Fastening to Concrete

4. Cast-in Anchors in Plastic Hinge Zones

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NEES-Anchor Tests

- Phase I: Unreinforced single anchors subjected to cyclic loading (UWM, Spring 2010)
- Phase II: Reinforced single anchors subjected to shear (UWM, Fall 2010)
- Phase III: Reinforced single anchors subjected to tension (UWM, Summer 2011)
- Phase IV: Anchor groups in plastic hinge zones of a concrete wall (NEES-UIUC, May 2012)
- Phase V: Reinforced single anchors in plastic hinge zones of columns (UWM, Spring 2012)
- Other Tests: Shear tests of anchor rods with exposed lengths (UWM, Summer 2011)

Anchors needed in Plastic hinge zon

Olive View Hospital,
1971

Problems in the field-2

Problems in the field-2

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Previous Tests

- Cannon (1982): 3 beams 15 expansion anchors
- Oehlers and Park (1992):studs in cracked slabs with longitudinal cracks
- Yong et al. (2001): cast-in anchors with preformed cracks
- Jang and Suh (2005): cast-in anchors with preformed cracks
- Hoehler and Eligehausen (2008): cyclic tension in cracked concrete and moving crack tests

Phase V: Cast-in anchors in plastic hinge zone of RC columns

- Evaluate the feasibility of installing headed anchors in plastic hinge zones
- Currently in ACI 318-11
  - Not allowed if concrete failure modes likely control
  - Anchor reinforcement should be provided
- Design and detailing of anchor reinforcement
  - Phase II for anchors shear reinforcement
  - Phase III for anchors tension reinforcement

Plastic hinge zones

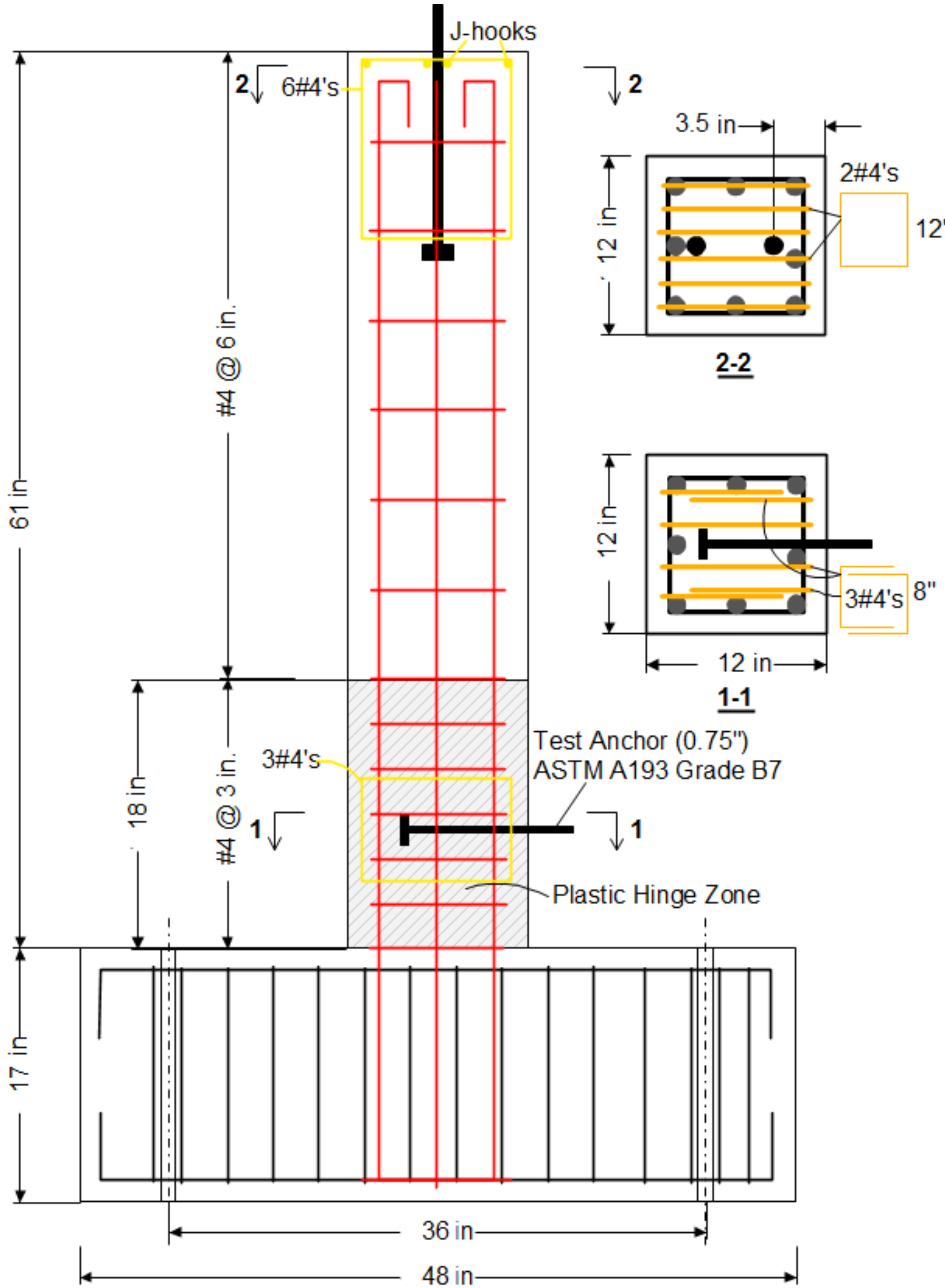

peer.berkeley.edu


Wenchuan (2008) earthquake

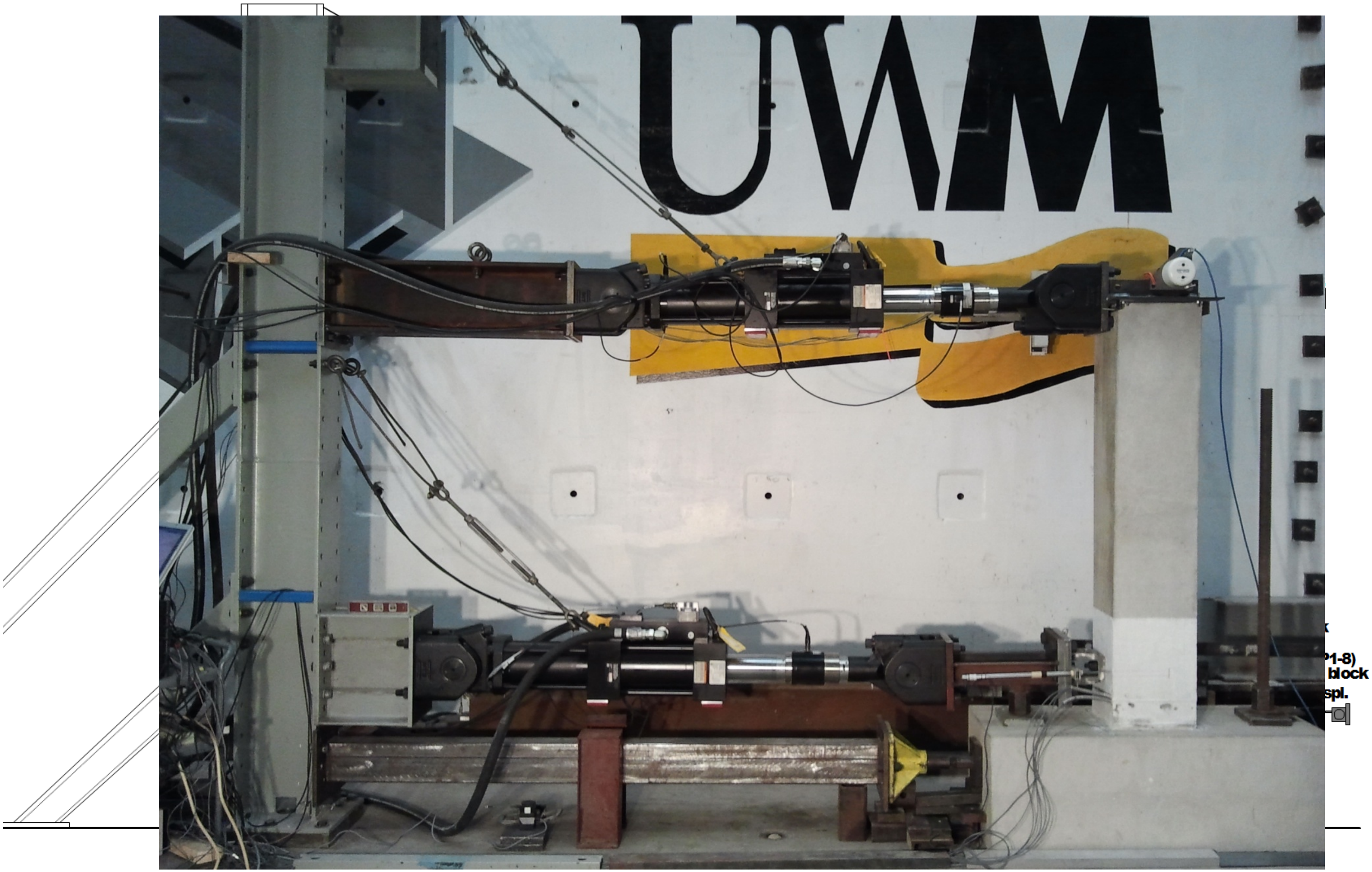
Phase V Test

- 3 specimens w/ single anchor in tension
- 3 specimens w/ two anchors in shear

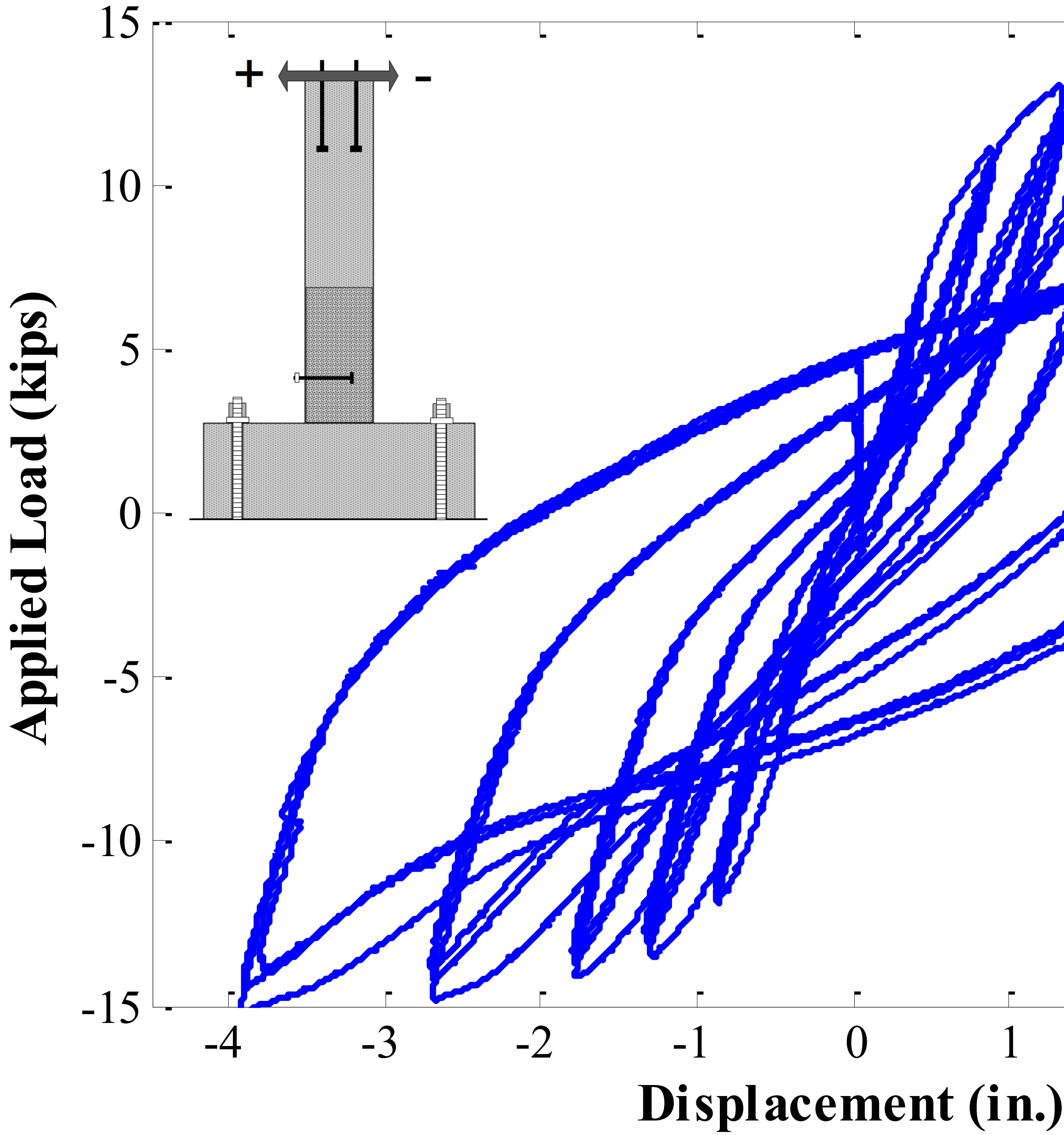
Phase V Test (Specimen)

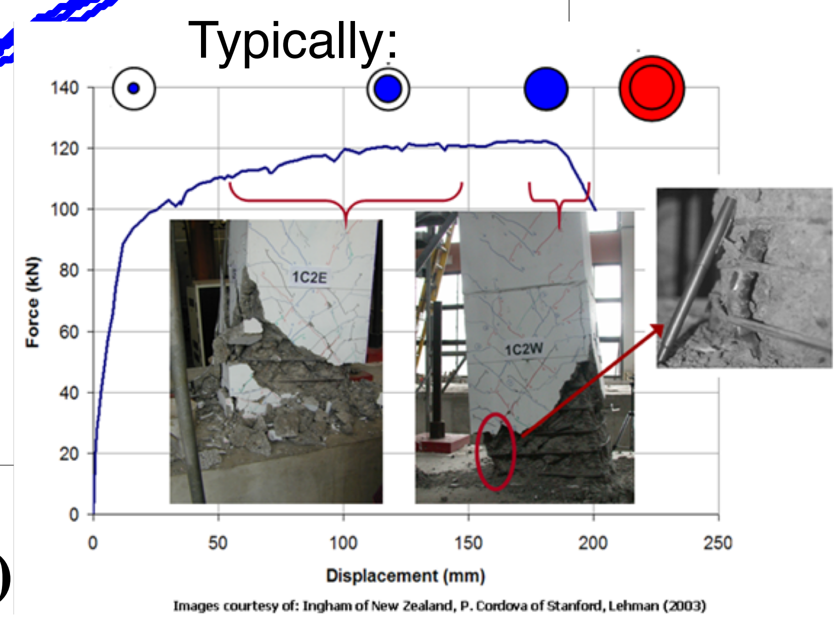


Phase V Test (setup and instrumentations)

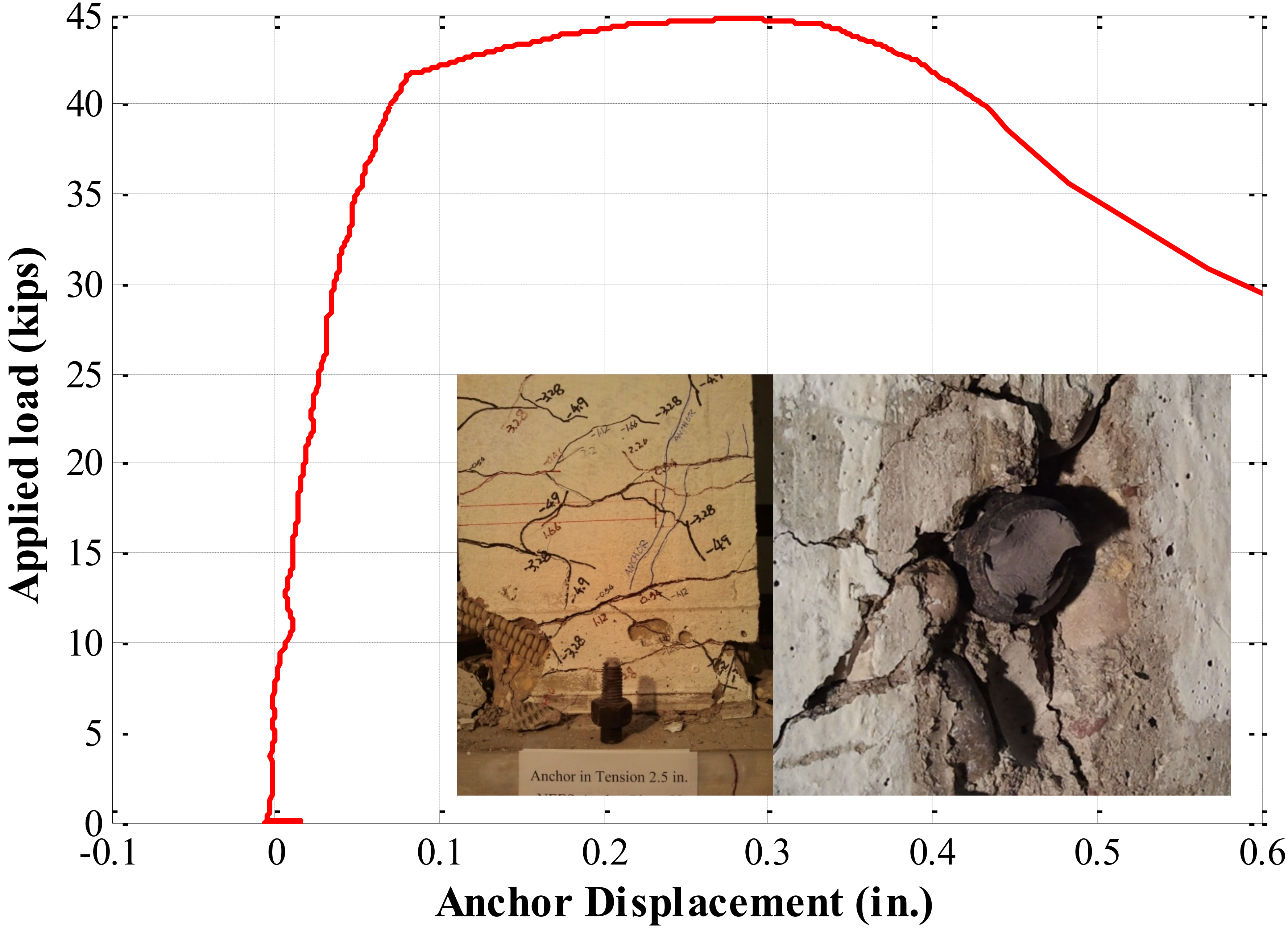


Summary of Phase V Tension Test Results

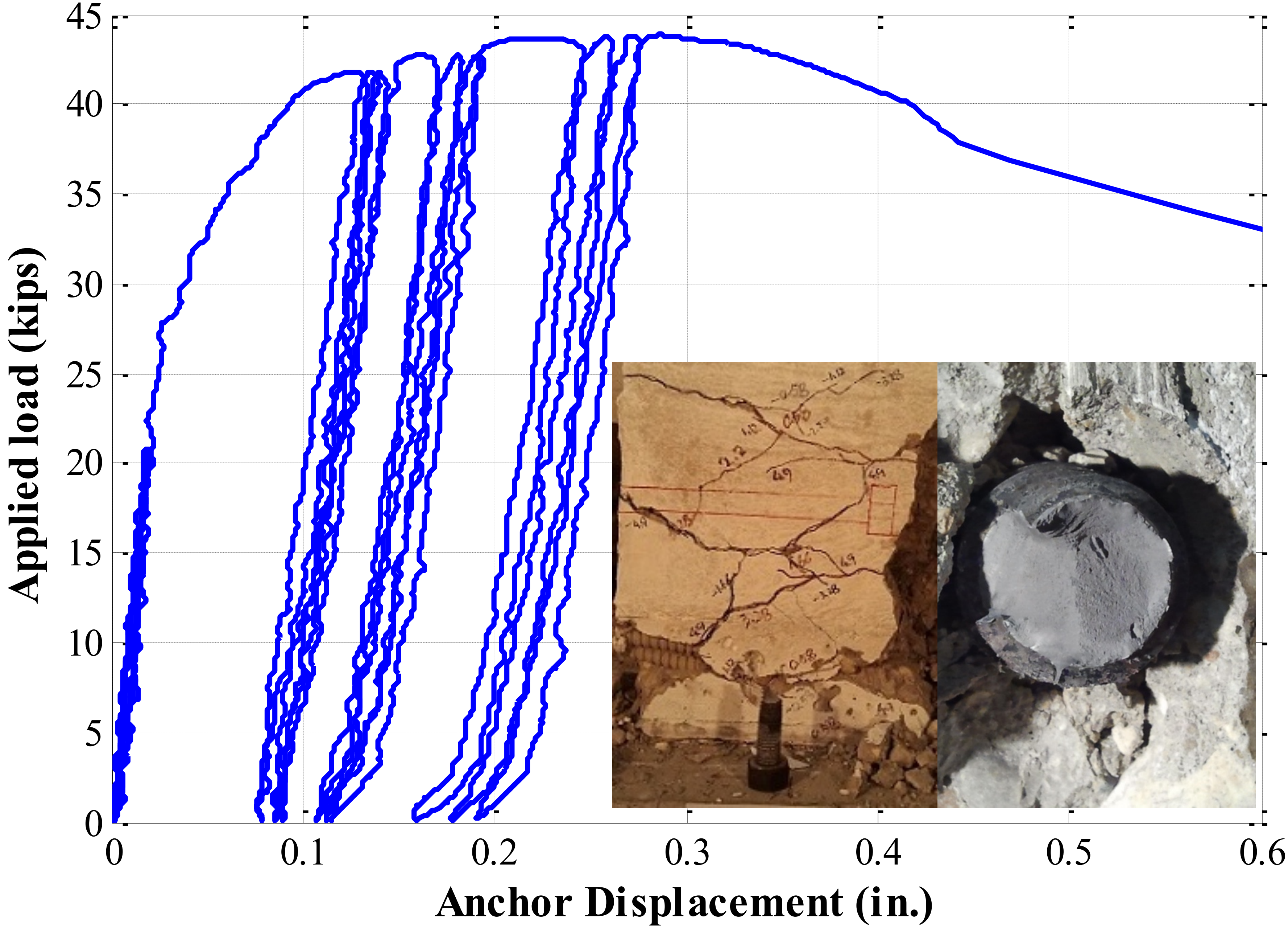




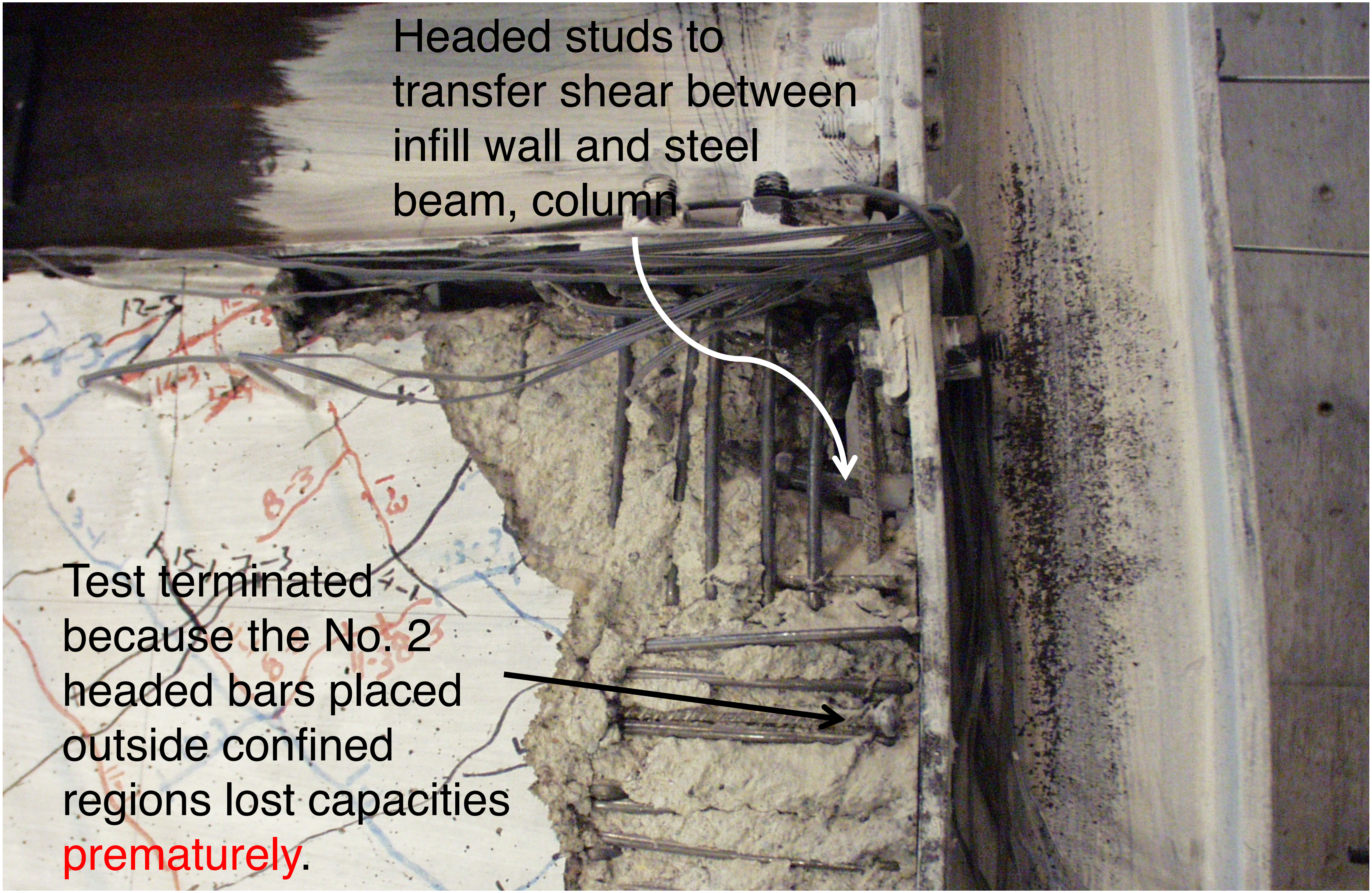
Summary of Phase V Tension Test Results (T2)



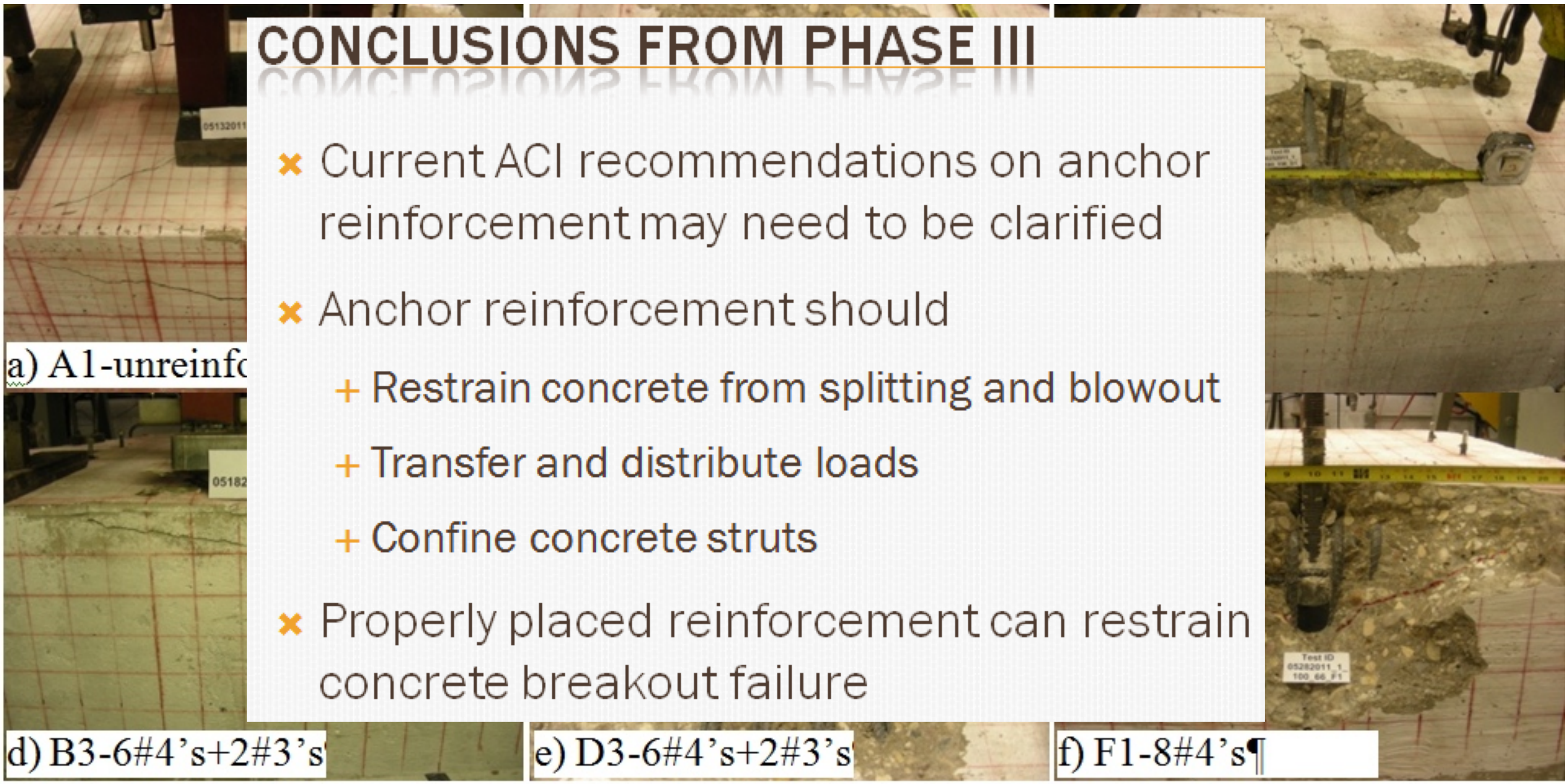
Summary of Phase V Tension Test Results (T3)



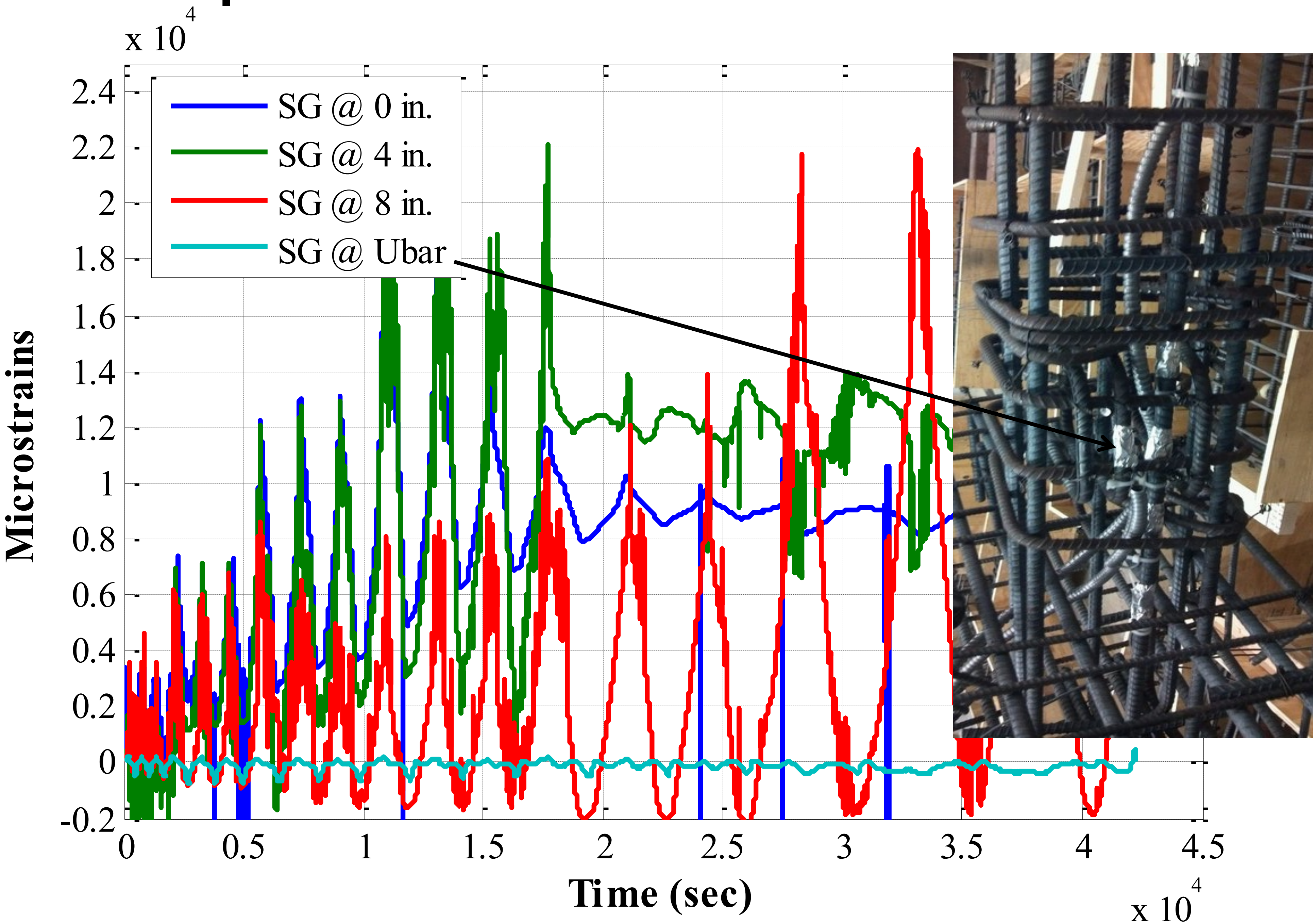
The observation reminds me ……



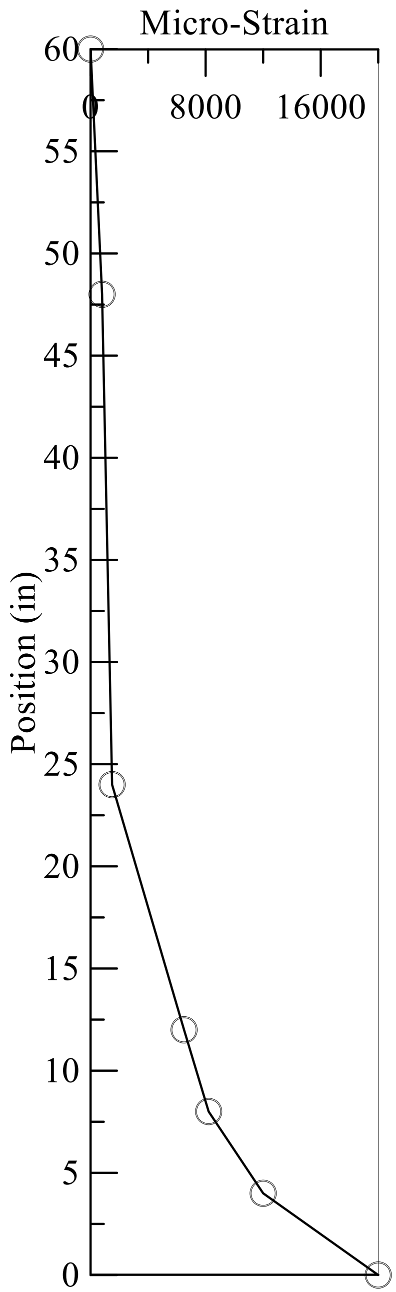
These remind us Phase III Tests …

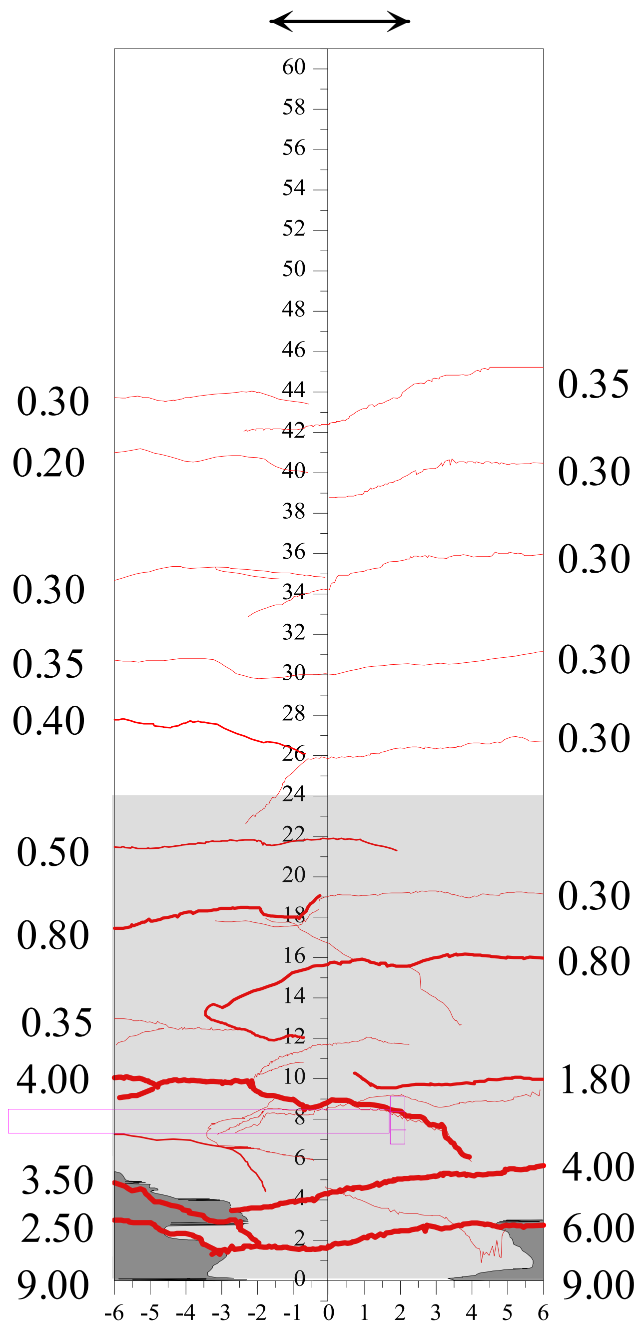


The impact of local confinement

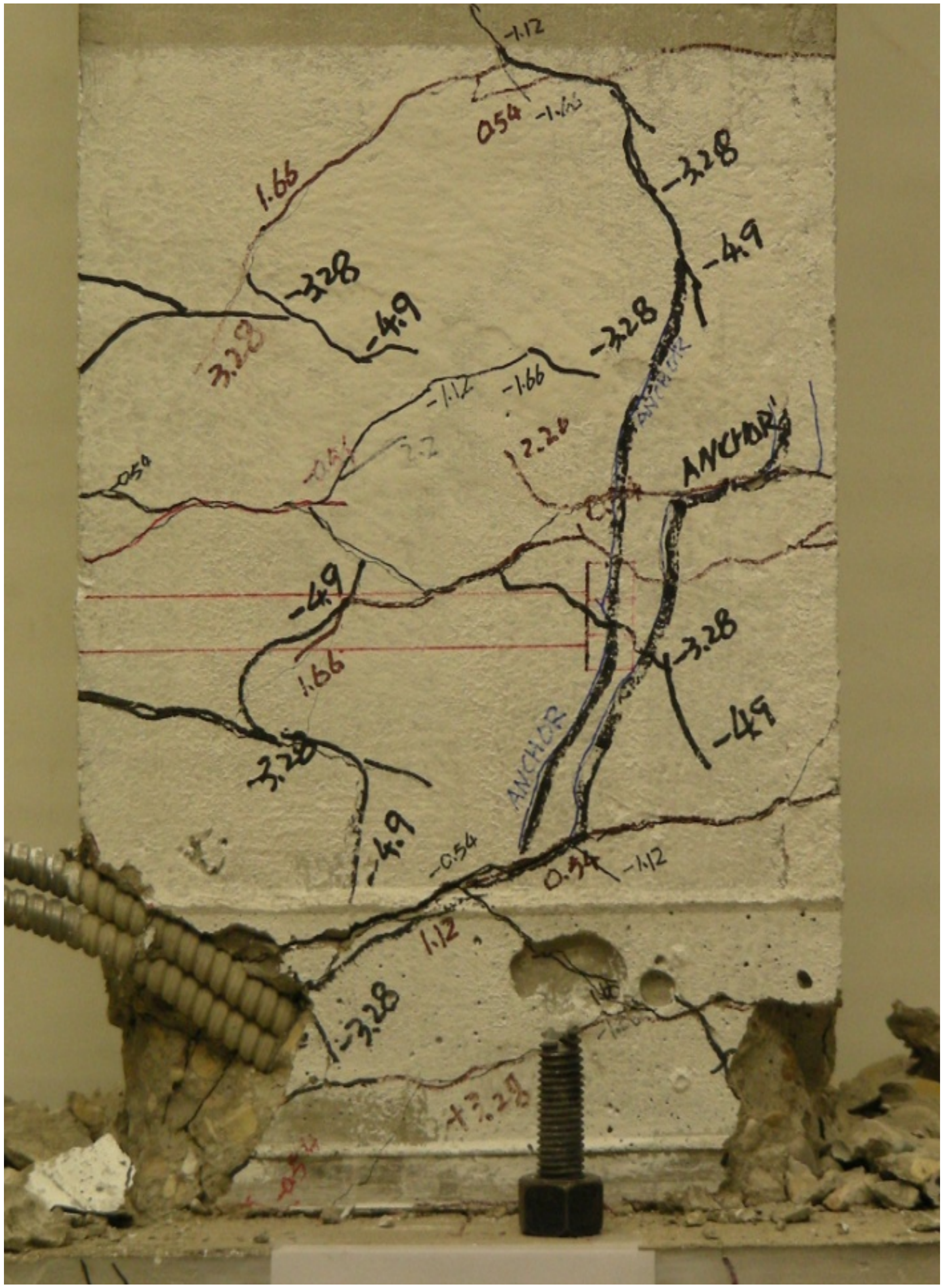


The impact of local confinement

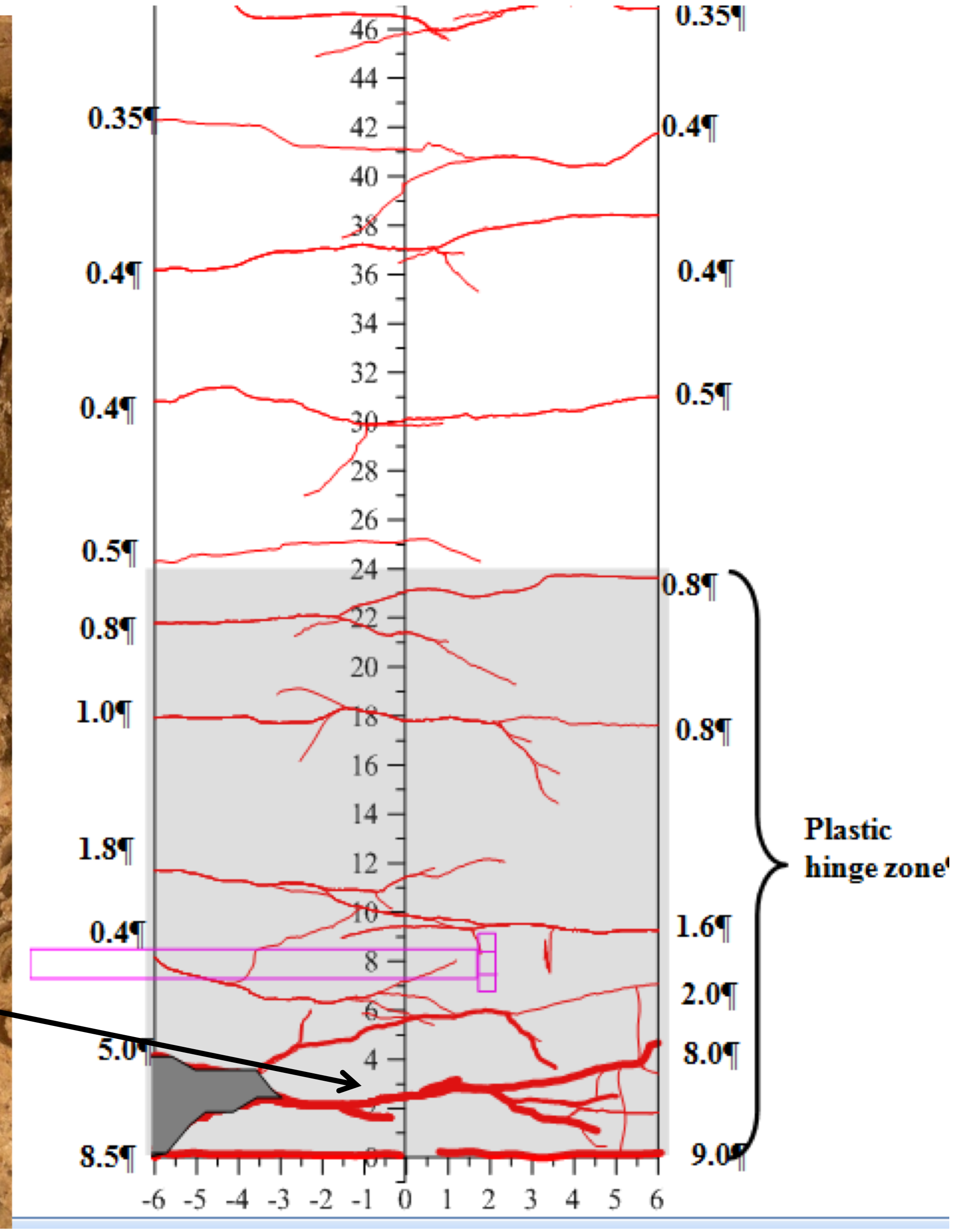




Core concrete



The impact of local confinement



Phase V Test (setup & instrumentation)

Phase V shear Test Results

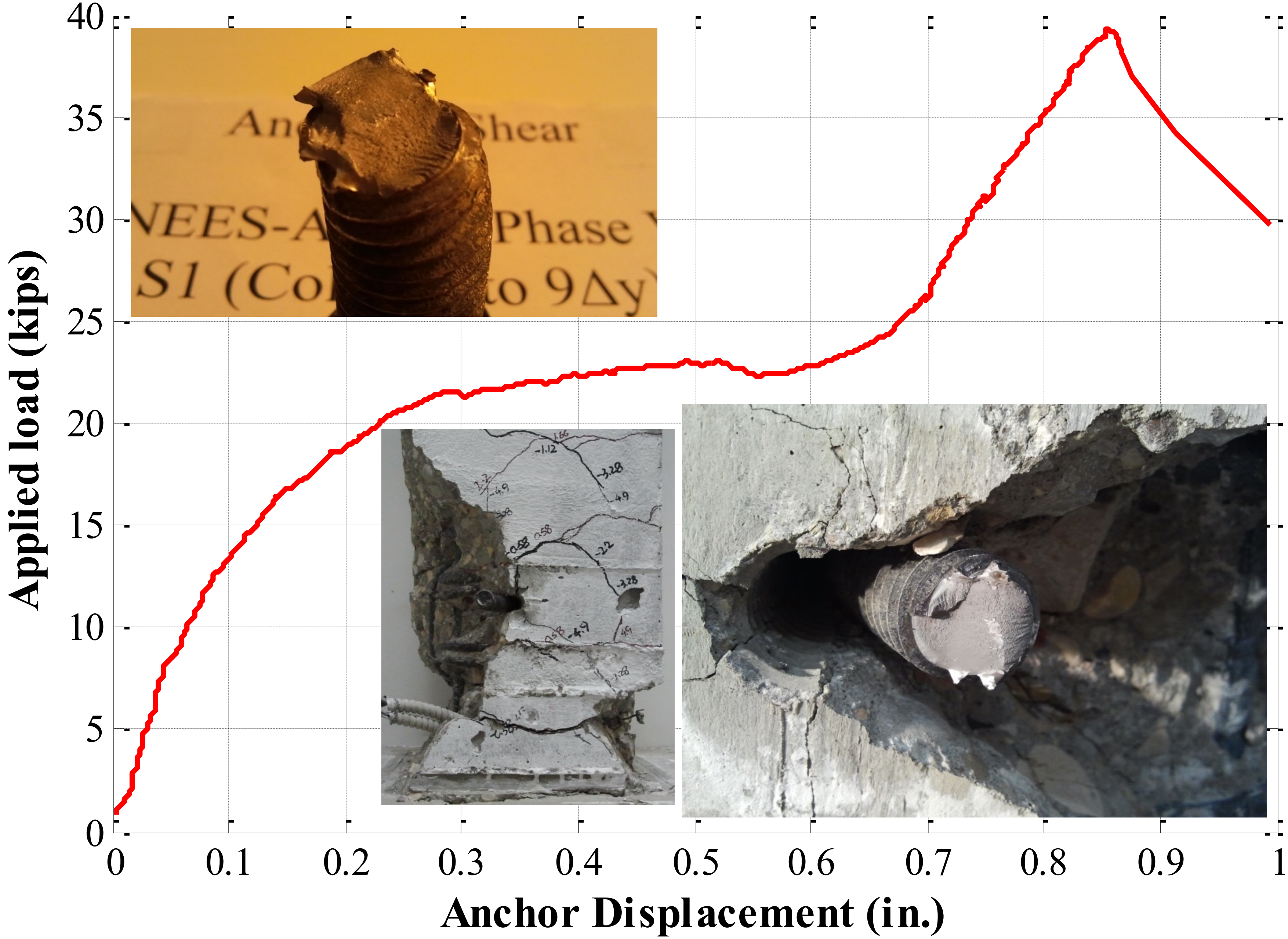
S1 (monotonic shear, at zero position)

S2 (cyclic shear along with cyclic column deformation)

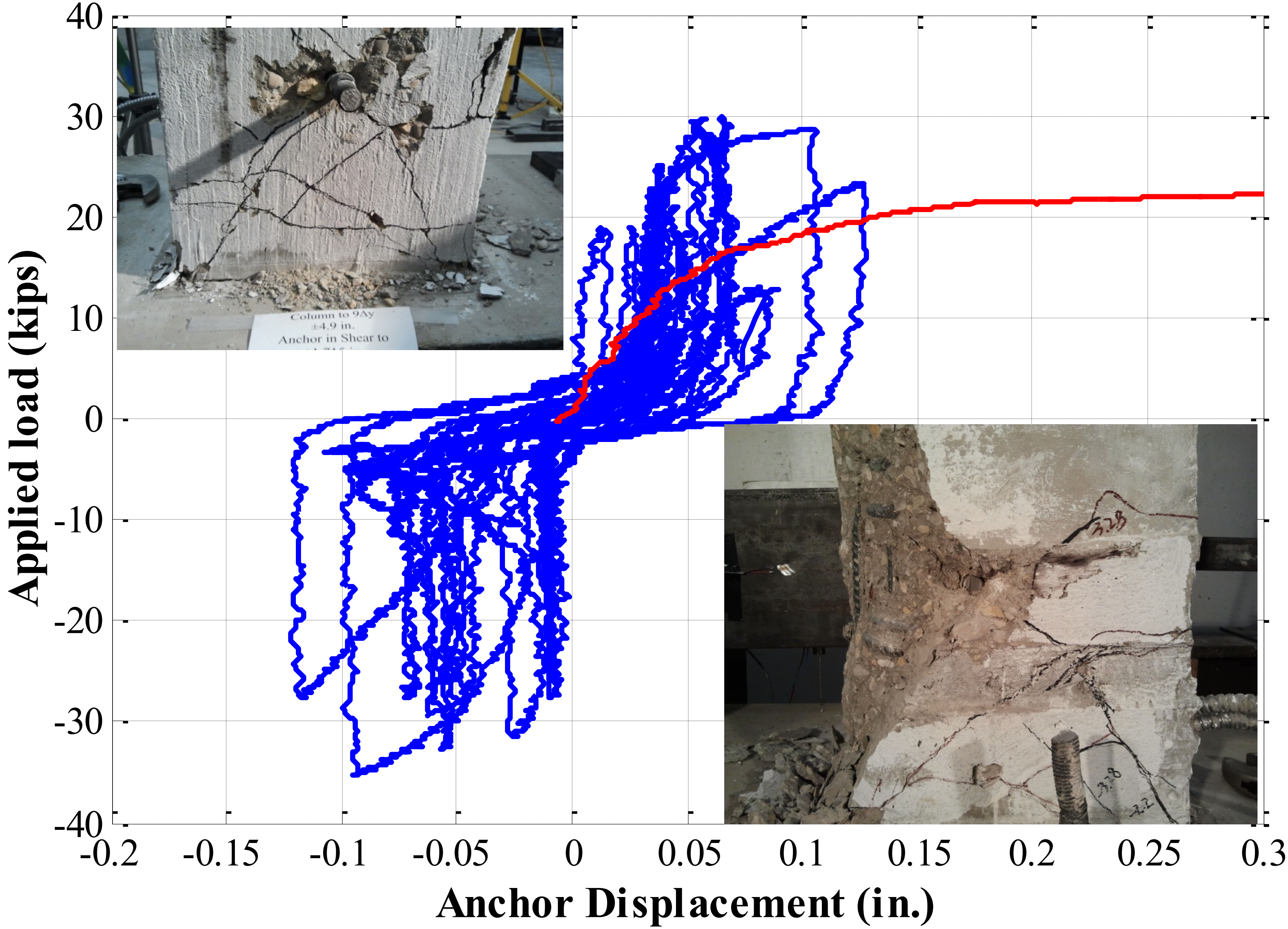
S3 (TBD)

Confining reinforcement

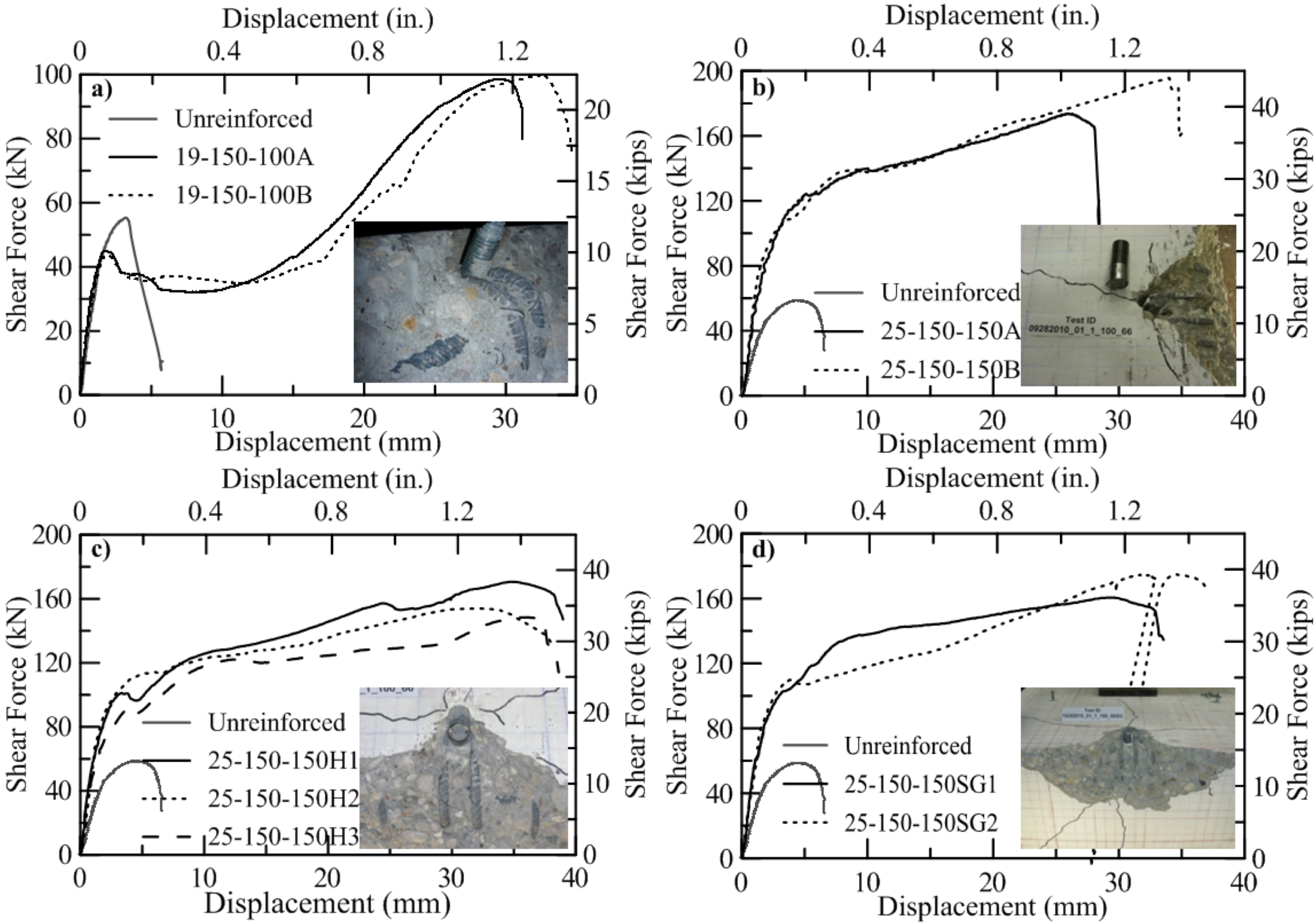
Summary of Phase V Shear Test Results (S1)



Summary of Phase V Shear Test Results (S2)



These remind us Phase II Tests ……



Observations from Phase V tests

- Well-confined core concrete can support anchors in plastic hinge zones
- Cover spalling leads to exposed anchor shaft
  - Shear capacity at cover spalling
  - Ultimate capacity
  - Estimation of exposed lengths
- The observations hold for through bolts in shear, which are widely used for retrofitting

Proposal for ACI 381 Adoption

17.4.2.9 — Anchor tension reinforcement

17.4.2.9.1 Anchor tension reinforcement shall be designed either by 17.4.2.9.2 for anchors and anchor groups in mass concrete, or 17.4.2.9.3 for anchors and anchor groups close to concrete edges.

17.4.2.9.2 Where anchor reinforcement is developed in accordance with 25.4 on both sides of the breakout surface, the design strength of the anchor reinforcement shall be permitted to be used instead of the concrete breakout strength in determining φN_n. A strength reduction factor of 0.75 shall be used in the design of the anchor reinforcement.

17.4.2.9.3 anchor tension reinforcement shall include 1) load-carrying reinforcement in the direction of the anchors; 2) crack-controlling reinforcement in all directions that has a limited edge distance; and 3) local confining reinforcement near the anchor head if side-face blowout may control the failure. The area of load-carrying reinforcement shall be determined by

$$A_{sa} = \frac{f_{uta} A_{se,N}}{f_{yt}} \qquad (17.4.2.9.3)$$

where the limitation of $1.9 f_{ya}$ on f_{uta} shall not be applied. The value of f_{yt} shall satisfy 20.2.2.4.

The design of the crack-controlling reinforcement can use two strut-and-tie models: one describing the load transfer from the anchor head to the load-carrying reinforcement, and the other describing the load transfer from the load-carrying reinforcement to the rest of the structure.

17.4.2.9 — Anchor tension reinforcement

17.4.2.9.1 Two design approaches for proportioning anchor reinforcement are included in 17.4.2.9.1. The provisions of 17.4.2.9.2 are similar to those of the 2011 Code. Section 17.4.2.9.3 allows an alternative design, in which closed stirrups and crack-controlling bars confine concrete around the anchors. The confined concrete along with the reinforcement transfers the tensile load to the structure.

R17.4.2.9.2 Same as the existing wording.

R17.4.2.9.3 With a goal to confine concrete in front of anchors and to prevent concrete breakout, the anchor reinforcement consists of closely spaced stirrups, corner bars, and crack-controlling bars distributed along all concrete faces as illustrated in Fig. R17.5.2.9.3.

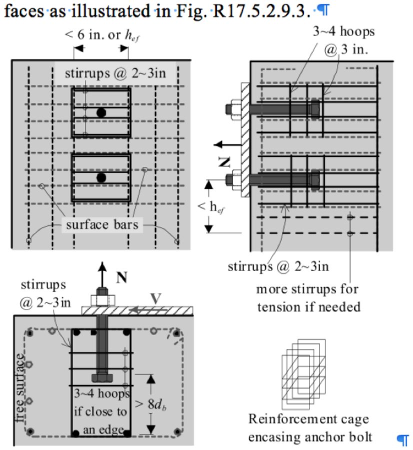


Fig. R17.4.2.9.3—anchor reinforcement for tension.

The load-carrying reinforcement should be proportioned to carry a force equal to the design tensile capacity of the anchors, and implemented using small-diameter closed stirrups. The closely spaced stirrups with a center-on-center spacing of 2 to 3 in. can extend up to $1.0h_{ef}$ from the anchor bolt.

Crack-controlling reinforcement are necessary crossing all possible cracks. All crack-controlling reinforcement should be proportioned using a steel stress of $0.6f_y$, and implemented using small diameter bars evenly distributed with a small and practical spacing in two orthogonal directions. In addition, the anchors and the load-carrying reinforcement close to the anchor can be encased by three or four closed hoops in the transverse direction near the anchor head if the anchors are close to a free side surface. With the anchor tension reinforcement, anchor shaft fracture is expected if other failure modes in 17.4 do not control the anchor behavior.

The quasi-static cyclic tests of the reinforced anchors in tension, conducted at the University of Wisconsin, Milwaukee showed insignificant capacity reduction. Therefore no capacity reduction is needed for reinforced anchors subjected to cyclic tensile loading.

Proposal for ACI 381 Adoption

17.5.2.9 — Anchor shear reinforcement

17.5.2.9.1 Anchor reinforcement shall be designed either by 17.5.2.9.2, which assumes well-developed anchor reinforcement provides shear resistance of anchors, or 17.5.2.9.3, which assumes well-confined concrete transfers shear load to the structural element.

17.5.2.9.2 Where anchor reinforcement is either developed in accordance with Chapter 12 on both sides of the breakout surface, or encloses the anchor and is developed beyond the breakout surface, the design strength of the anchor reinforcement shall be permitted to be used instead of the concrete breakout strength in determining φV_n. A strength reduction factor of 0.75 shall be used in the design of the anchor reinforcement.

17.5.2.9.3 The anchor reinforcement shall consist of closed stirrups encasing corner bars and crack-controlling bars distributed along all concrete surfaces. The area of anchor reinforcement shall be determined by

$$A_{sa} = \frac{0.6 f_{uta} A_{se,V}}{f_{yt}} \qquad (17.5.2.9.3)$$

where the limitation of $1.9 f_{ya}$ on f_{uta} shall not be applied. The value of f_{yt} shall satisfy 20.2.2.4.

The required anchor reinforcement shall be provided in terms of closed stirrups parallel to anchors evenly distributed at both sides of anchors with a maximum spacing of 3 in. Crack-controlling bars can be designed using strut-and-tie model, and shall be at least $0.5A_{sa}$, evenly distributed along the top and front surfaces.

The nominal strengths of D.6.1.2 shall be multiplied by a 0.75 factor for reinforced anchors in shear.

17.5.2.9 — Anchor shear reinforcement

17.5.2.9.1 Two design approaches for proportioning anchor reinforcement are included in 17.5.2.9.1. The provisions of 17.5.2.9.2 are similar to those of the 2011 Code. The assumption must be satisfied that concrete breakout cracks form at the ultimate load. Section 17.5.2.9.3 allows an alternative design, in which closed stirrups and crack-controlling bars confine concrete around the anchors. The confined concrete along with the reinforcement transfers the shear load to the structure.

R17.5.2.9.2 Same as the existing wording.

R.6.2.9.3 With a goal to confine concrete in front of anchors and to prevent concrete breakout, the anchor reinforcement consists of closely spaced stirrups, corner bars, and crack-controlling bars distributed along all concrete faces as illustrated in Fig. R17.5.2.9.3.

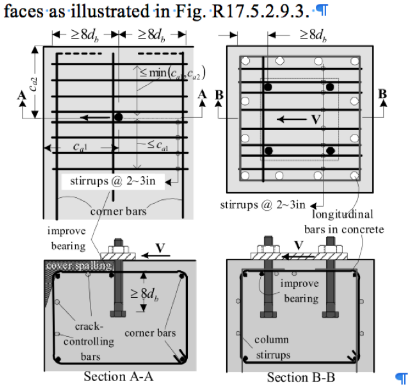


Fig. R17.5.2.9.3—anchor reinforcement for shear.

Crack-controlling bars shall be determined based on strut-and-tie models for the structural element. Diagonal struts from the anchor shaft to the outmost stirrups indicate that the splitting force can be 50 percent of the design shear force for the anchor.

With the anchor shear reinforcement, concrete breakout can be prevented and anchor shaft fracture is expected at ultimate. Cover concrete in front of the anchor bolts crushes, causing the loss of concrete support to the top portion of the anchor shaft. The full anchor steel capacity in shear cannot be achieved because the exposed anchor bolts were subjected to a combination of shear, bending, and tension at failure. A strength reduction factor of 0.75 (slightly lower than that of ACI 318-11 on anchors with a grout pad) can be used to determine the shear capacity of reinforced anchors.

Quasi-static cyclic tests of the reinforced anchors in shear showed insignificant capacity reduction. Therefore no capacity reduction is needed for reinforced anchors subjected to cyclic shear loading.

Final Thoughts

- What to expect with anchor reinforcement?
- How to define supplementary reinforcement?
- New construction vs. existing construction?
- Cast-in anchors vs. post-installed anchors?
- Retrofitting anchors?
- External reinforcement for anchors in shear?

Final test at NEES@Illinois

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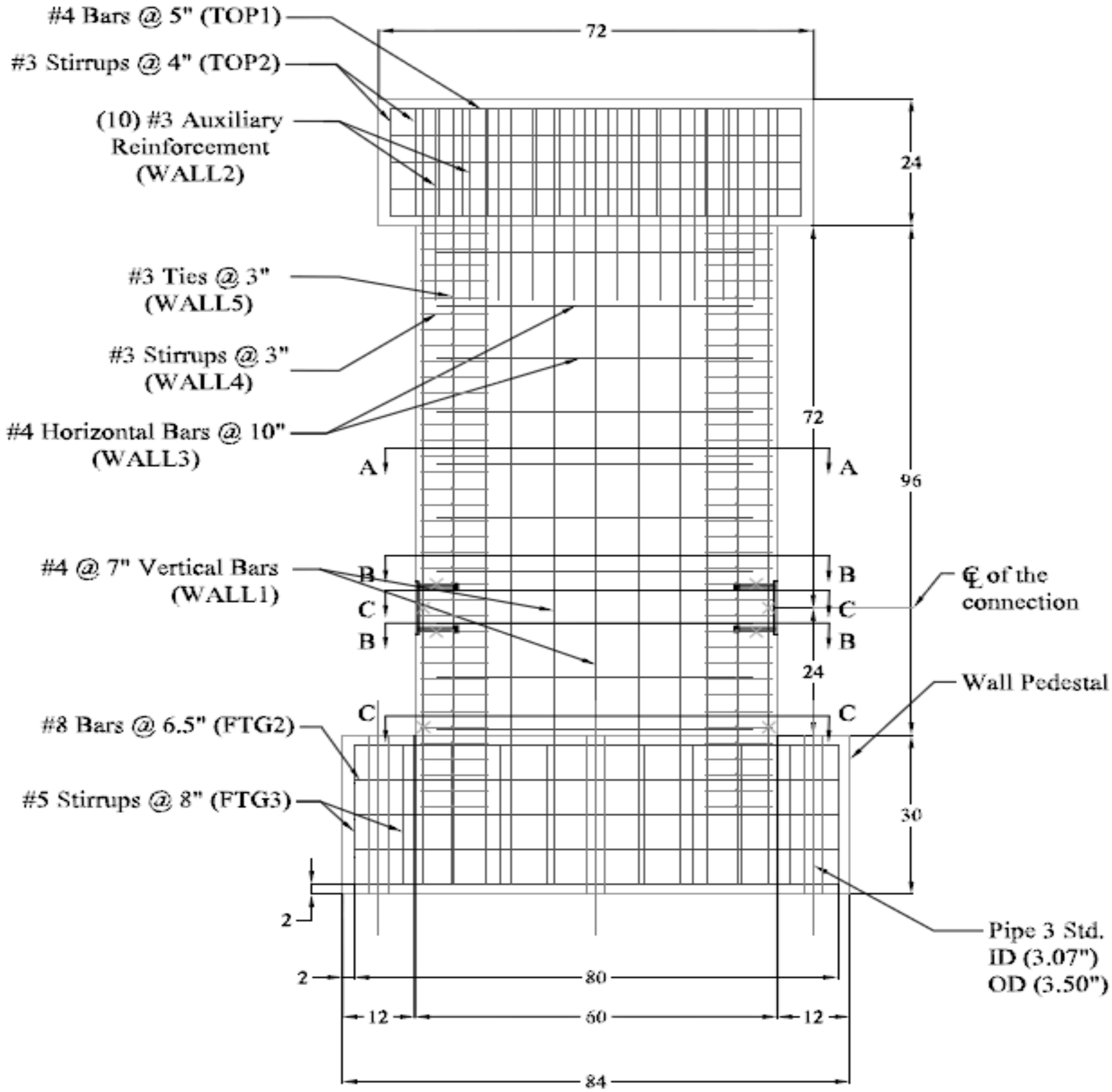
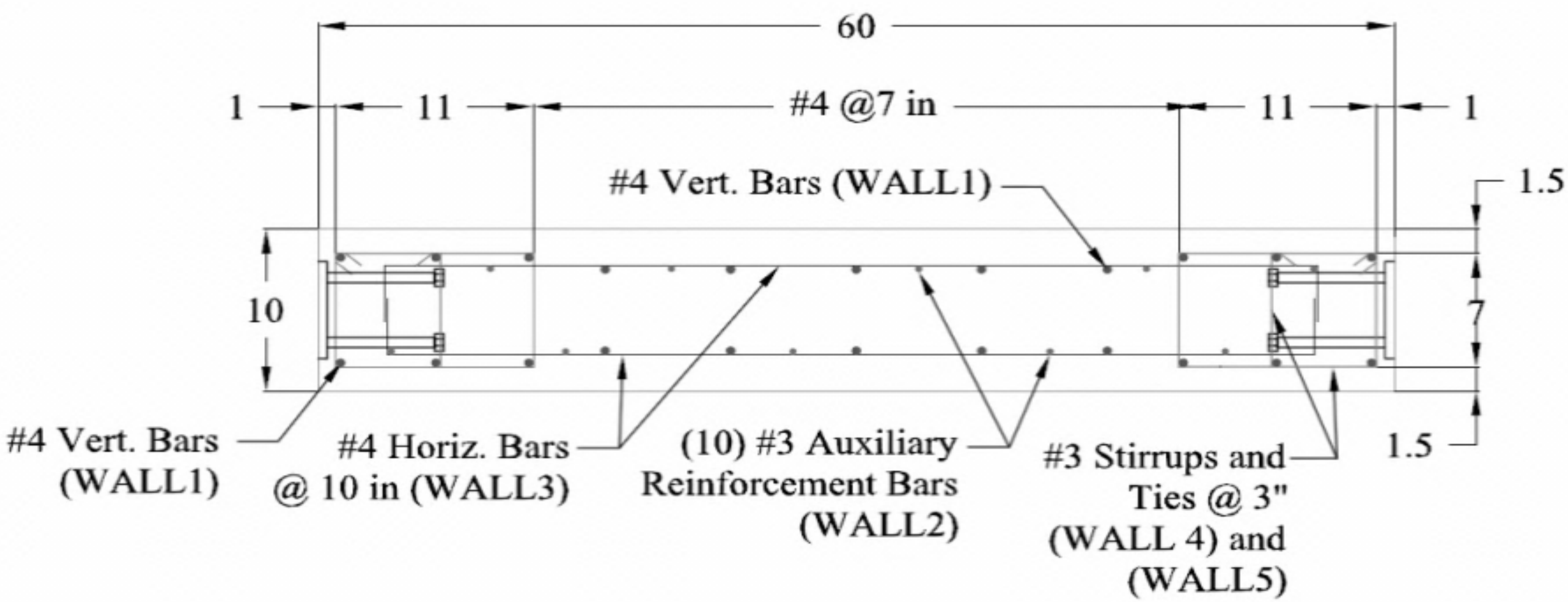


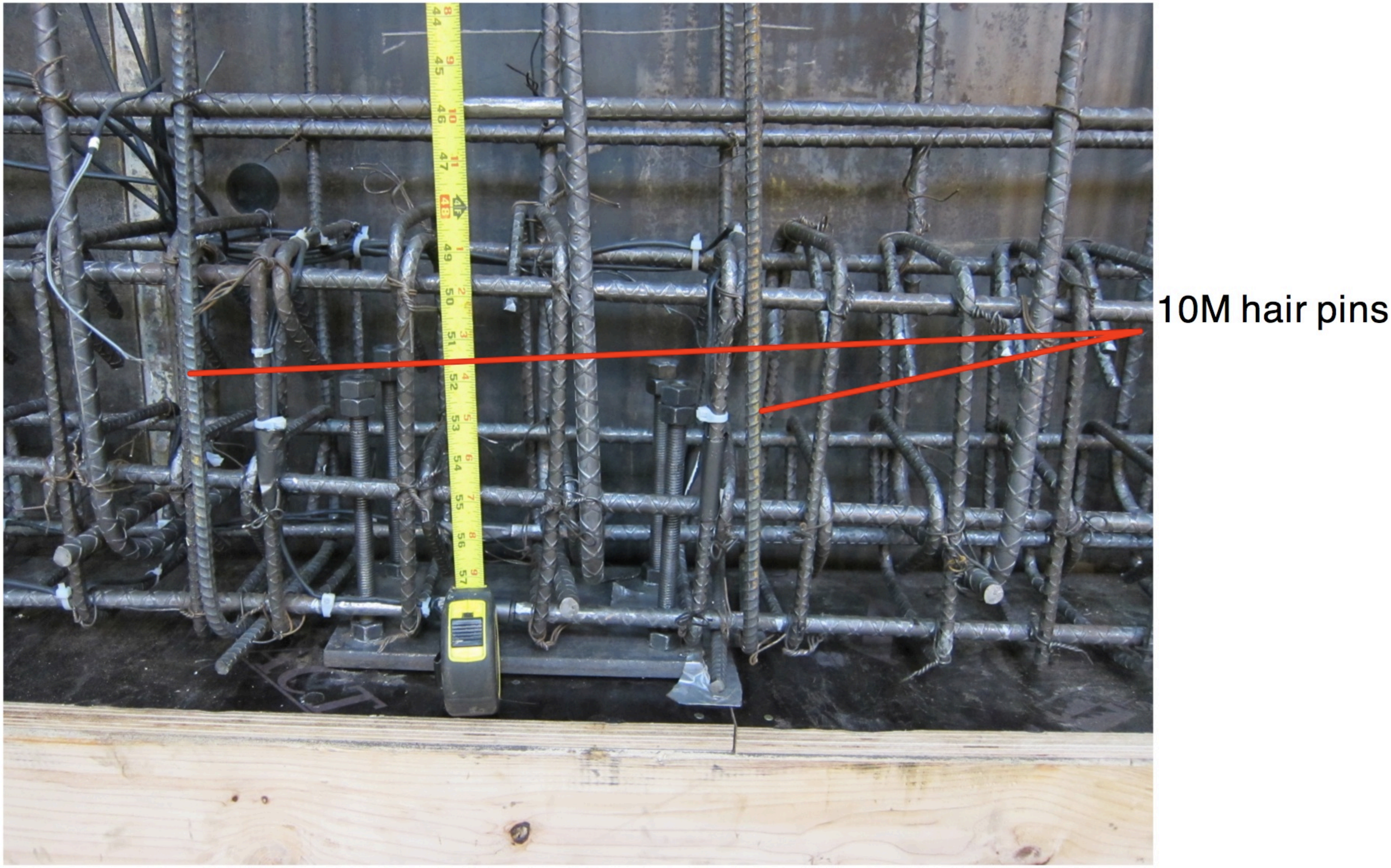
SIDE VIEW OF THE RECTANGULAR WALL

Final test at NEES@Illinois



SECTION A-A

Final test at NEES@Illinois



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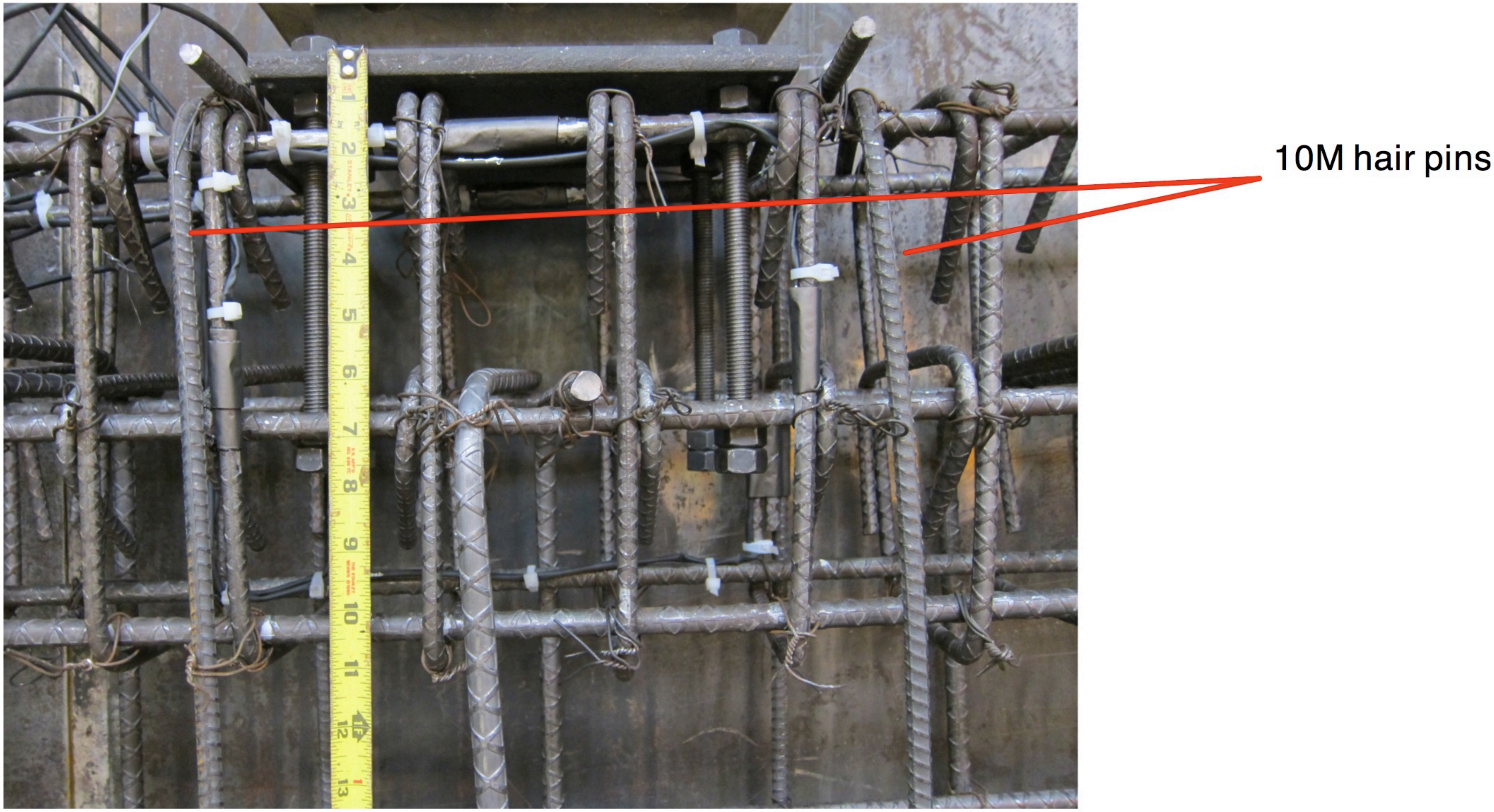


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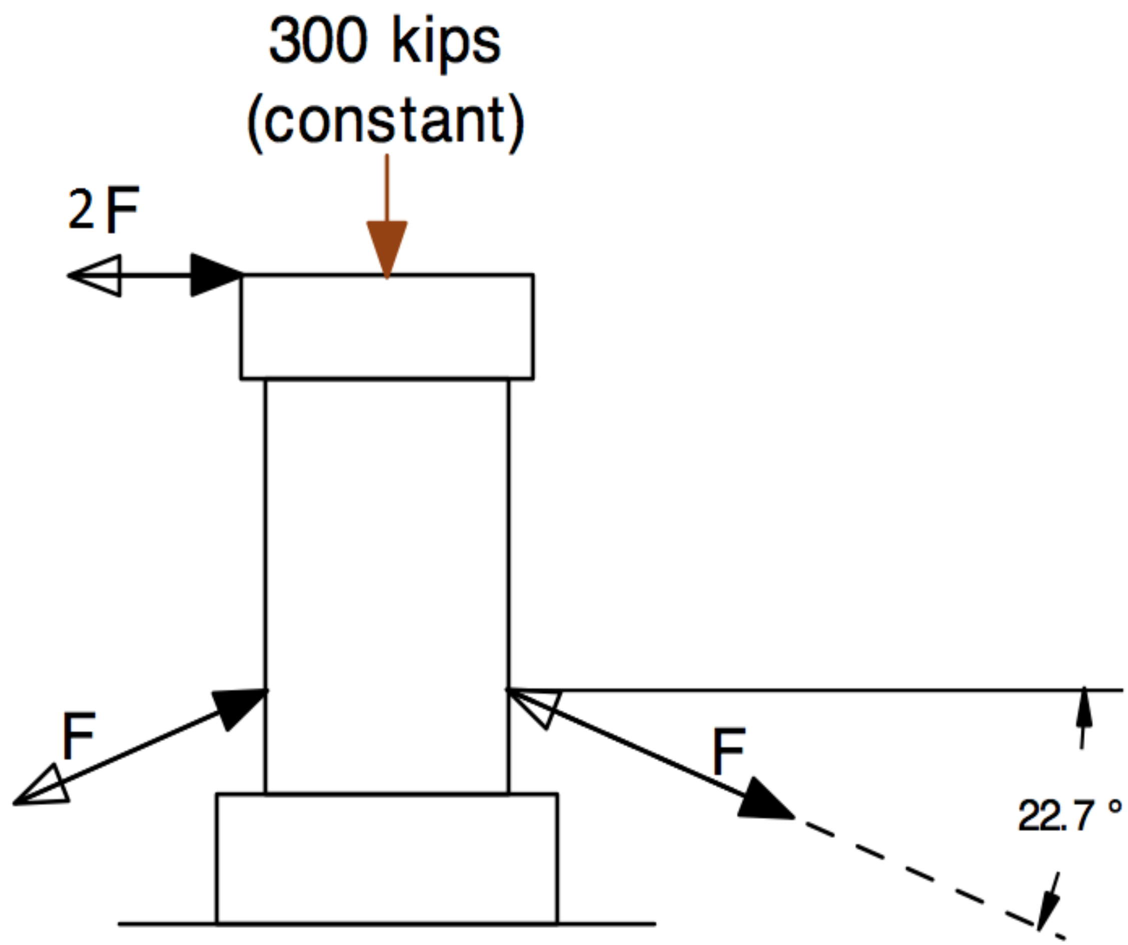
OF ILLINOIS

Final test at NEES@Illinois



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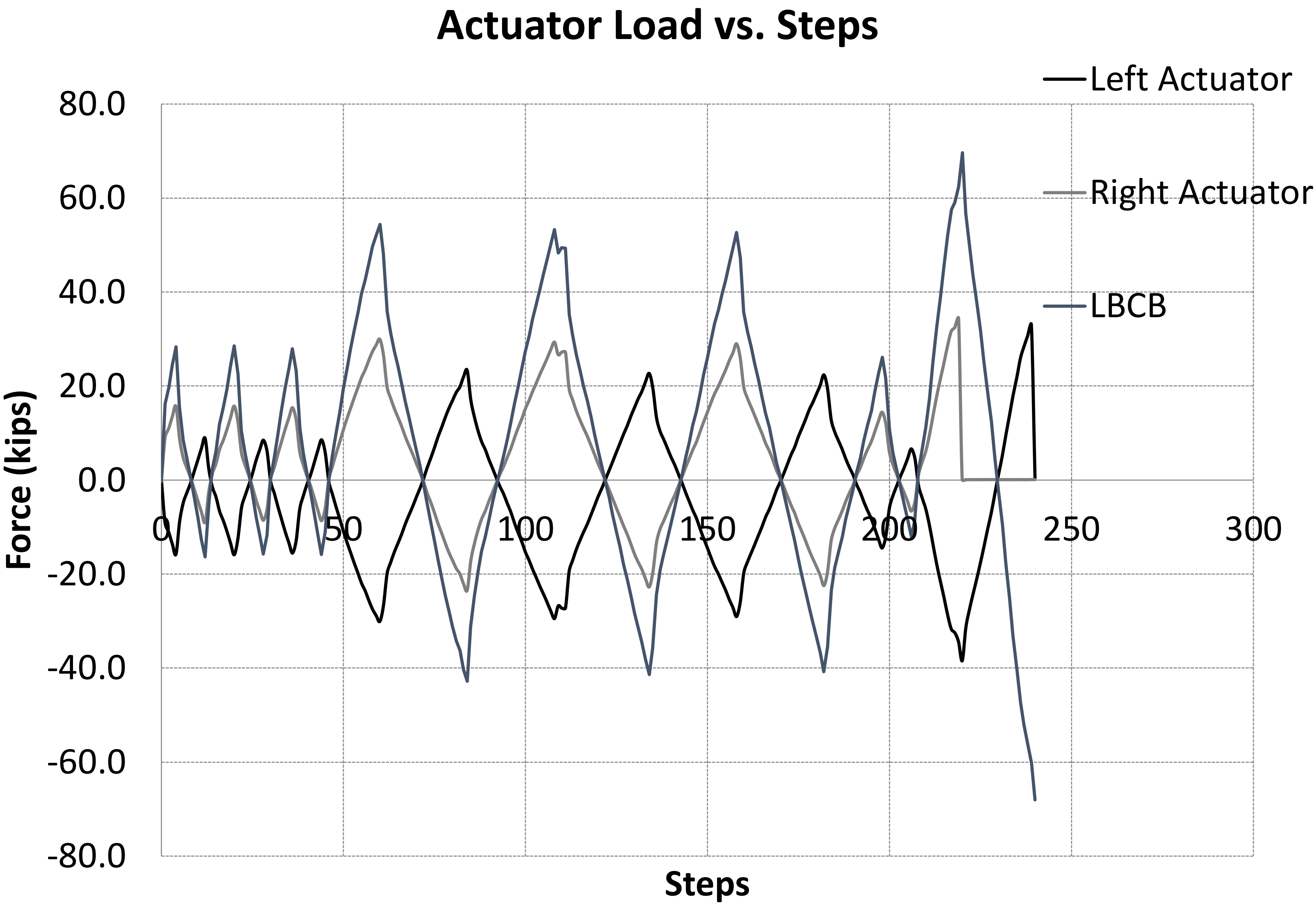

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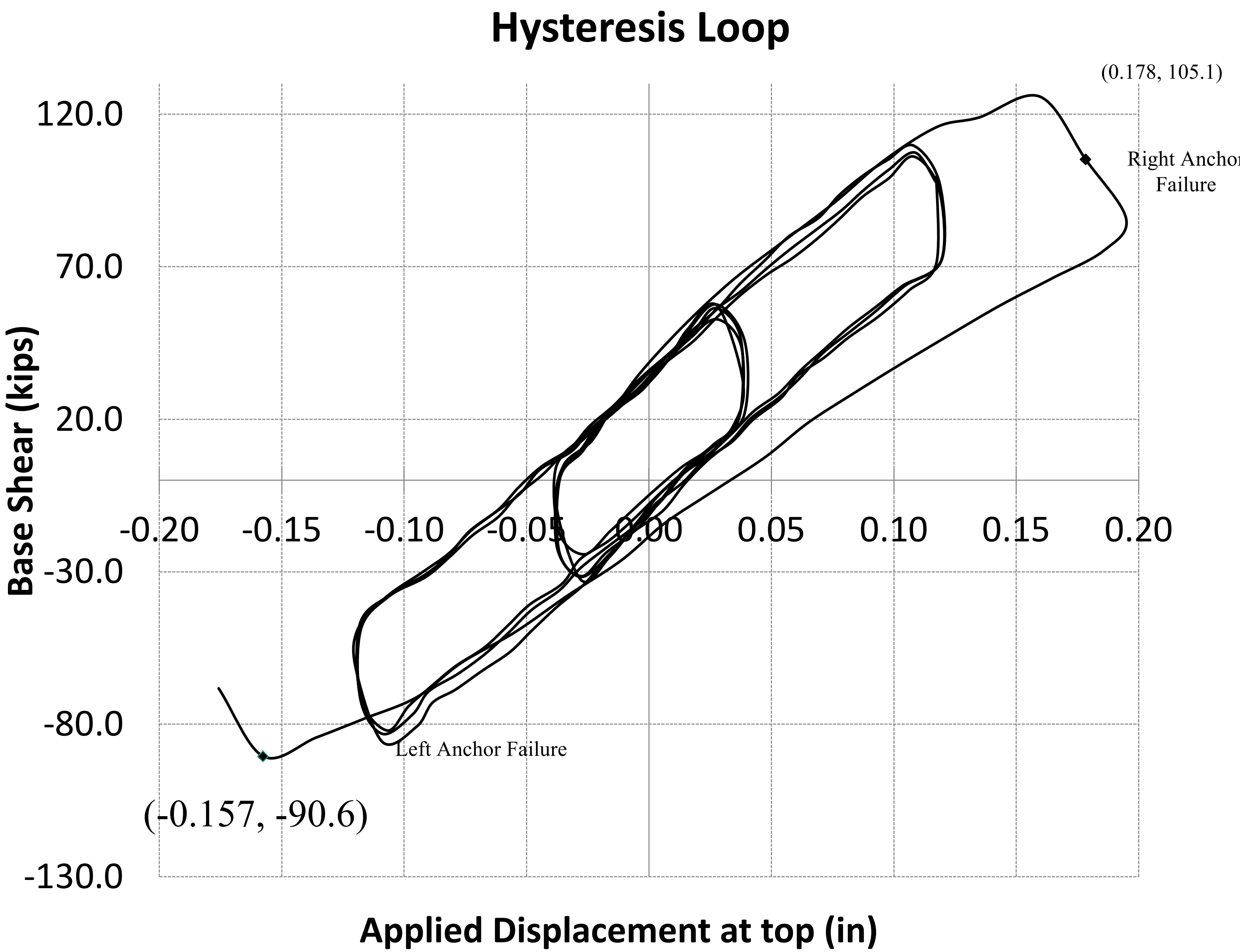

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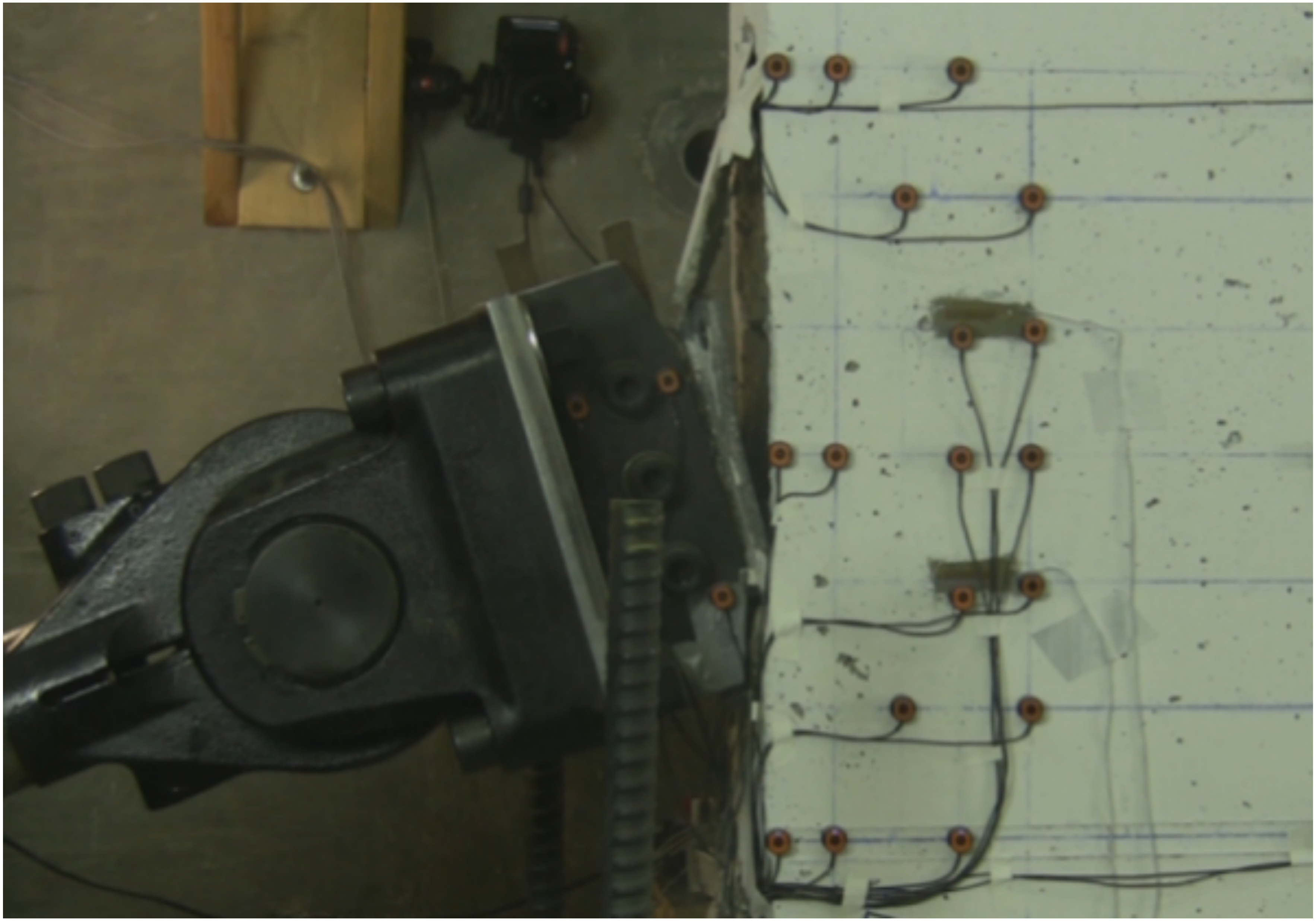

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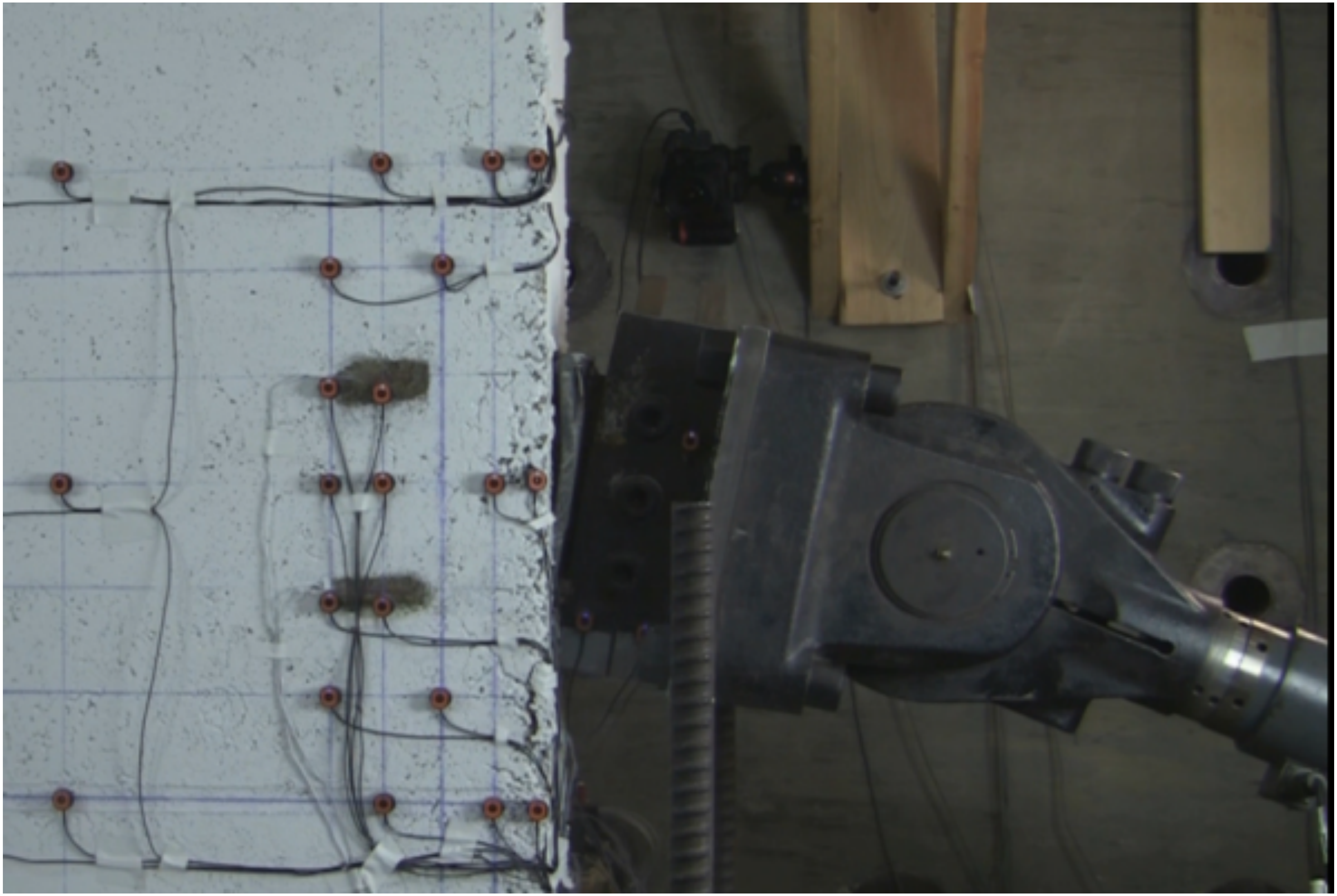

Acknowledgements

University of Wisconsin UW Milwaukee

NSF

University of Cincinnati

Spancrete Building Innovation.

CMC Contractors Materials Co.

Prestress Services Industries LLC

Powers Fastening Innovations

QuakeWrap Stronger Than Steel

ernst concrete

Baker Concrete Construction expect more

https://www.designsafe-ci.org/data/browser/public/nees.public/NEES-2009-0725.groups

http://nees-anchor.ceas.uwm.edu

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NEES

National Science Foundation
WHERE DISCOVERIES BEGIN