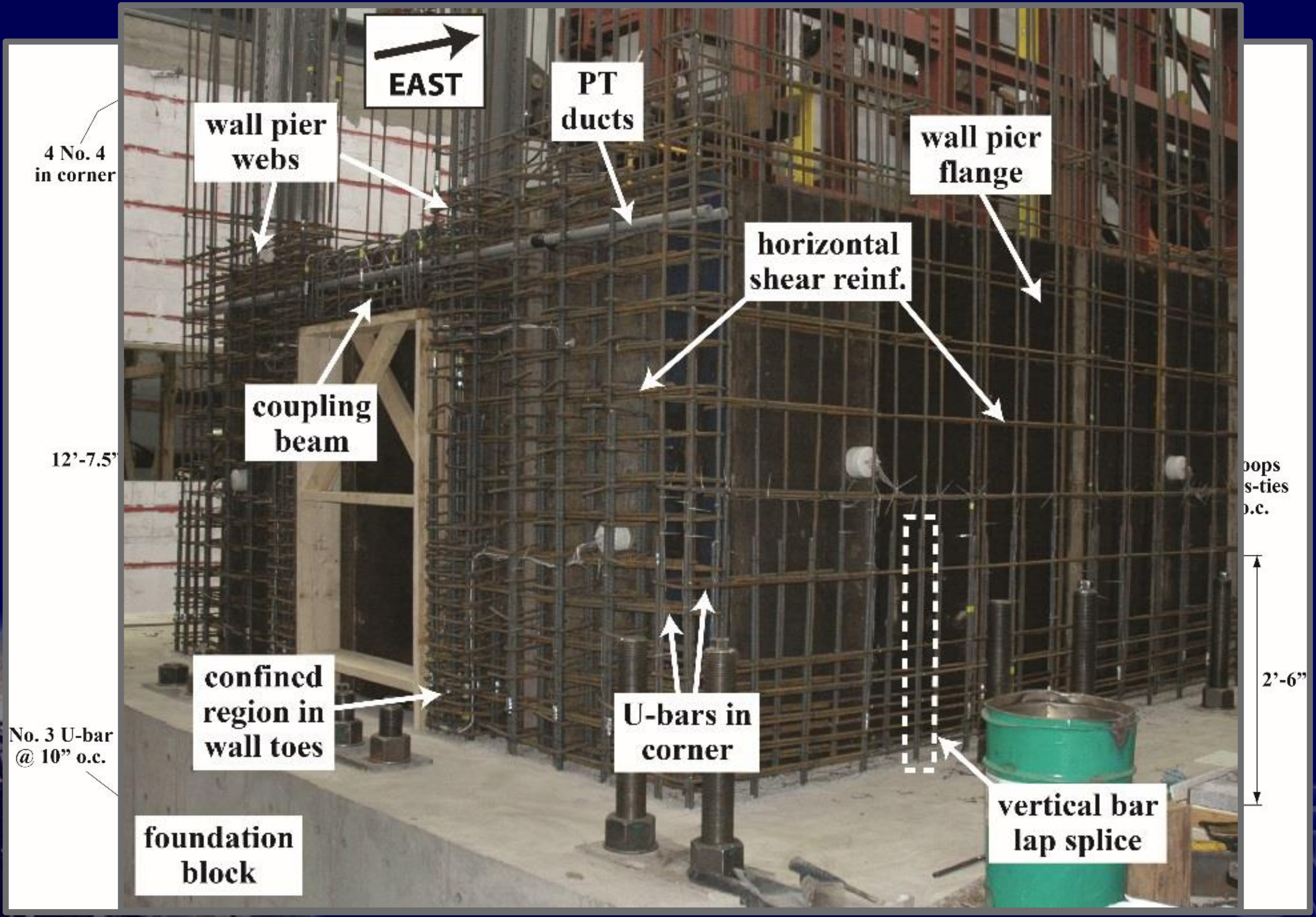
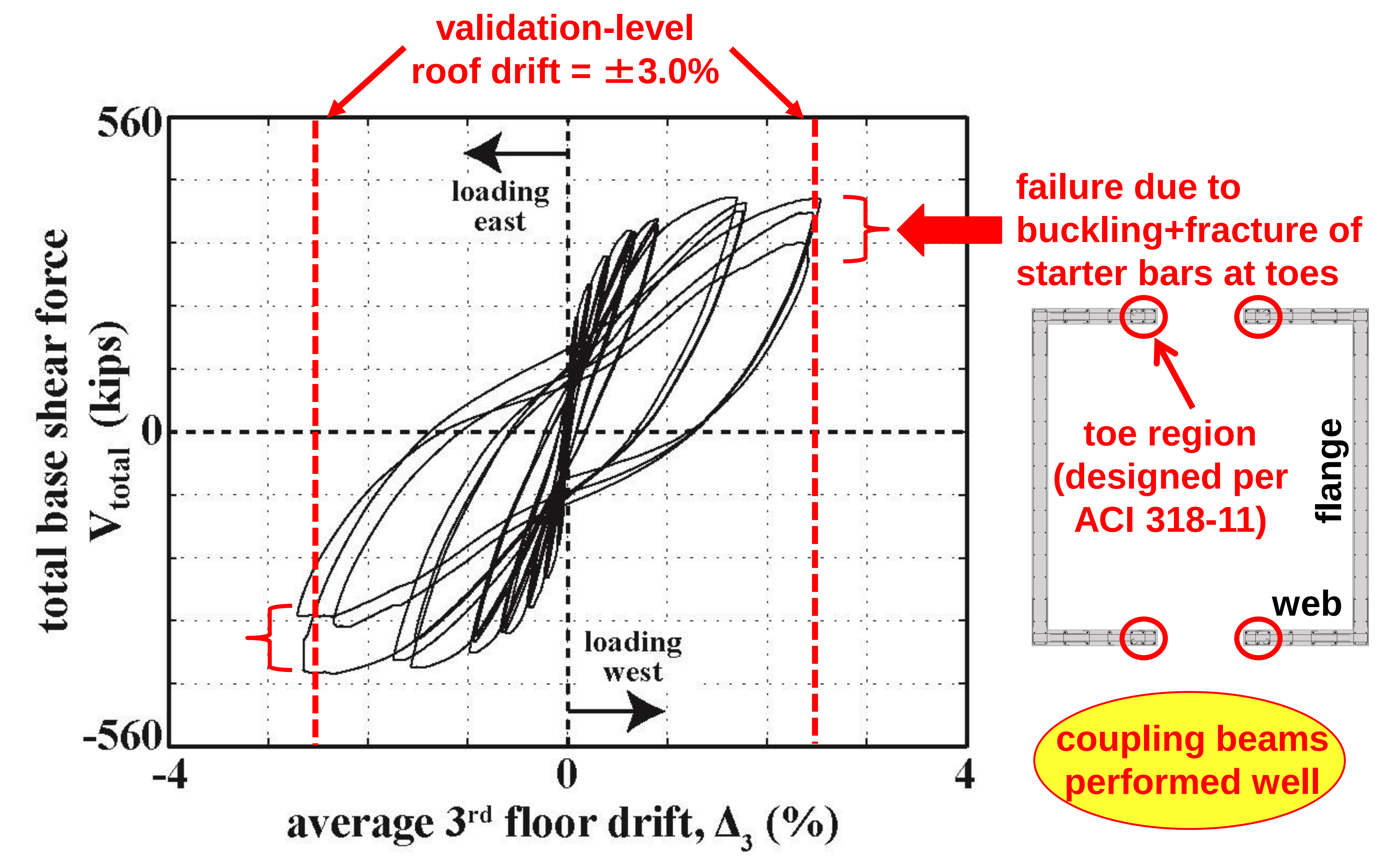
Coupling Beam Reinforcement (Specimen 1)



Wall Pier Reinforcement (Specimen 1)

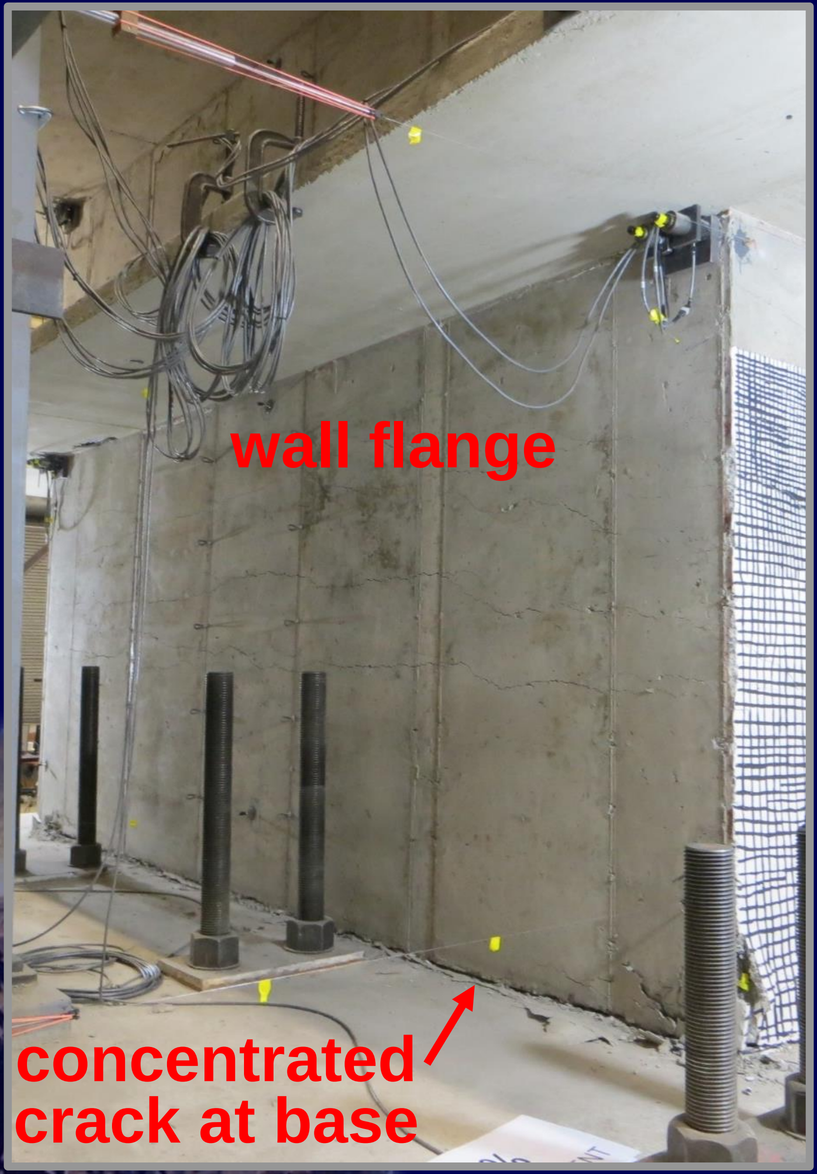


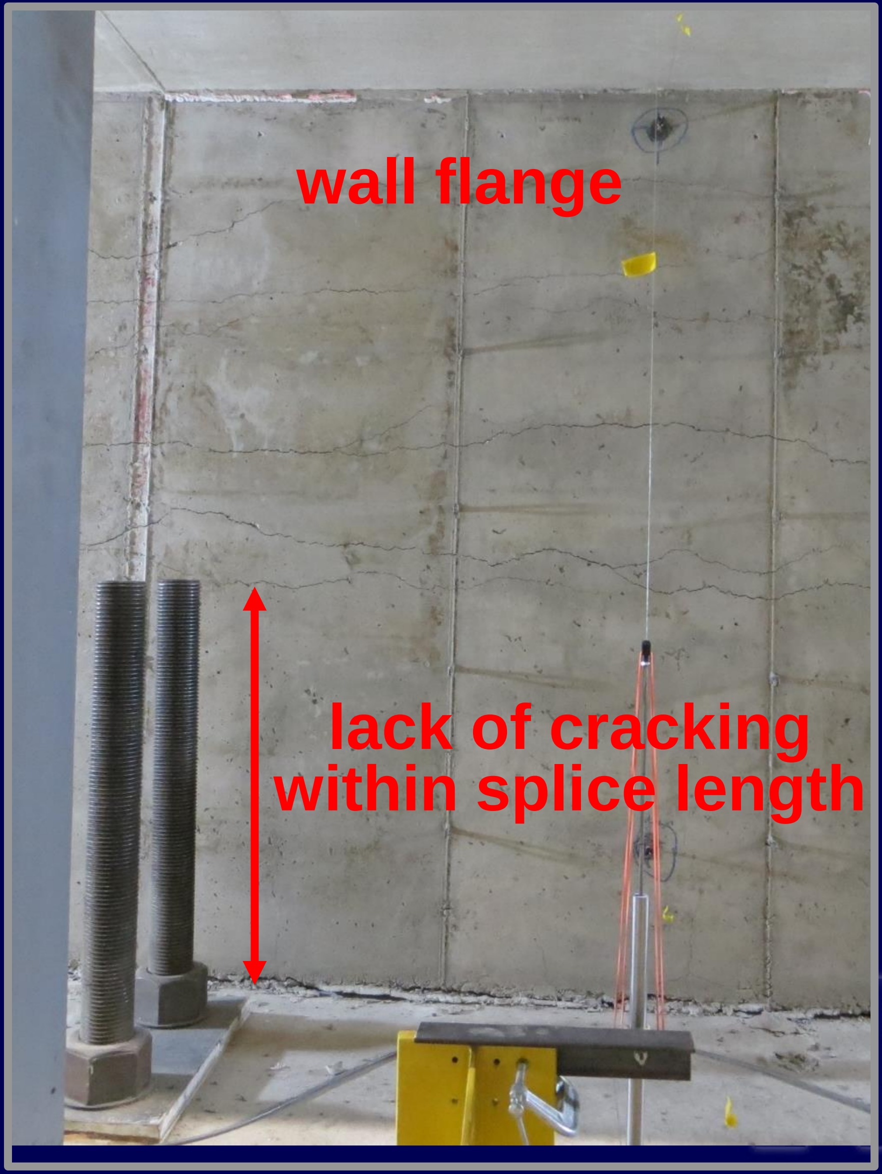
Total Base Shear versus 3rd Floor Drift (Specimen 1)



Reasons for Starter Bar Fracture

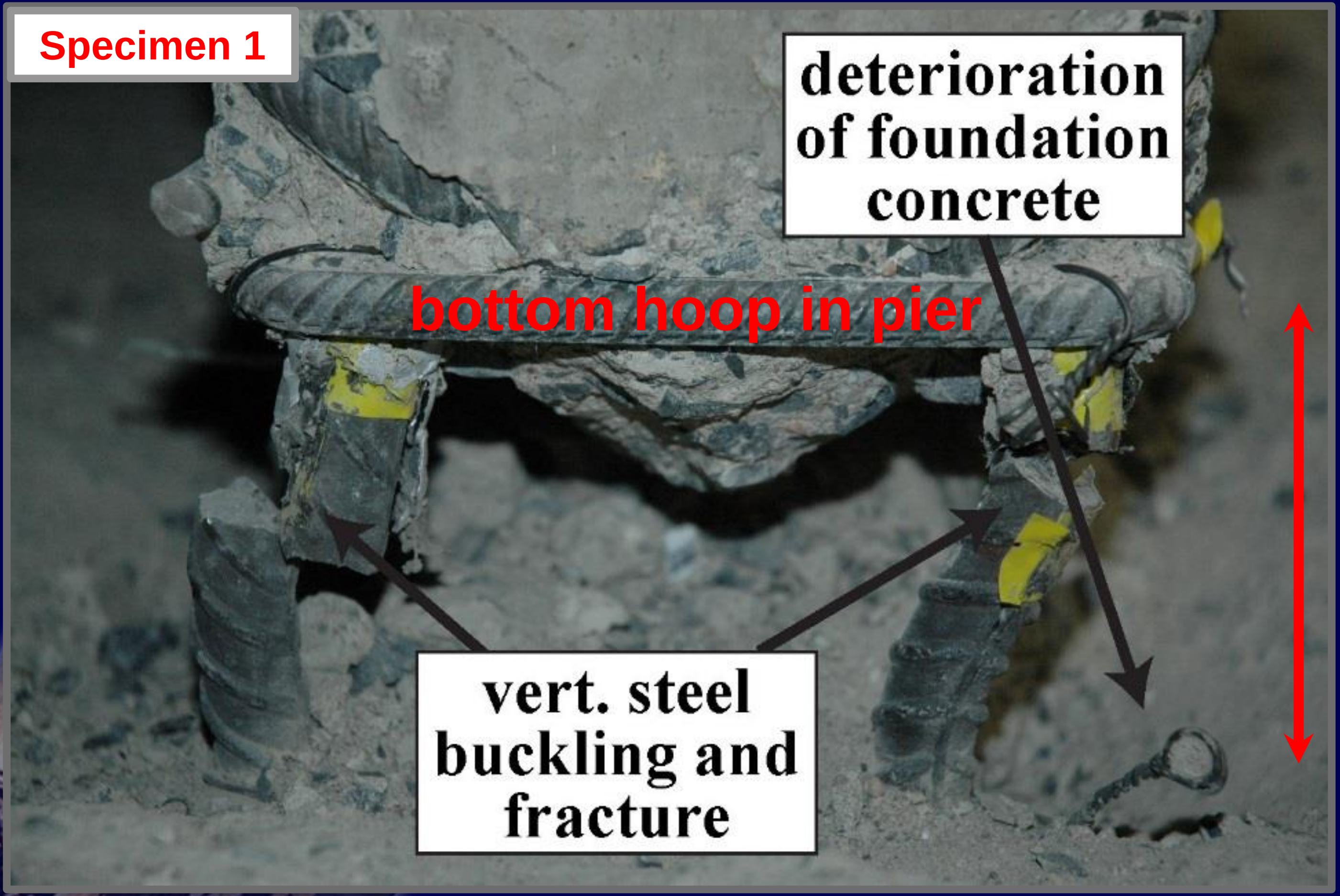
1. Lap splices above foundation





Reasons for Starter Bar Fracture

2. Deterioration of concrete at top of foundation



increased unsupported length of starter bars

Presentation Outline

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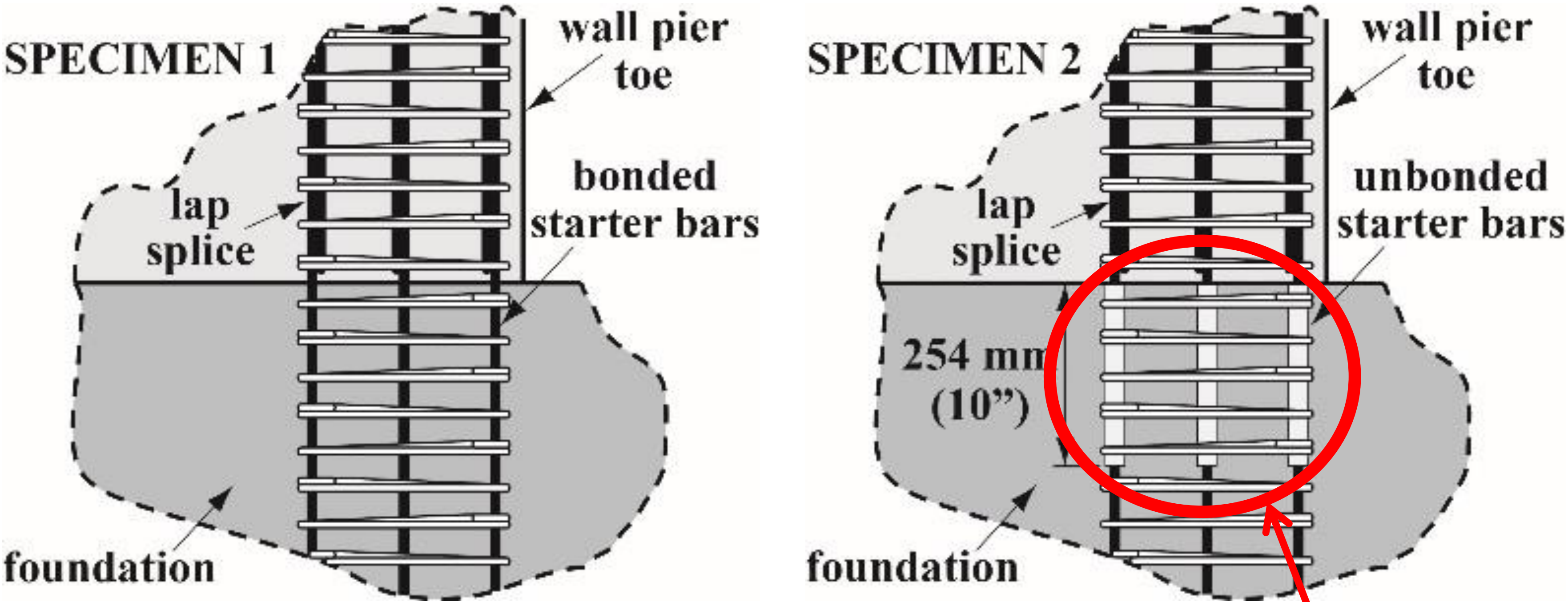
Detail Change in Wall Pier Toes

Specimen 1
(per ACI 318-11)

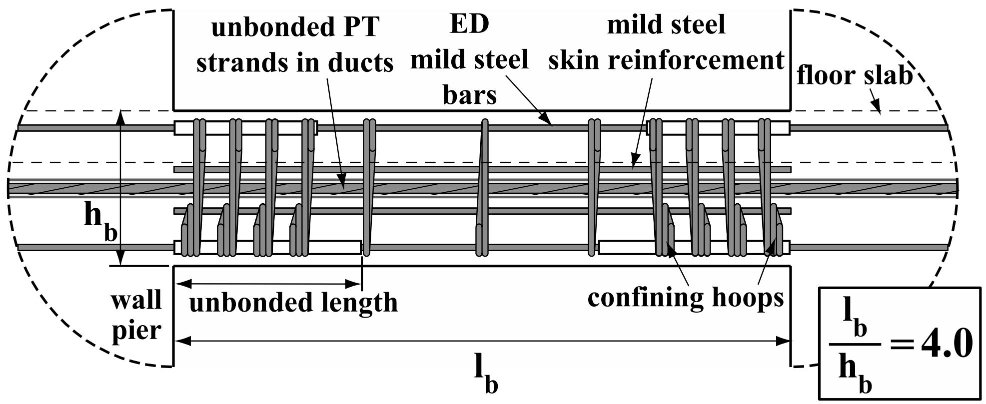
Specimen 2
(with debonded bars)



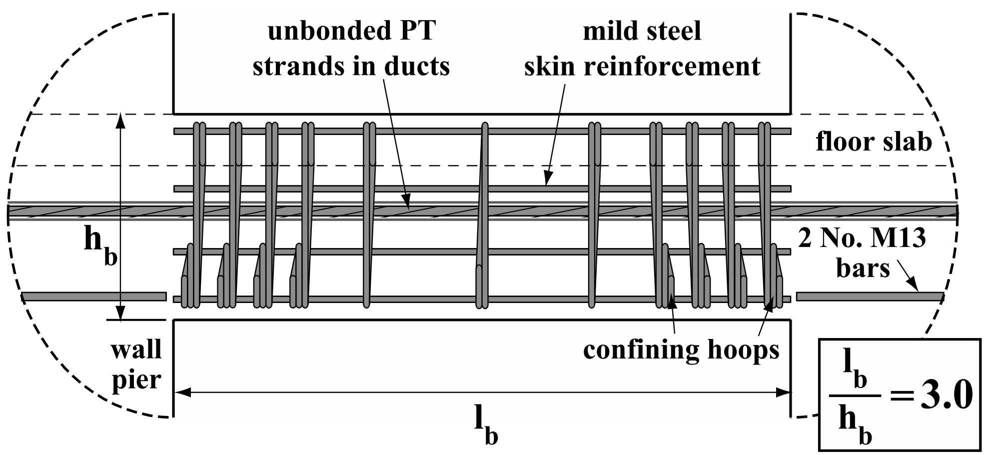
10" unbonded length

Coupling Beam Changes

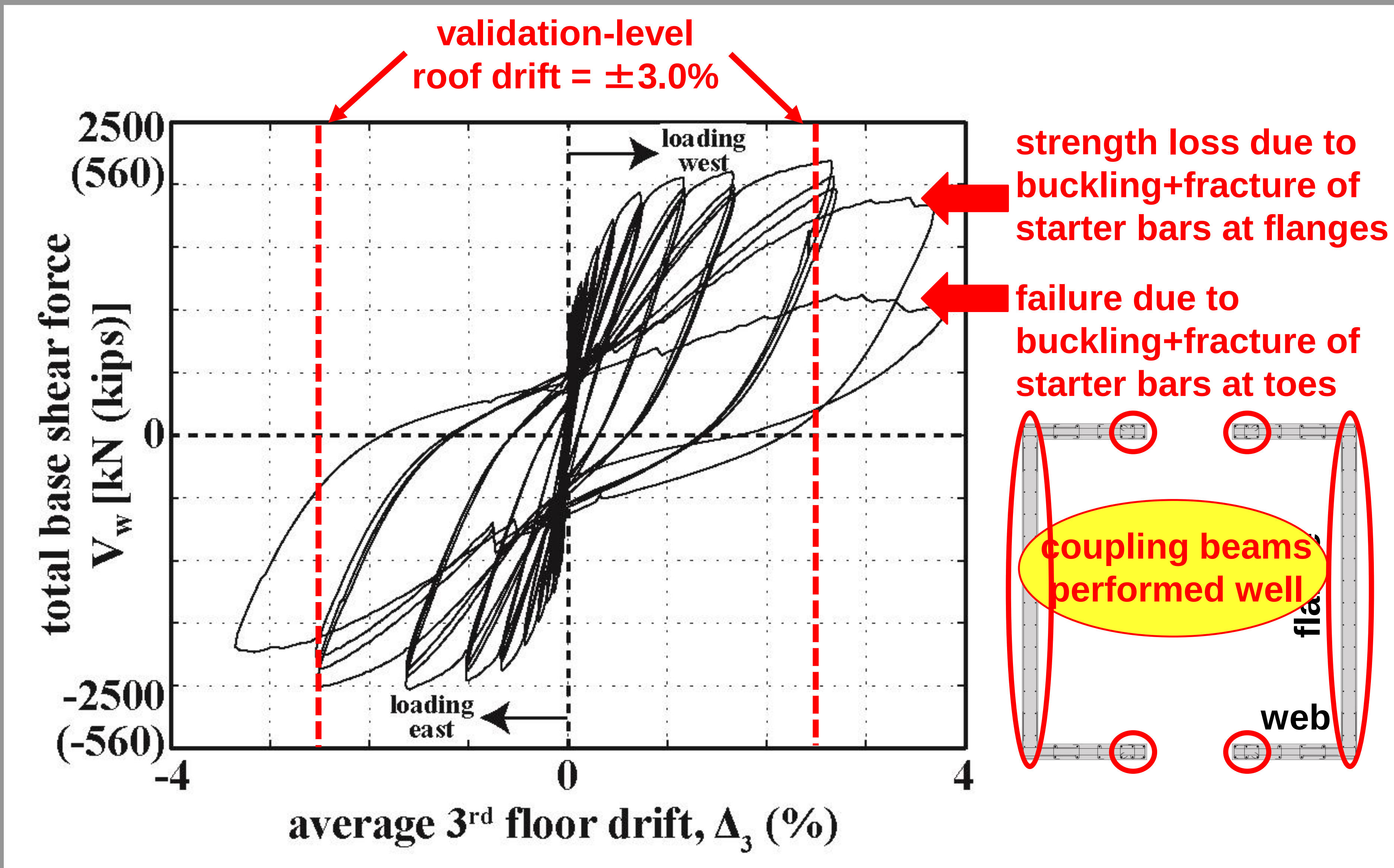
Specimen 1



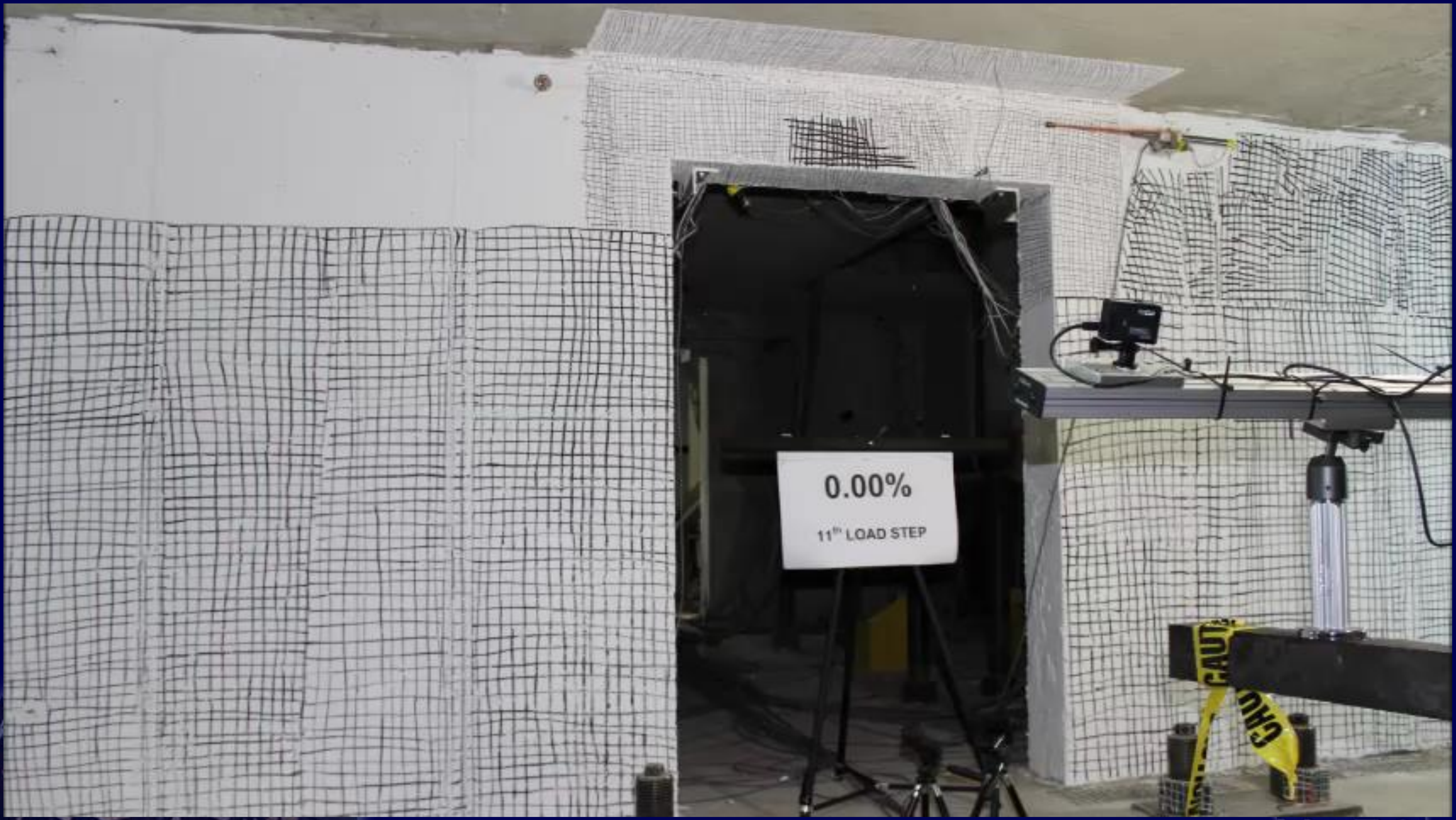
Specimen 2



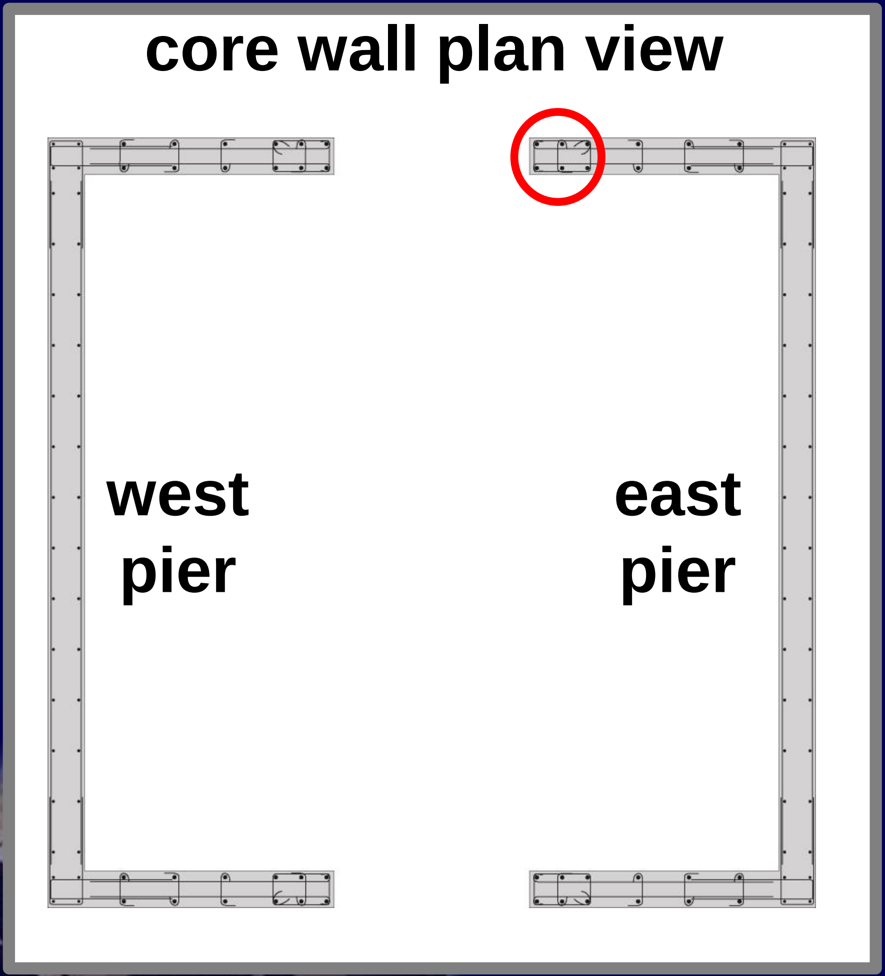
Total Base Shear versus 3rd Floor Drift (Specimen 2)

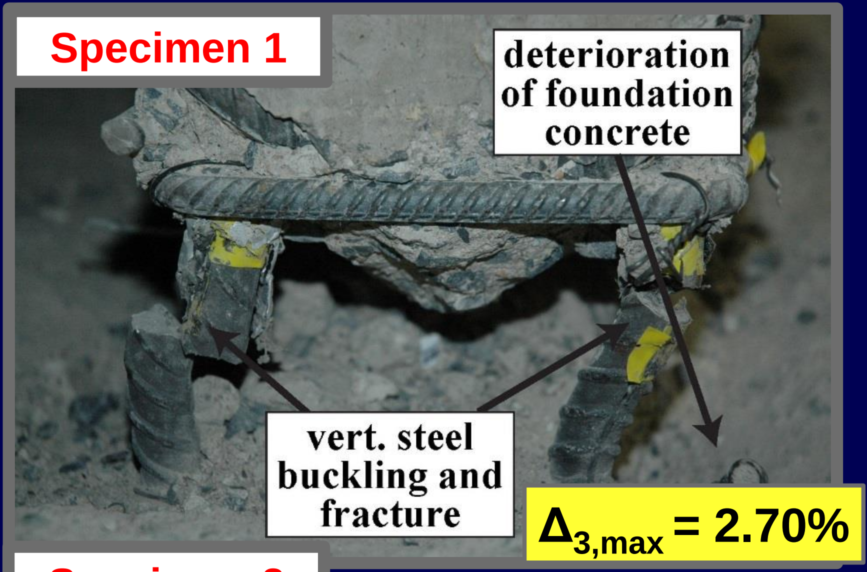


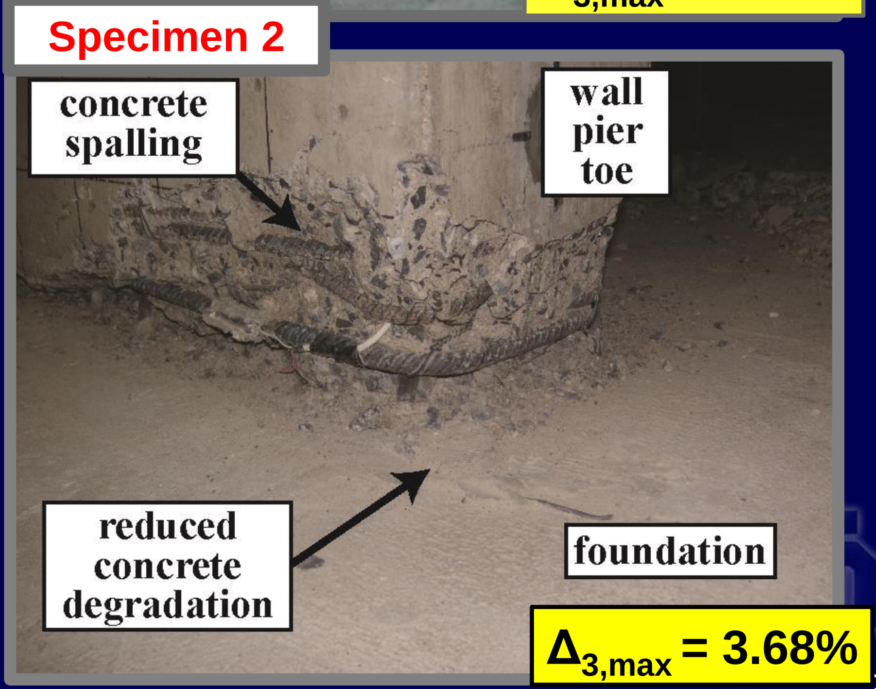
1st Story Damage Progression (Specimen 2)



Comparison of Wall Pier Toe Damage

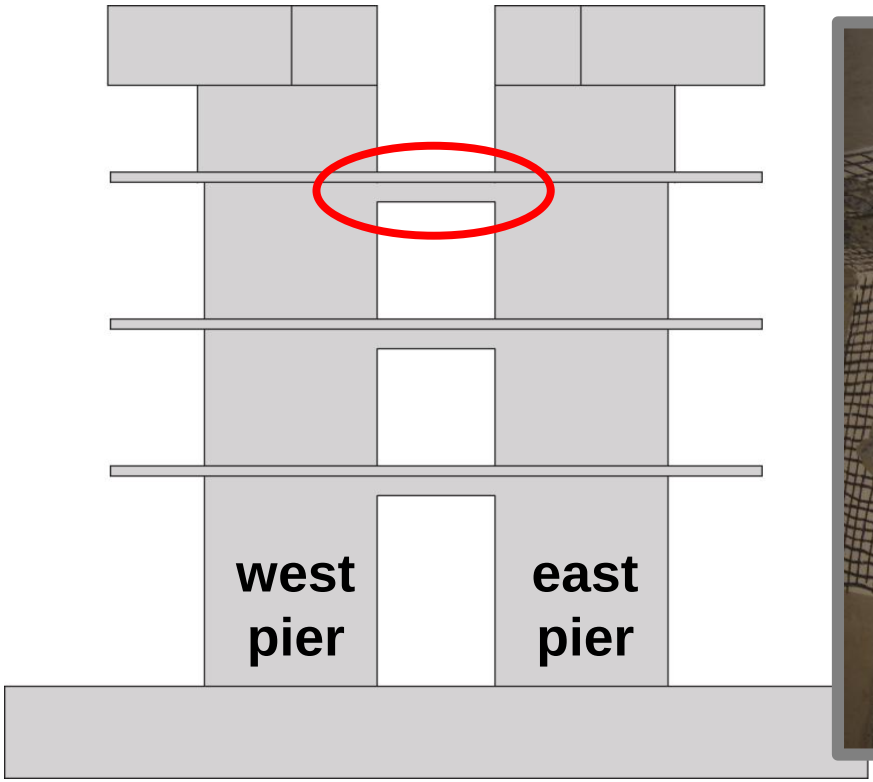


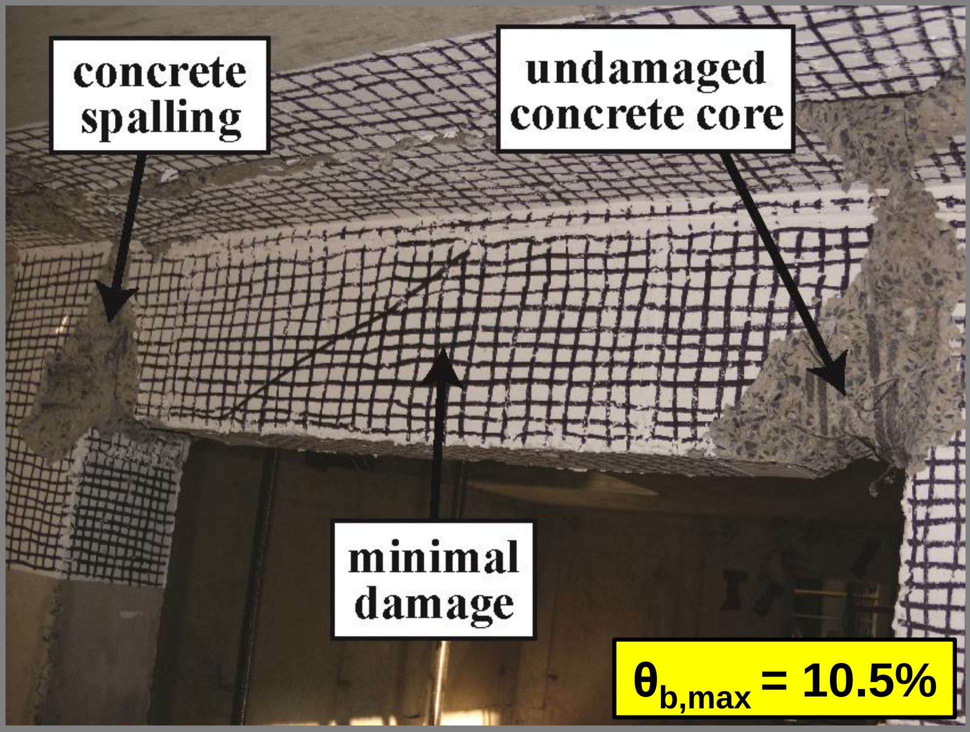




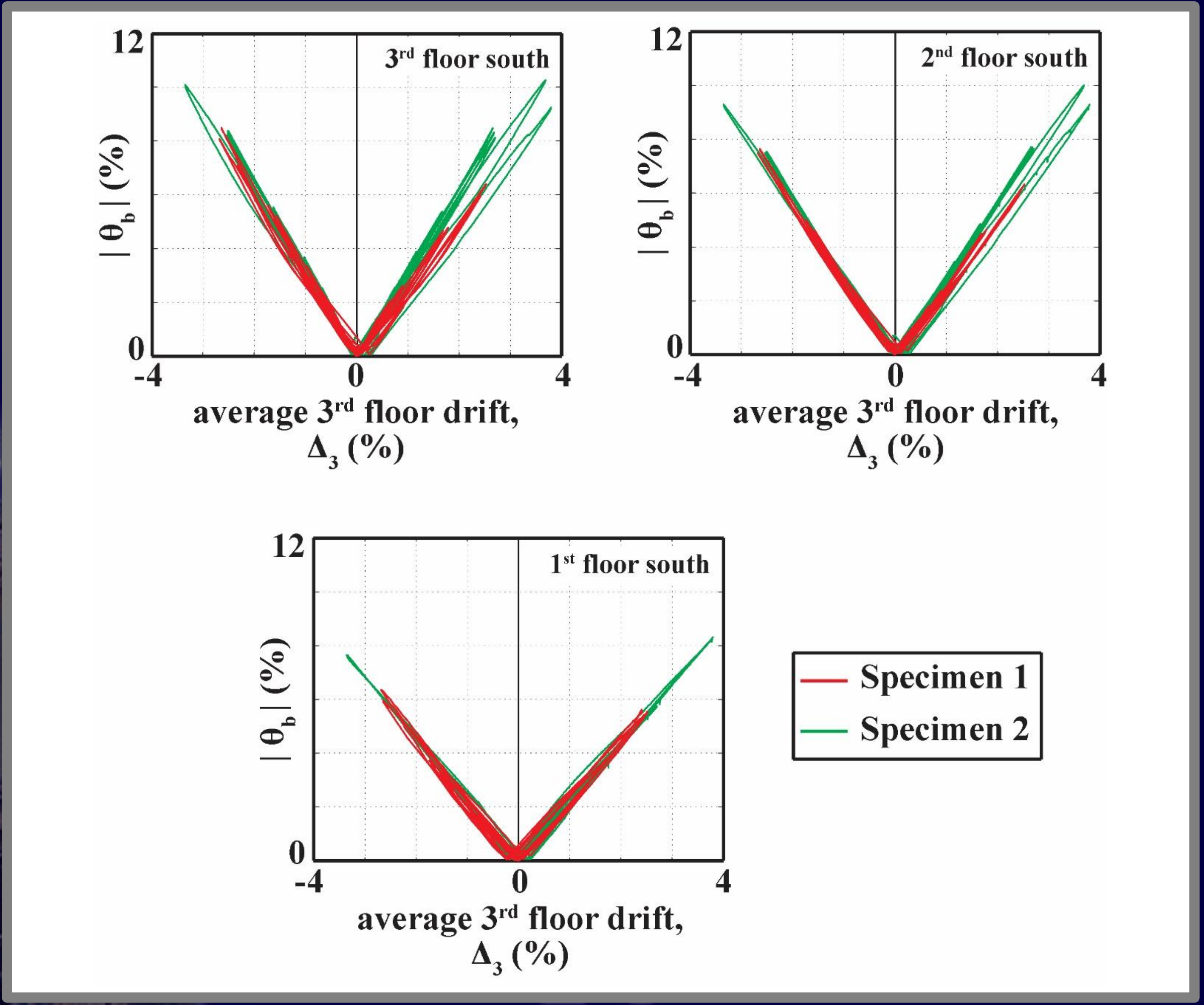
Coupling Beam Damage

specimen elevation view

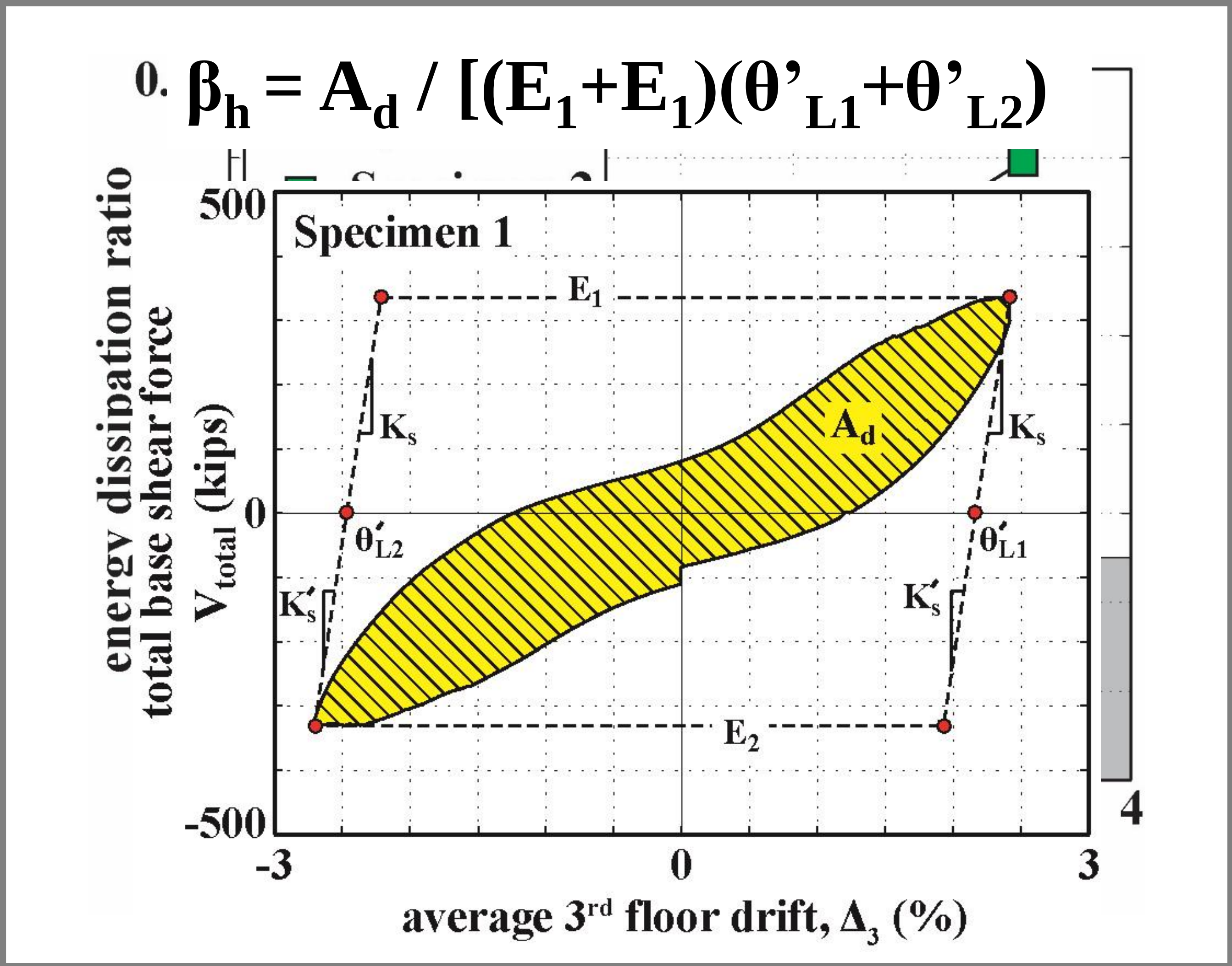




Beam End Rotations



Energy Dissipation



Conclusions (PT Coupling Beams)

- **Completed 2 large-scale system-level experimental tests**
- **Performed as predicted and validated the design approach**
- **Demonstrated ductile behavior up to 10.5% beam end rotation**
- **Coupling beams provided adequate and stable coupling in both specimens (30% coupling)**
- **Support the classification of unbonded PT coupled wall structures as "special" RC shear walls**
- **Demonstrated intended behavior and advantages of the new coupling system**
- **Fully-PT beams may be preferred over partially-PT beams**

Conclusions (Wall Pier Bases)

- Lap splices of vertical starter bars above foundation resulted in concentration of cracking at wall base (with little distributed cracking within spliced wall height)
- There was also significant deterioration to concrete at top of foundation
- Failure in Specimen 1 occurred due to buckling and subsequent fracture of starter bars in wall pier toes
- Unbonding of starter bars in toes improved behavior of Specimen 2 by delaying buckling/fracture of starter bars
- General recommendation for RC shear walls:
  - consider lack of cracking over splice length of starter bars
  - unbonding of starter bars may delay bar fracture

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  - **Undergraduate Students:**
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    - **Mathu Davis, Amy Breden, Fannie Tao, Eric Salazar (REU)**
- **University of Texas at Tyler**
  - **Graduate Student: Michelle Holloman**
  - **Undergraduate Student: Michael Lisk**

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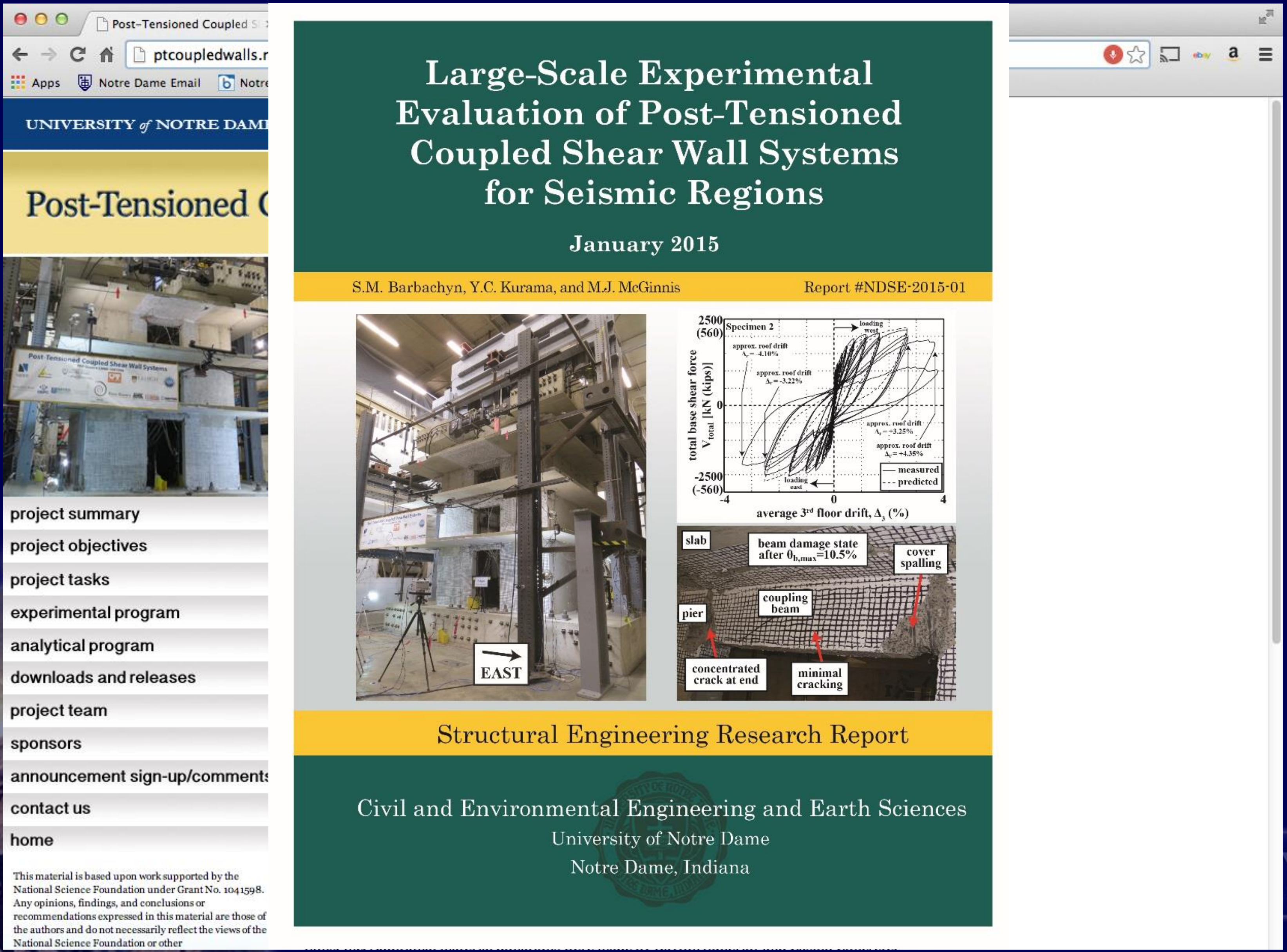

Questions?

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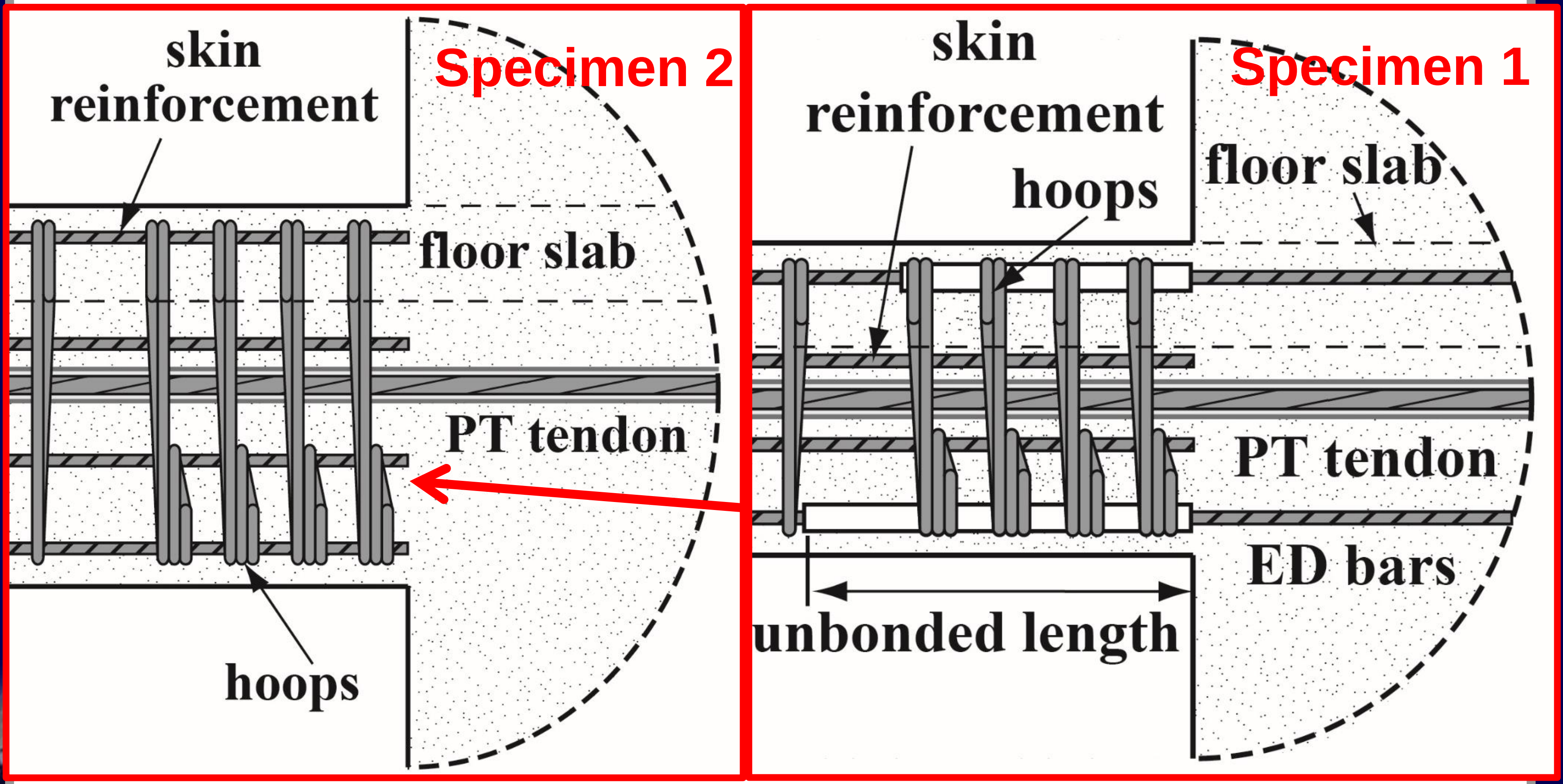
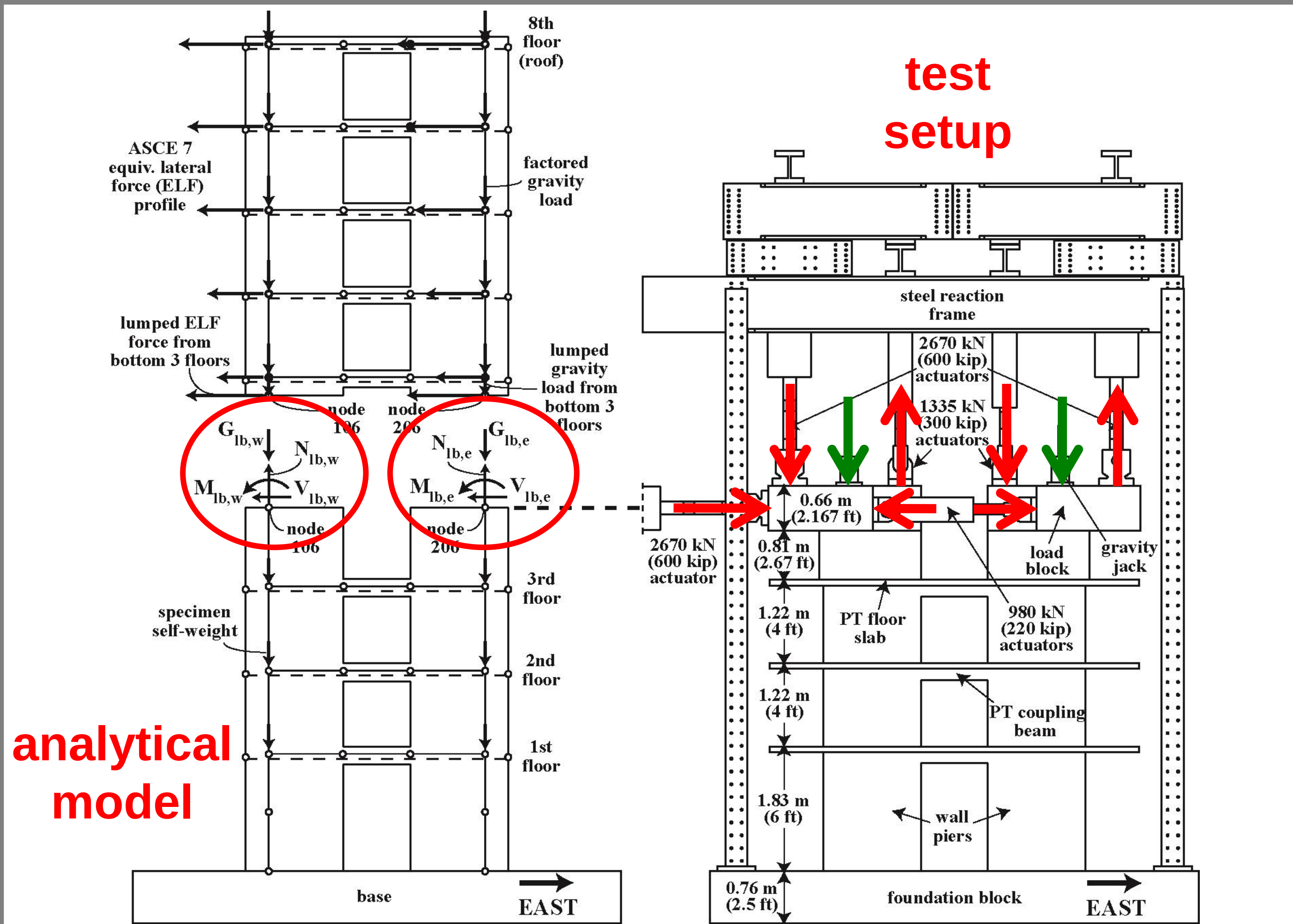
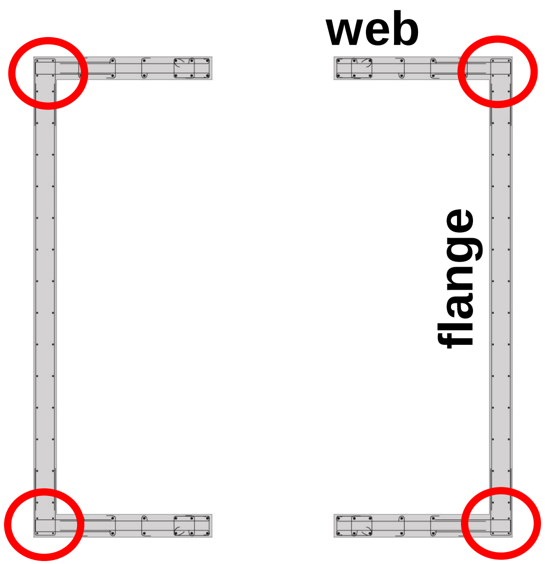
Post-Tensioned Coupling Beams



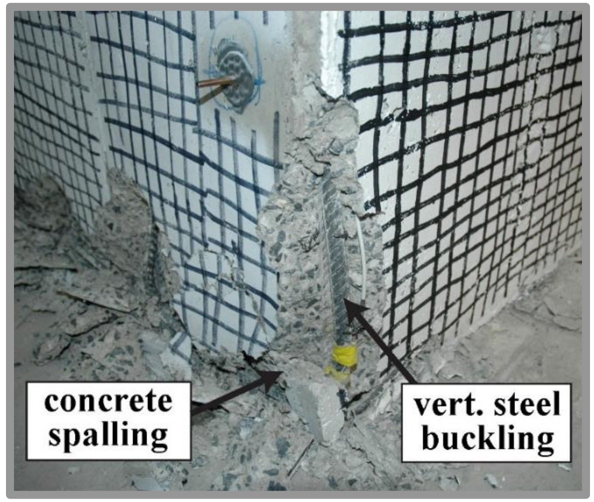
Load Application



Detail Change in Wall Pier Corners

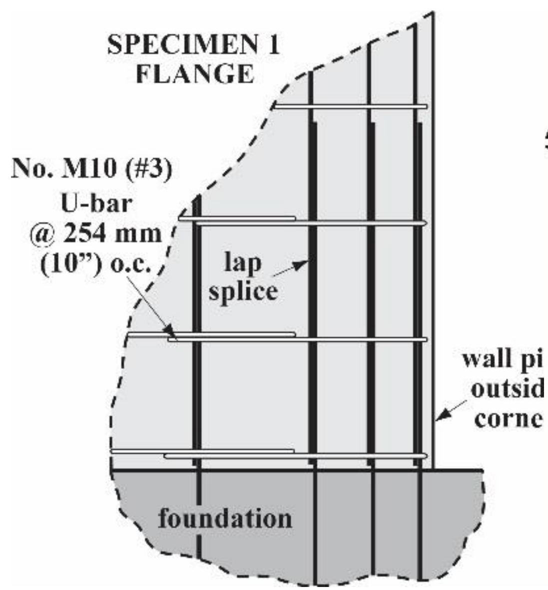


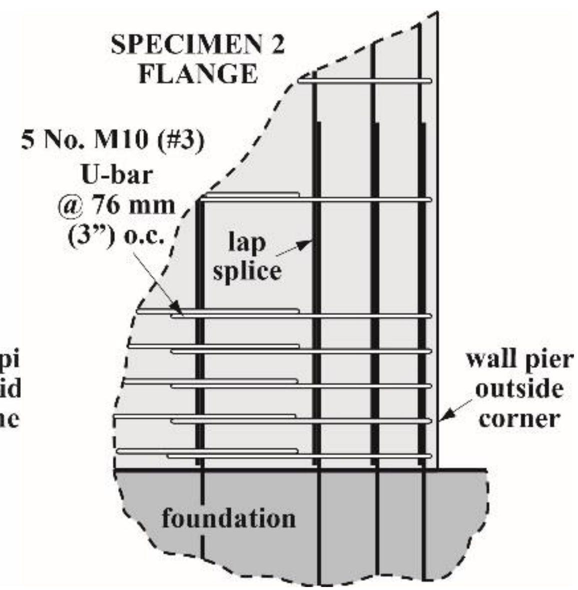
Specimen 1



Specimen 2

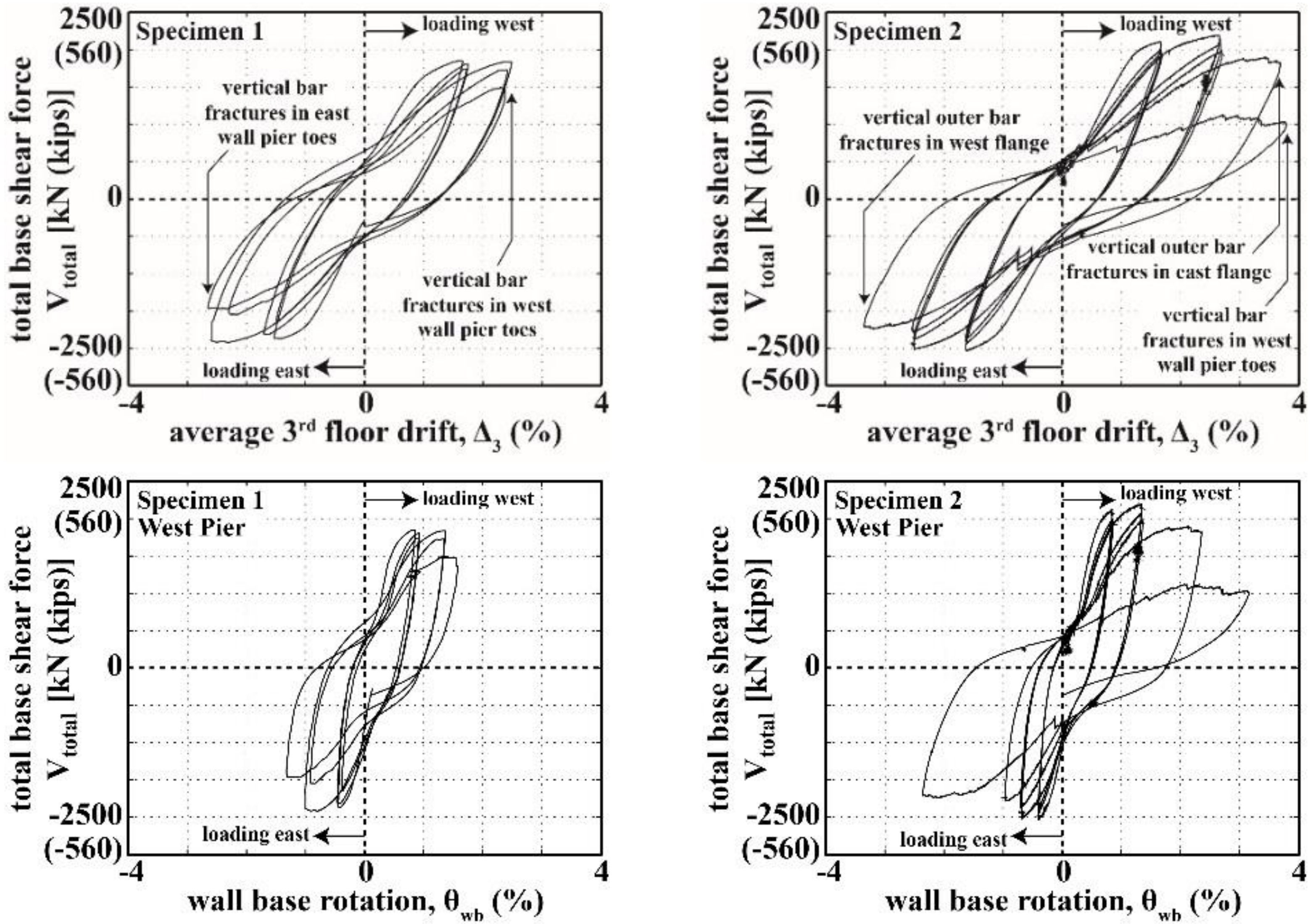
closely-spaced U-bars



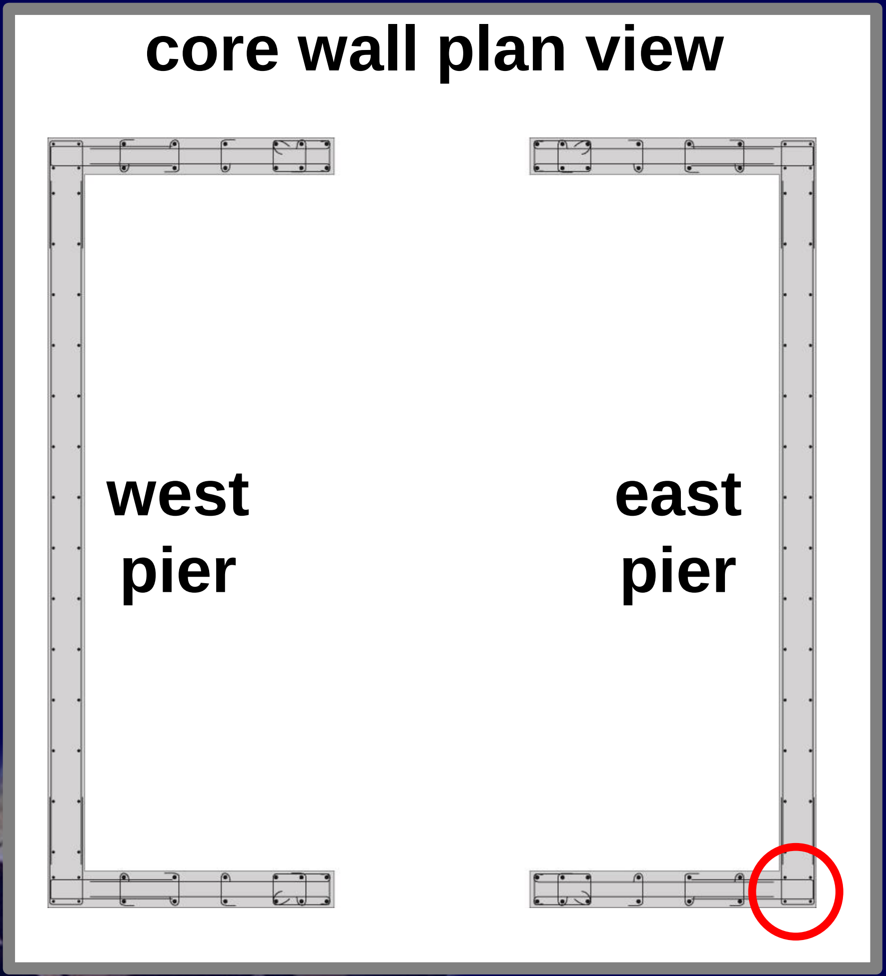


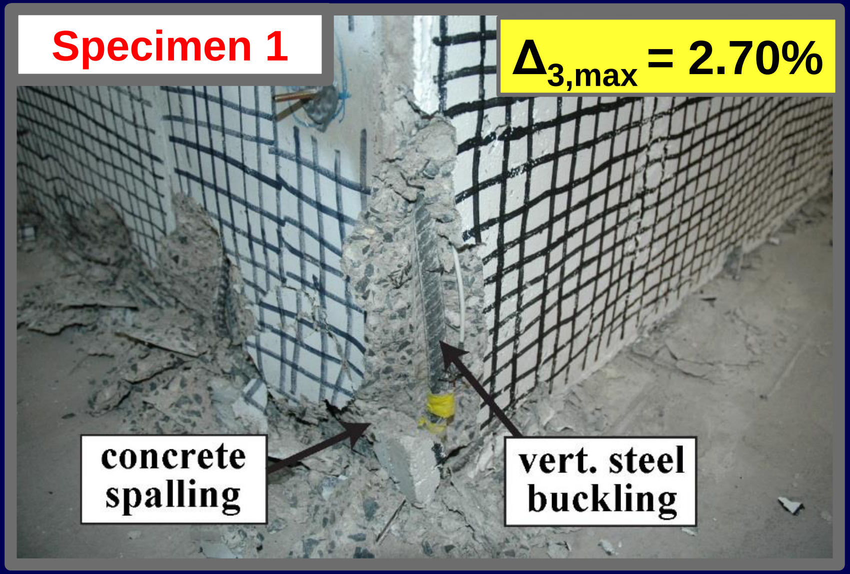
Comparison of Large Drift Response

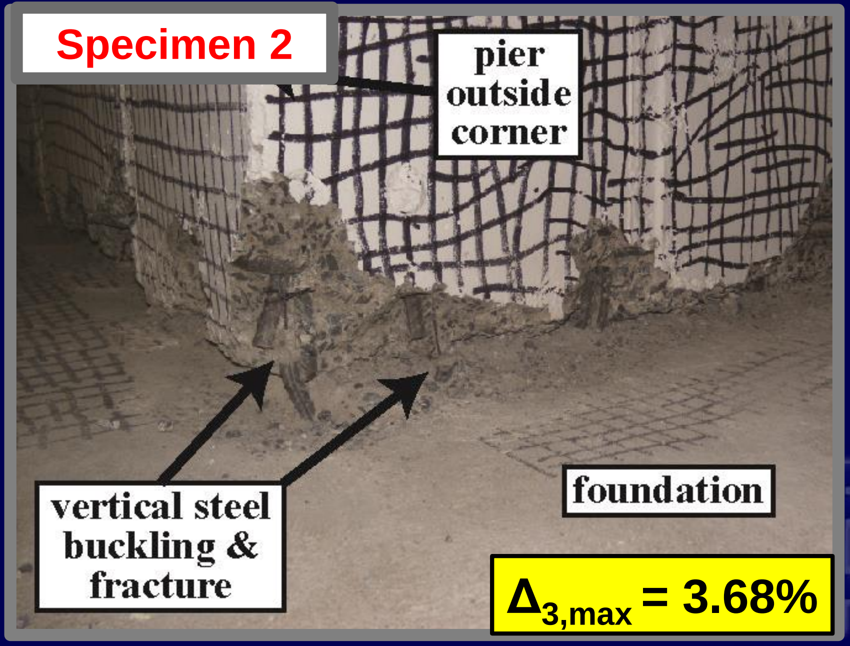
Specimen 1 | **Specimen 2**



Comparison of Wall Pier Corner Damage



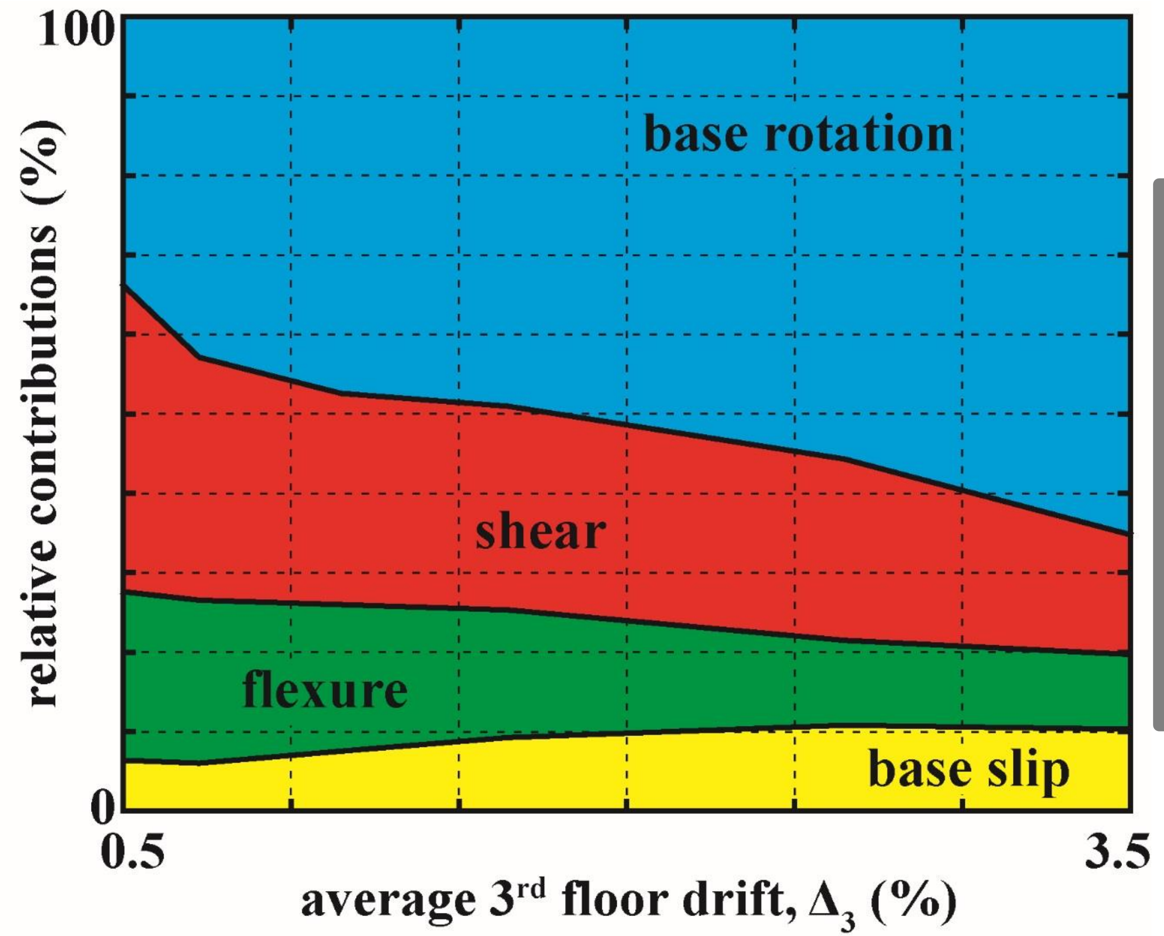


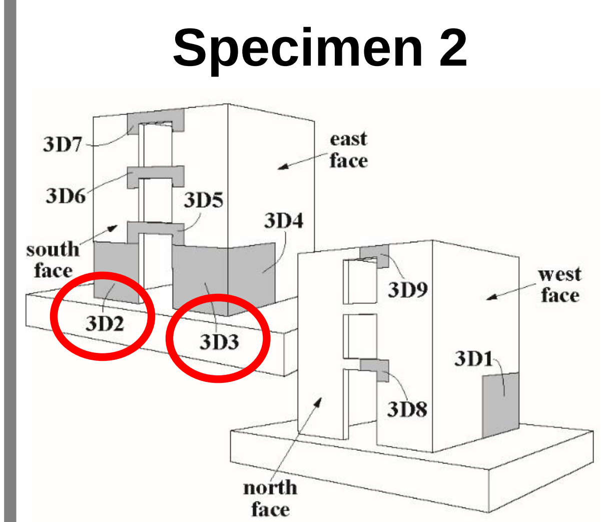


Specimen 1 Movie

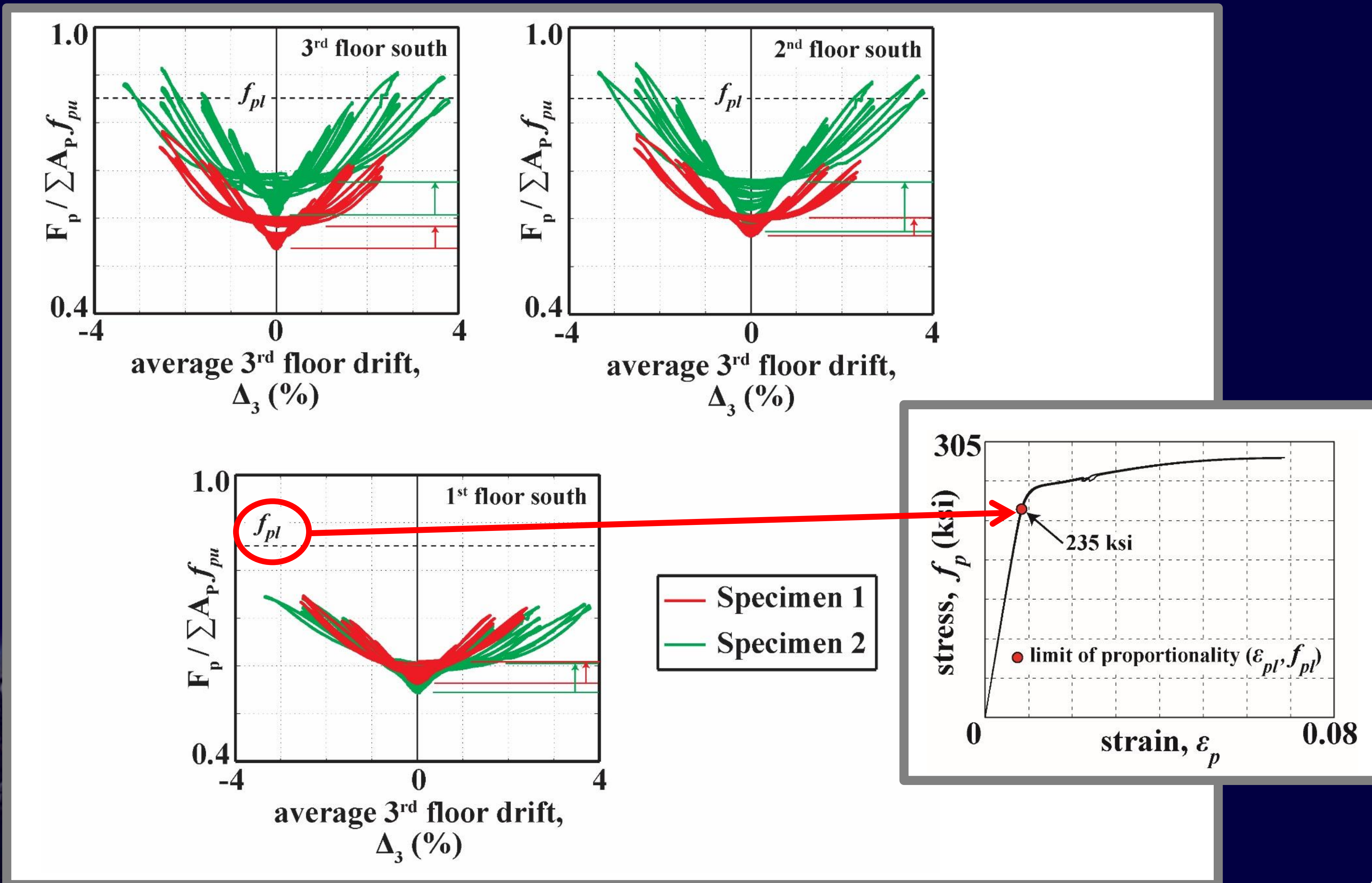
[YouTube]()

3rd Floor Drift Components (Specimen 2)





Beam PT Stresses



Energy Dissipation