# Combined and Isolated Effects of High-Strength Concrete and High-Strength Headed Rebar in Shear Critical Nuclear RC Structures

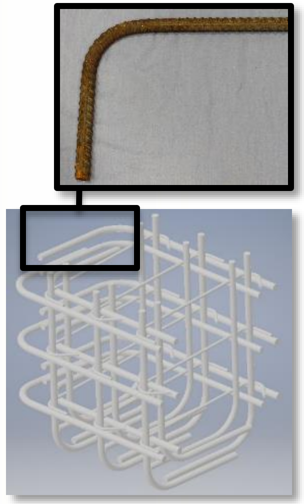
Robert D. Devine, Steven M. Barbachyn, Ashley P. Thrall, Yahya C. Kurama, Scott E. Sanborn, Matthew Van Liew, Joshua Hogancamp

# Primary Objective

Reduce field construction times and fabrication costs of reinforced concrete nuclear shear walls through:

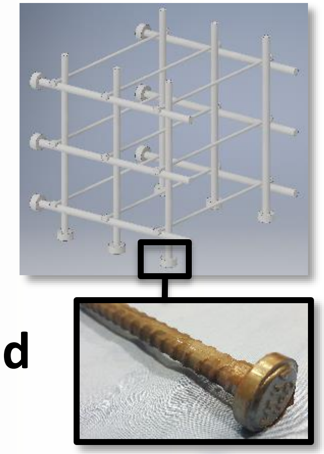
1) High-strength rebar ($f_y$=100 ksi)
2) Prefabricated rebar assemblies, including headed anchorages
3) High-strength concrete ($f_c'$=15.0 ksi)

**Most Congested (current)**



*Multiple layers of hooked Grade 60 bars*

*Fewer layers of <u>headed</u> high-strength bars*



**Least Congested (envisioned)**

# Presentation Outline

1. Introduction
2. Monotonic Deep Beam (Wall Slice) Tests
3. Reversed-Cyclic Shear Wall Tests

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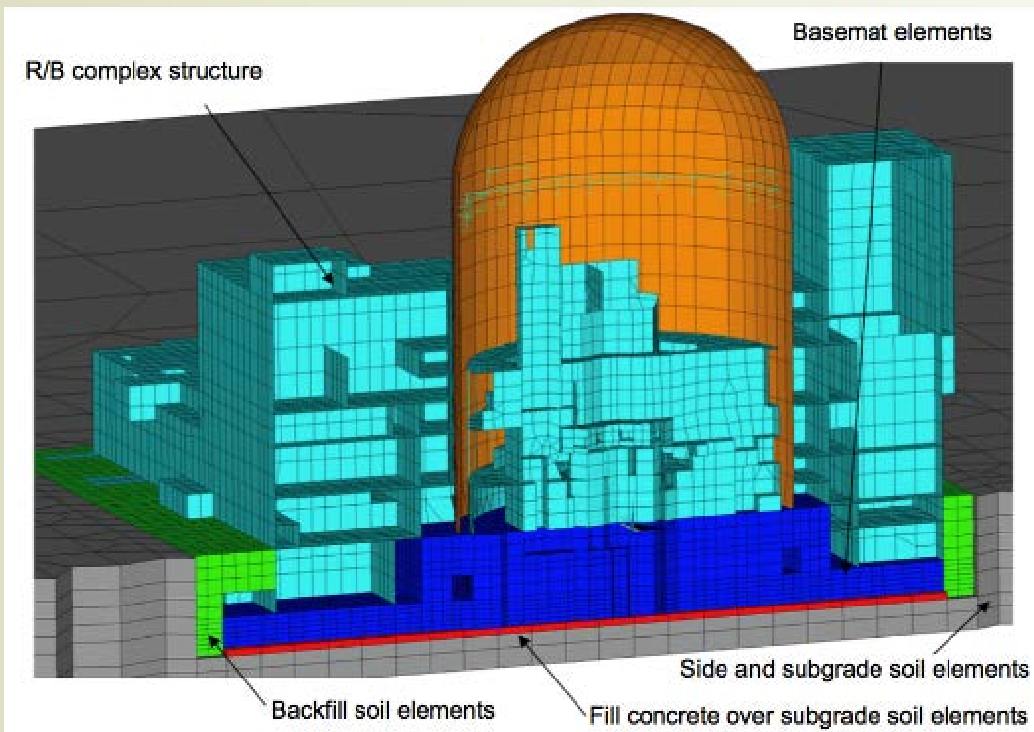
# Deep Beam Test Introduction

- “Generic wall” dimensions determined using publicly-available design control documents
- Deep beam specimens represent a “wall slice” from the reduced-scale shear walls




US-APWR design control doc.

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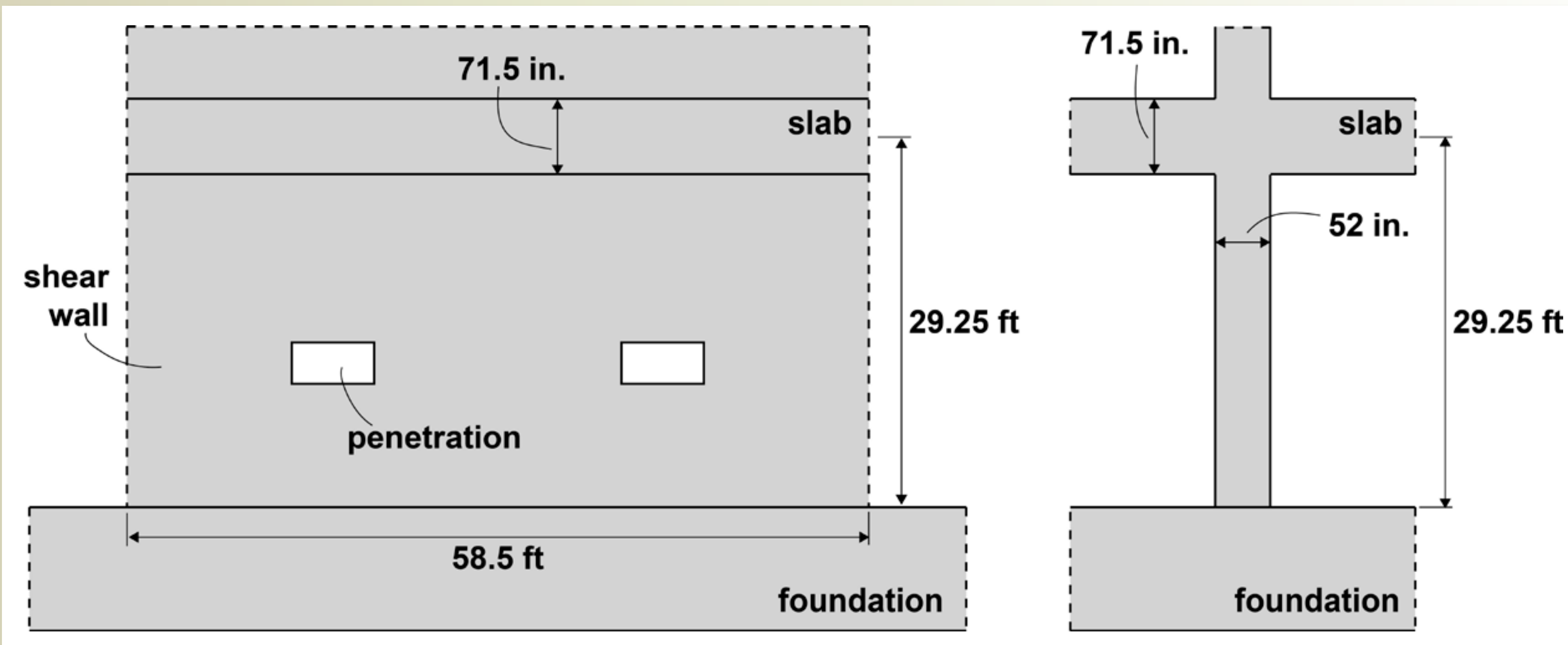

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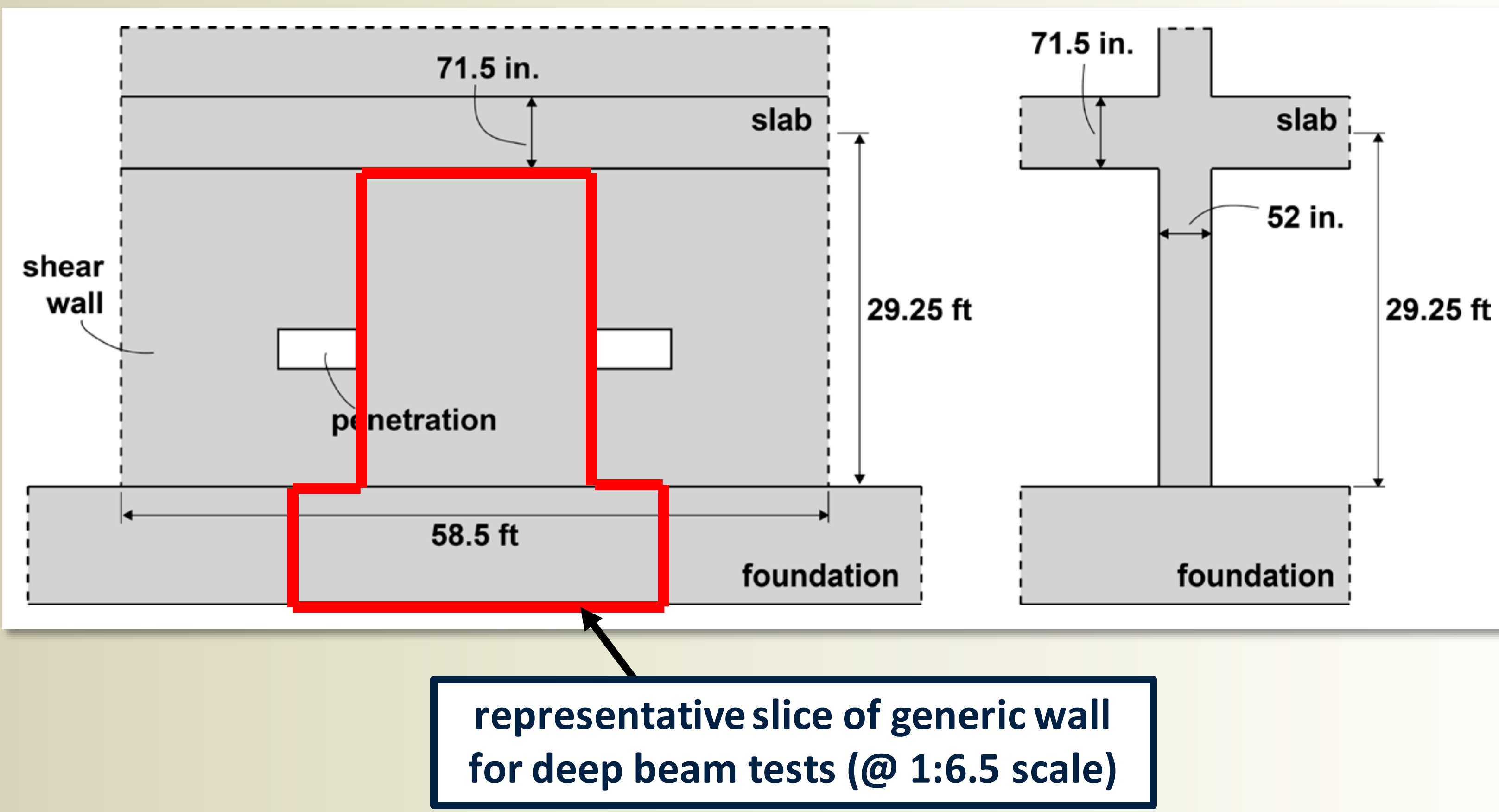

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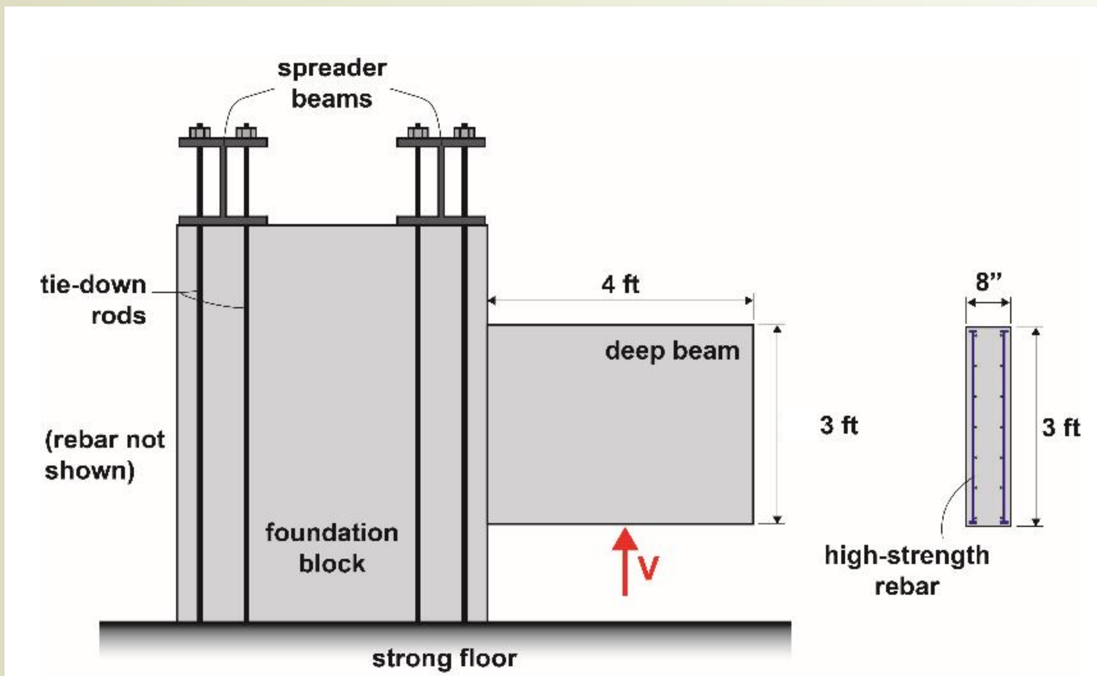
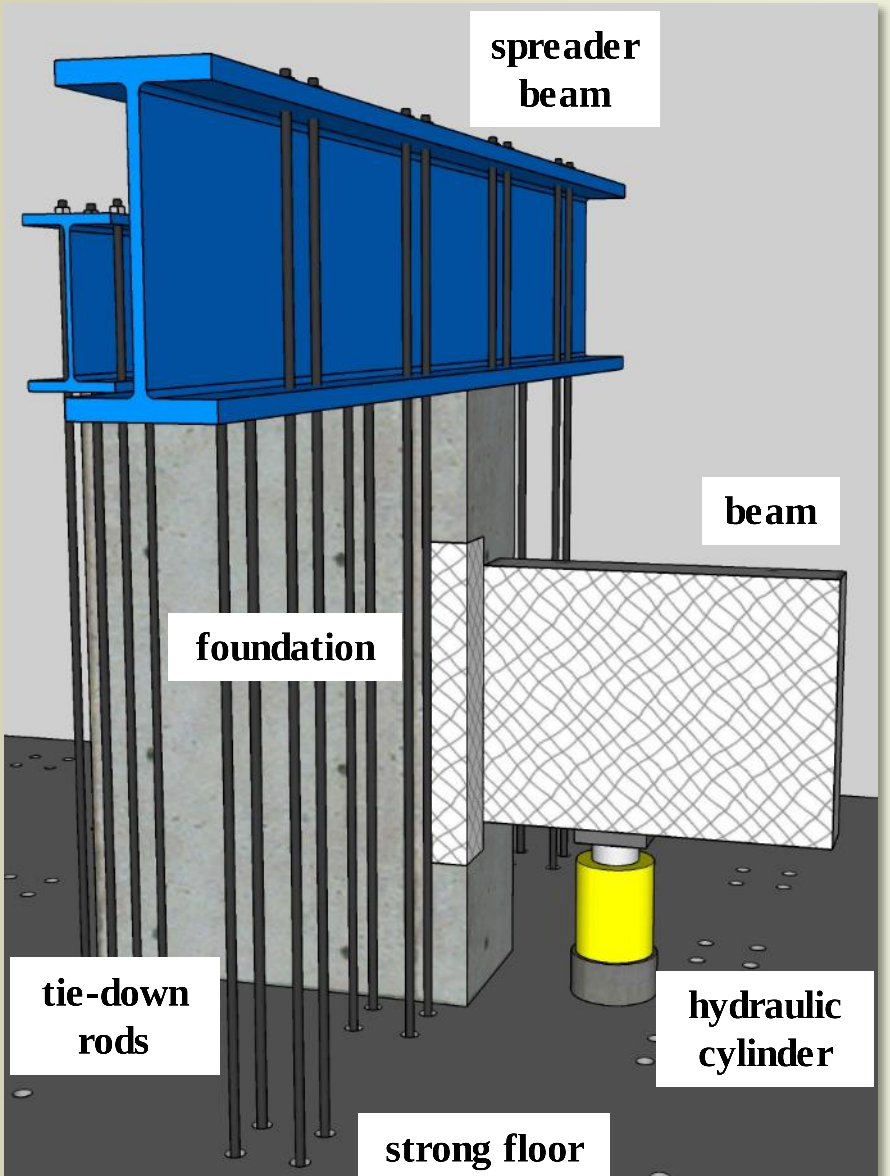


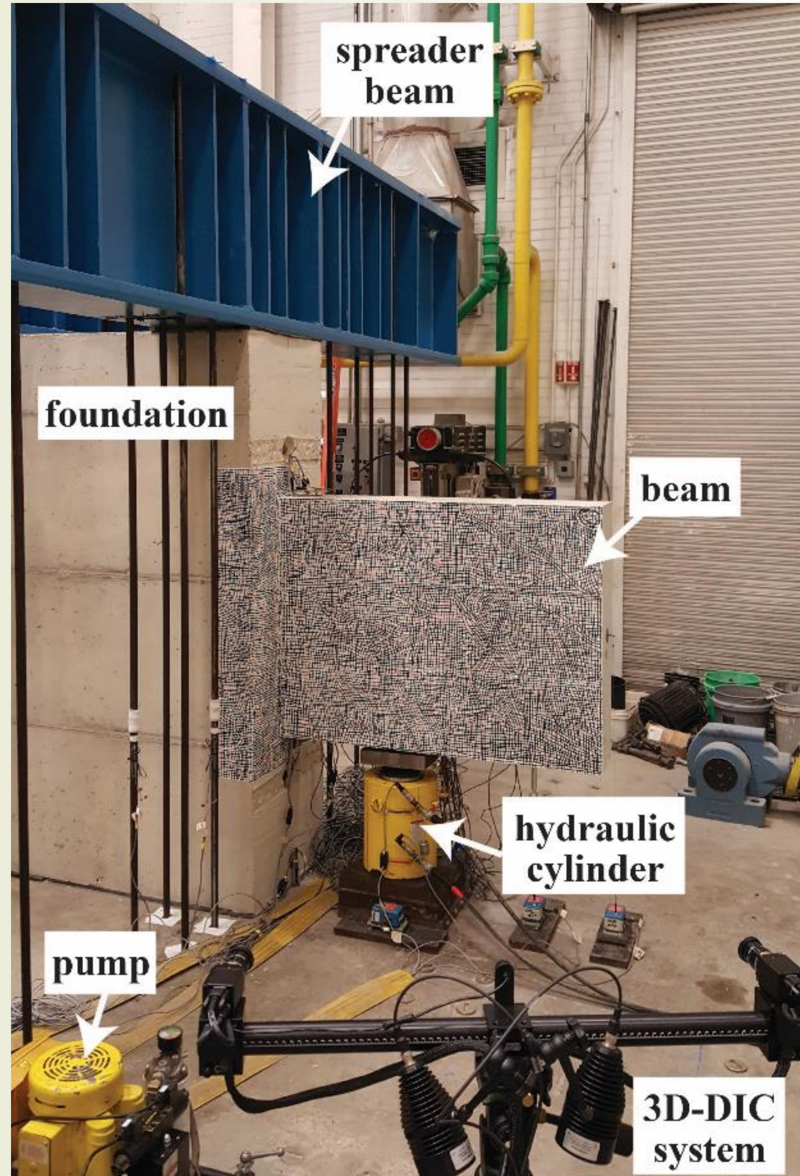
# Deep Beam Test Parameters

| Specimen | $f'_c$ (psi) | $f_y$ (ksi) | $\rho_s$ (%) | $M/(Vl_w)$ |
|---|---|---|---|---|
| DB1 | 6500 | 70 | 0.833 | 0.5 |
| DB2 | 6500 | 133 | 0.833 | 0.5 |
| DB3 | 14960 | 70 | 0.833 | 0.5 |
| DB4 | 14960 | 133 | 0.833 | 0.5 |

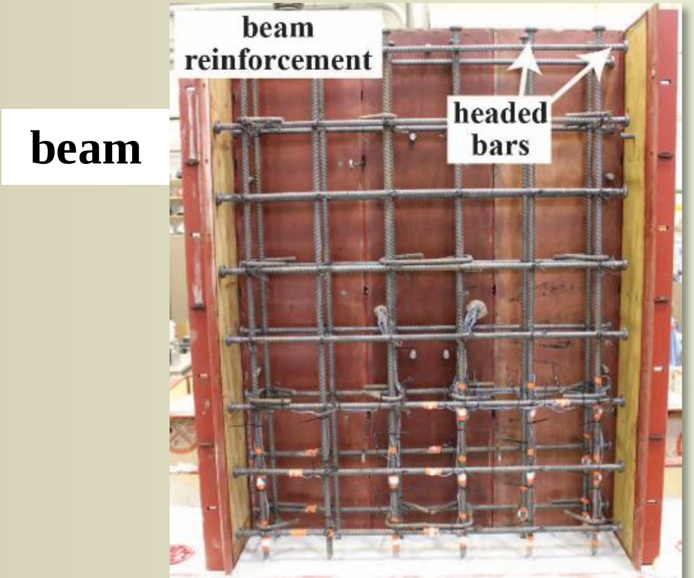
**Definitions: $f'_c$ – concrete 28 day compressive strength (3 in. x 6 in. cylinders)**
**$f_y$ – rebar yield strength, determined by tensile tests and 0.2% offset method**
**$\rho_s$ – reinforcement ratio, symmetric for longitudinal and transverse rebar**

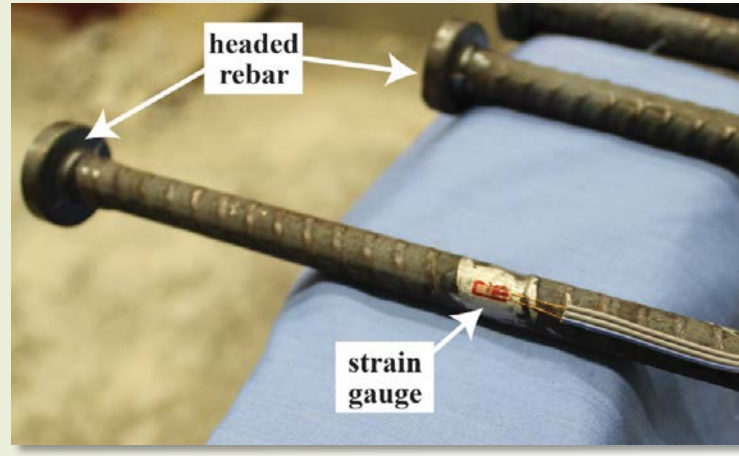
# Deep Beam Test Setup

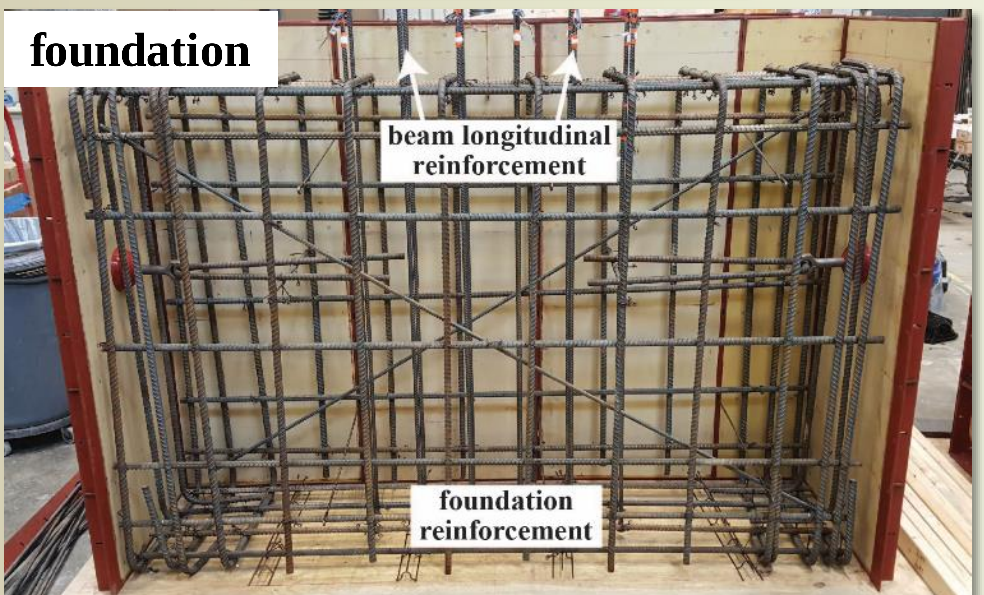


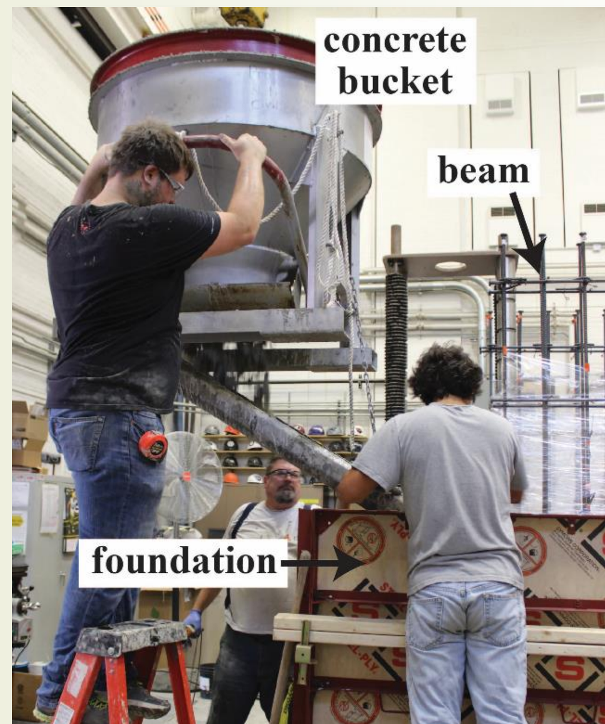



# Deep Beam Construction



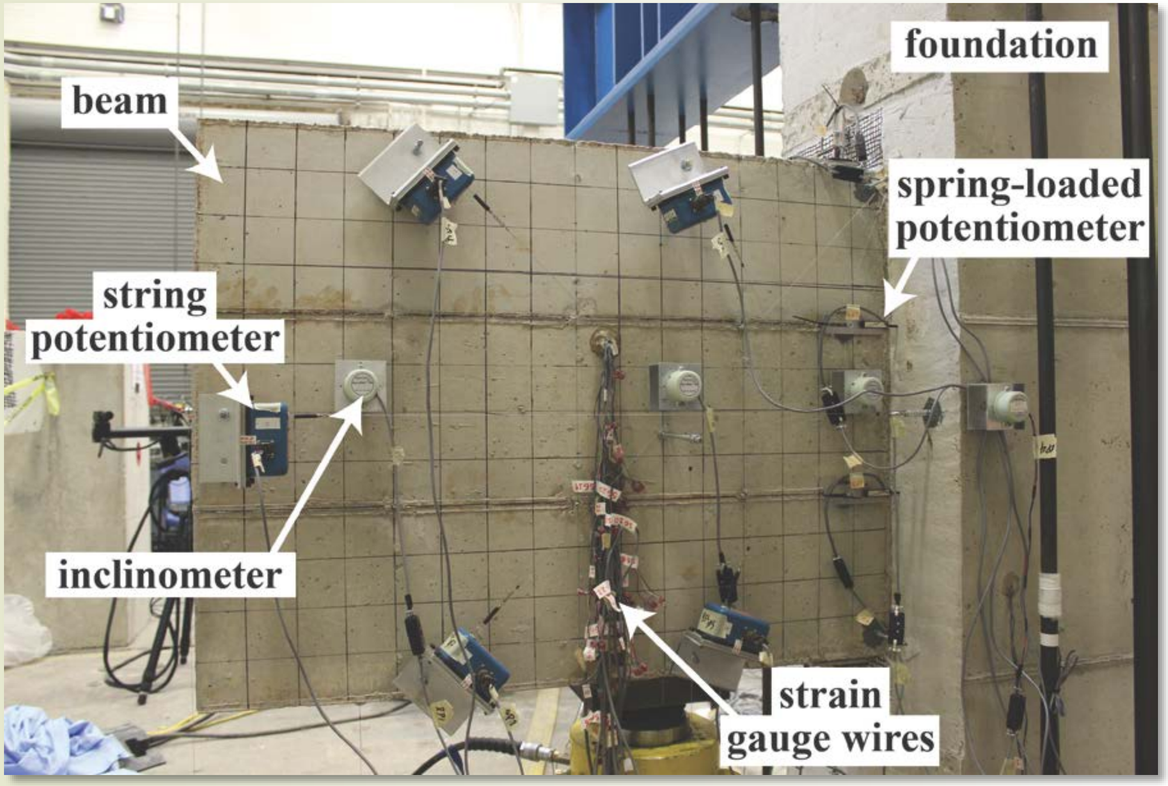



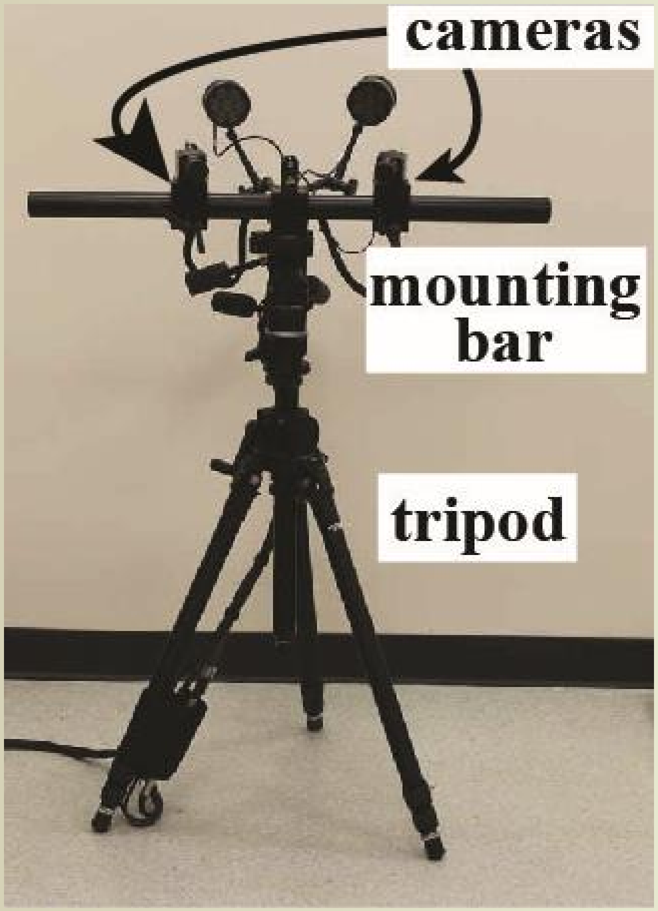



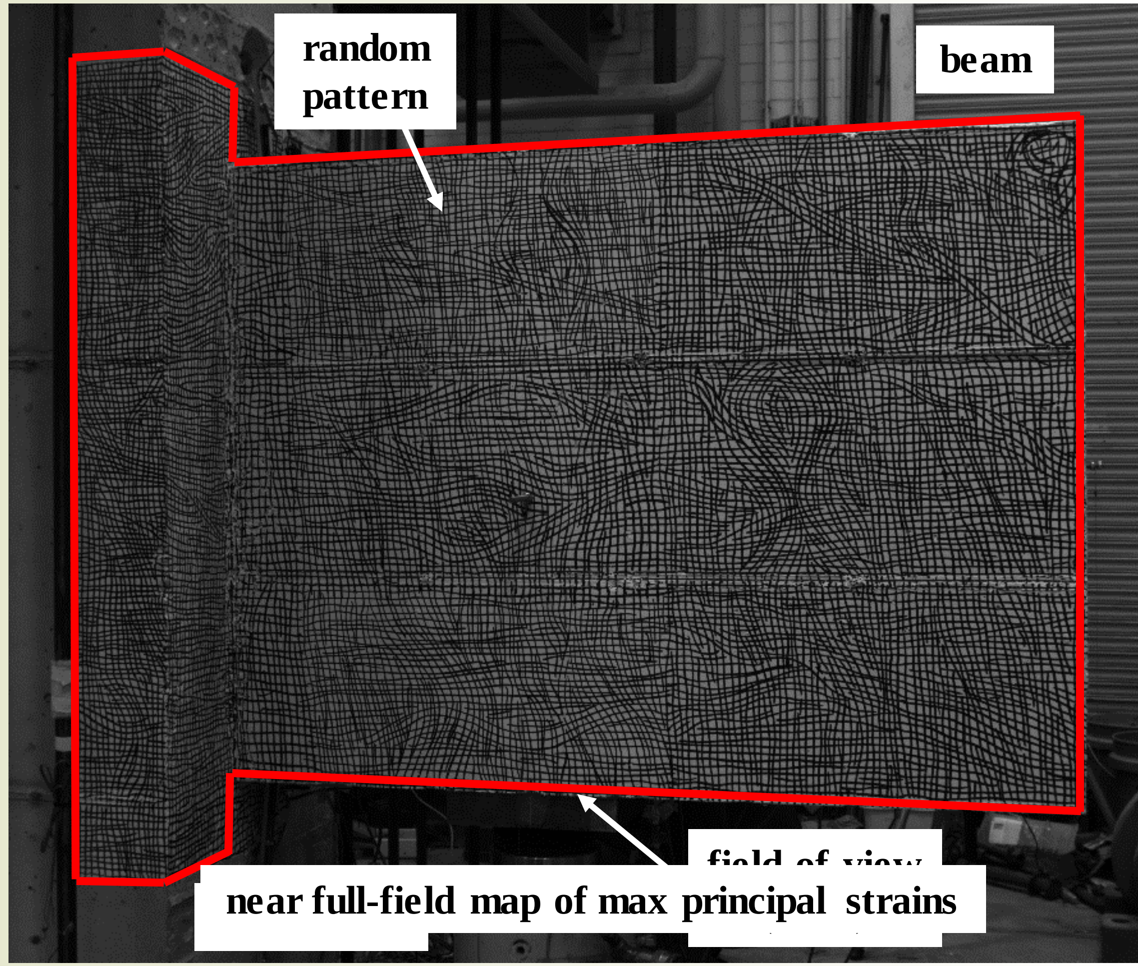
# Deep Beam Instrumentation

| Type | Number |
|---|---|
| pressure transducer | 2 |
| string potentiometer | 9 |
| spring-loaded potentiometer | 8 |
| inclinometer | 4 |
| strain gauge | 42 |
| **TOTAL** | **65** |



# 3D Digital Image Correlation



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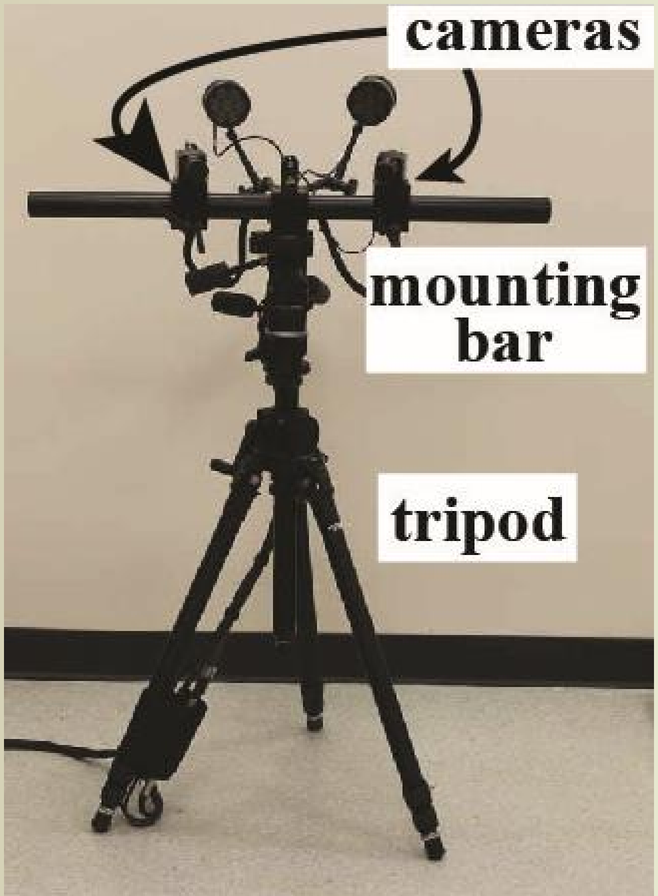
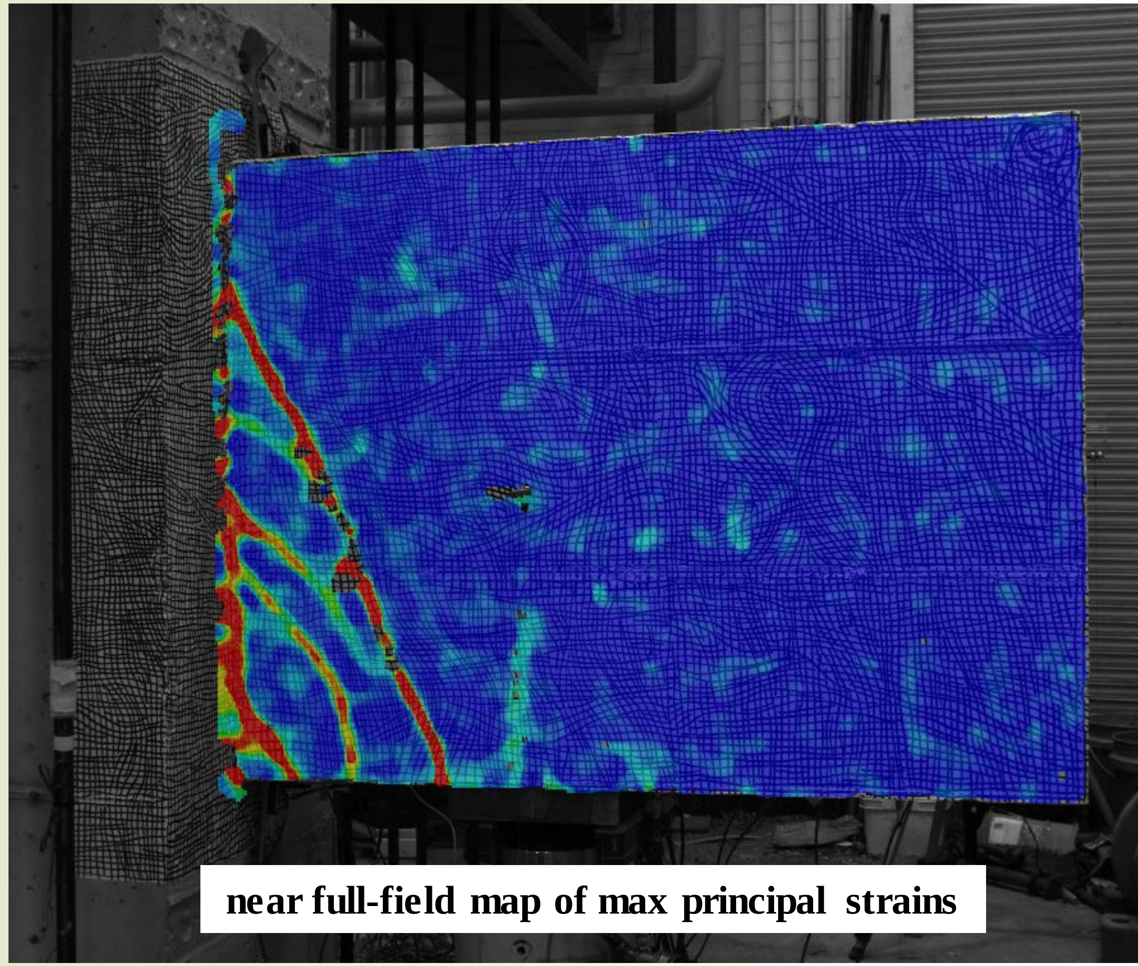
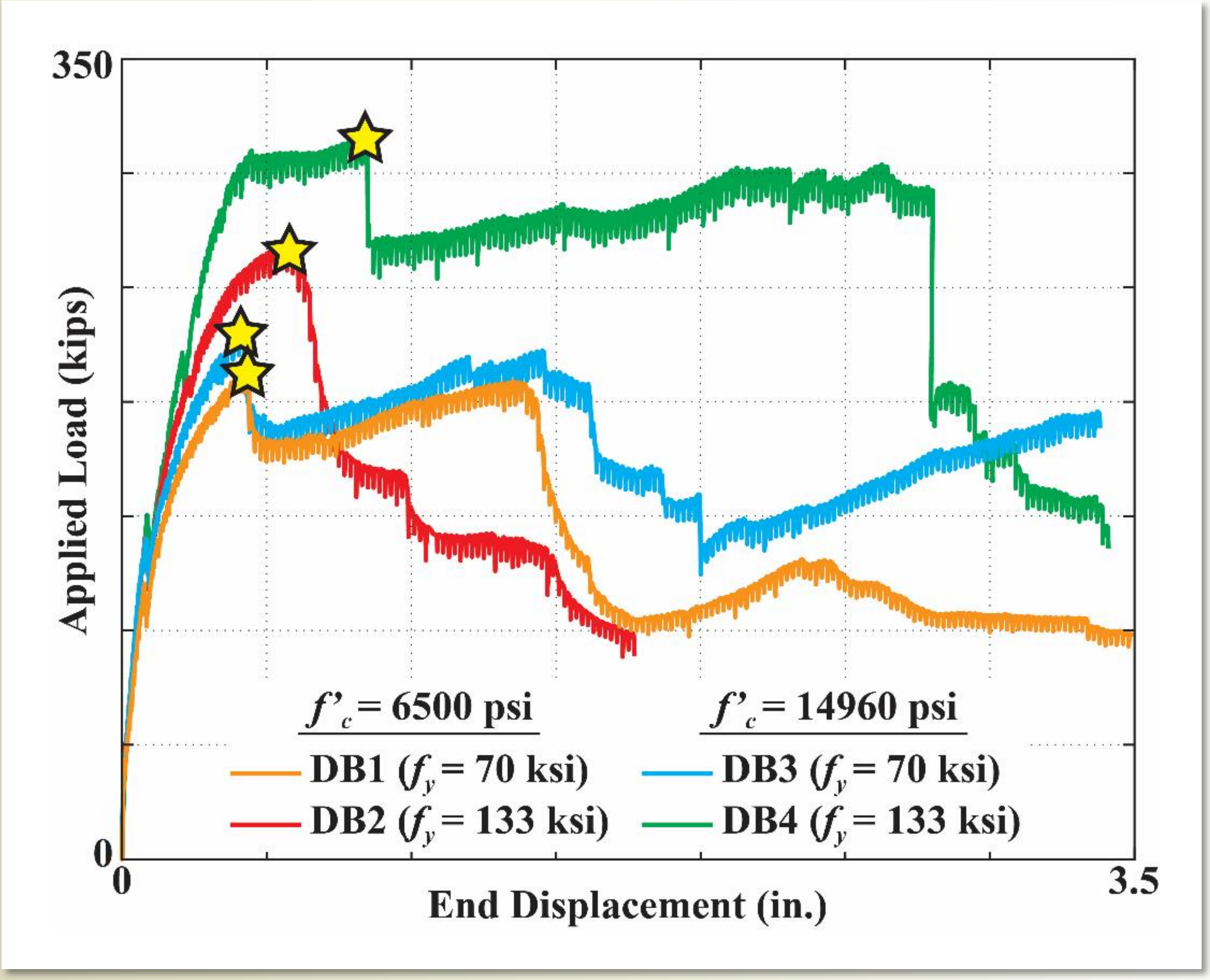


# Deep Beam Specimen Response



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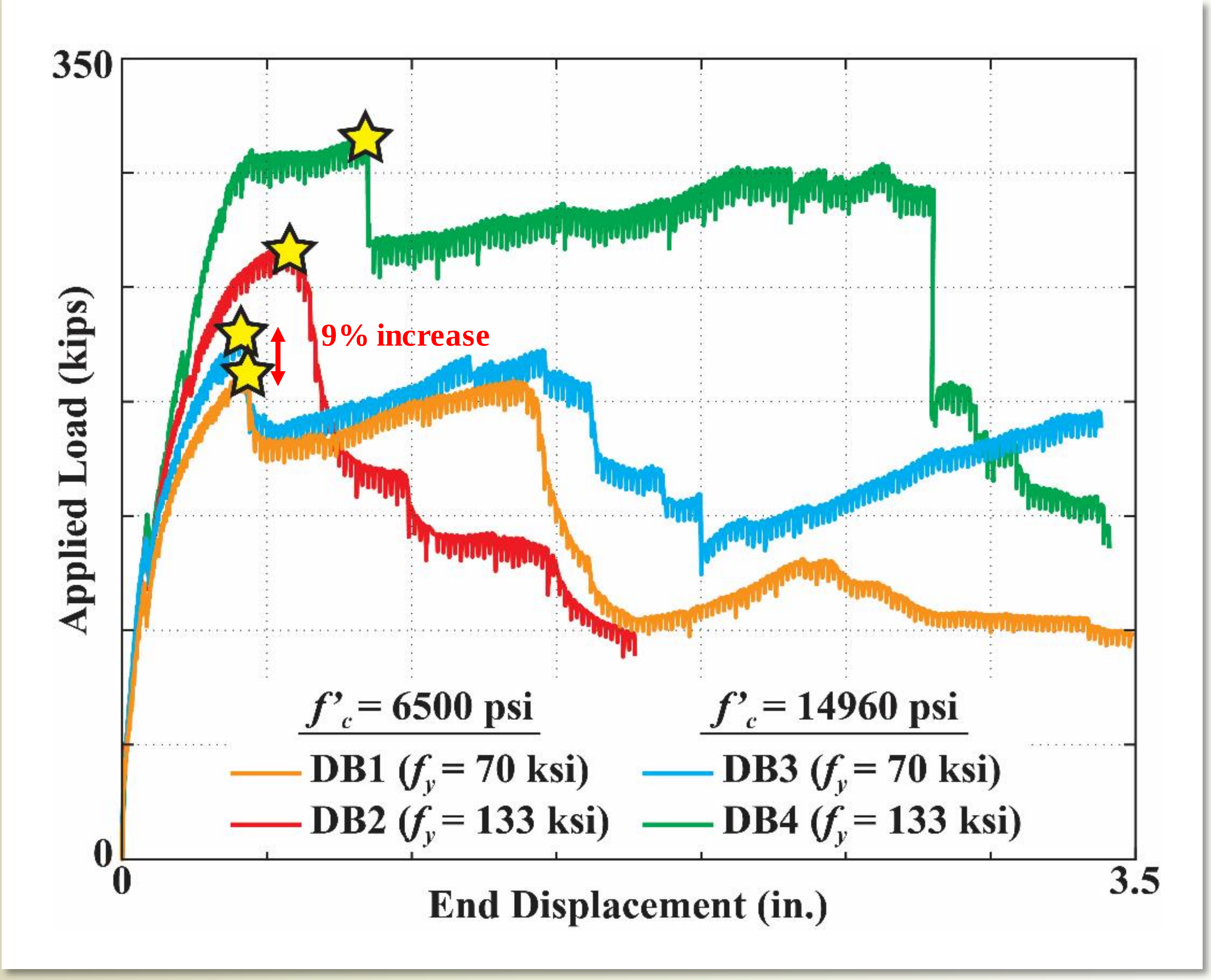

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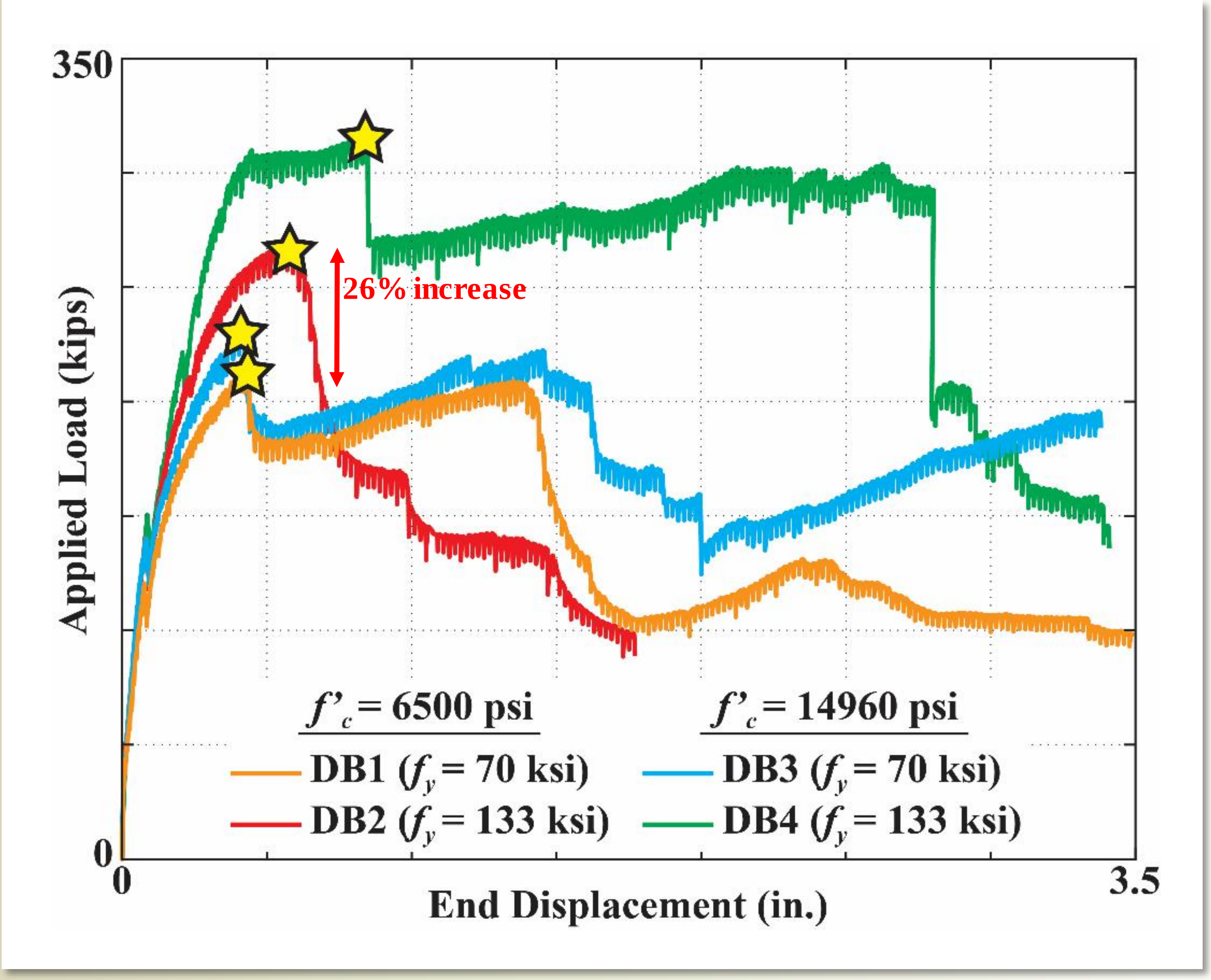

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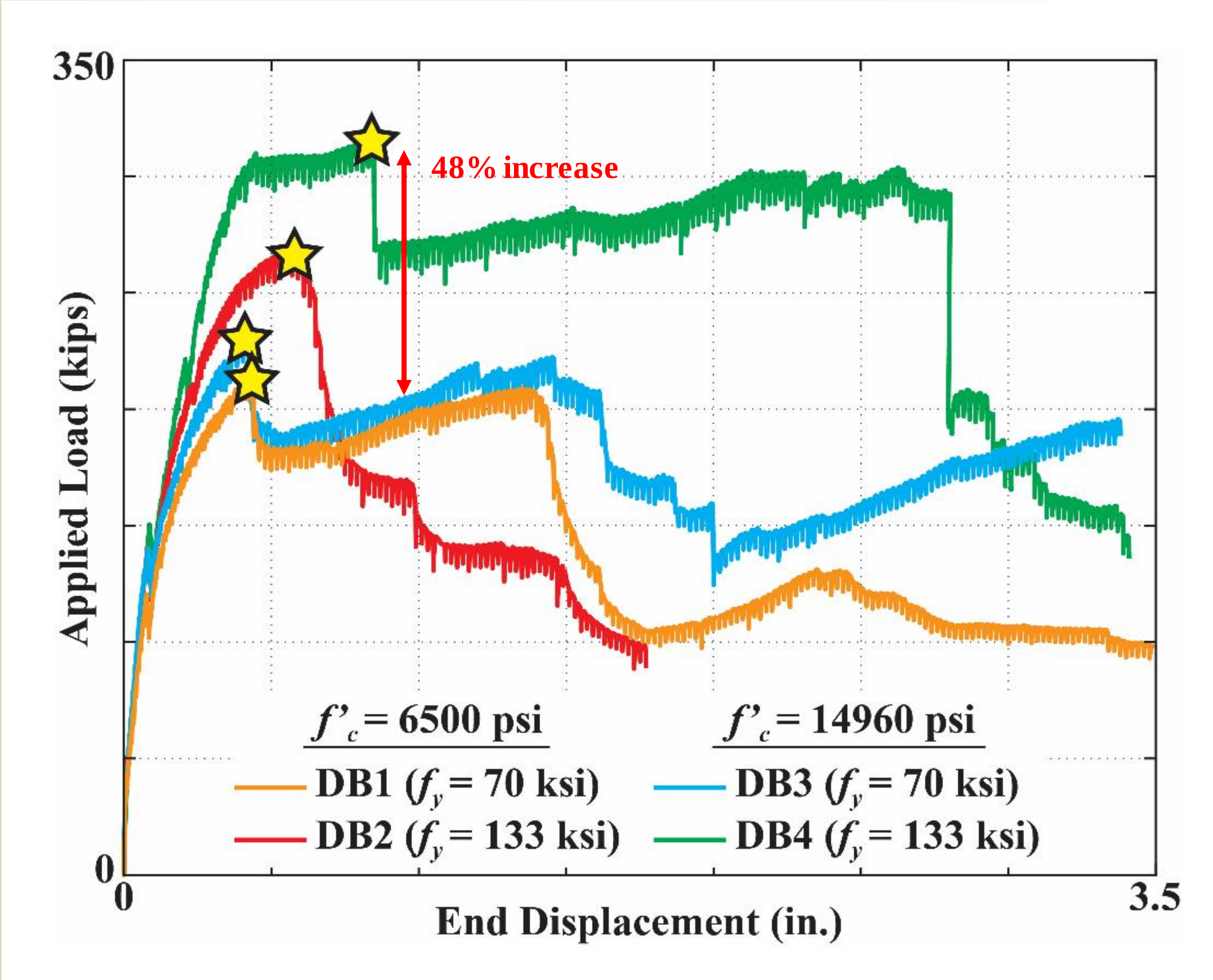

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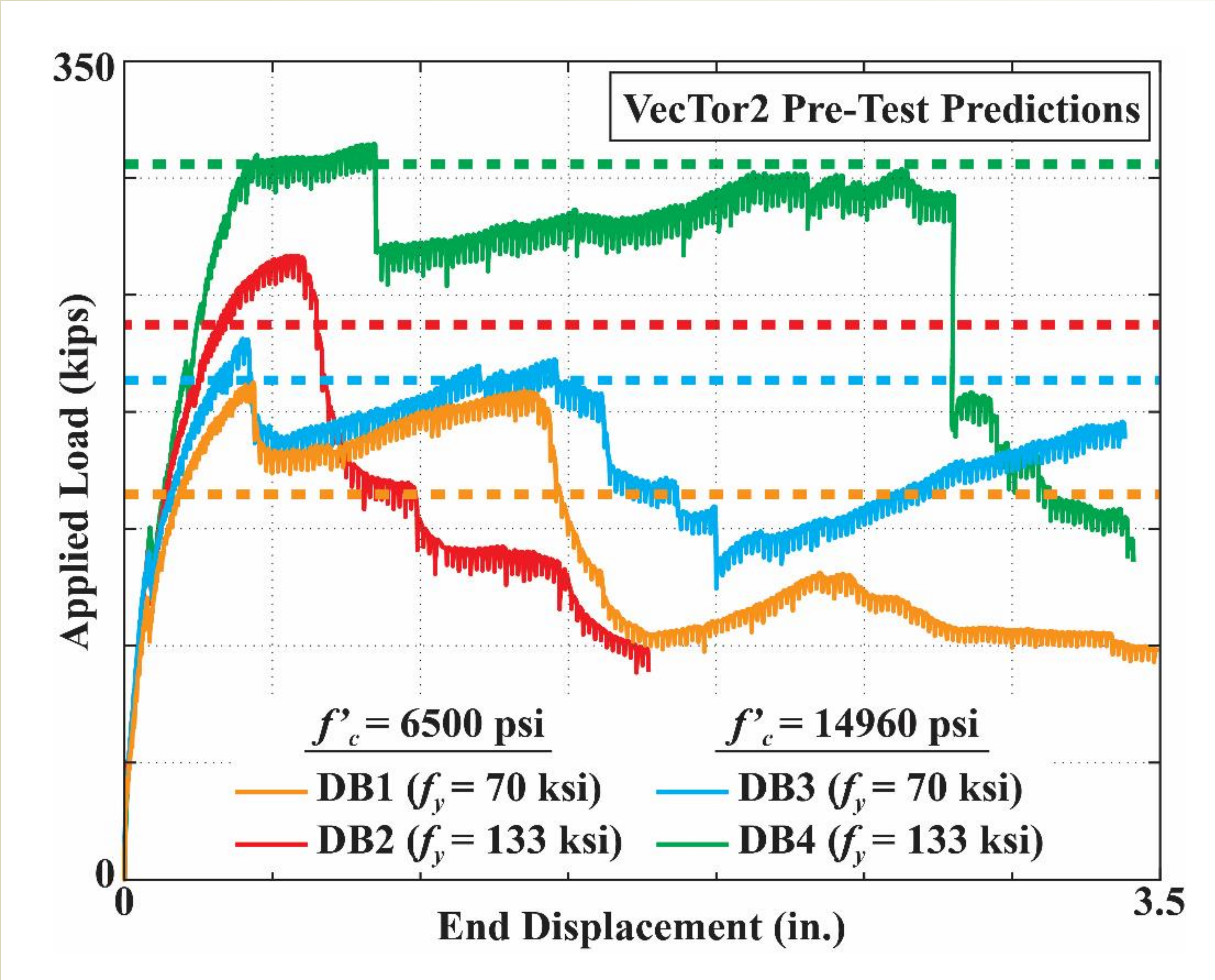
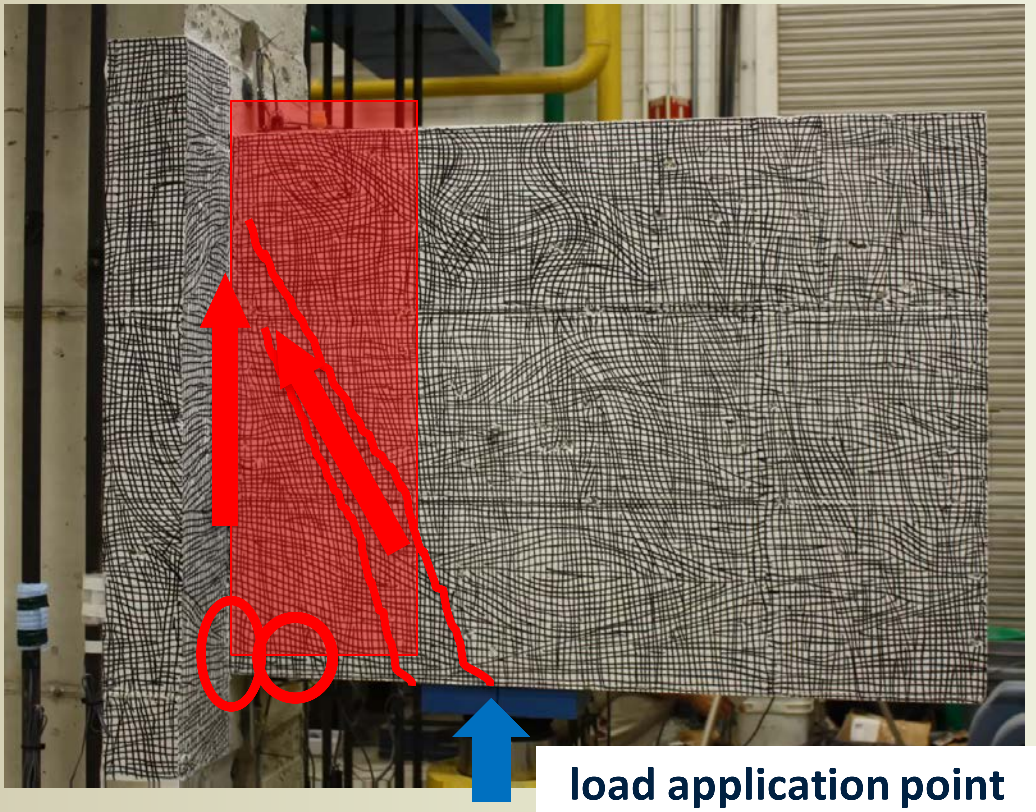


# DB4 ($f'_c$ = 14960 psi, $f_y$ = 133 ksi)





Significant concrete degradation through beam depth

VIDEO

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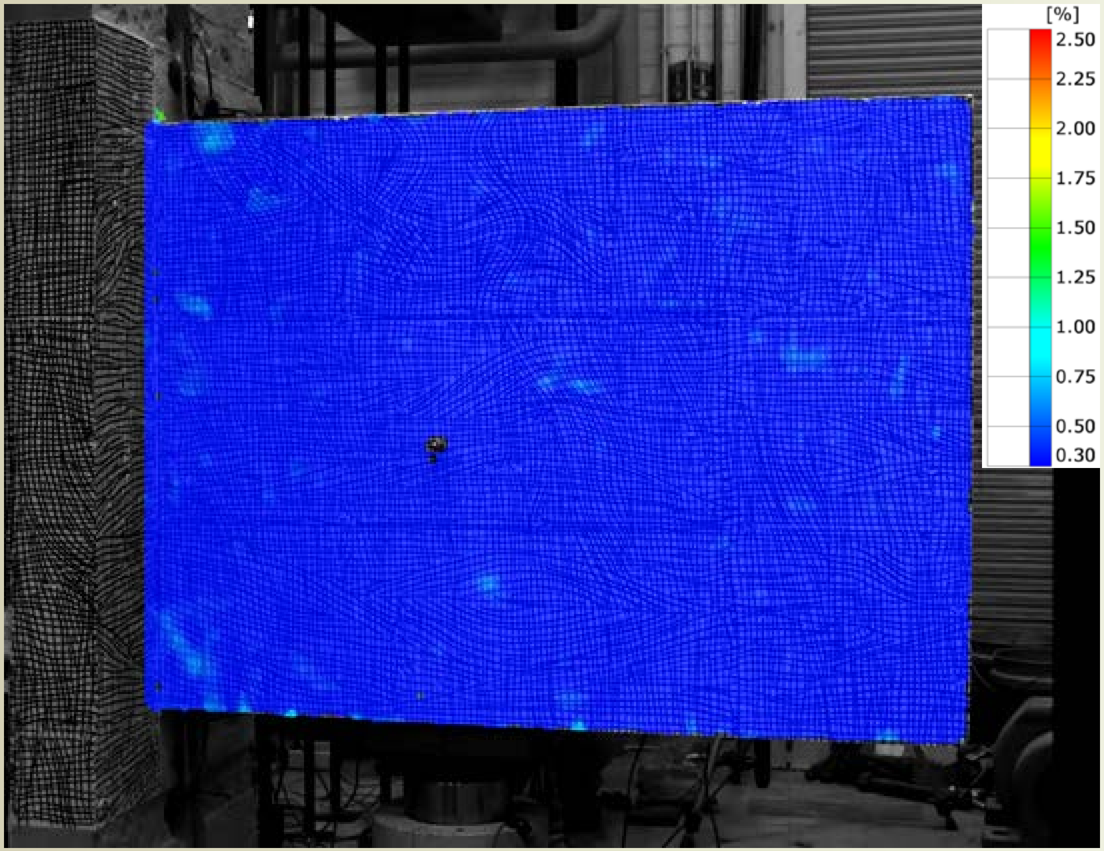


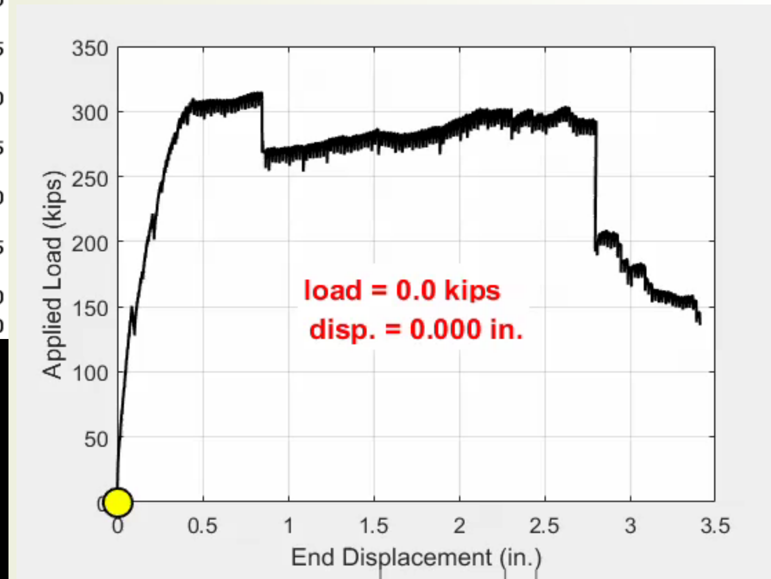


VIDEO

# Summary of Deep Beam Tests

- Increasing the rebar strength had a greater effect on lateral strength (26% increase) than increasing the concrete compression strength (9% increase)
- Increase in lateral strength (48% increase) was greatest when using high-strength materials together
- Combination of high-strength materials also resulted in greatest deformation capacity
- Pre-test analyses provided reasonable and conservative predictions for all specimens

Devine, RD, Barbachyn, SM, Thrall, AP, and Kurama, YC "Experimental Evaluation of Deep Beams with High-Strength Concrete and High-Strength Rebar," *ACI Structural Journal*, Accepted.

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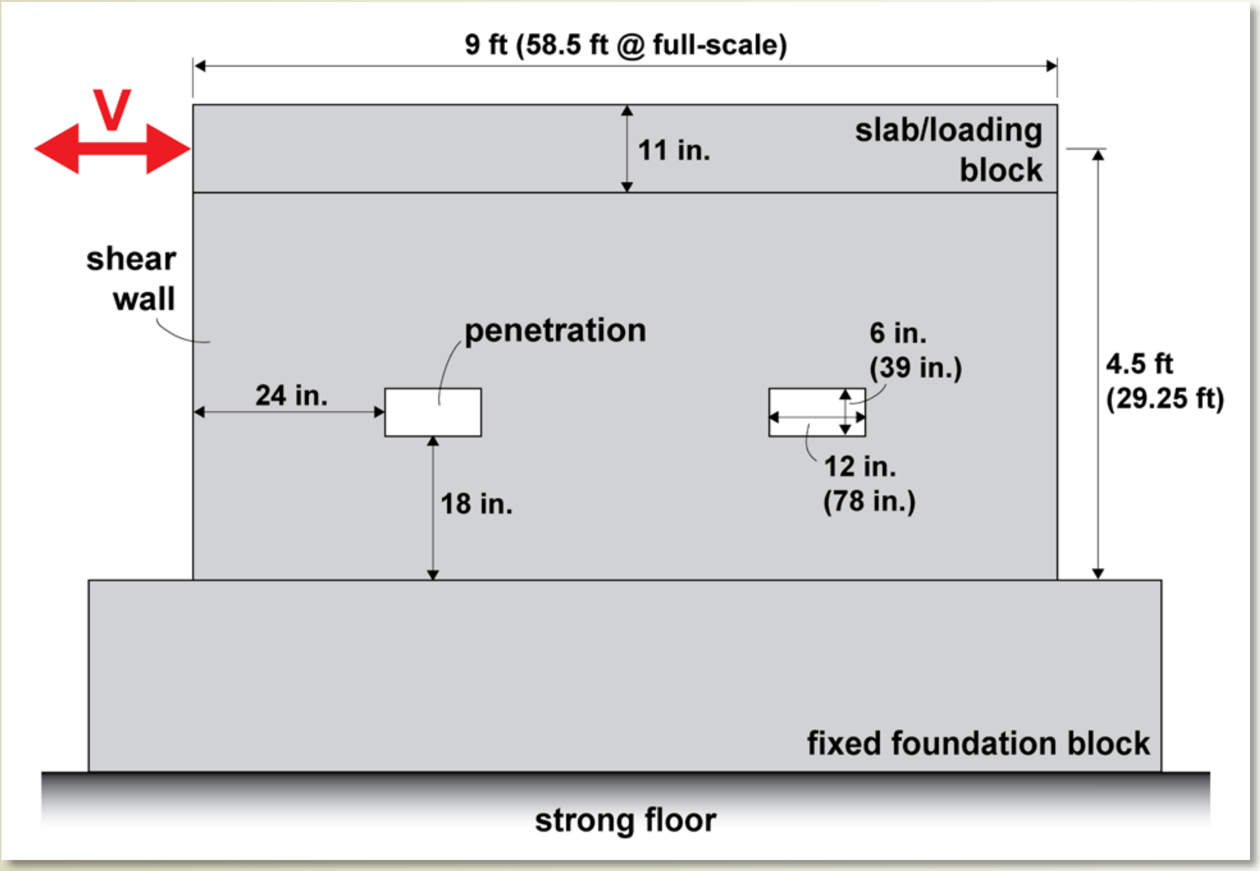
# Shear Wall Test Introduction

- 1:6.5 scale of "generic wall"
- Being tested under cyclic lateral loads



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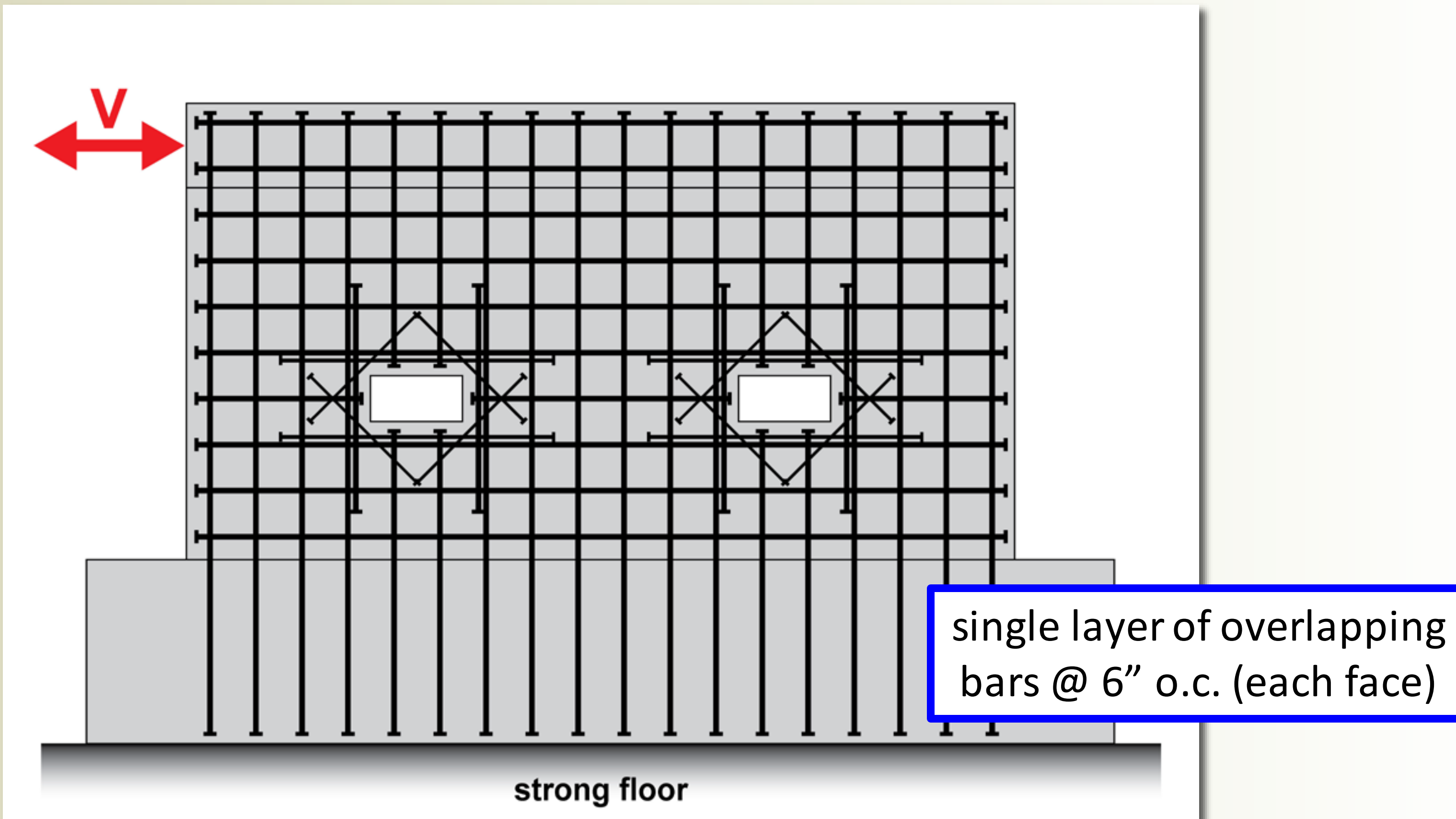

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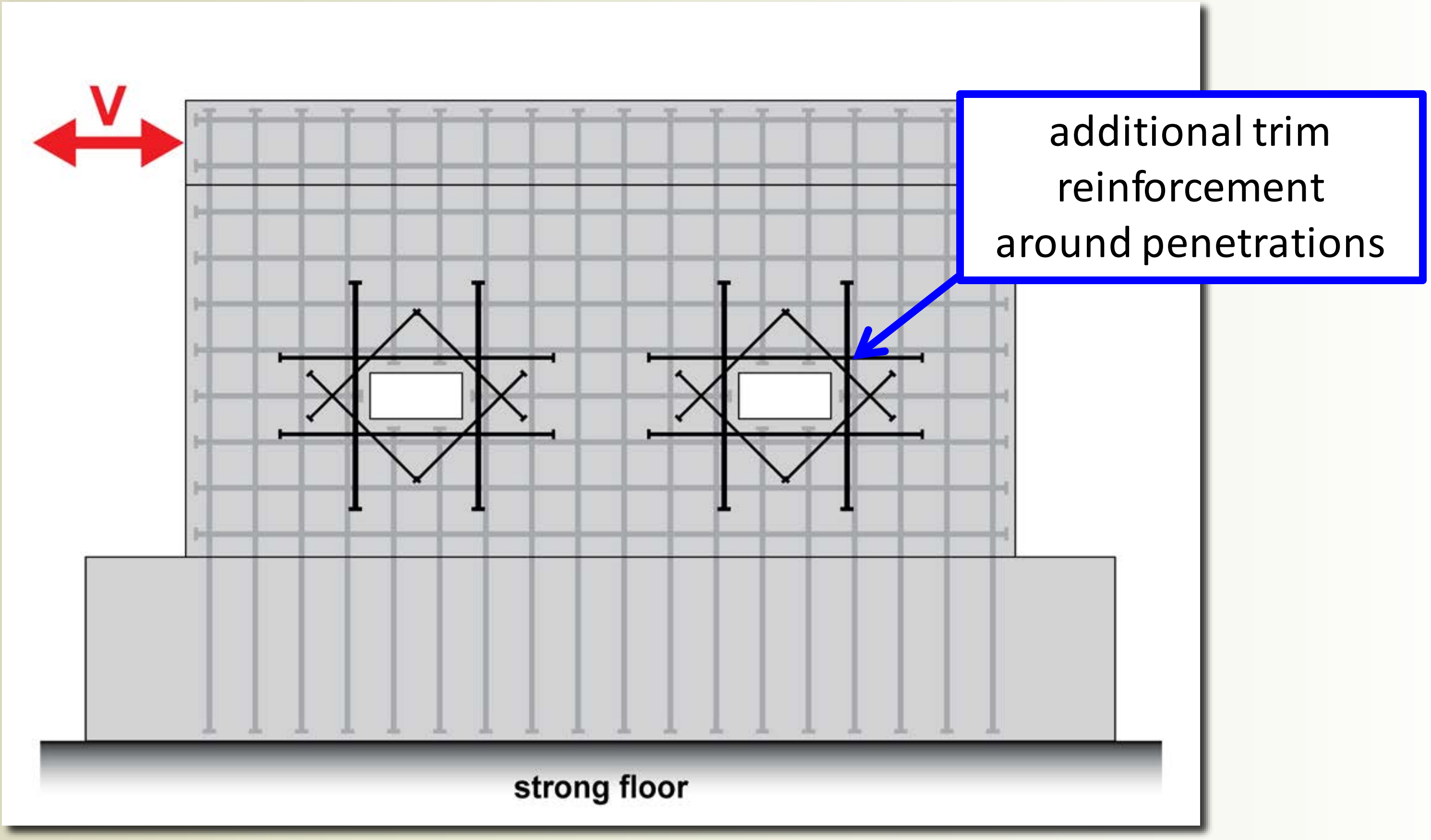
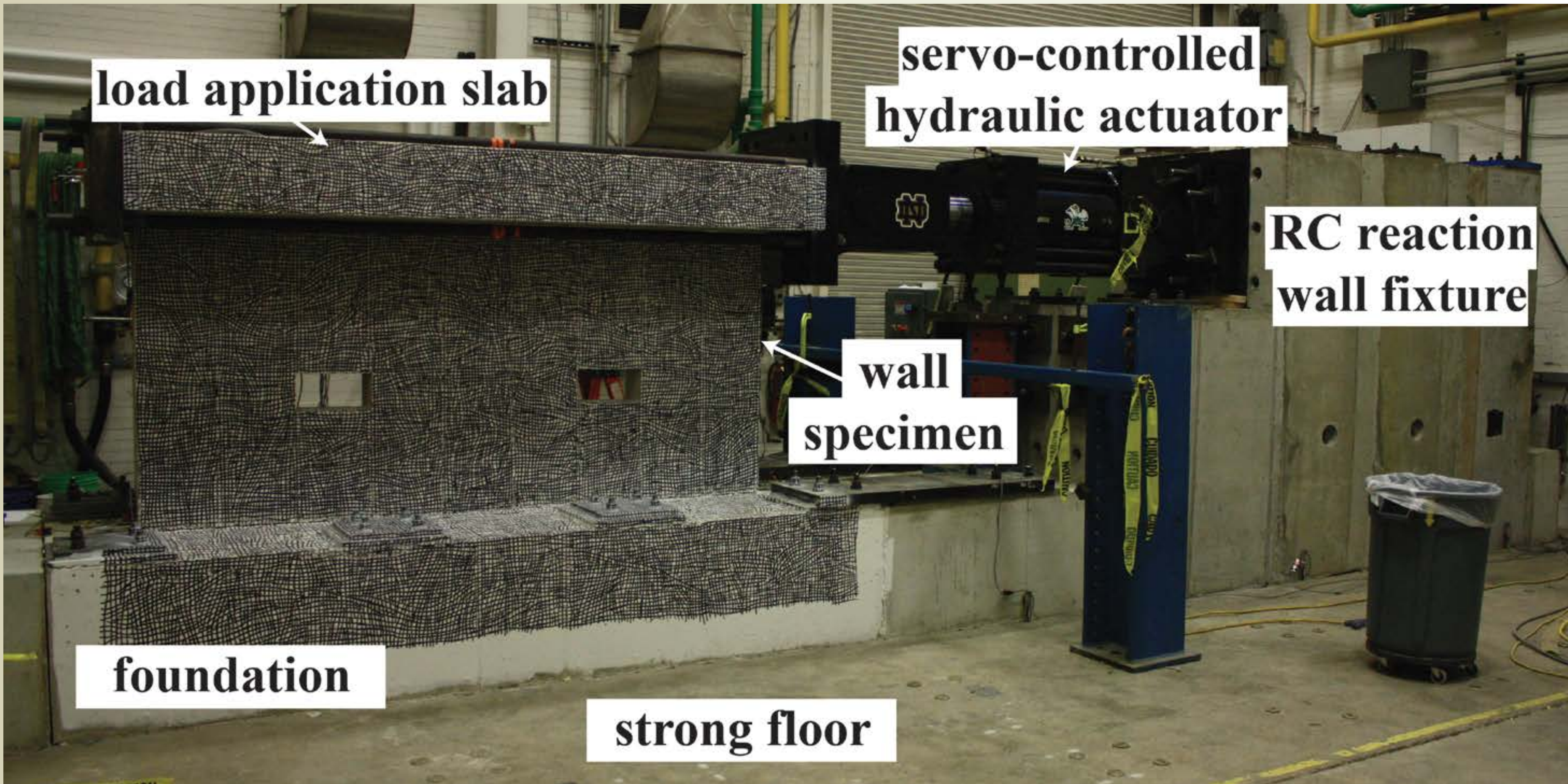


# Shear Wall Parameters and Test Setup

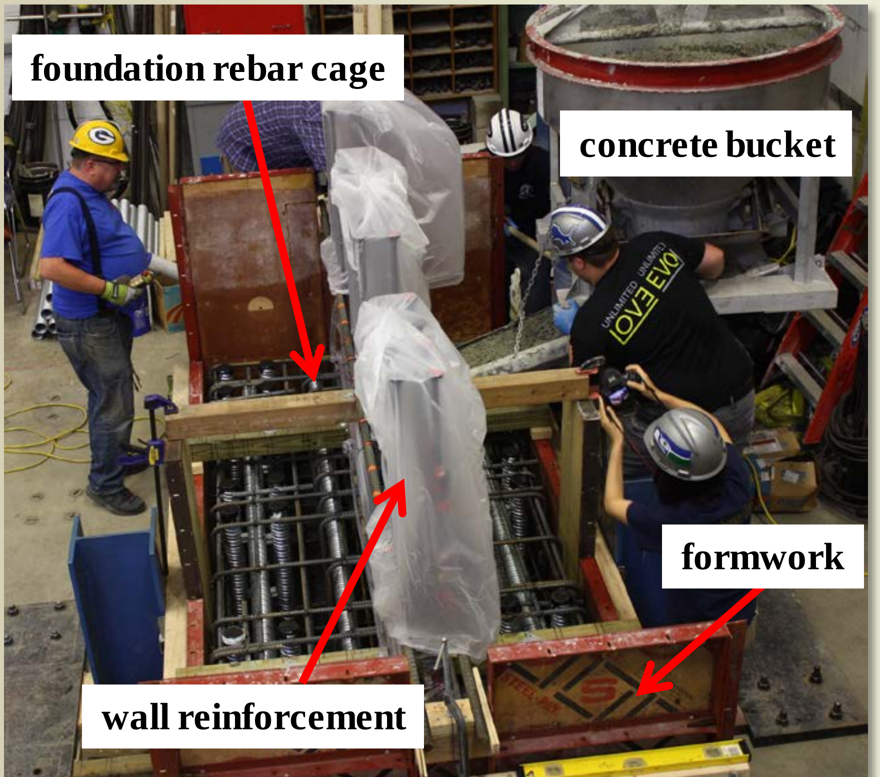
| Specimen | $f'_c$ (psi) | $f_y$ (ksi) | $\rho_s$ (%) | $M/(Vl_w)$ |
|---|---|---|---|---|
| CW1 | 6290 | 74 | 1.833 | 0.5 |
| CW2 | 15000 | 100 | 0.833 | 0.5 |
| CW3 | Parameters TBD | | | |

**Definitions:** $f'_c$ – concrete 28 day compressive strength (3 in. x 6 in. cylinders)
$f_y$ – rebar yield strength, determined by tensile tests and 0.2% offset method
$\rho_s$ – reinforcement ratio, symmetric for longitudinal and transverse rebar

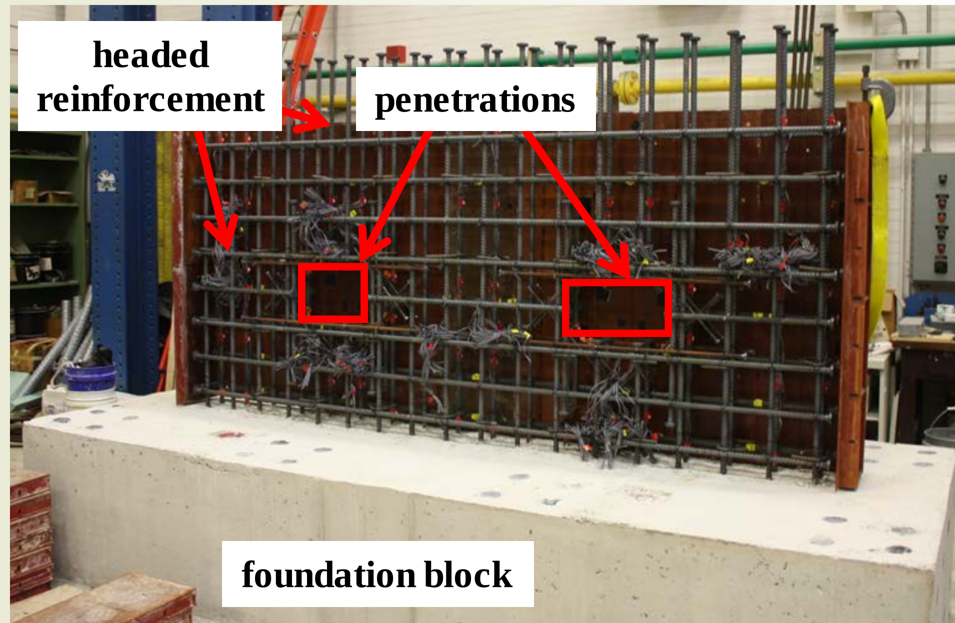
# Shear Wall Parameters and Test Setup



# Shear Wall Construction



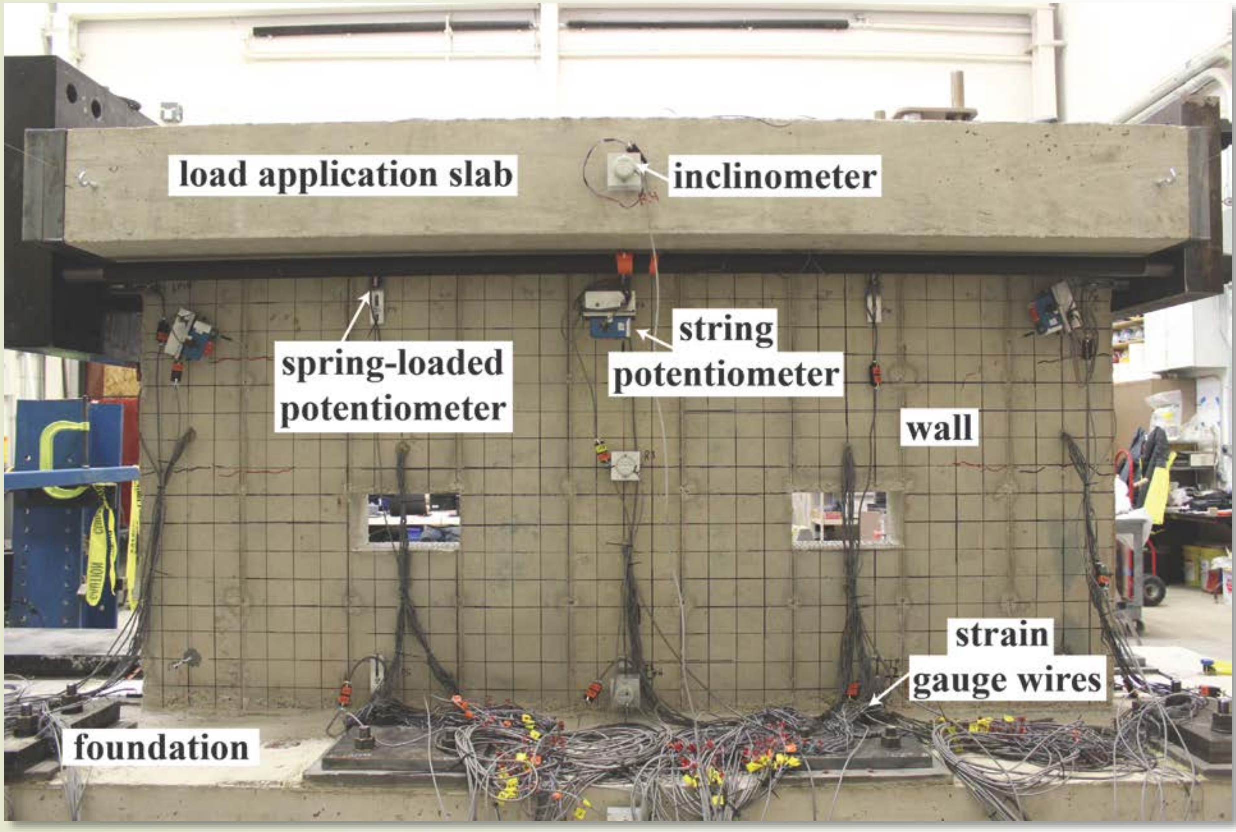

Concrete Placement in Wall Foundation Block



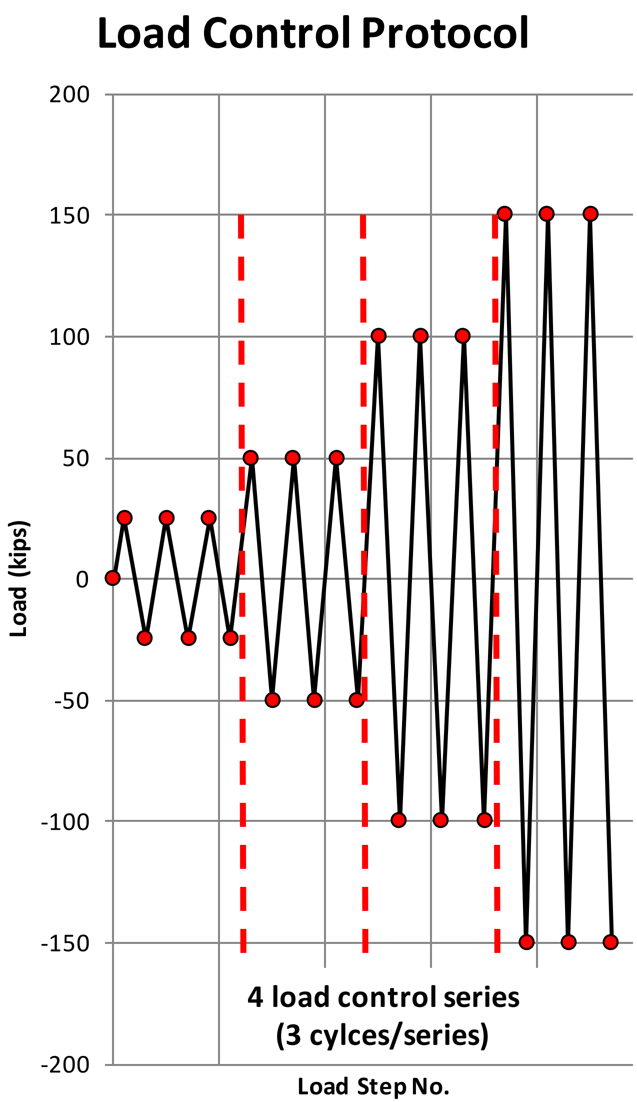

Shear Wall Reinforcement Prior to Concrete Placement

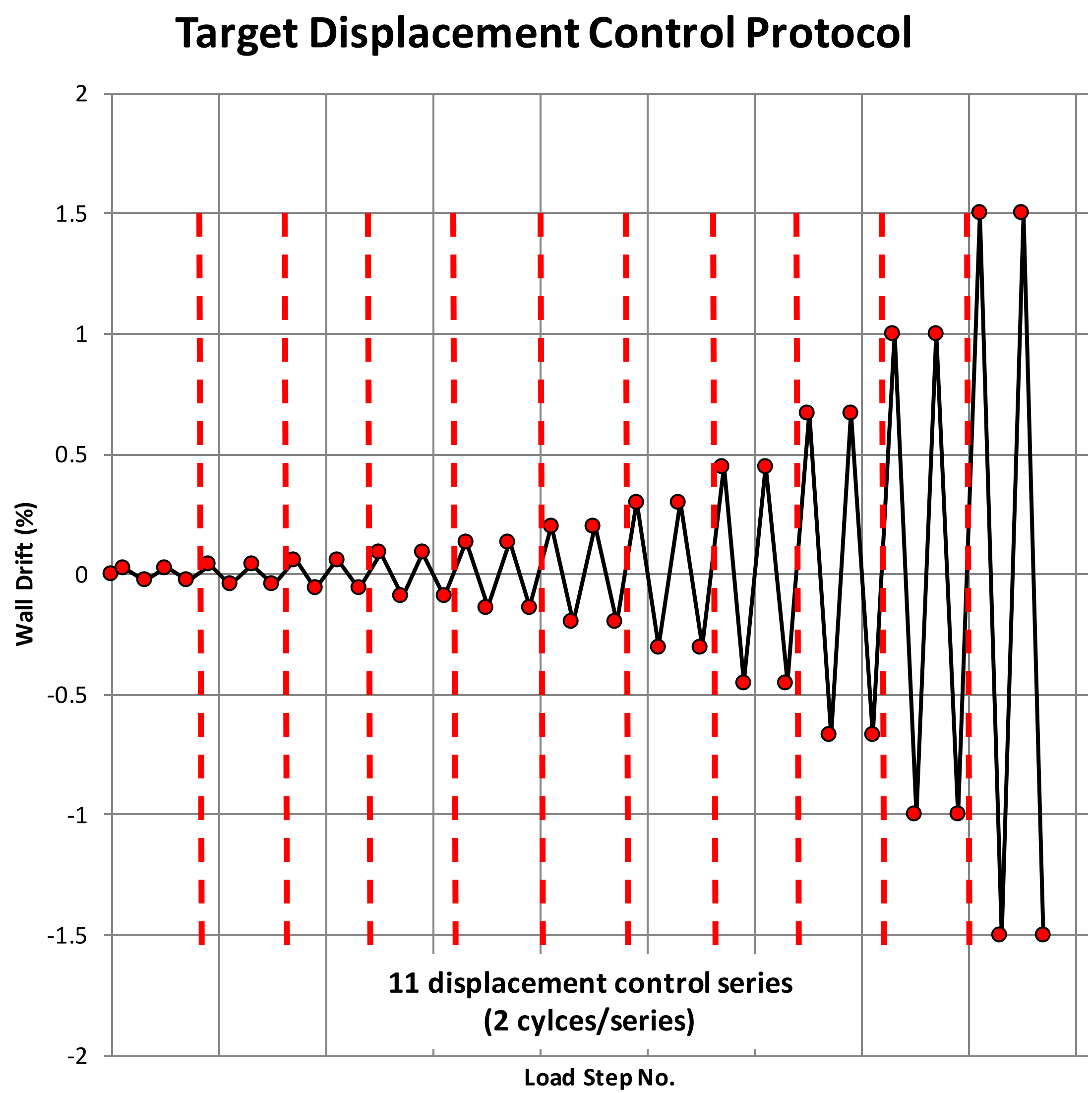
# Shear Wall Instrumentation

| Type | Number |
|---|---|
| pressure transducer | 2 |
| string potentiometer | 12 |
| spring-loaded potentiometer | 24 |
| inclinometer | 4 |
| strain gauge | 104 |
| **TOTAL** | **146** |

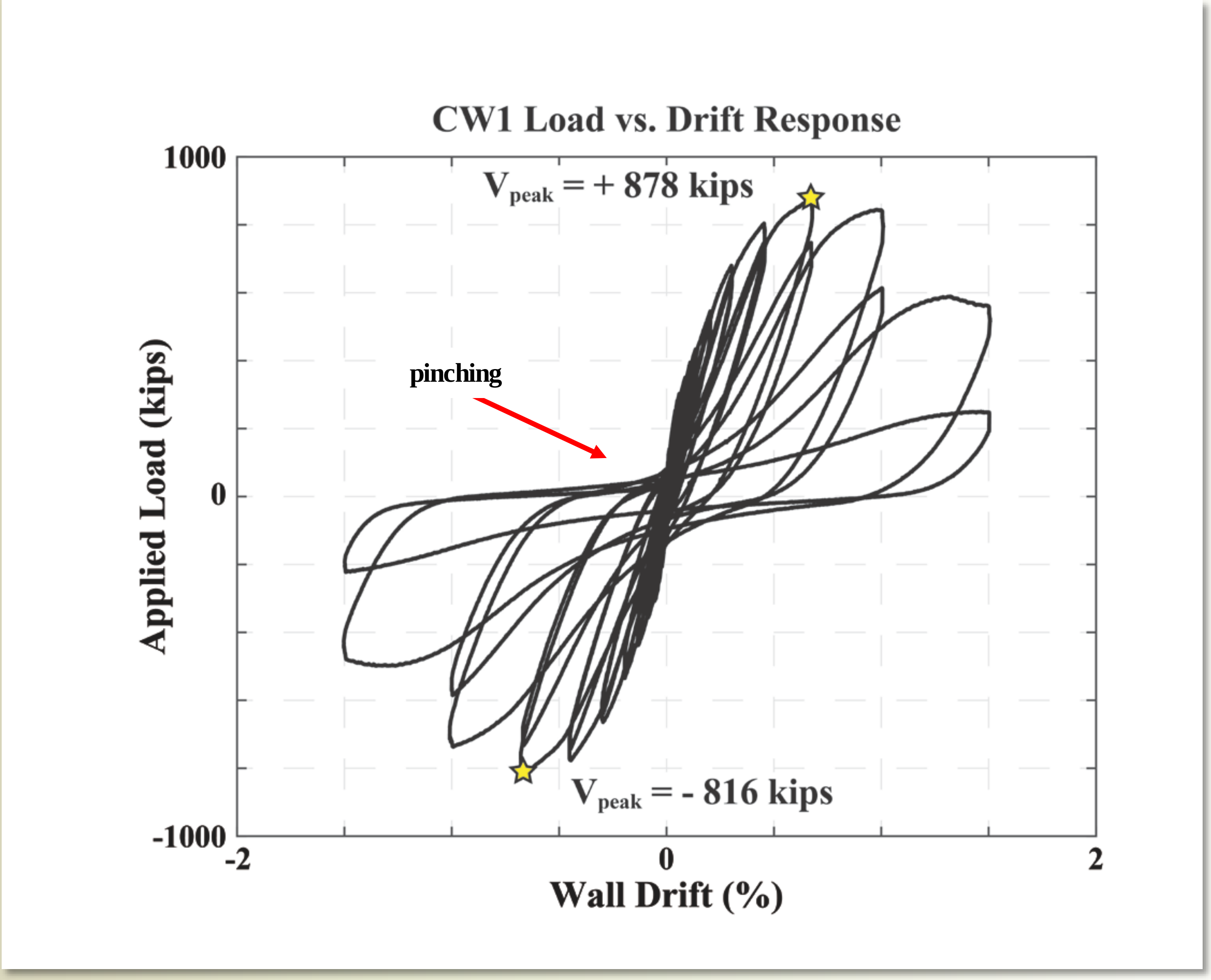


# Shear Wall Loading Protocol



# CW1 Specimen Response



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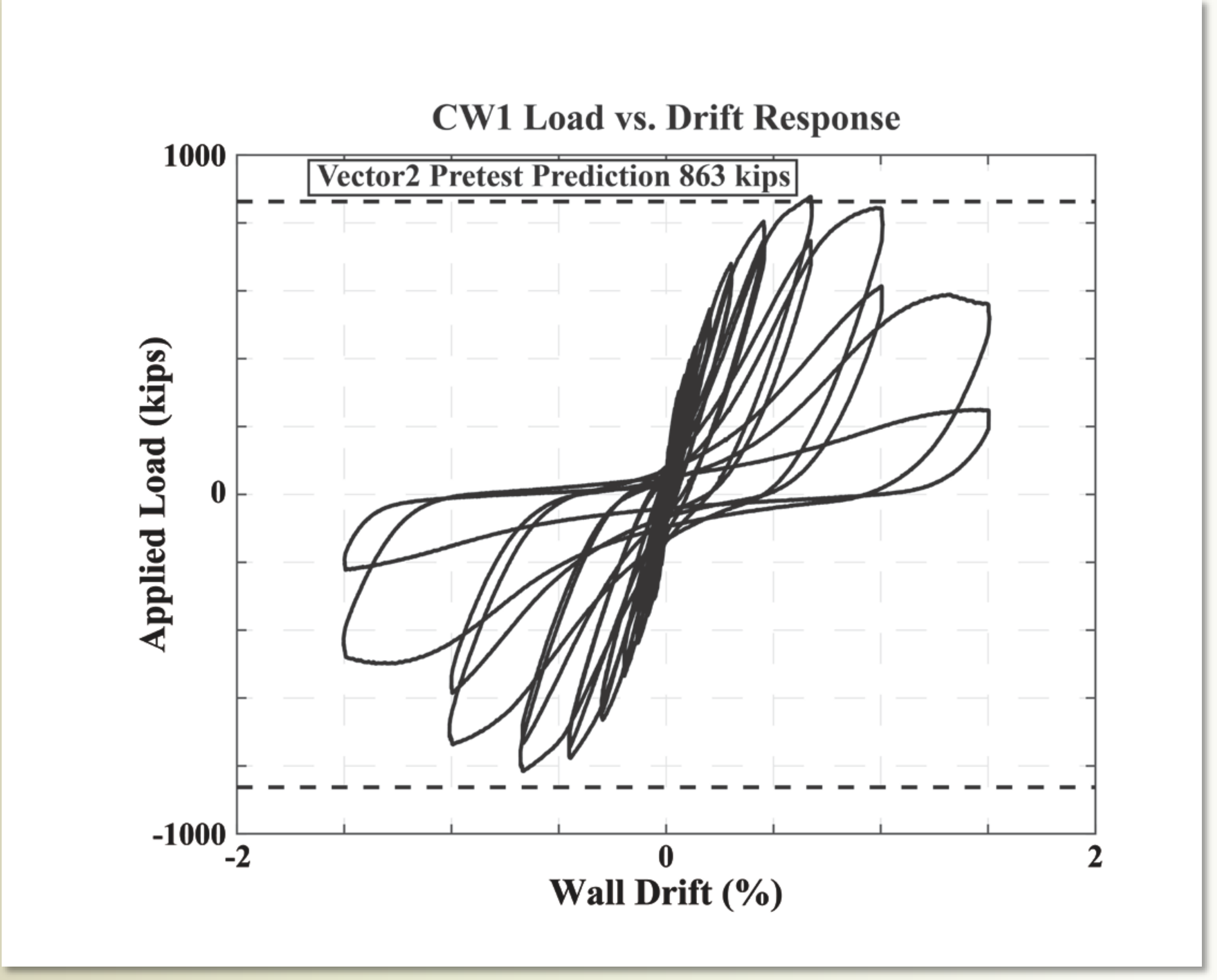
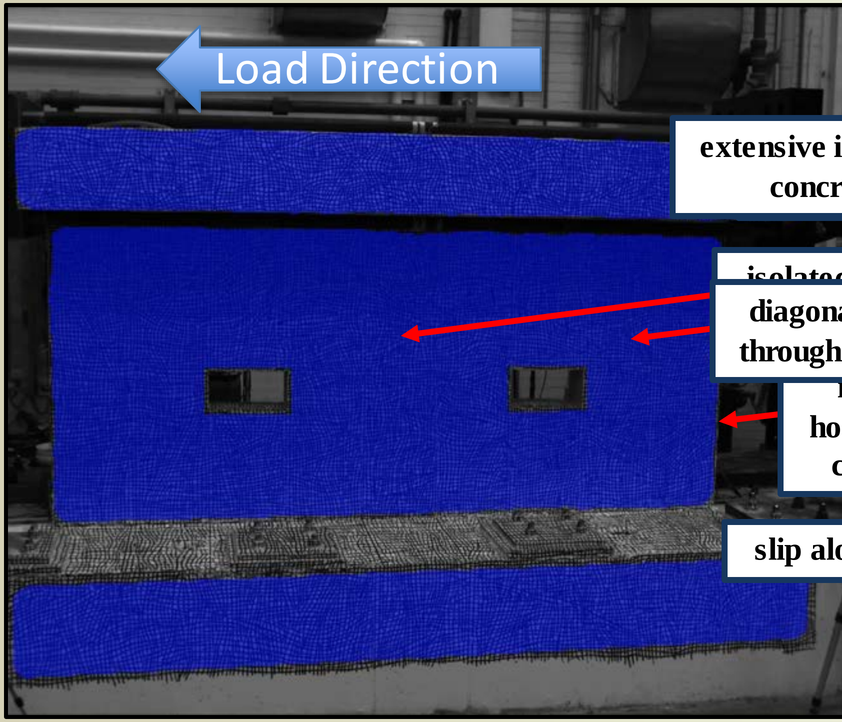
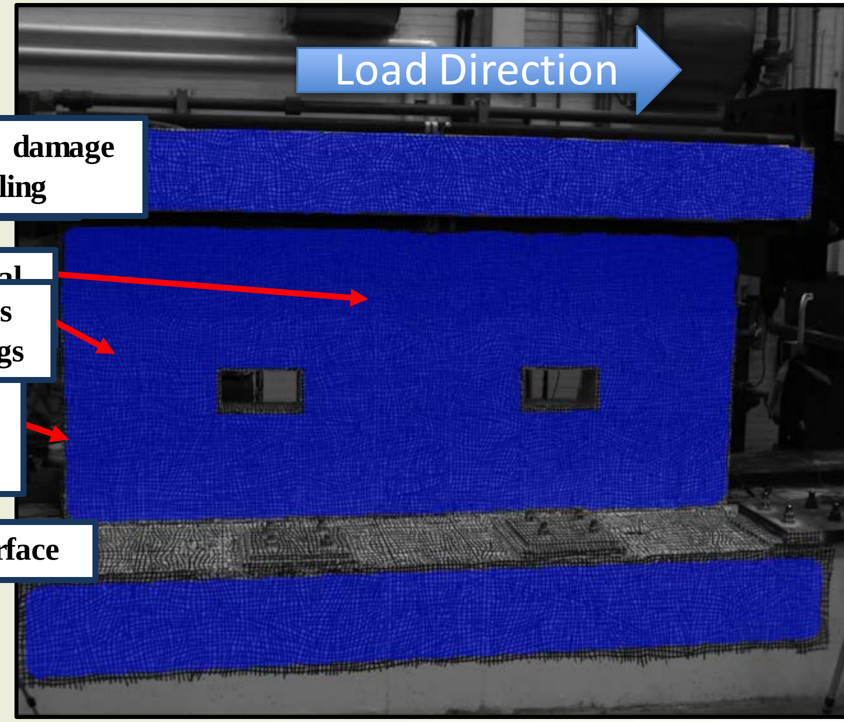


# CW1 ($f'_c$ = 6950 psi, $f_y$ = 74 ksi)



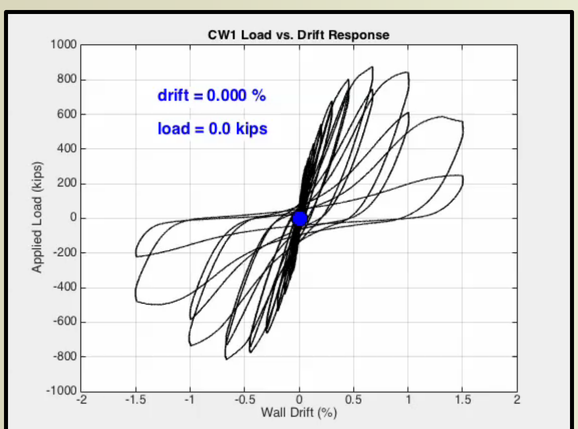

extensive interface damage
concrete spalling

isolated diagonal

diagonal cracks
through openings

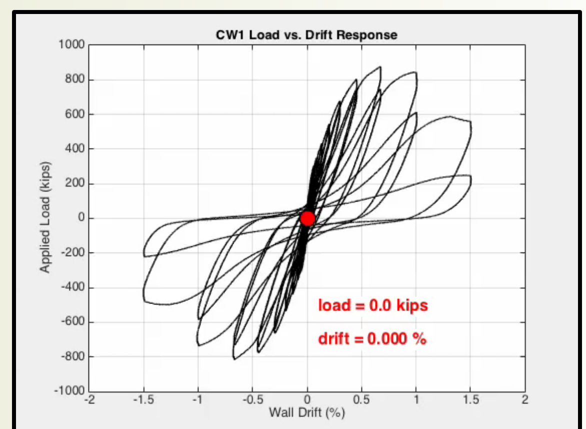
initial
horizontal
cracks

slip along interface




displacement
control series 4

VIDEO



# Shear Wall Preliminary Conclusions

- Finite-element model provided accurate prediction of lateral strength
- Wall experienced well-distributed diagonal cracking prior to peak load
- Failure occurred due to wall slip above cold joint and concrete degradation
- Global behavior of wall was not negatively influenced by wall openings

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# Shear Wall Future Work

- Detailed data analysis of CW1 is underway
- CW2 is under construction and will be tested this spring
- Comparisons between CW1 and CW2 will
  - Reveal effect of high-strength materials; and
  - Inform parameters for CW3

# Acknowledgements


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- Material/Fabrication Donations:

  | | |
  |---|---|
  | Dayton Superior Corp. | MMFX Steel |
  | Essve Tech, Inc. | Nucor Corporation |
  | Harris Rebar | Sika Corp. U.S. |
  | HRC, Inc. | |

- Undergraduate Researchers: Coleman Blakely, Laura Bobich, Greg Demet, Max Ducey, Marlena Fernandez, Chris Garcia, Claire Gasser, Molly Phillips, Madalyn Sowar


# Questions?

*http://phsrc-nuclearwalls.nd.edu*

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High Strength Materials Prefabrication
Sandia National Laboratories
AECOM
NEUP Nuclear Energy University Programs
Department of Energy United States of America