Hybrid Precast Concrete Shear Walls for Seismic Regions

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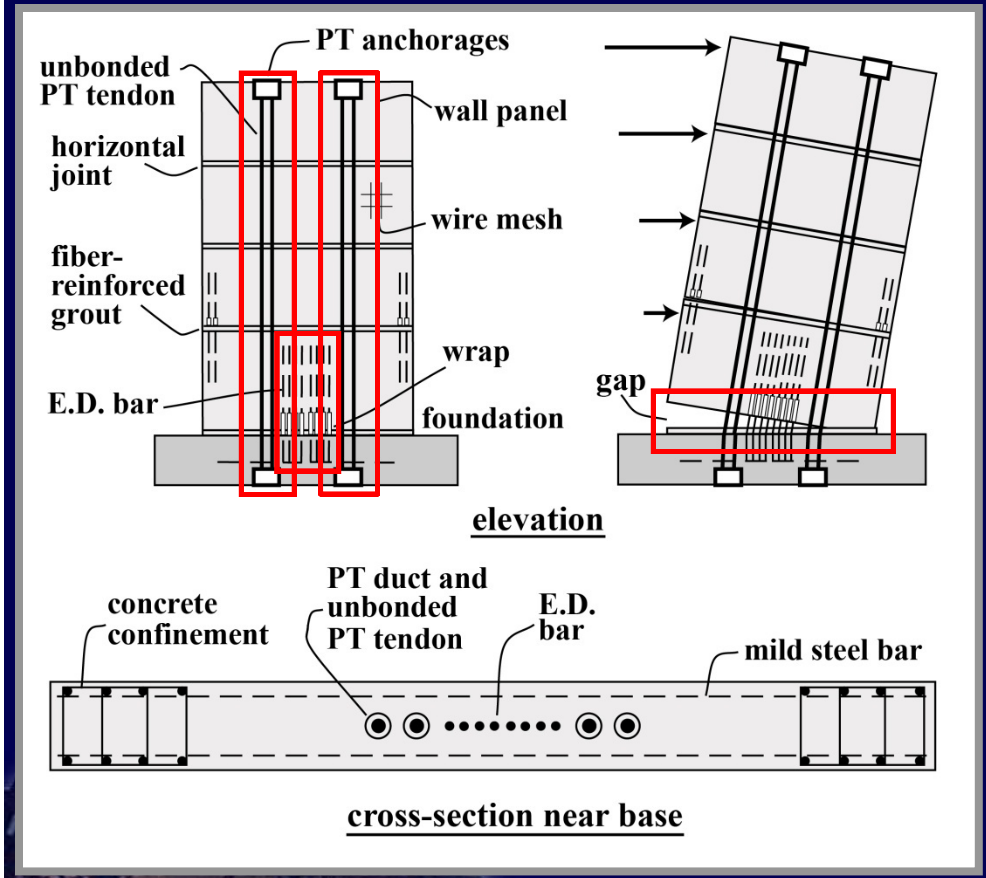
Hybrid Precast Shear Walls



- Precast Concrete Wall Panels with Horizontal Joints
- During Large Earthquake, Gap Opens at Base Joint
  - High Strength Unbonded Post-Tensioning Strands Provides Re-Centering Force
  - Mild (E.D.) Steel Bars Provide Energy Dissipation

Market Need & Research Objectives

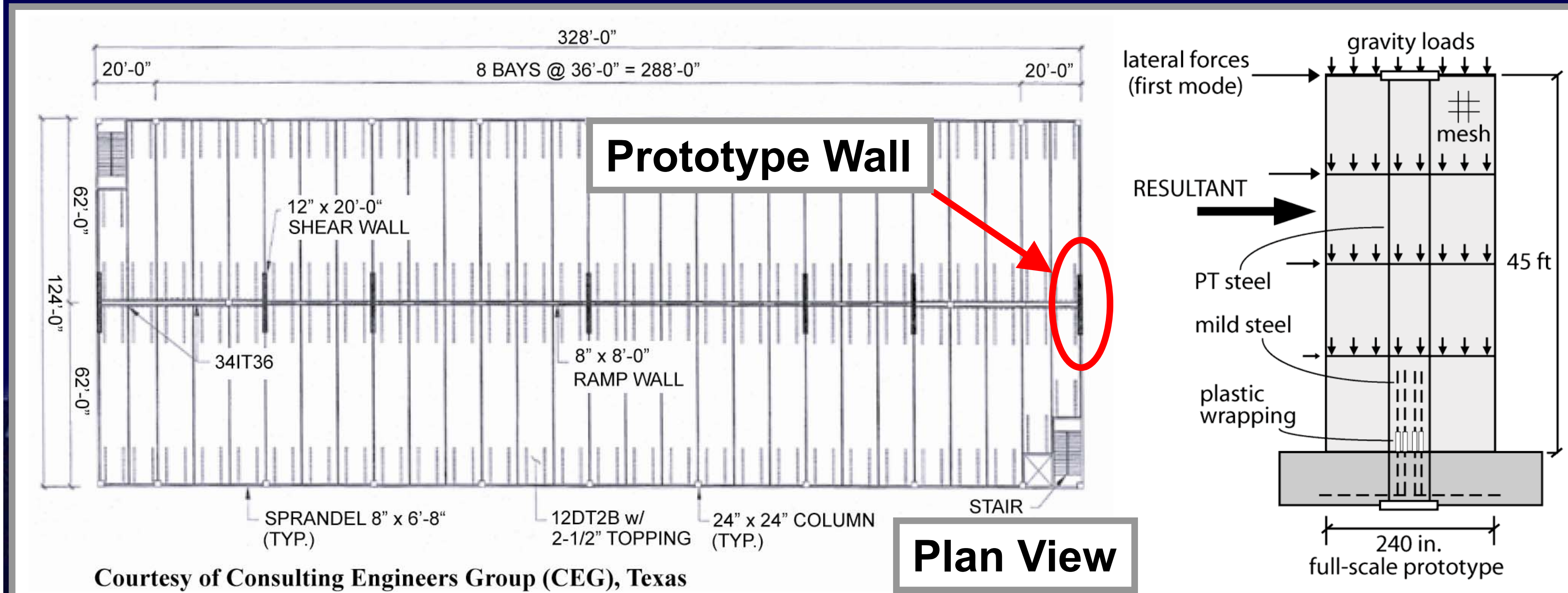
- **Code Approval of Hybrid Wall System**
  - Categorized as “Non-Emulative” Structure
  - Requires Experimental Validation
  - ACI ITG-5.1 Provides Validation Criteria
  - ACI ITG-5.2 Provides Roadmap for Wall Design
- **Research Objectives**
  - Develop Experimental, Analytical, and Design Validations to Allow for Code Adoption of Hybrid Precast Walls
  - Develop Design Procedure Document for Moderate and High Seismic Regions

Outline

- Introduction & Objectives
- Experimental Program
- Seismic Design Approach
- Analytical Investigation
- Summary and Acknowledgements

Prototype Building & Wall

- Six Test Specimens
- Design Based on Prototype Parking Garage Building
- Seismic Category D in Los Angeles, CA 90045
  - $S_S = 1.500$; $S_1 = 0.640$; $C_S = 0.167$; $R = 6.0$; $C_D = 5.0$
- Base Moment for Full-Scale Wall ~20,000-kip-ft
- Structures Designed with Minimal Over-strength/Over-detailing

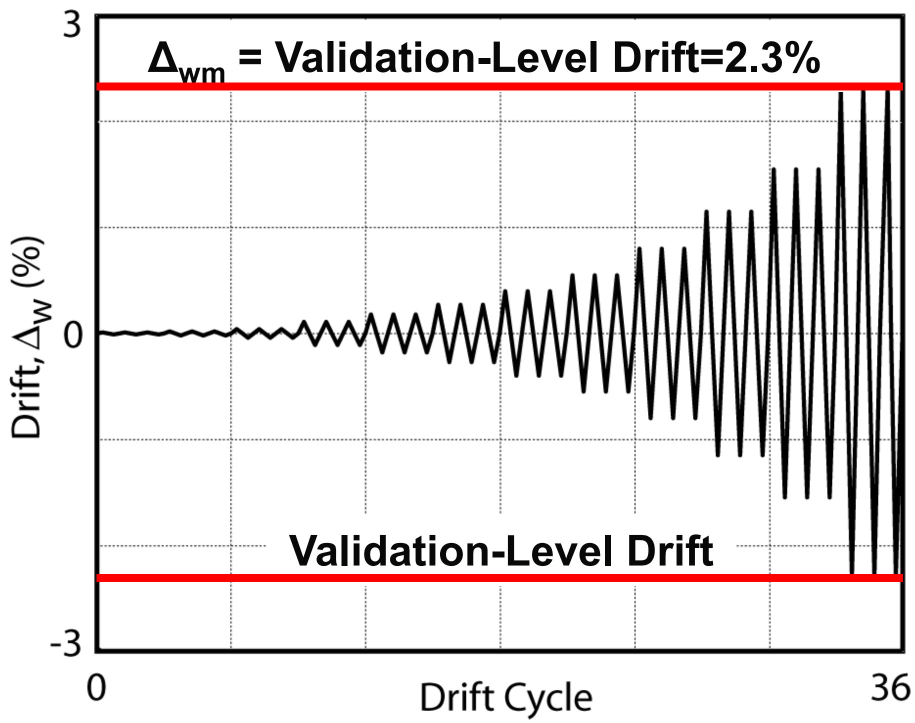


Experimental Program

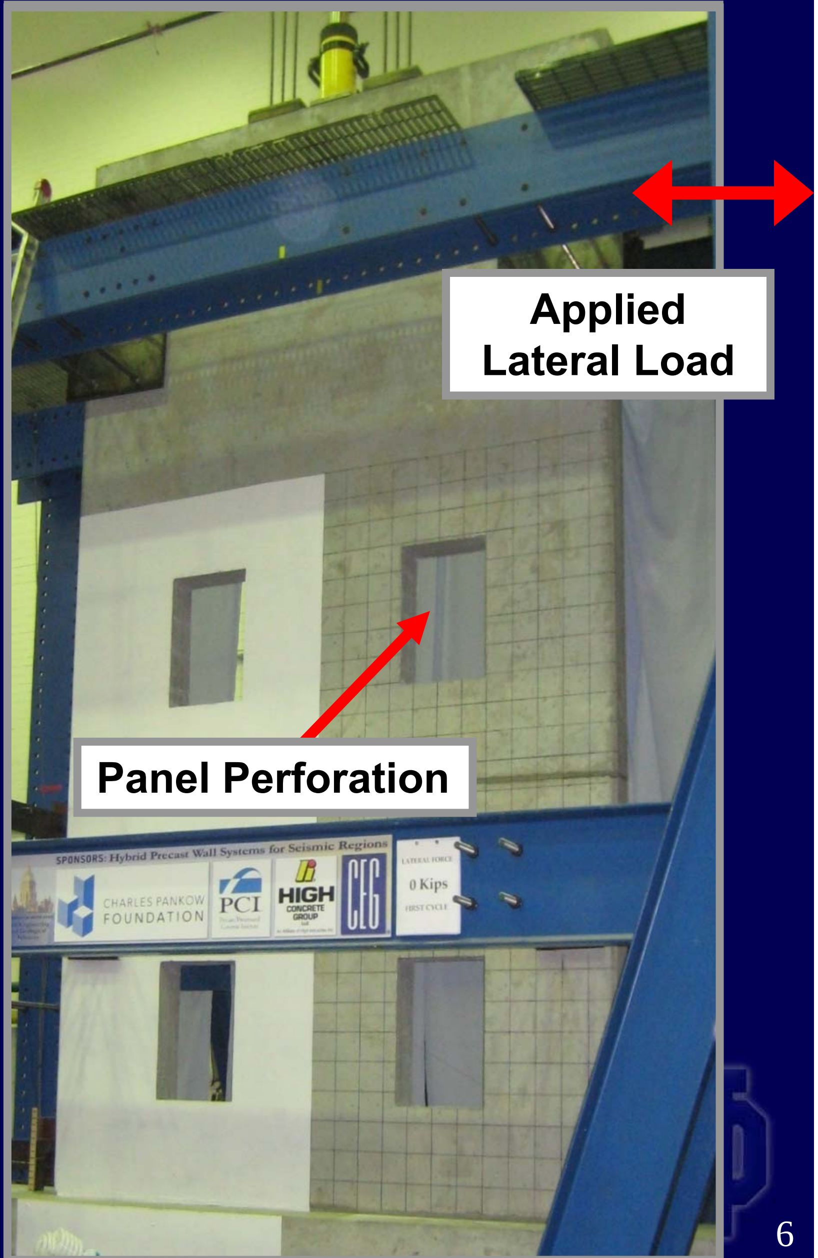
- **0.4 Scaled Test with Two Wall Panels**
- **Specimen Design Parameters:**

Δ_{wd} = 0.54% - 0.87%; Δ_{wm} = 2.30%
(H_w / L_w = 2.25)

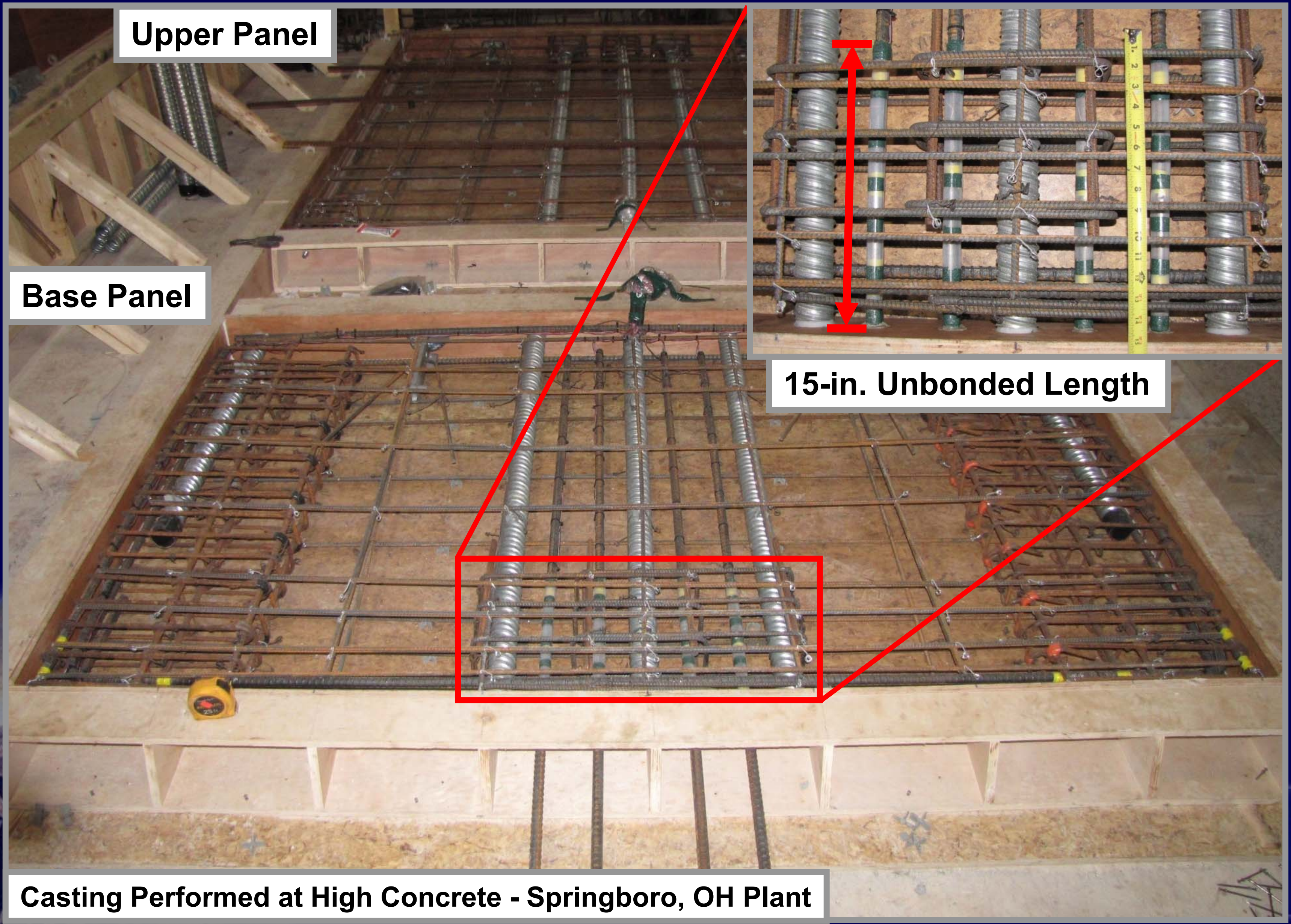
ACI Required Drift History



Δ_{wm} = 0.90% ≤ 0.80(H_w / L_w) + 0.5 ≤ 3.0%

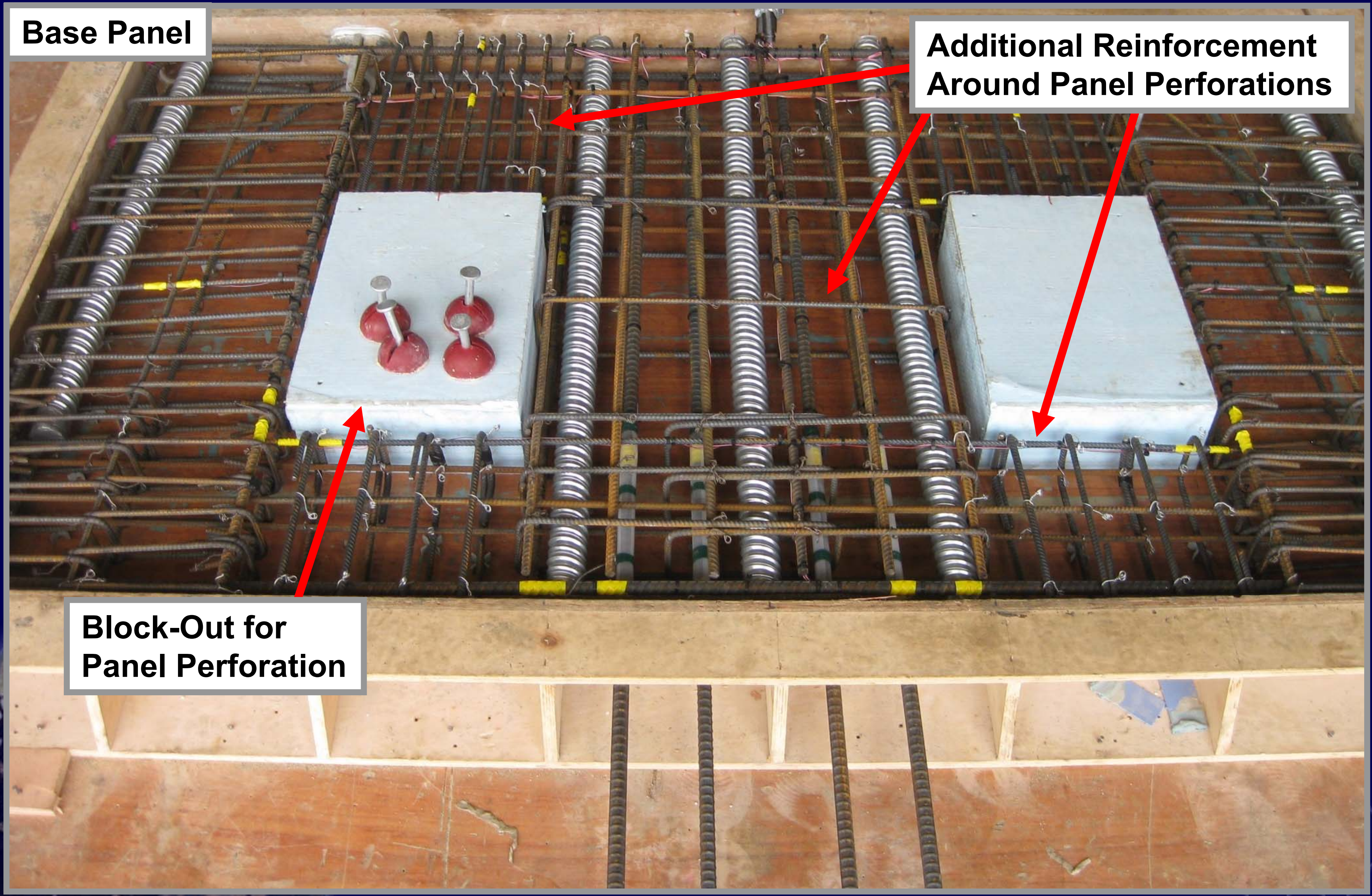


Specimen HW3 - Reinforcement Details



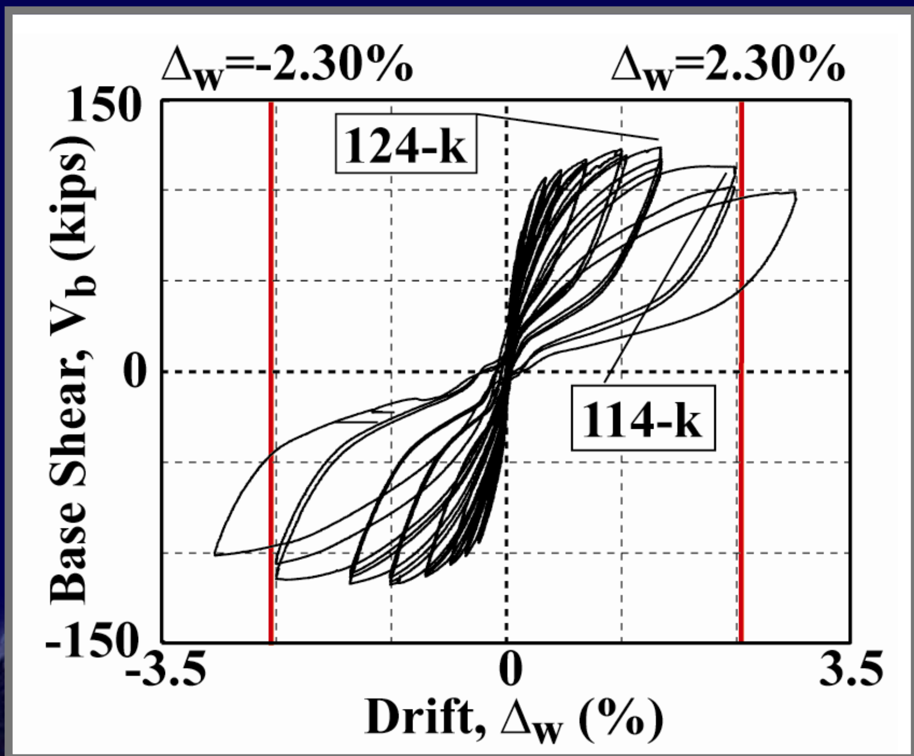
Casting Performed at High Concrete - Springboro, OH Plant

Specimen HW4 - Reinforcement Details

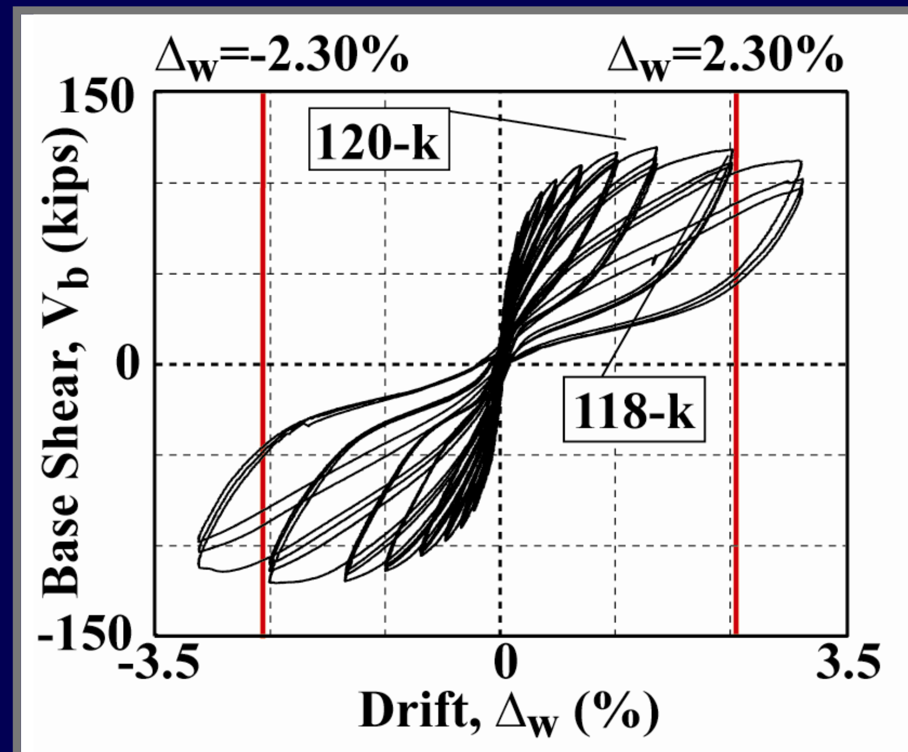


Hysteretic Behavior of Validated Hybrid Walls

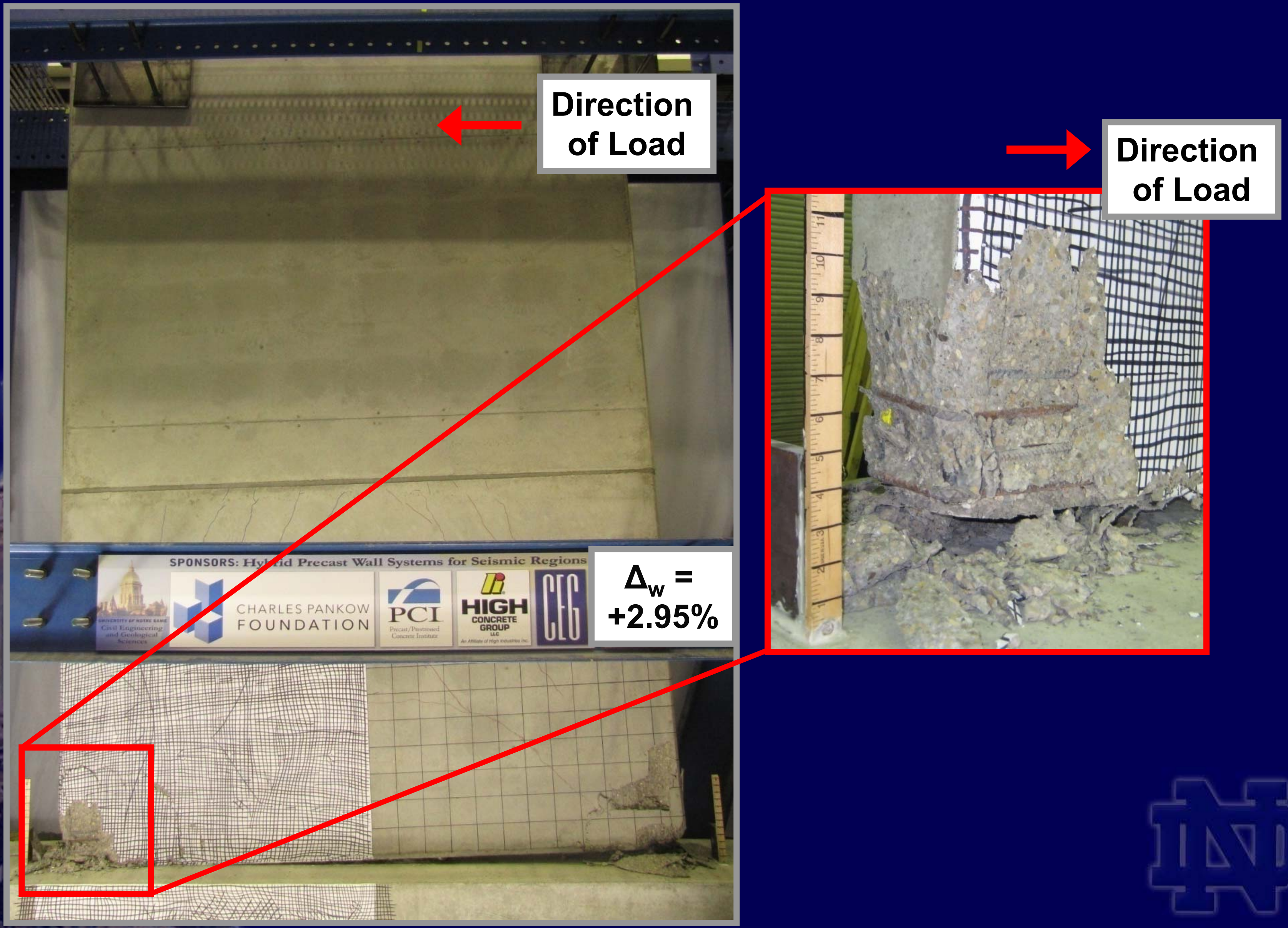
HW3: Solid Wall



HW4: Perforated Wall



Damage State of Specimen HW3



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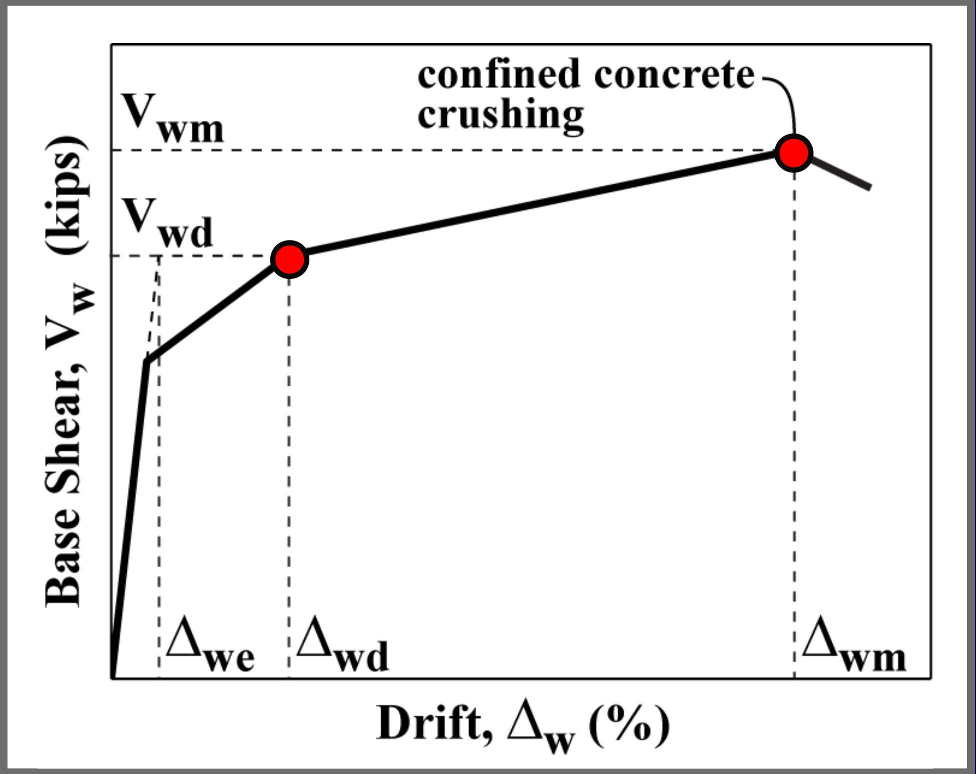
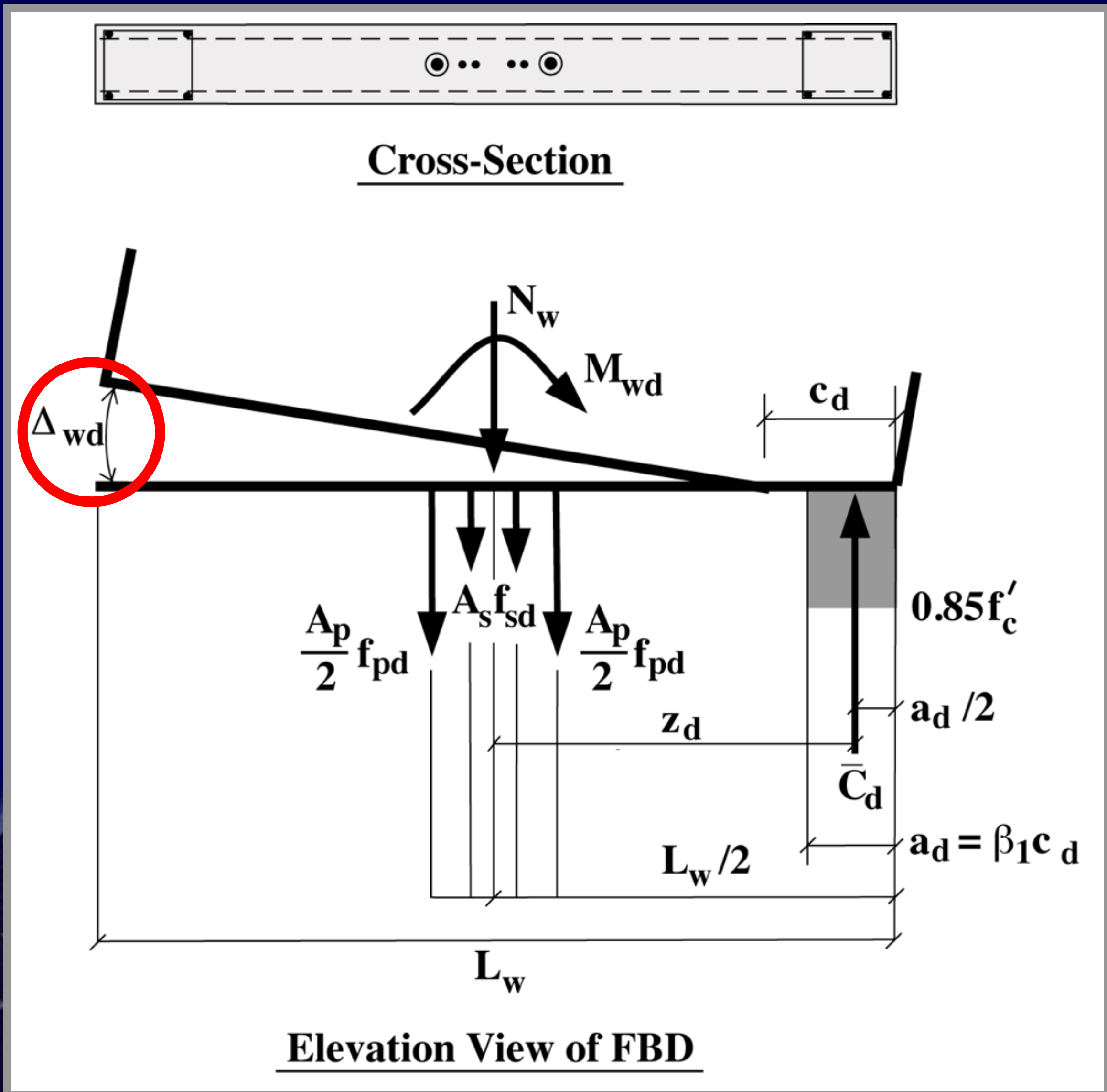
Performance Objectives

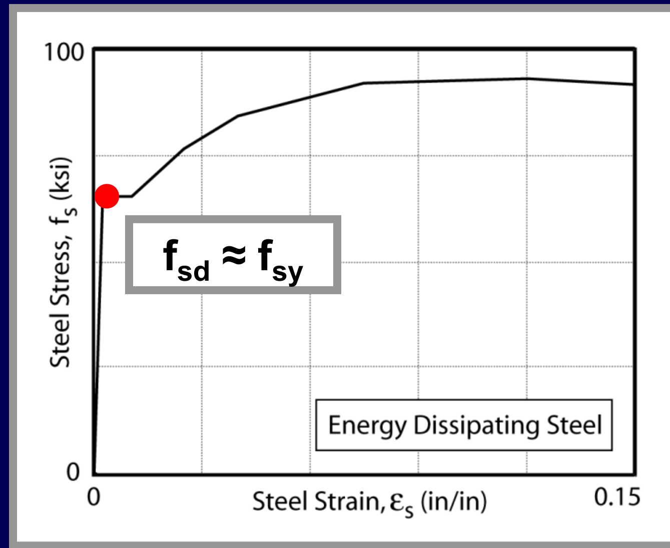
Idealized Wall Behavior



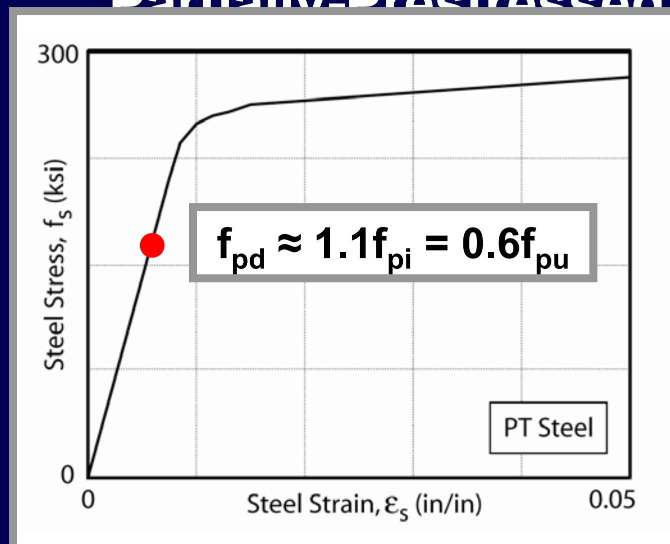
- **Design-Level Drift**
  - Gap Opening at Base Joint
  - Yielding of E.D. Bars
  - PT Steel Linear-Elastic
  - Minor Concrete Cracking
  - Cover Concrete on Verge of Spalling
- **Maximum-Level Drift**
  - No Significant Gap Opening at Upper Joints
  - No Significant Residual Vertical Wall Uplift Upon Unloading
  - No Significant Slip at Joints
  - No Fracture of E.D. Bars
  - No Fracture or Significant Yielding of PT Steel
  - Confined Core Concrete on Verge of Crushing

Design-Level Drift, Δ_{wd}

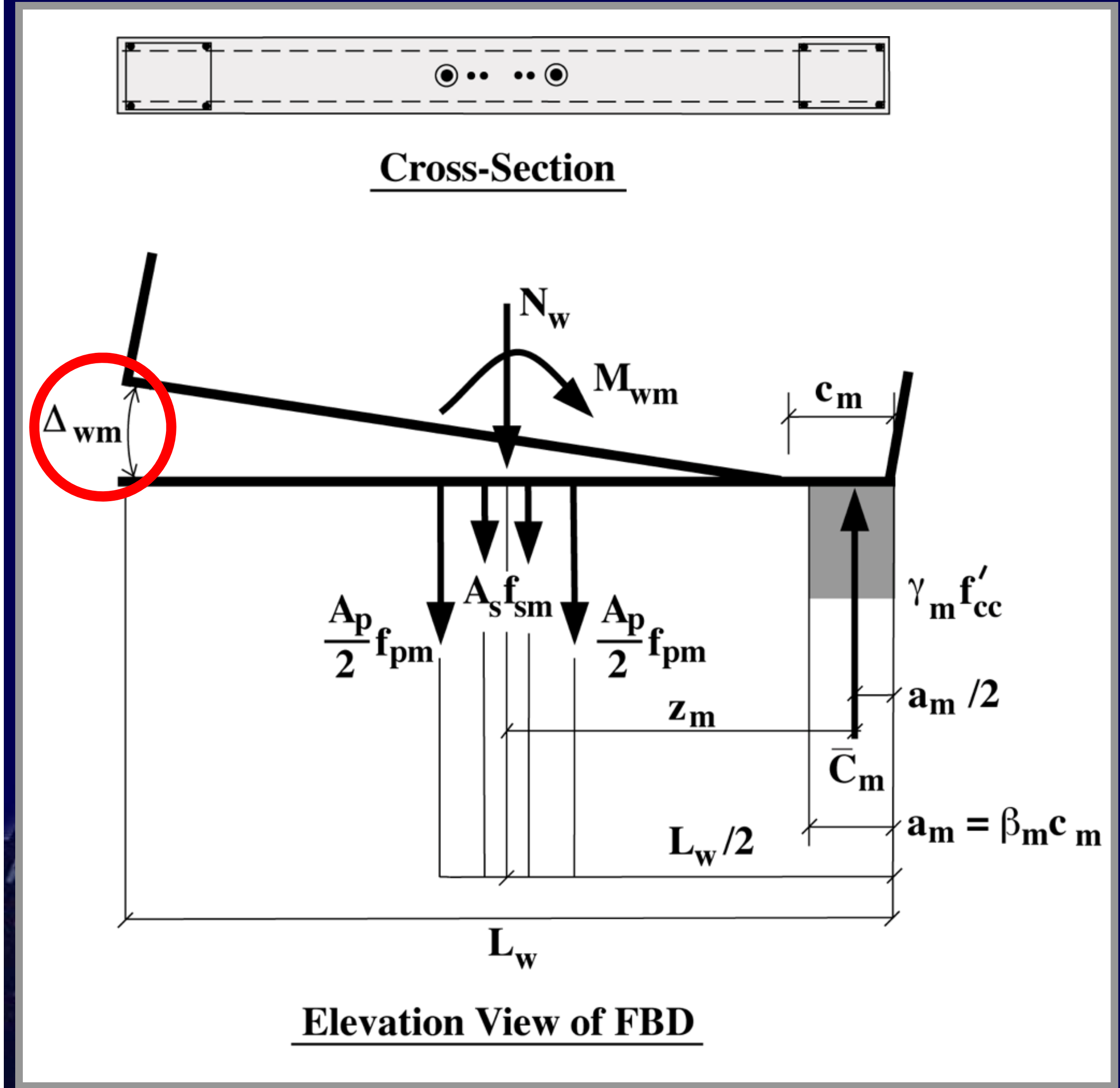


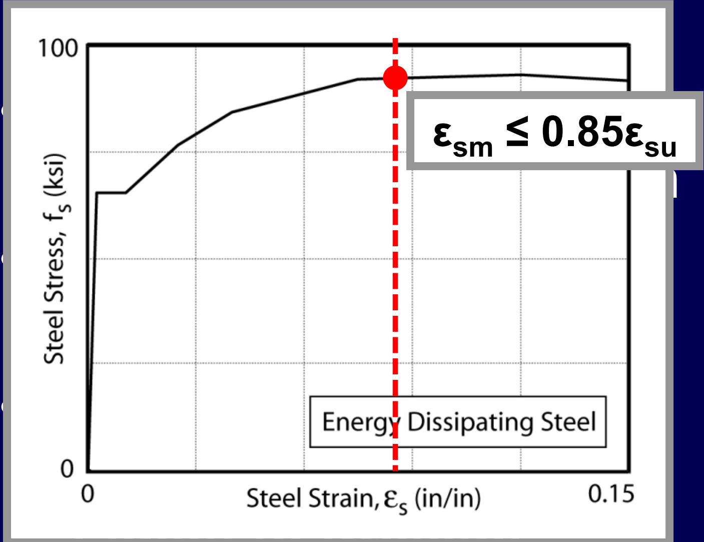


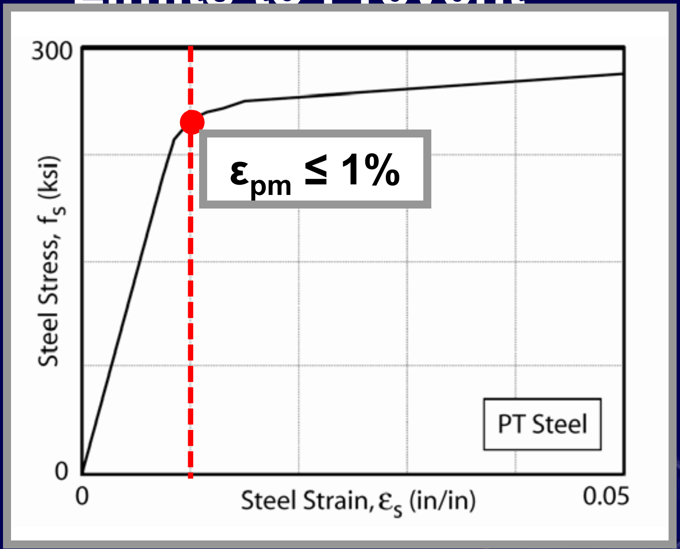
Partially-Prestressed



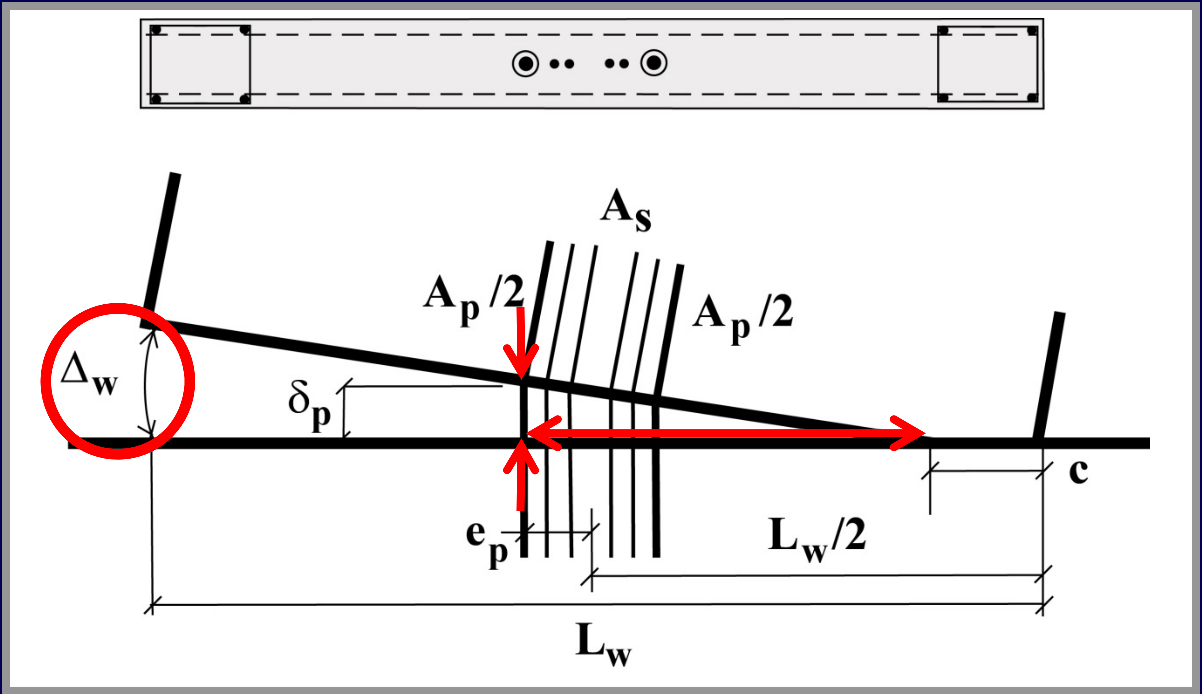
Maximum-Level Drift, Δ_{wm}







Estimation of Steel Strains



$$\delta_p = \Delta_w \left(\frac{L_w}{2} + e_p - c \right)$$

$$\varepsilon_p = \frac{f_{pi}}{E_p} + \frac{\delta_p}{l_p}$$

initial strain

strain due to gap

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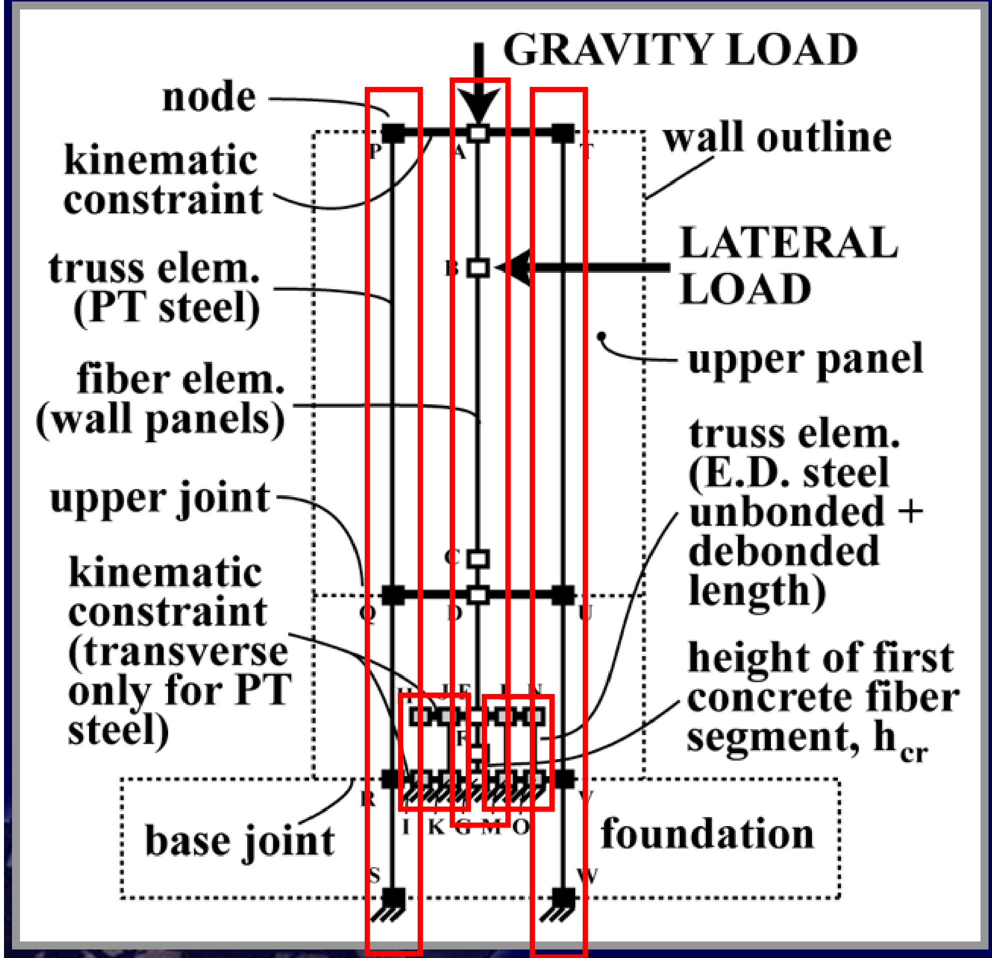
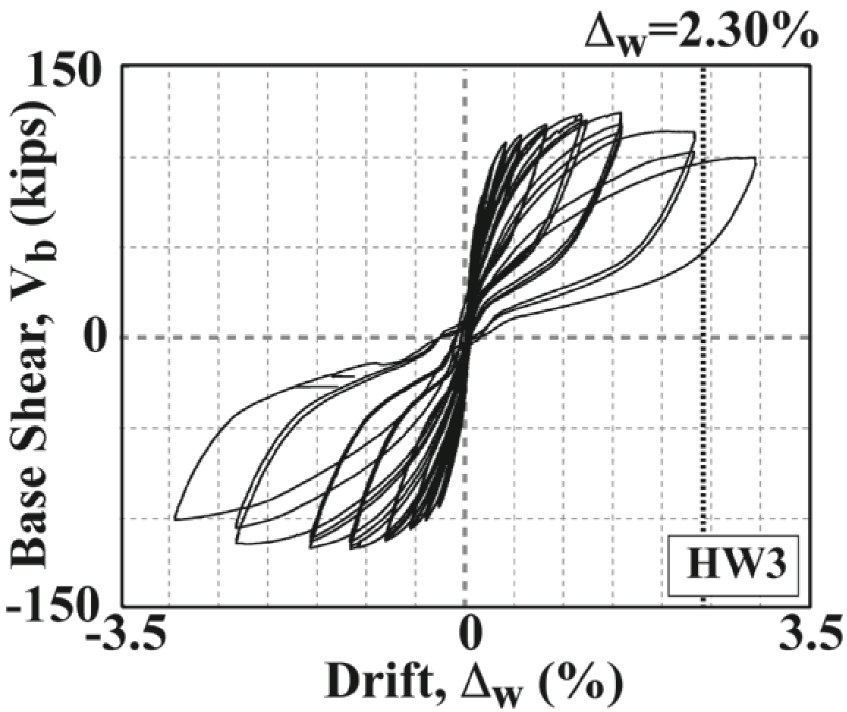
Fiber Element Model



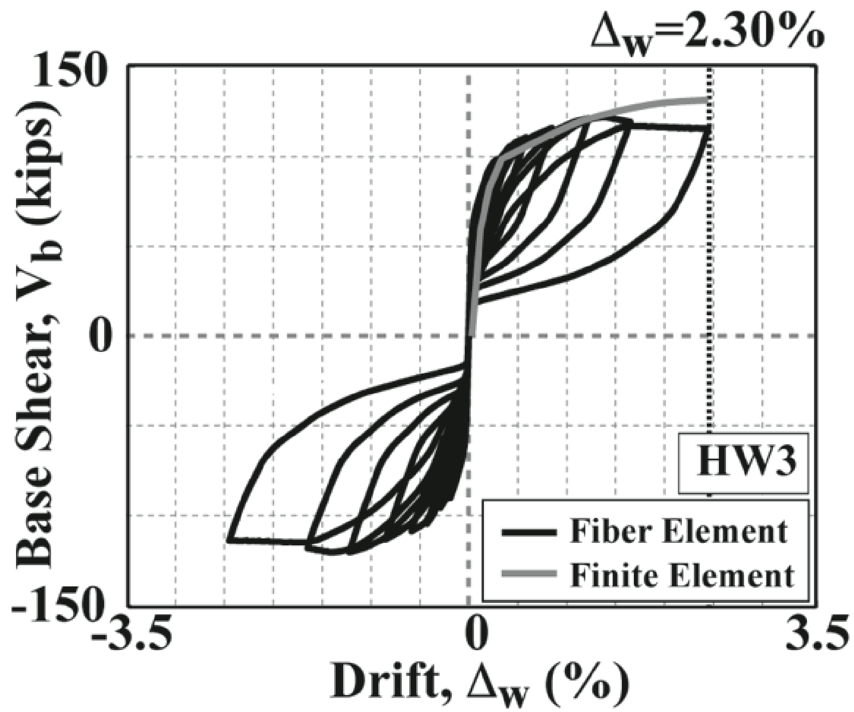
- DRAIN-2DX Program
- Concrete Wall Panels
  - Fiber Beam-Column Elements
- Unbonded PT Steel
  - Truss Elements
- E.D. Steel
  - Truss Elements

Lateral Load versus Deflection Behavior

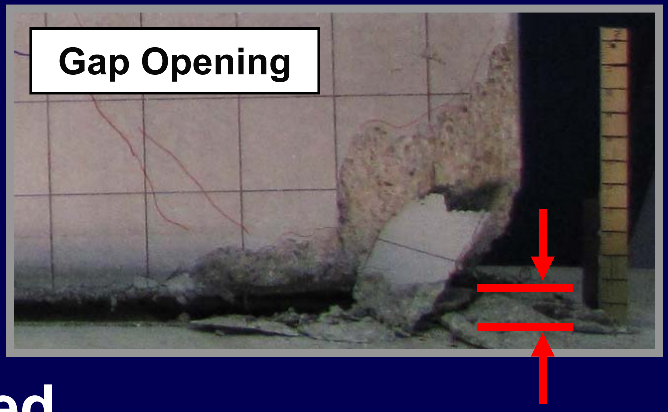
Measured

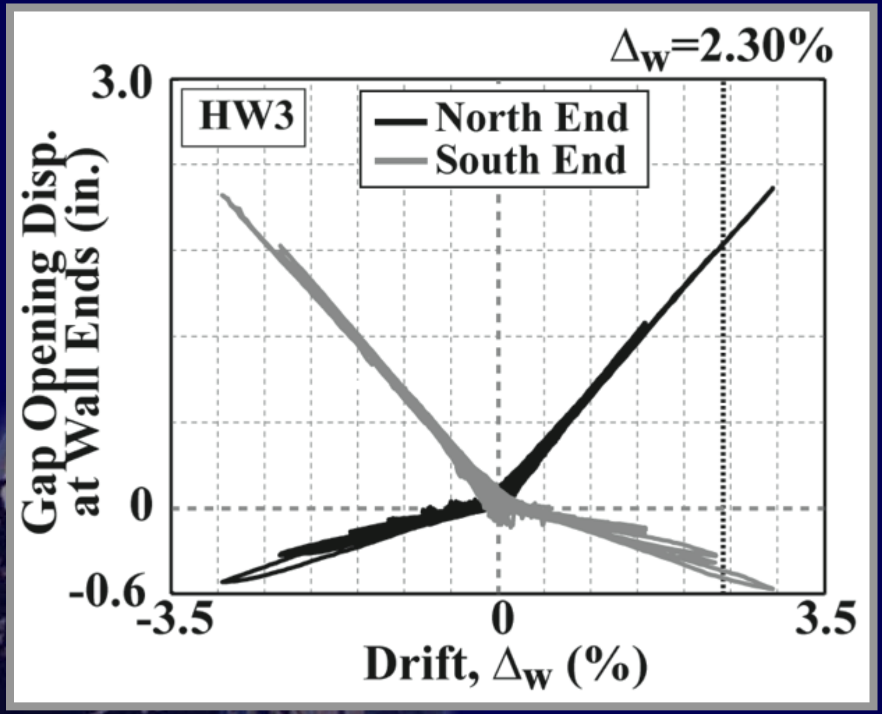


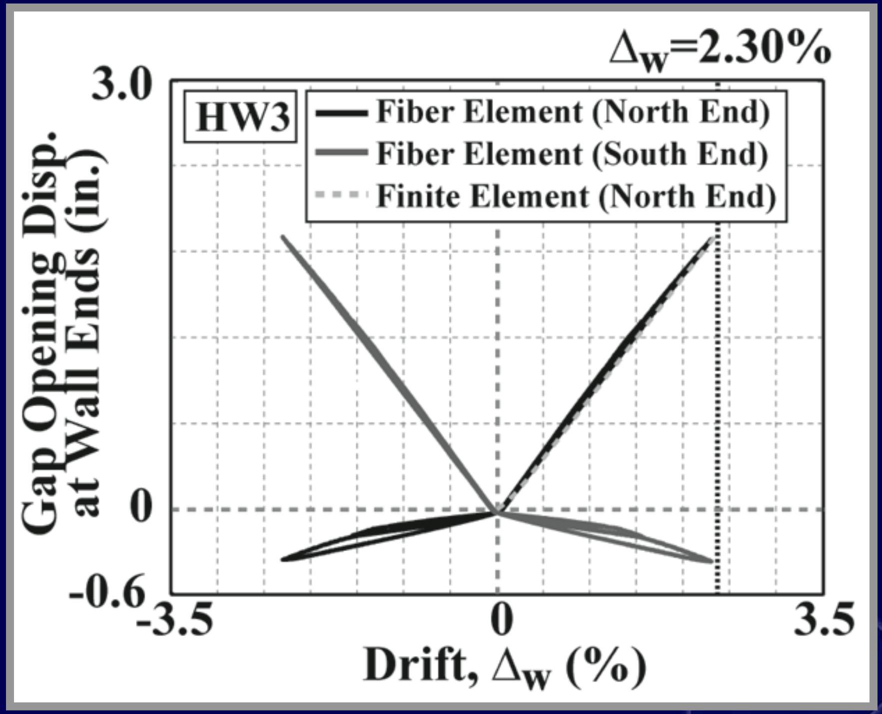
Analytical



Gap Opening Displacements

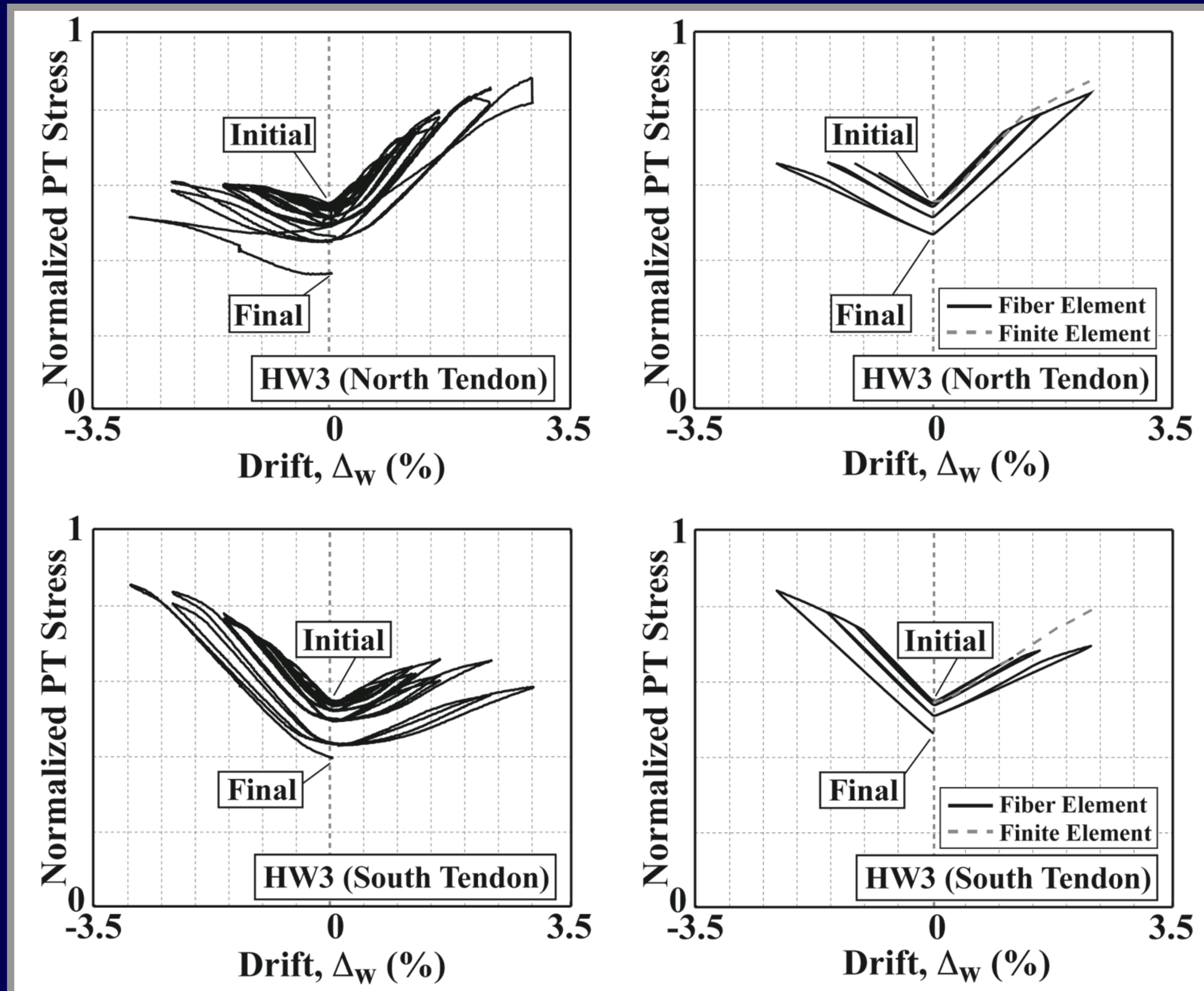




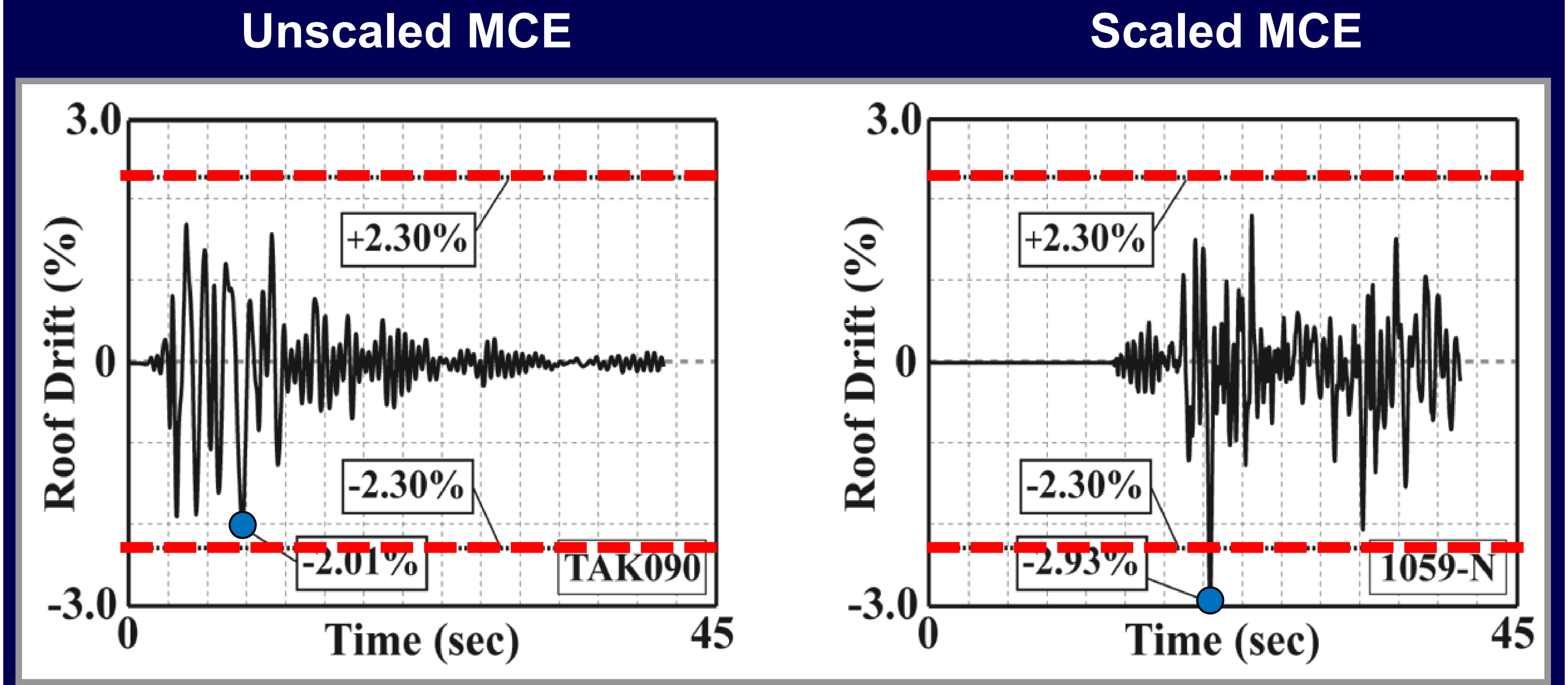


PT Steel Stresses

Measured **Analytical**

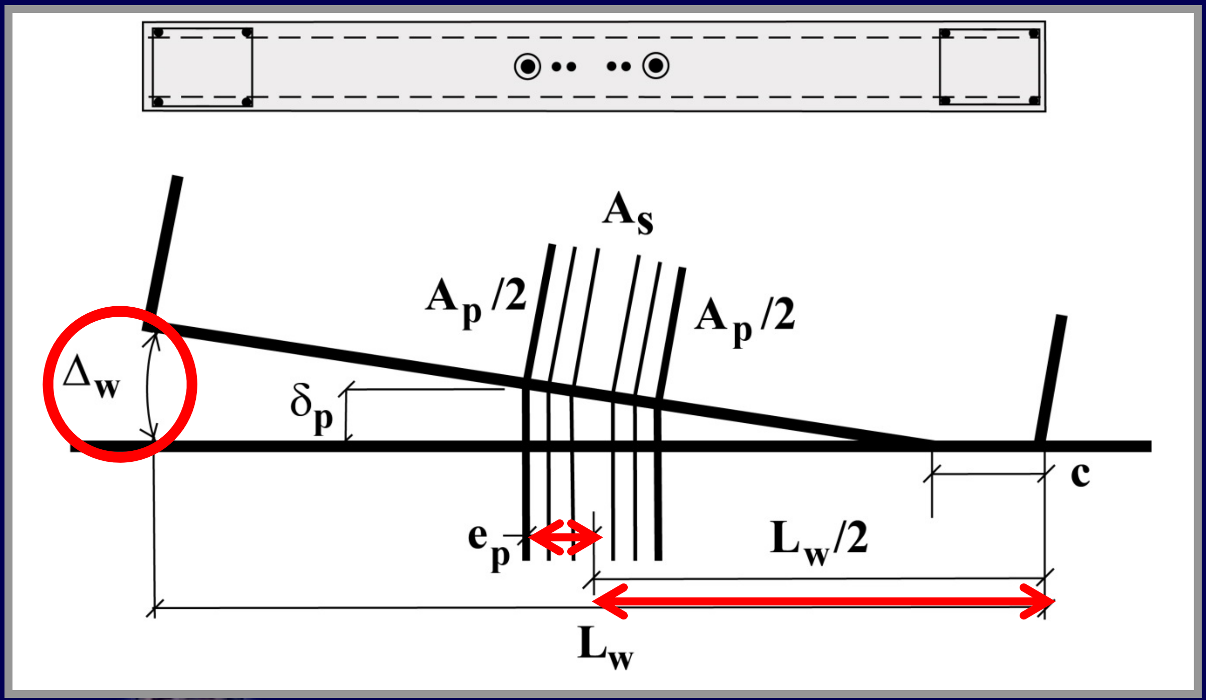


MCE Level Dynamic Peak Drift Demands



- Δ_{wm} = 2.30% Reasonable for Validation-Level Drift

Factors that Affect PT Strain Demands

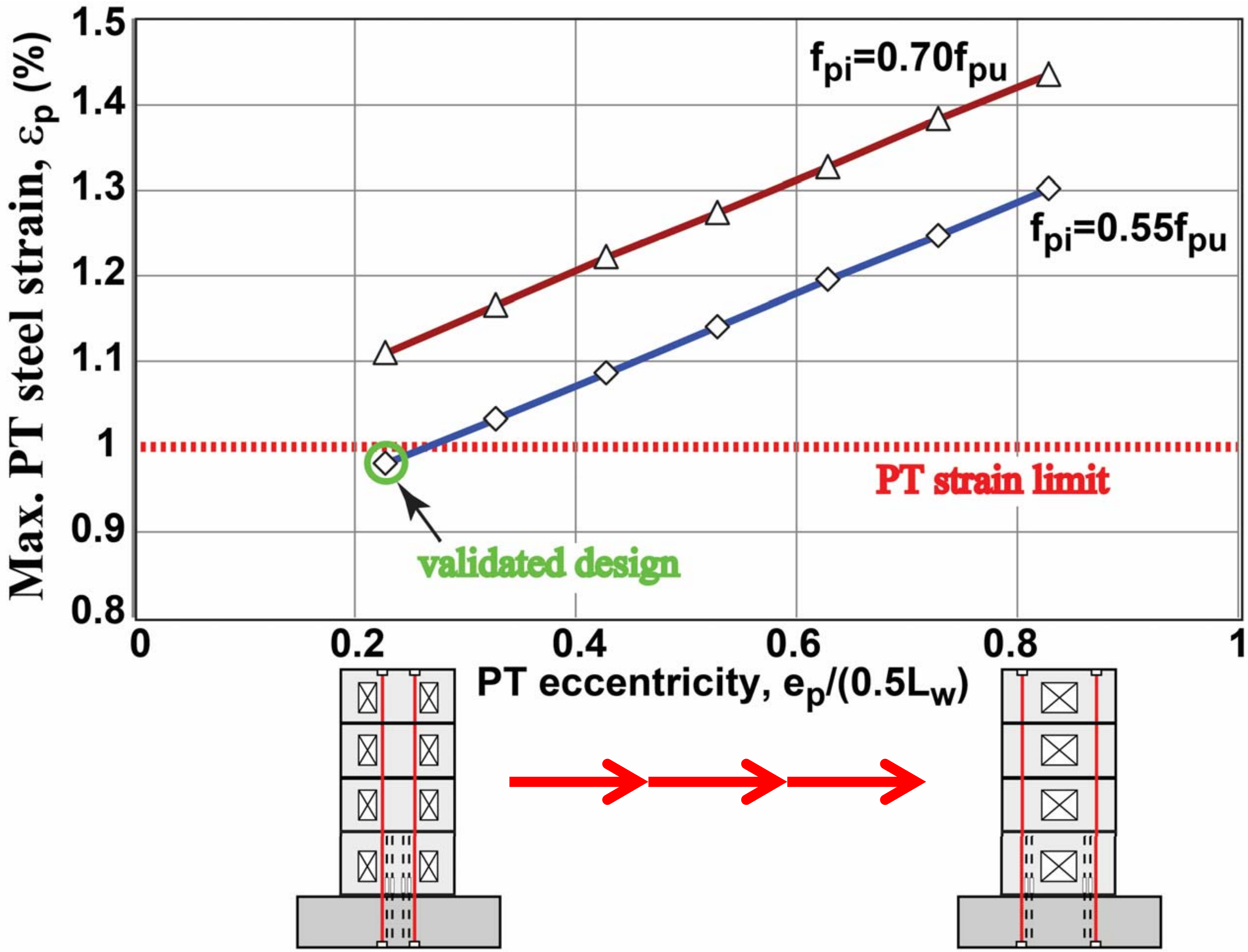


$$\delta_p = \Delta_w\left(\frac{L_w}{2} + e_p - c\right)$$

$$\varepsilon_p = \frac{f_{pi}}{E_p} + \frac{\delta_p}{l_p}$$

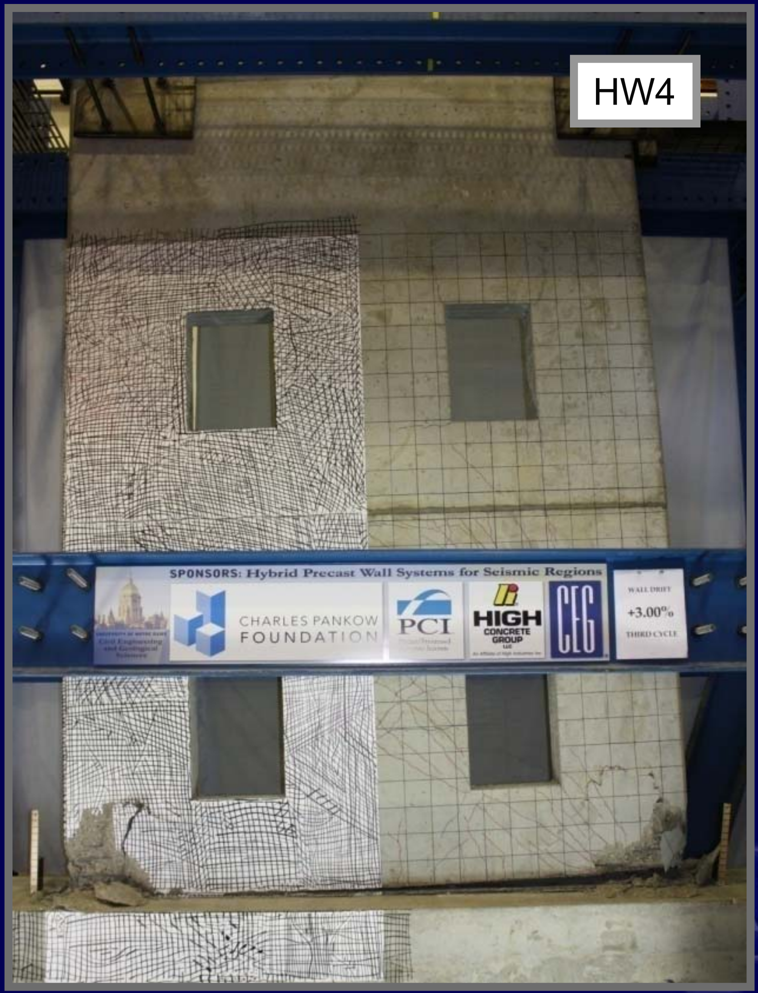
- **Factors that affect ε_p:**
  - Wall drift demand, Δ_w
  - Wall length, L_w
  - PT tendon eccentricity, e_p
  - Initial stress, f_{pi}
  - Unbonded length, l_p

Effect of PT Eccentricity and Initial Stress



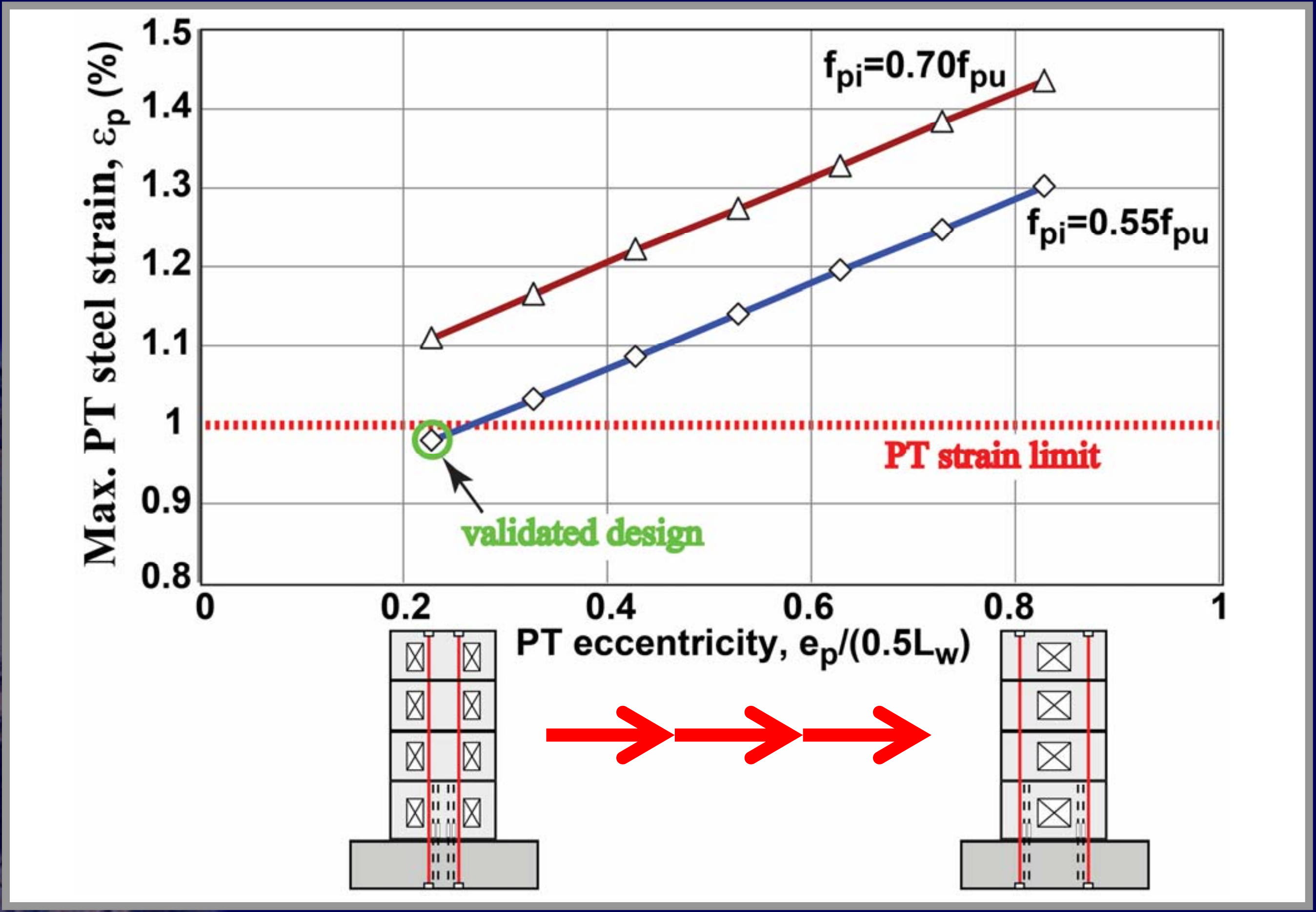
Summary

- **Tested Six 0.4-Scaled Specimens**
  - **Developed Validation Evidence for Hybrid Walls as Special RC Shear Walls in Seismic Regions**



Implications for Unbonded Post-Tensioning

- Large PT Strain Demands Under Extreme Loading
- Strand-Anchorage Systems up to 2% Strain Capacity May be Needed for Seismic Regions



Acknowledgements

- **Sponsors**
  - The Charles Pankow Foundation
  - PCI Research & Development Committee
  - High Concrete Group, LLC
  - The Consulting Engineers Group – Texas
  - PCI Central Region
  - University of Notre Dame
- **Advisory Panel**
  - Walt Korkosz - The Consulting Engineers Group, Inc.
  - Ken Baur - High Concrete Group, LLC
  - Neil Hawkins - Univ. of Illinois Urbana-Champaign
  - S.K. Ghosh - S.K. Ghosh Associates, Inc.
  - Dave Dieter - Mid-State Precast, LP
- **Industry Support**
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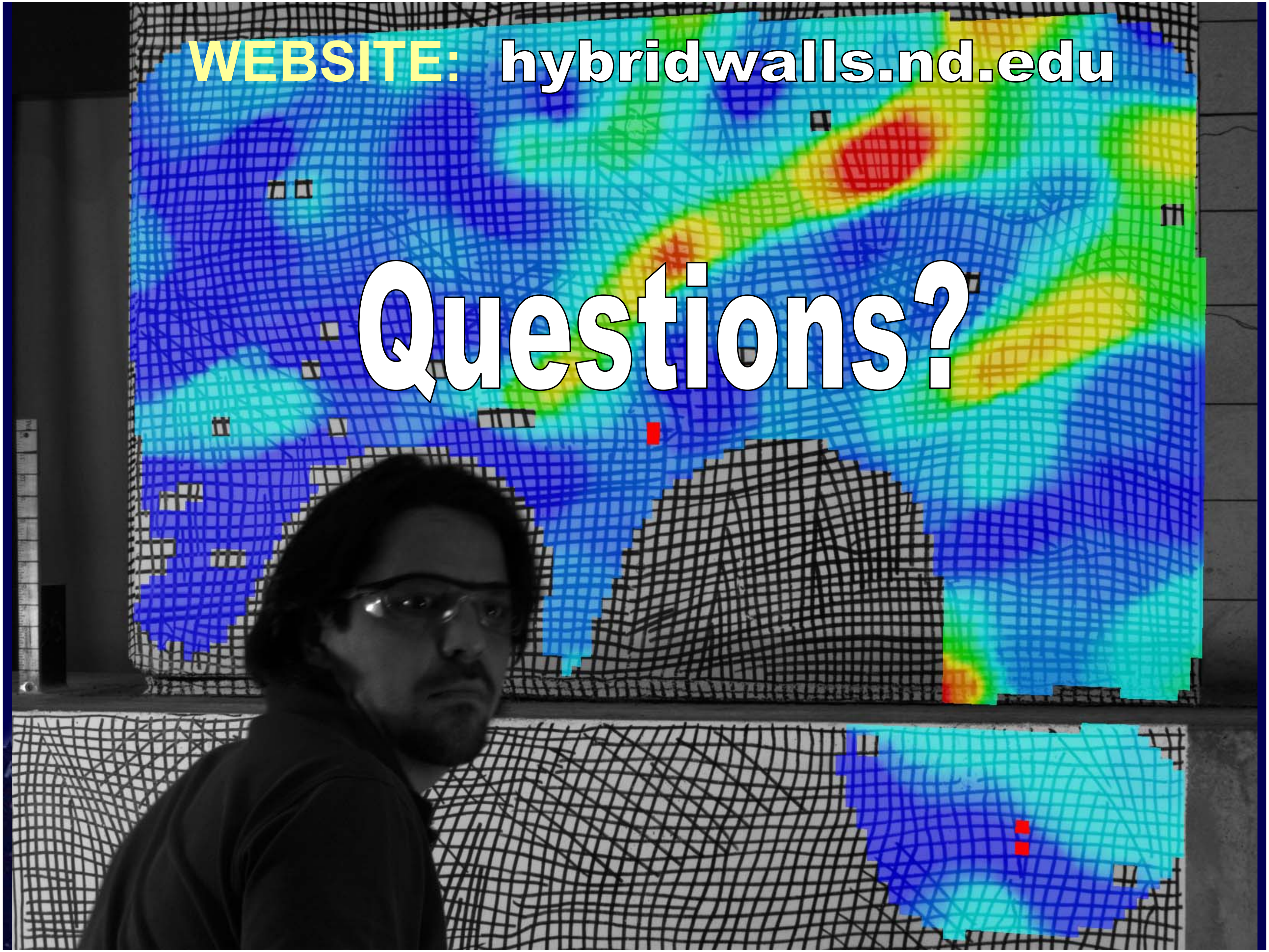
  - ECCO Manufacturing
  - Enerpac Precision
    SURE-LOCK
  - Essve Tech, Inc.
  - Prestress Supply, Inc.
  - Sumiden Wire Products Corp.
  - Summit Engineered Products
  - Ambassador Steel Corp.


WEBSITE: hybridwalls.nd.edu
Questions?