PERFORMANCE OF ANCHORAGES UNDER PREDOMINANT MOMENT LOADING: AN EXPERIMENTAL INVESTIGATION

Authors: Gaurav Chobe[1], Akanshu Sharma[2]

[1]Ph.D. Candidate, [2]Jack and Kay Hockema Associate Professor

Lyles School of Civil and Construction Engineering, Purdue University, West Lafayette, Indiana, USA

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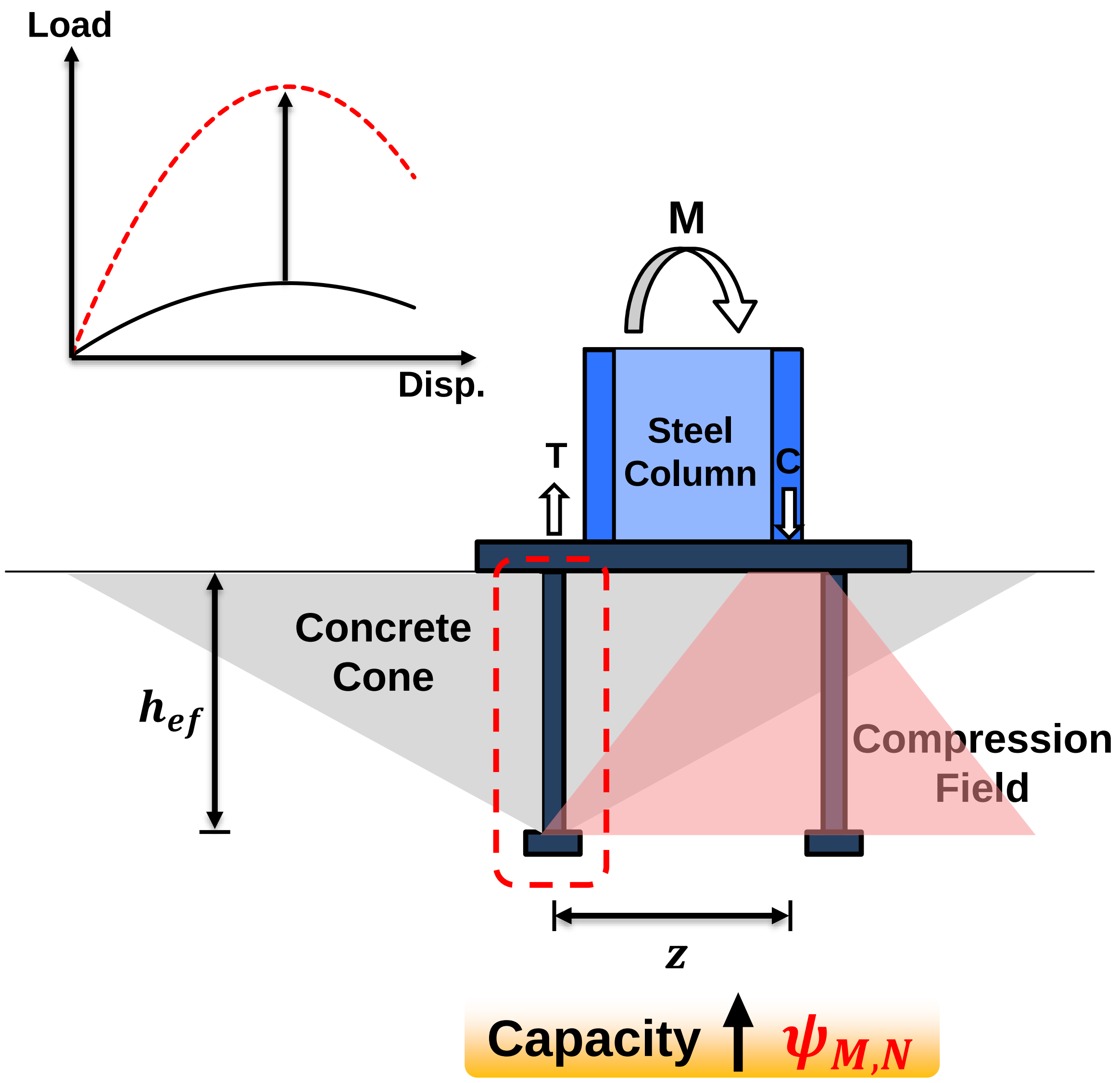
PURDUE UNIVERSITY

Basic Mechanics



- The compression from the baseplate suppresses the formation of concrete cone which leads to an increased capacity of the tension anchors

$$\psi_{M,N} = 2 - \frac{z}{1.5h_{ef}}$$

- Currently, the factor $\psi_{M,N}$ is only valid for pure concrete cone failure

EN1992-4 (2018): Eurocode 2

Upcoming ACI 318-25

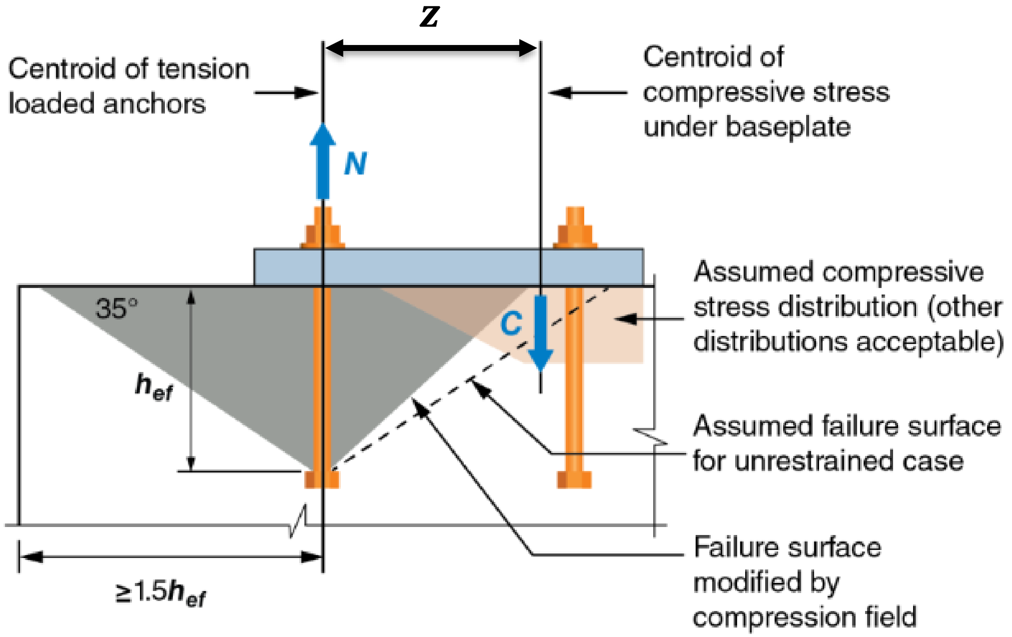


Fig. R17.6.2.7.1 — Example of anchor group subjected to an overturning moment.

17.6.2.7 *Breakout compression field factor,* $\psi_{cm,N}$

17.6.2.7.1 Modification factor for breakout compression field effect, $\psi_{cm,N}$, to be applied to all tension-loaded anchors as part of a tension-compression couple where the tension-loaded anchors are located 1.5 h_{ef} or farther from any free concrete edge and where the ratio of the resultant compression to tension forces is greater than 0.8 shall be calculated by:

$$\psi_{cm,N} = 2 - \frac{z}{1.5h_{ef}} \geq 1.0 \quad (17.6.2.7.1)$$

R17.6.2.7 *Breakout compression field factor,* $\psi_{cm,N}$

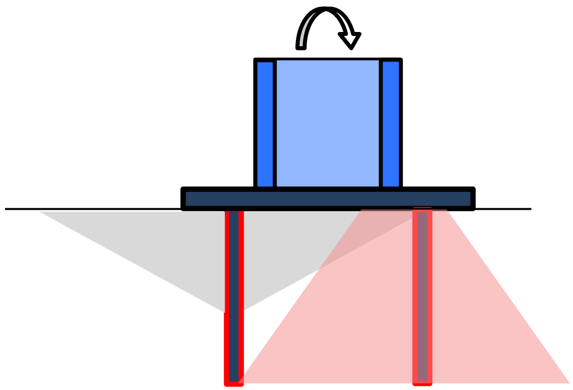
R17.6.2.7.1 For grouted baseplates or baseplates in direct contact with the concrete, where the internal lever arm, z, of the tension-compression couple resulting from a moment on an anchor plate is sufficiently small relative to the anchor embedment depth, the compression field developed in the concrete inhibits formation of the tension breakout cone associated with the tension-loaded anchor(s) as shown in Fig. R17.6.2.7.1. This effect is accounted for with $\psi_{cm,N}$.

(Eligehausen et al. 2006b) The effect of the compression field on the breakout strength of the tension-loaded anchors is neglected in cases where a) the tension and compression resultants are separated by more than 1.5 h_{ef}, b) the ratio between the resultant compression and tension forces acting on the group is reduced, e.g., by uplift on the connection, or c) the breakout strength is influenced by concrete edges.

Determination of the compression resultant location and the value of z for a given combination of applied moments and axial force should correspond to a reasonable engineering model.

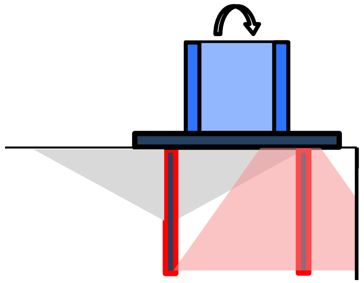
Open Questions

1. Is $\psi_{cm,N}$ valid for combined pullout & concrete cone (CC+PO) failure?

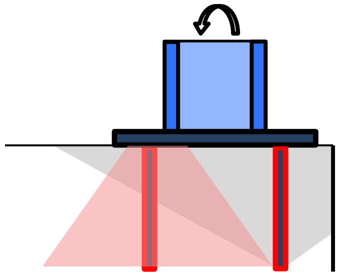


2. Is $\psi_{cm,N}$ valid for anchor group located close to an edge?

   A. In case of CC+PO failure mode

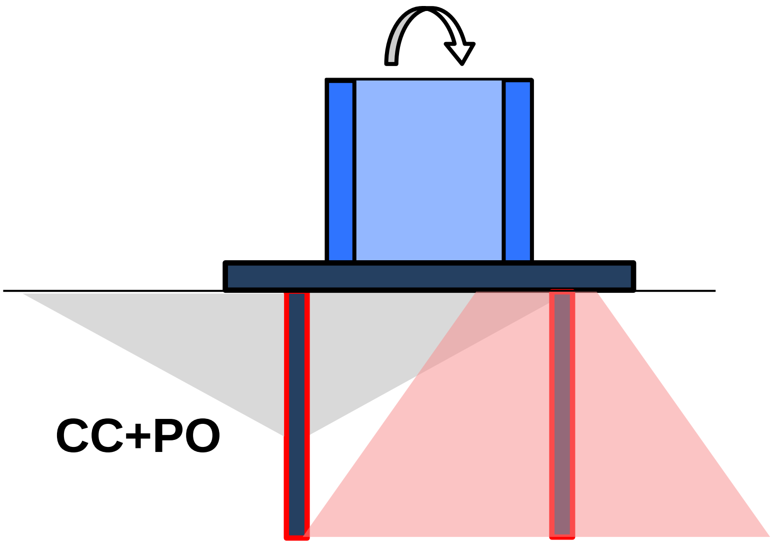


   B. In case of CC failure mode



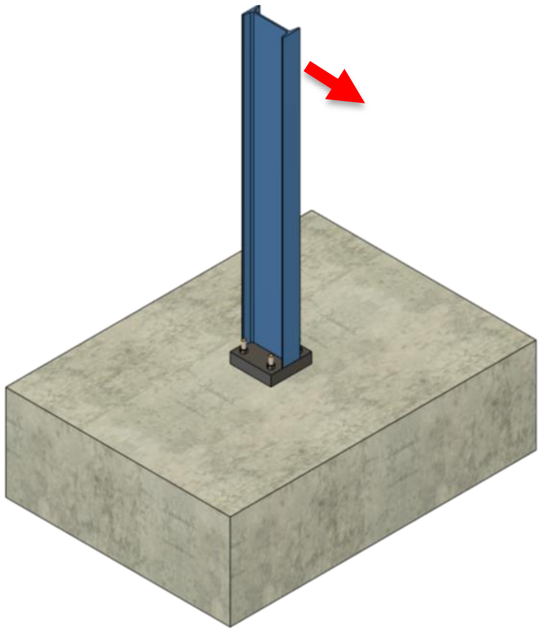
Objectives and Experimental Program

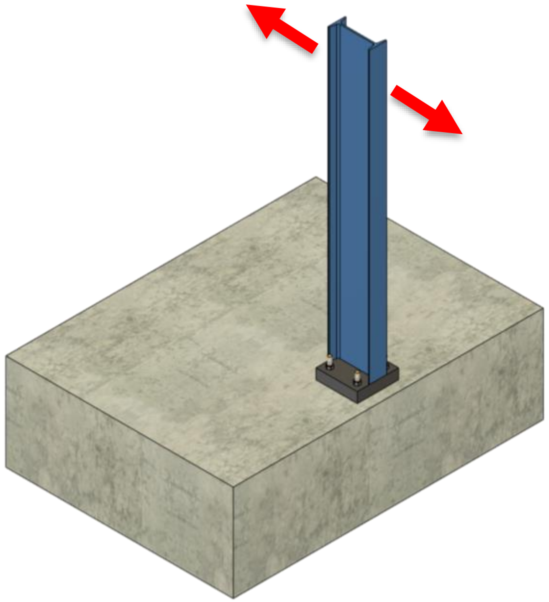
Targeted Failure Mode



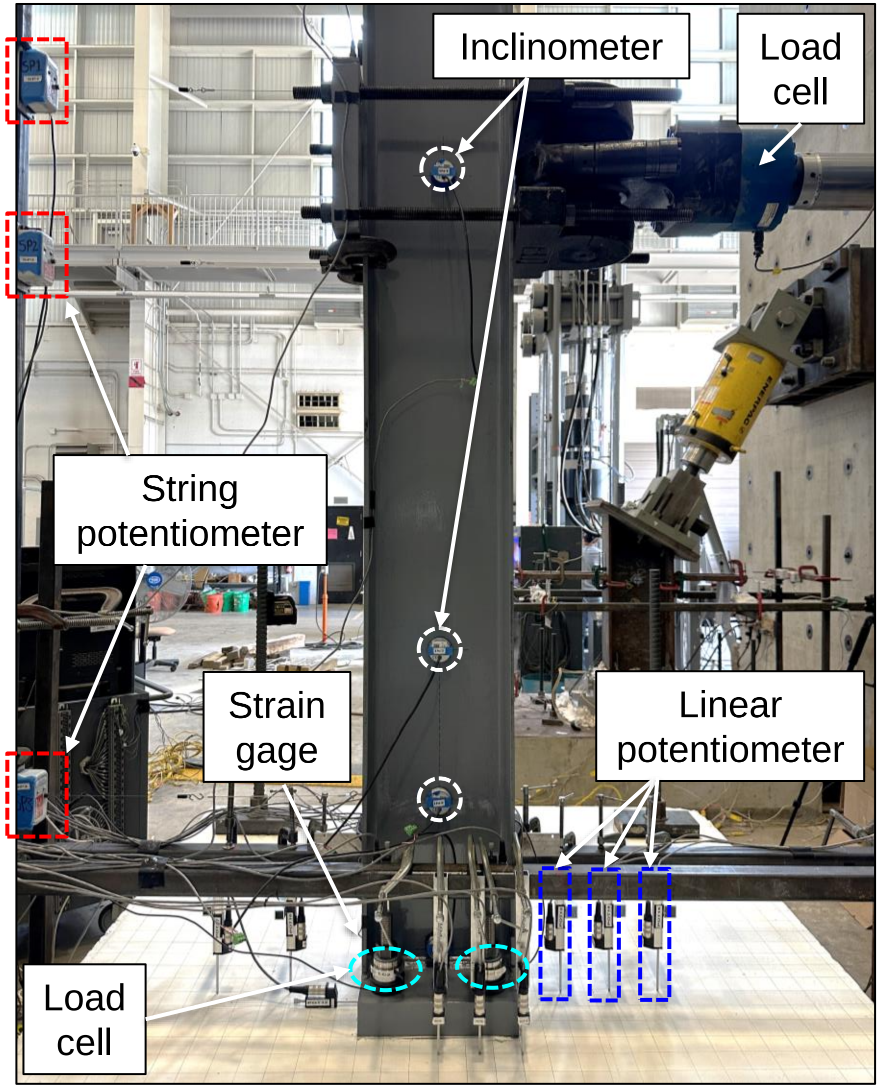
2X2 Group of Bonded Anchors
(d = 1 in., h_{ef} = 10 in., s = 8 in.)

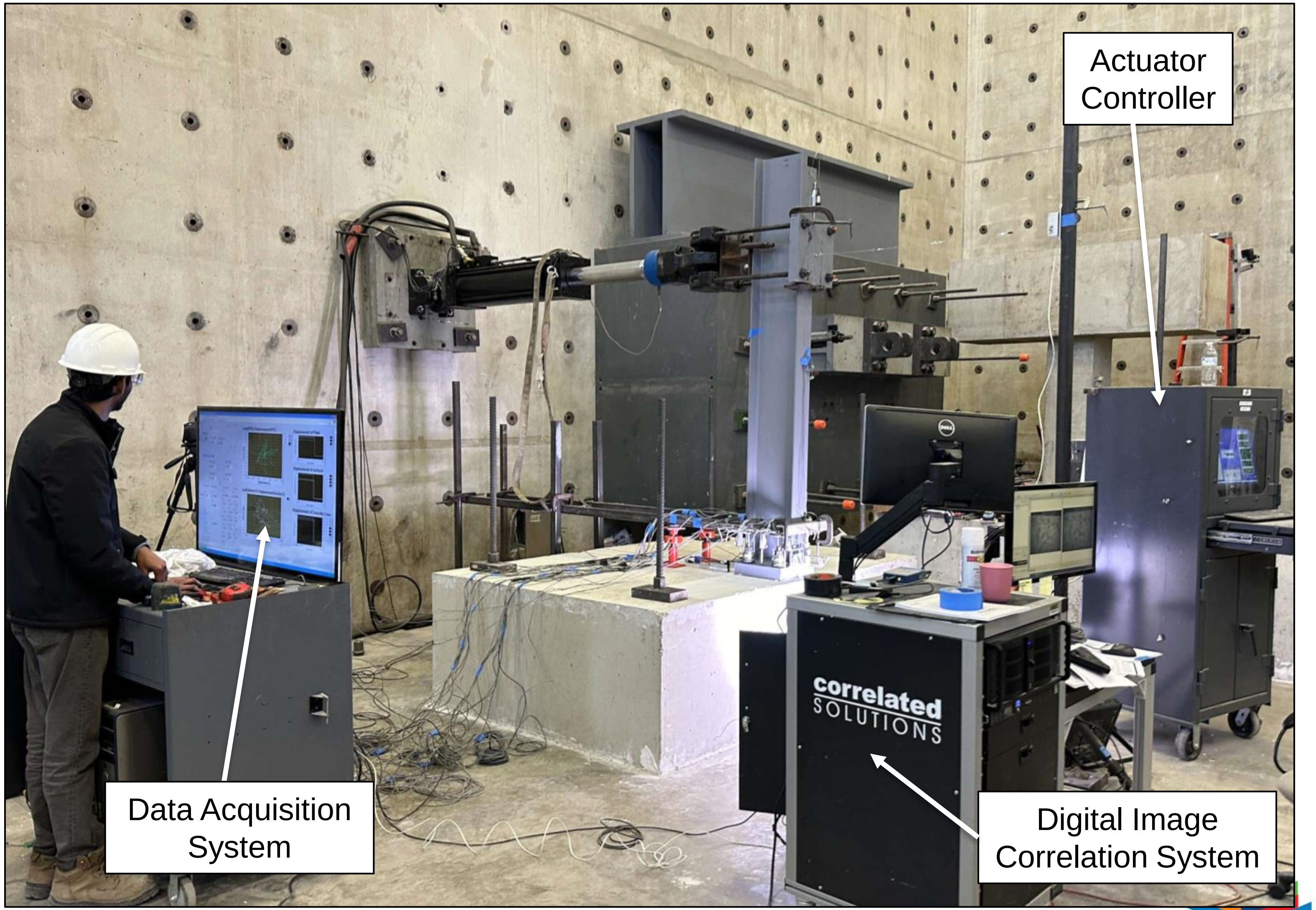
- **No Edge Influence** ($c_{a,min} > 1.5h_{ef}$)
- **Edge Influence** ($c_{a,min} = 0.5h_{ef}$)
  - **Loading Away From Edge**
  - **Loading Towards Edge**



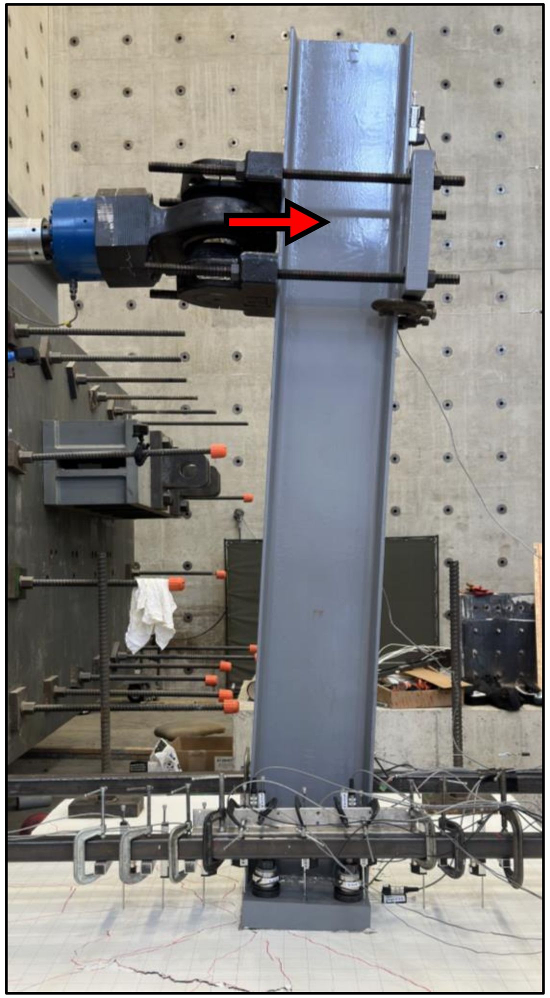


Experimental Setup

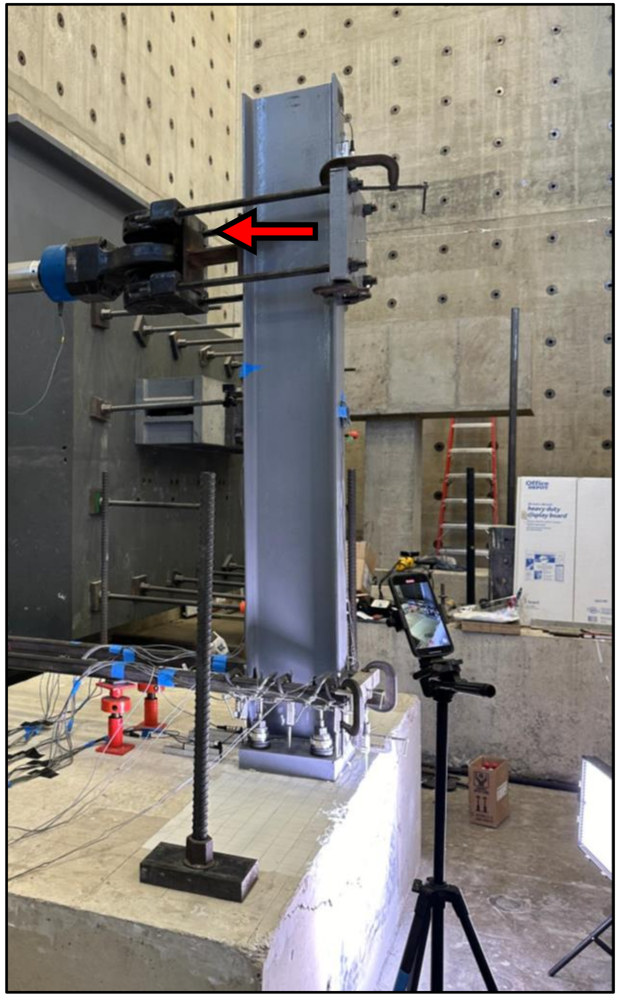




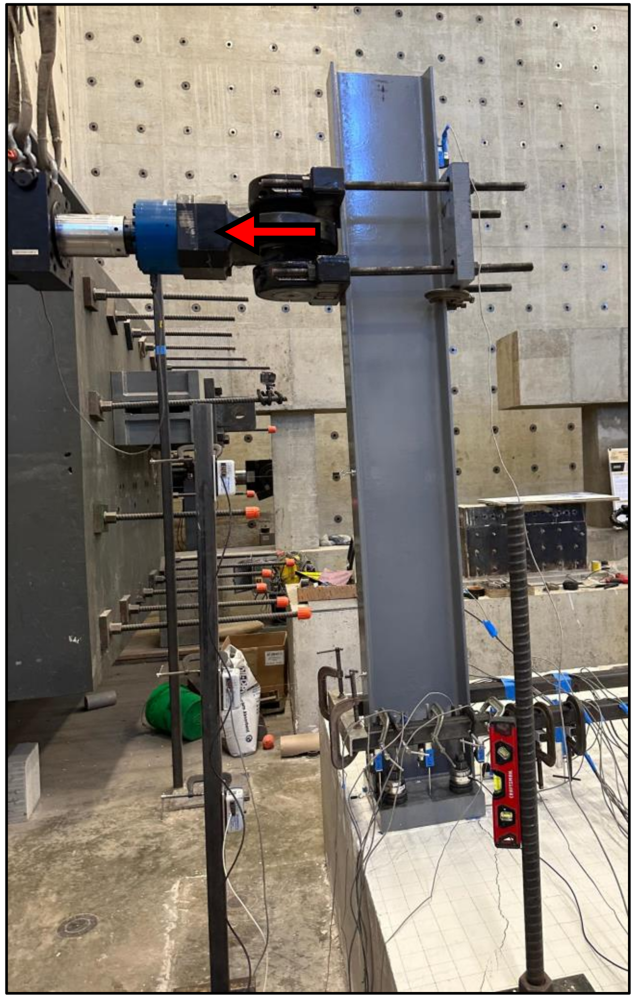
Experimental Setup



No edge influence



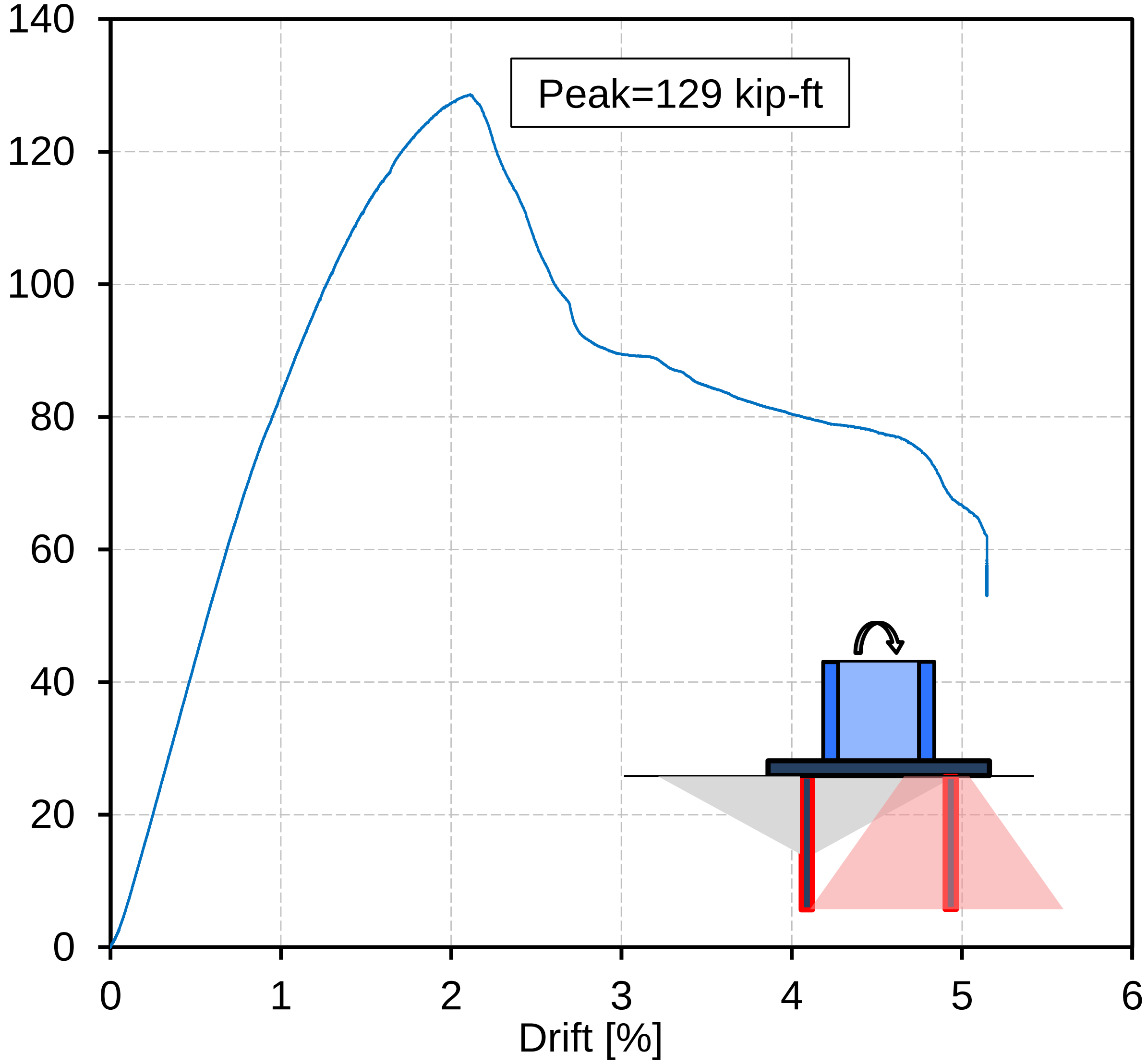
Edge influence – Loading away from edge



Edge influence – Loading towards edge

Results: No Edge Influence

Base Moment vs Drift



$$N_{sa} = nA_{se,N}f_{uta} = 236\ kips$$

$$N_{cbg} = \frac{A_{Nc}}{A_{Nc0}}\psi_{ec,N}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b\,\psi_{cm,N}$$

$$2 - \frac{z}{1.5h_{ef}} = 1.4$$

$$N_b = 1.33k_c\lambda_a\sqrt{f'_c}h_{ef}^{1.5} = 55\ kips$$

$$N_{cbg} = 135\ kips$$

$$N_{ag} = \frac{A_{Na}}{A_{Na0}}\psi_{ed,Na}\psi_{cp,Na}\psi_{ec,Na}N_{ba}$$

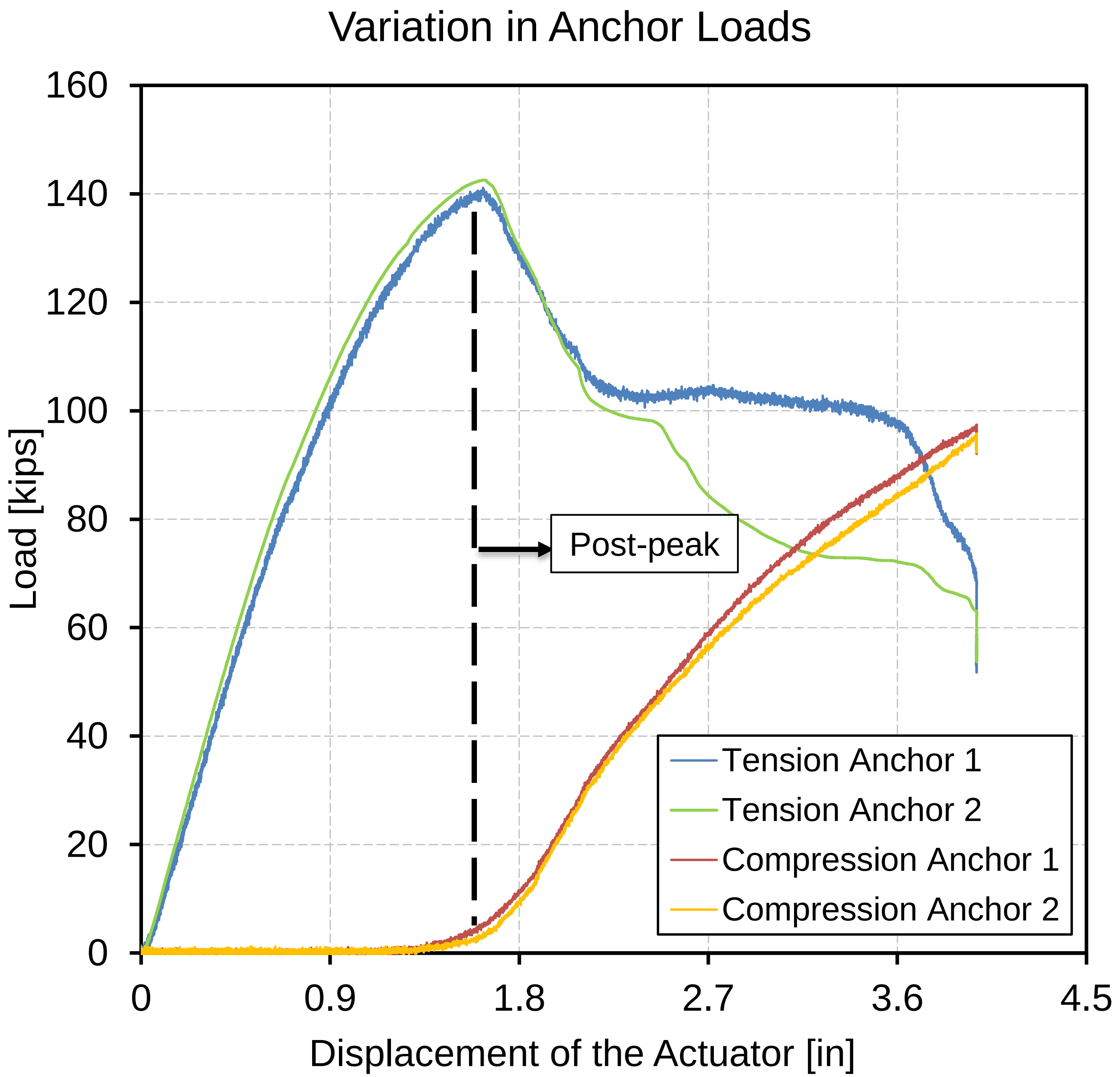
$$N_{ba} = 0.75\pi d h_{ef}\tau_b = 94\ kips$$

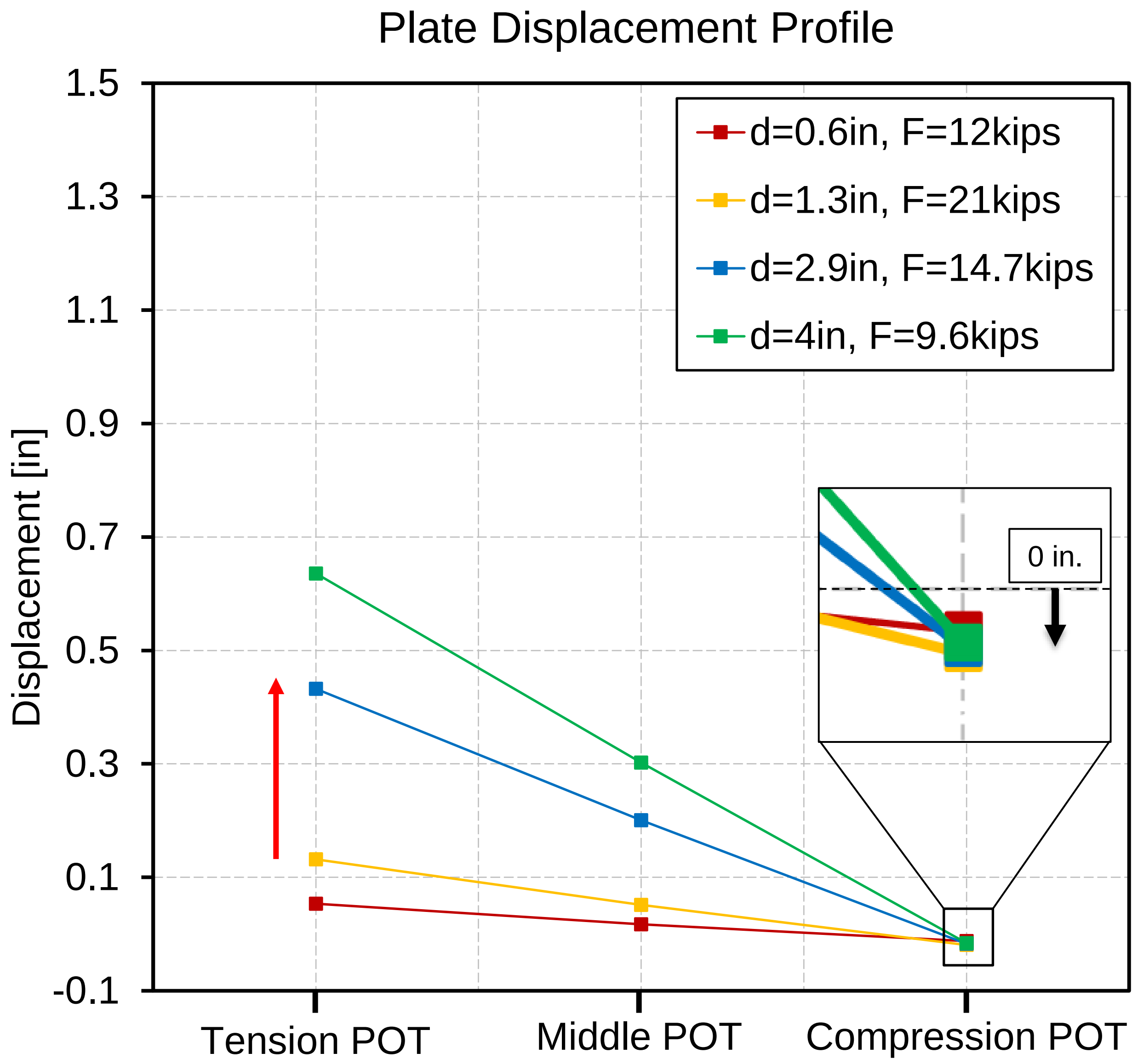
$$N_{ag} = 114\ kips$$

$$M_{ACI} = N_{ag}z = 86\ kip - ft$$

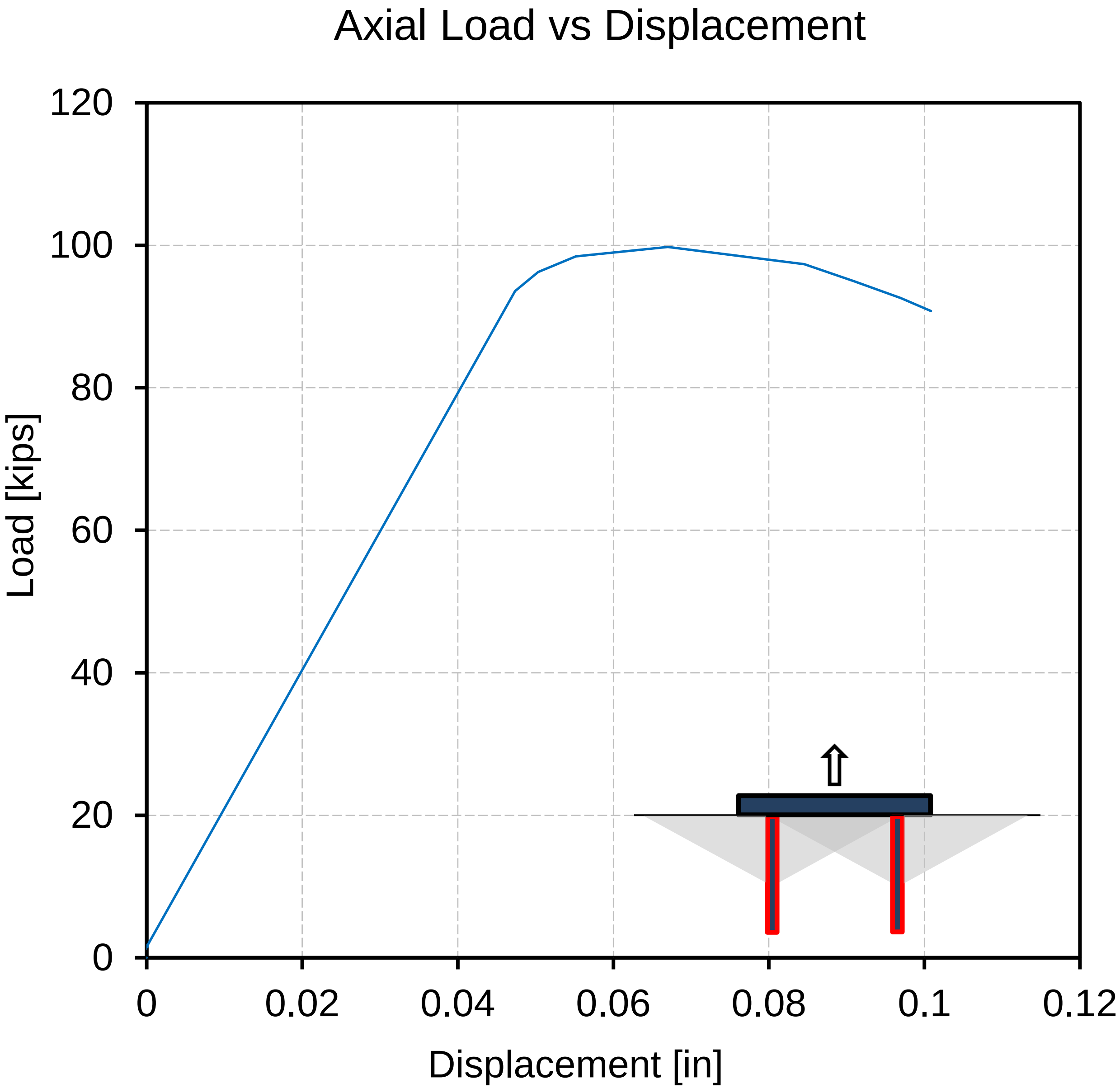
→ Pullout & Concrete Cone

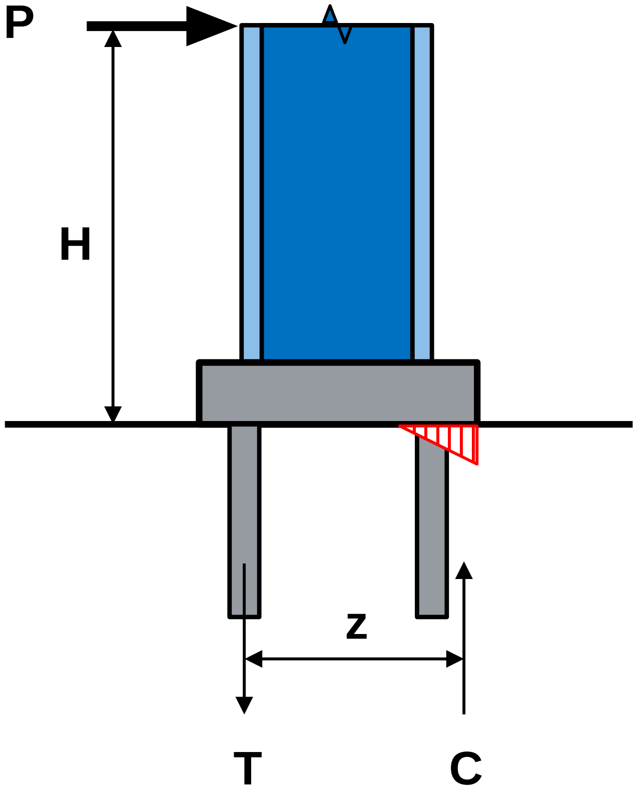
Results: No Edge Influence





Results: No Edge Influence





$$P * H = T * z$$

$$P = 23\ kips$$

$$H = 67\ in$$

$$z = 0.9 * d_{eff} = 9\ in$$

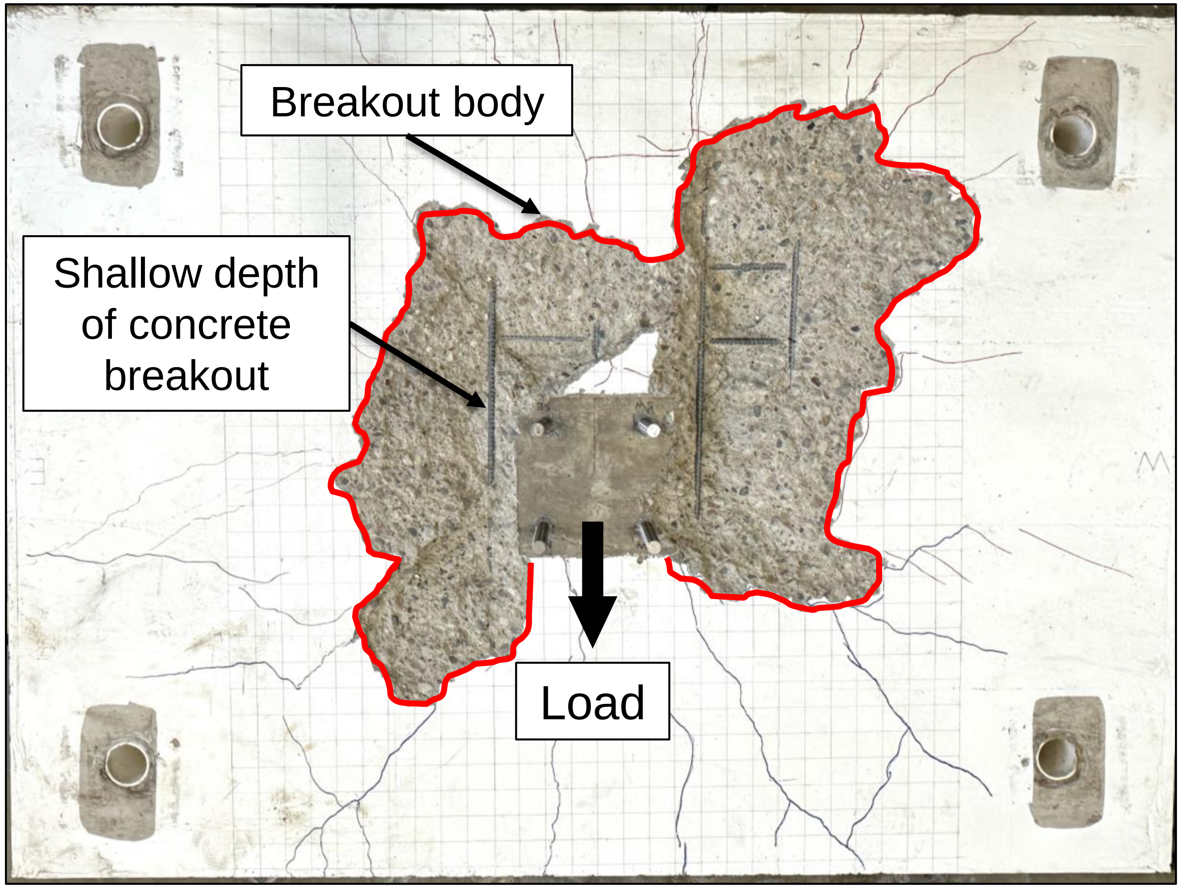
$$23 * 67 = T * 9$$

$$T = 171\ kips$$

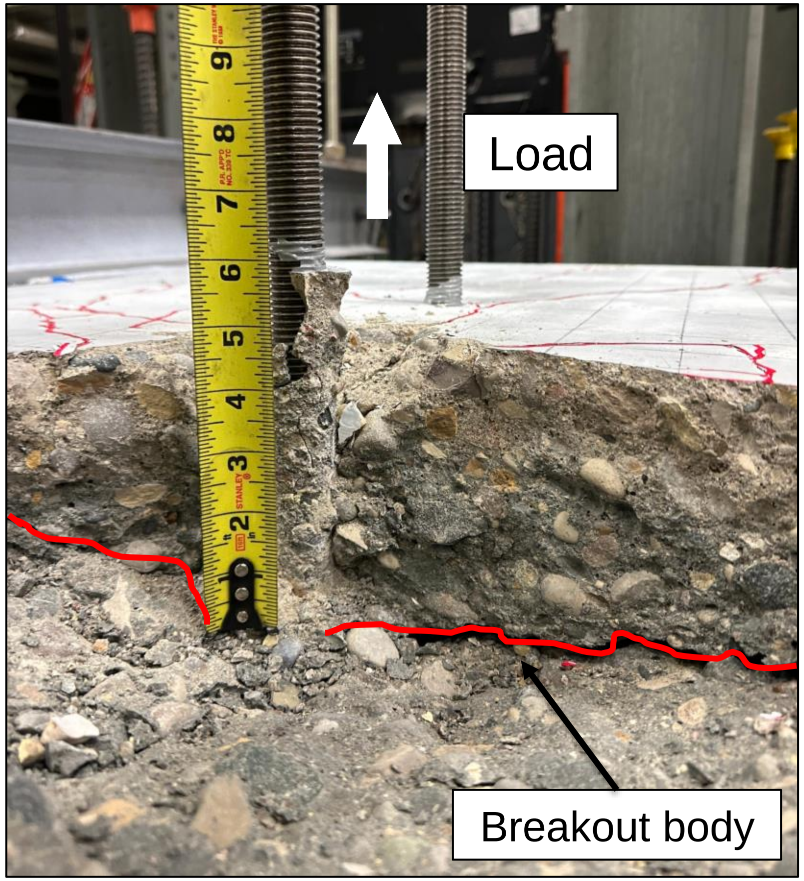
$$\psi_{cm,N} = \frac{\text{Tension force in the anchors influenced by compression}}{\text{Tension force in the anchors under pure tension}}$$

$$\psi_{cm,N} = \frac{171}{101} = 1.7$$

Crack Pattern



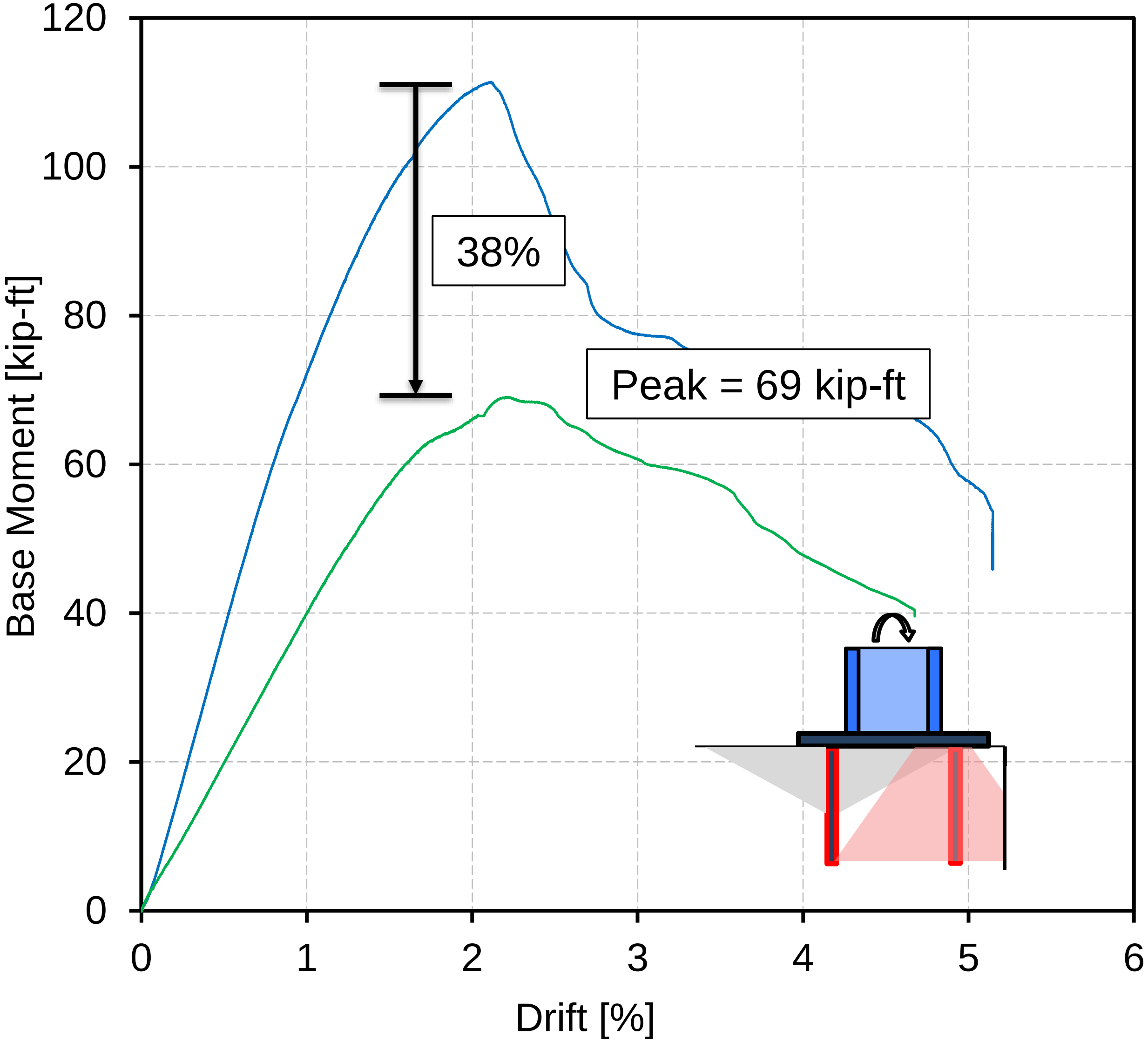
Moment Loading



Tension Loading

Pullout and Concrete Cone failure → **Positive influence of baseplate compression applicable in CC+PO**

Results: Edge Influence, Loading Towards Edge



$$N_{sa} = nA_{se,N}f_{uta} = 236\ kips$$

$$N_{cbg} = \frac{A_{Nc}}{A_{Nc0}}\psi_{ec,N}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b\psi_{cm,N}$$

1

$$N_{cbg} = 74\ kips$$

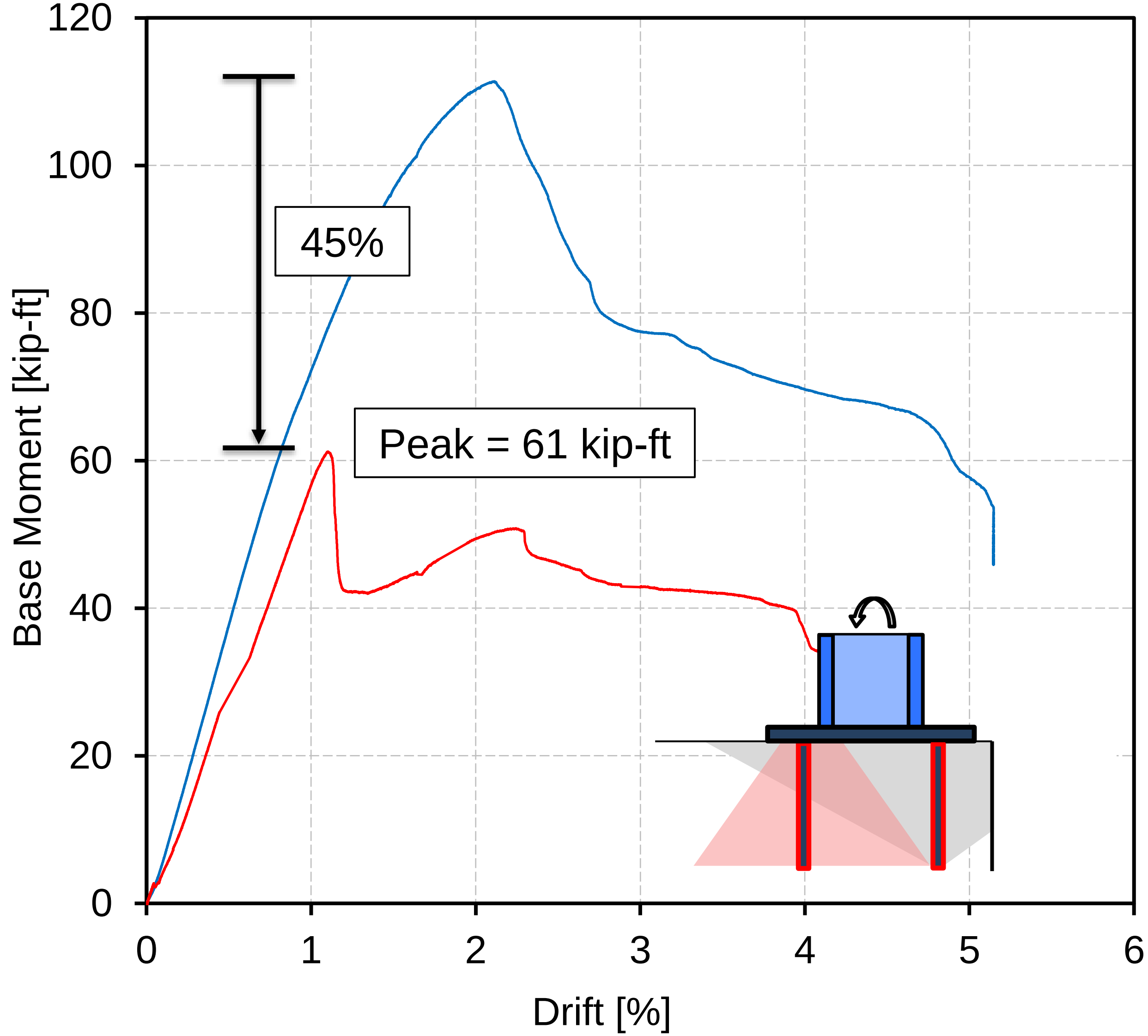
$$N_{ag} = \frac{A_{Na}}{A_{Na0}}\psi_{ed,Na}\psi_{cp,Na}\psi_{ec,Na}N_{ba}$$

$$N_{ag} = 94\ kips$$ ← CC+PO

$$M_{ACI} = N_{ag}z = 56\ kip-ft$$ → $\psi_{cm,N} = 1.38$

Results: Edge Influence, Loading Away From Edge

Normalized Base Moment vs Drift



$$N_{sa} = nA_{se,N}f_{uta} = 236\ kips$$

$$N_{cbg} = \frac{A_{Nc}}{A_{Nc0}}\psi_{ec,N}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b\,\psi_{cm,N}$$

1

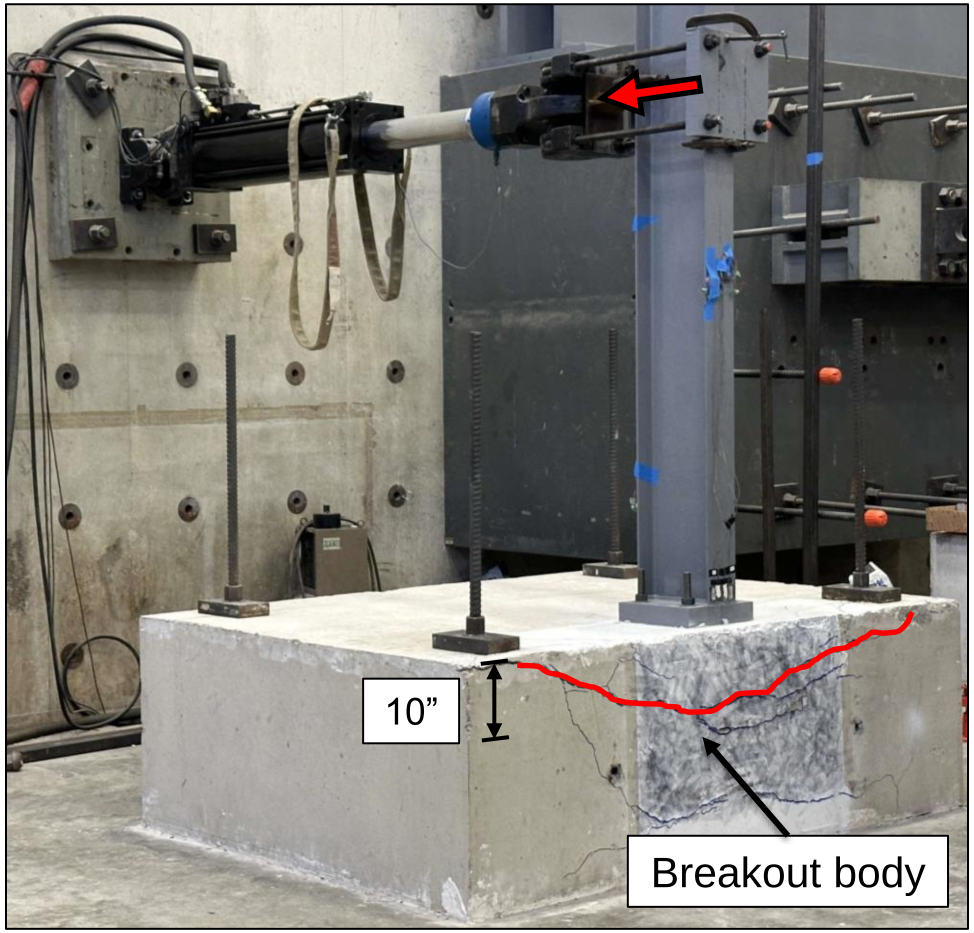
$$N_{cbg} = 44\ kips$$ ← CC

$$N_{ag} = \frac{A_{Na}}{A_{Na0}}\psi_{ed,Na}\psi_{cp,Na}\psi_{ec,Na}N_{ba}$$

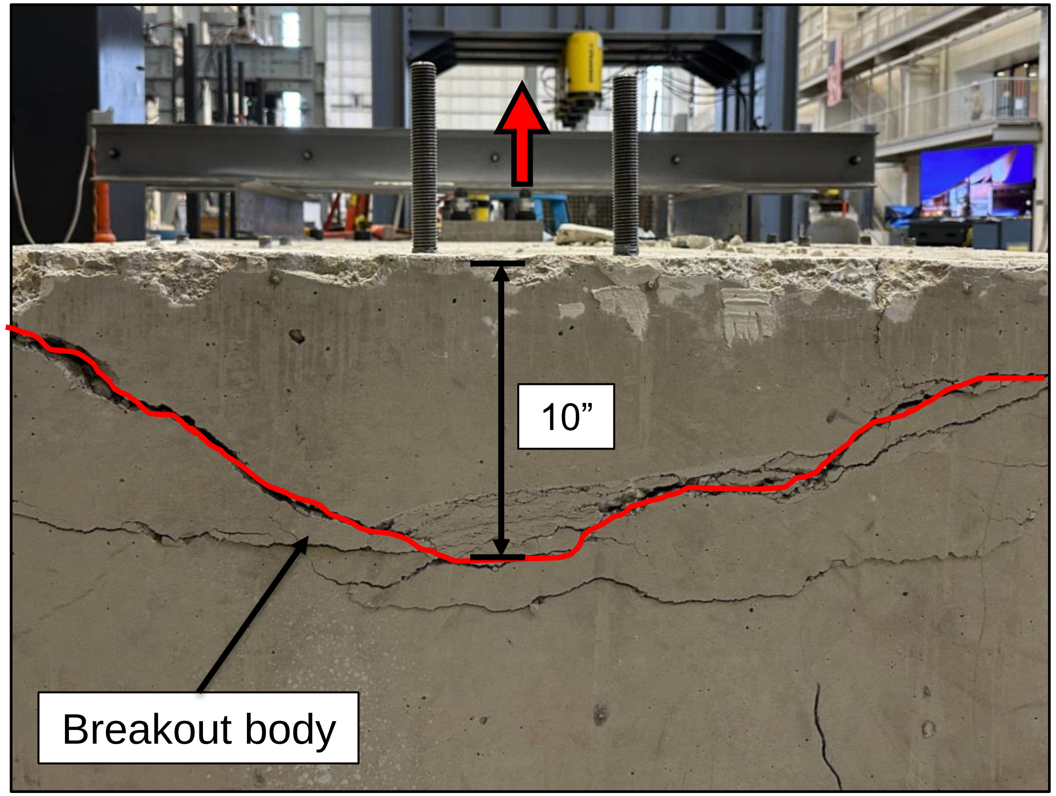
$$N_{ag} = 61\ kips$$

$$M_{ACI} = N_{cbg}z = 33\ kip-ft$$ → $$\psi_{cm,N} = 1.83$$

Crack Pattern



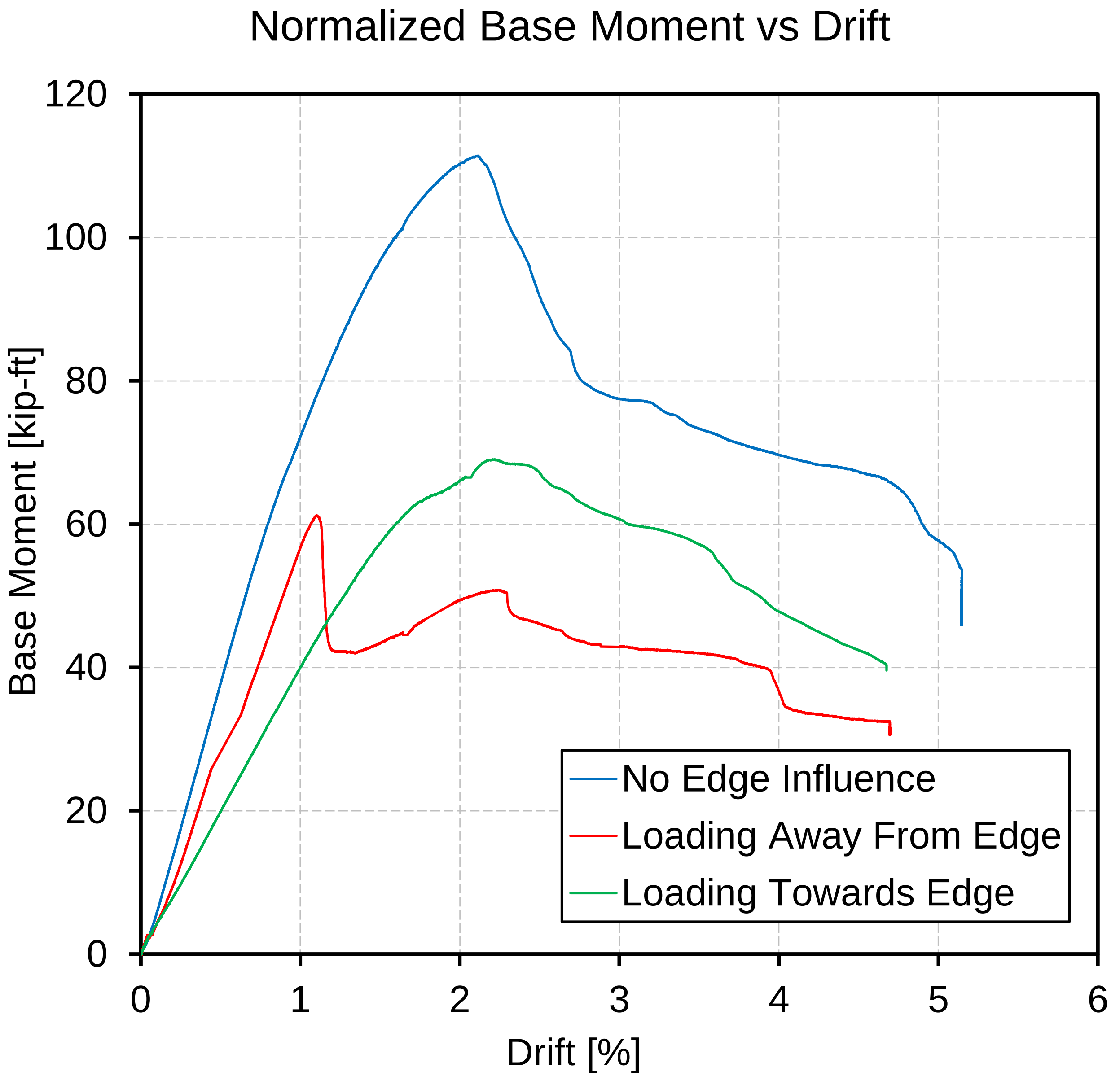
Moment Loading



Tension Loading

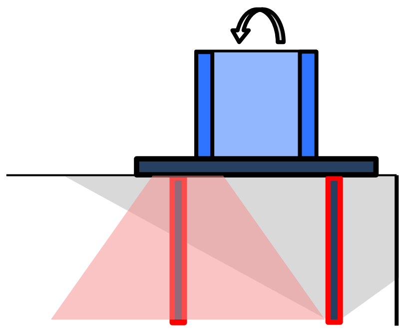
Concrete Cone failure → **Positive influence of baseplate compression applicable for $c_{a,min} < 1.5h_{ef}$**

Comparison of Experimental Results



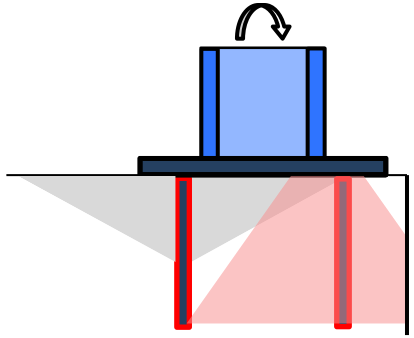
Loading away from the edge:

- Concrete available for breakout ↓
- Positive influence of compression ↑

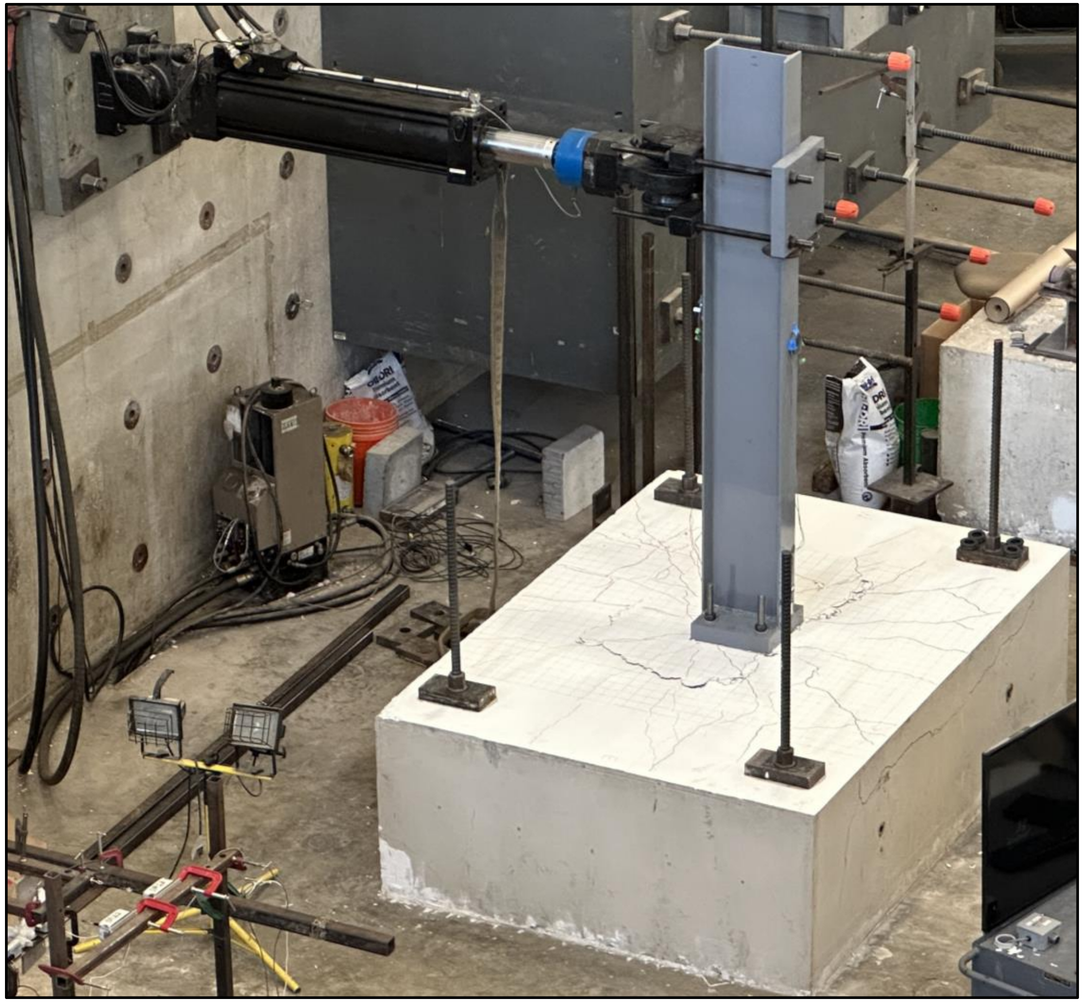


Loading towards the edge:

- Concrete available for breakout ↑
- Positive influence of compression ↓



Finite Element Studies



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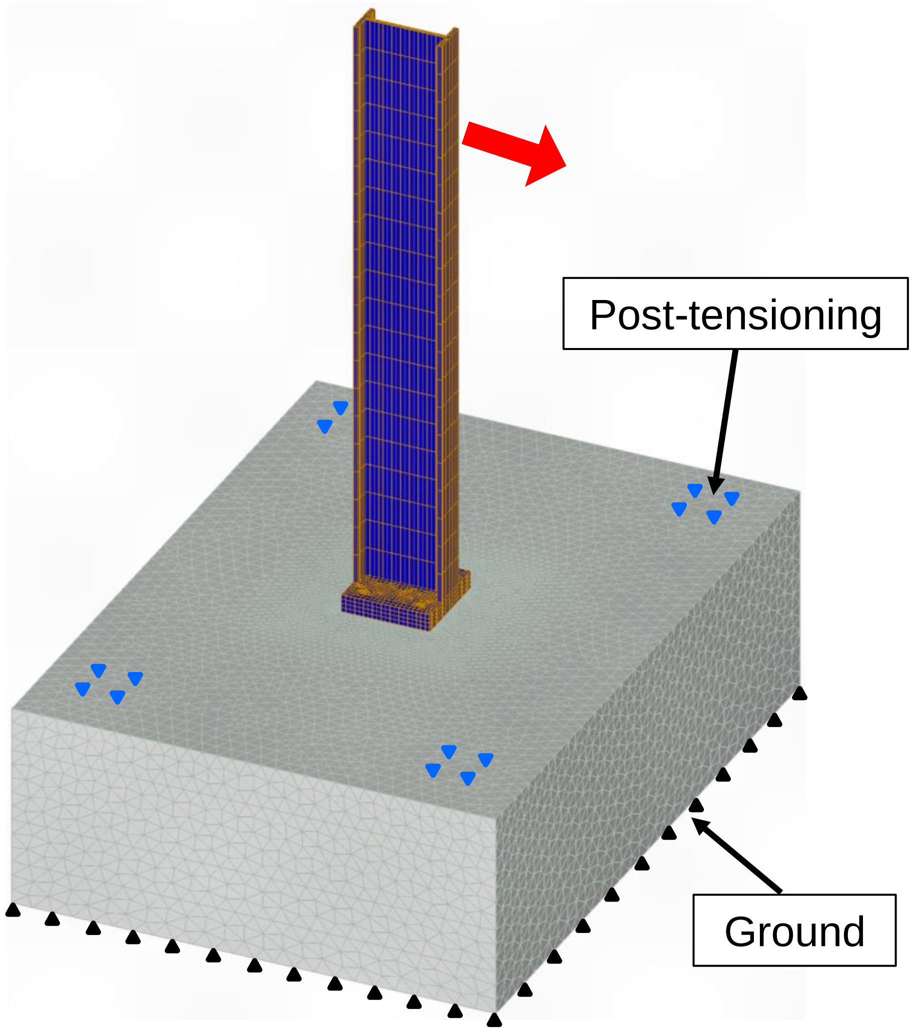
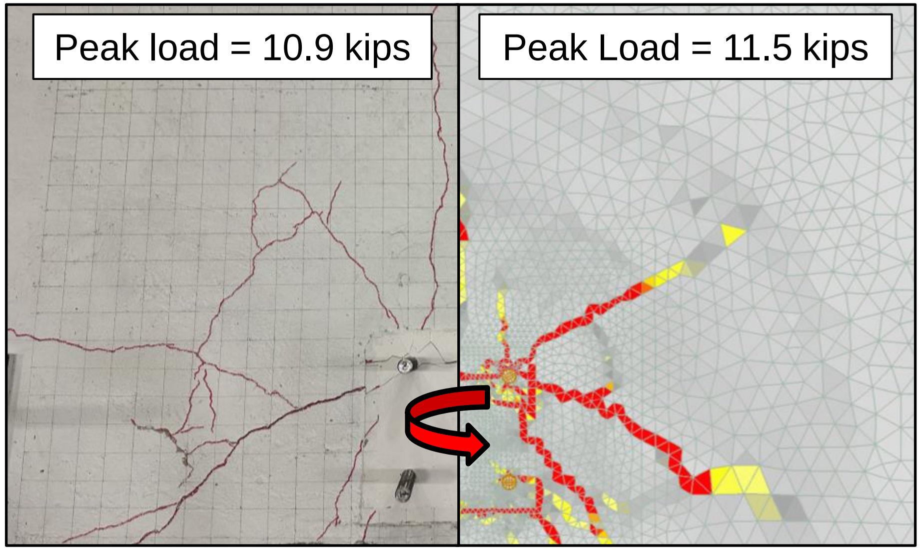


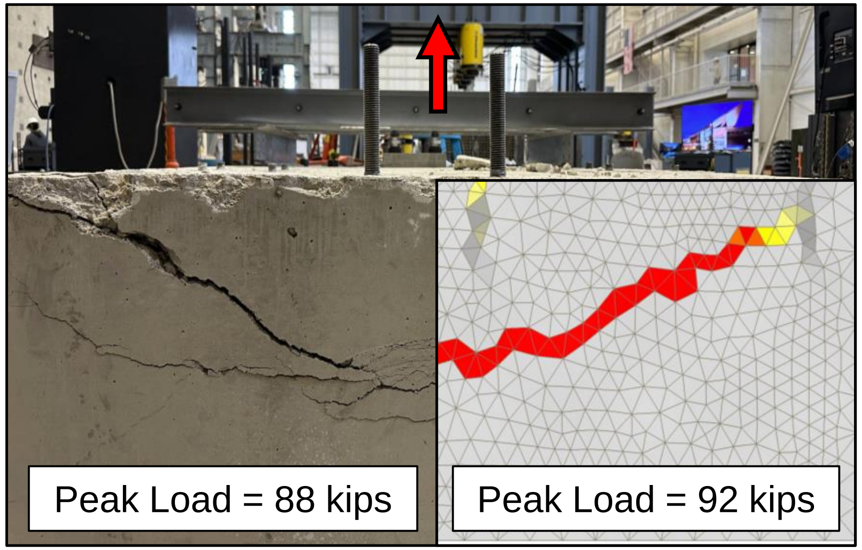
3D Nonlinear FE Analysis using MASA

Ozbolt, J., Li, Y., and Kozar, I. (2001). Microplane model for concrete with relaxed kinematic constraint. International Journal of Solids and Structures

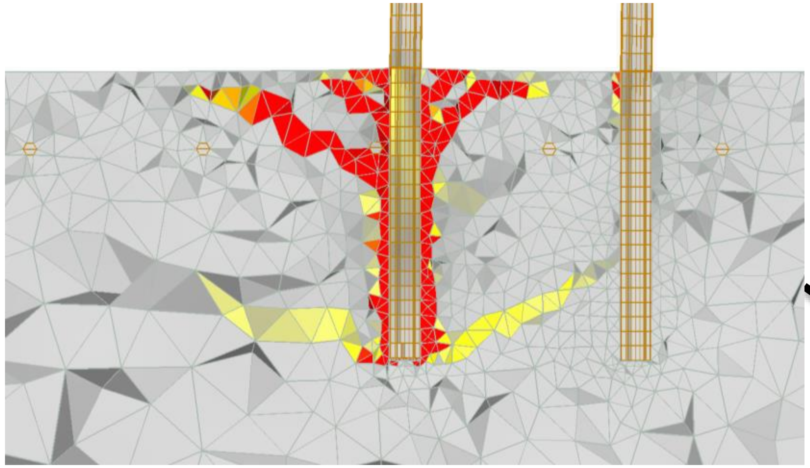
Validation of Finite Element Model



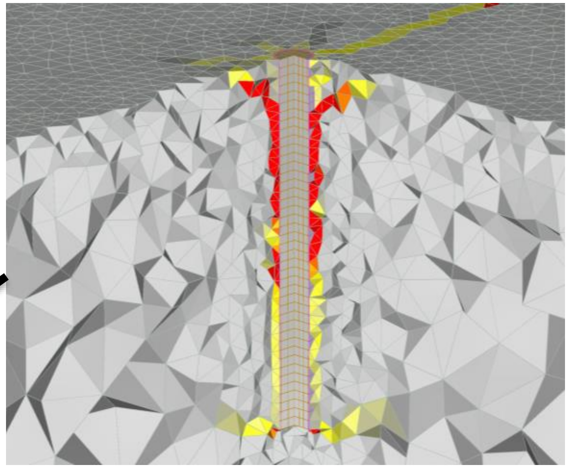
Moment Loading



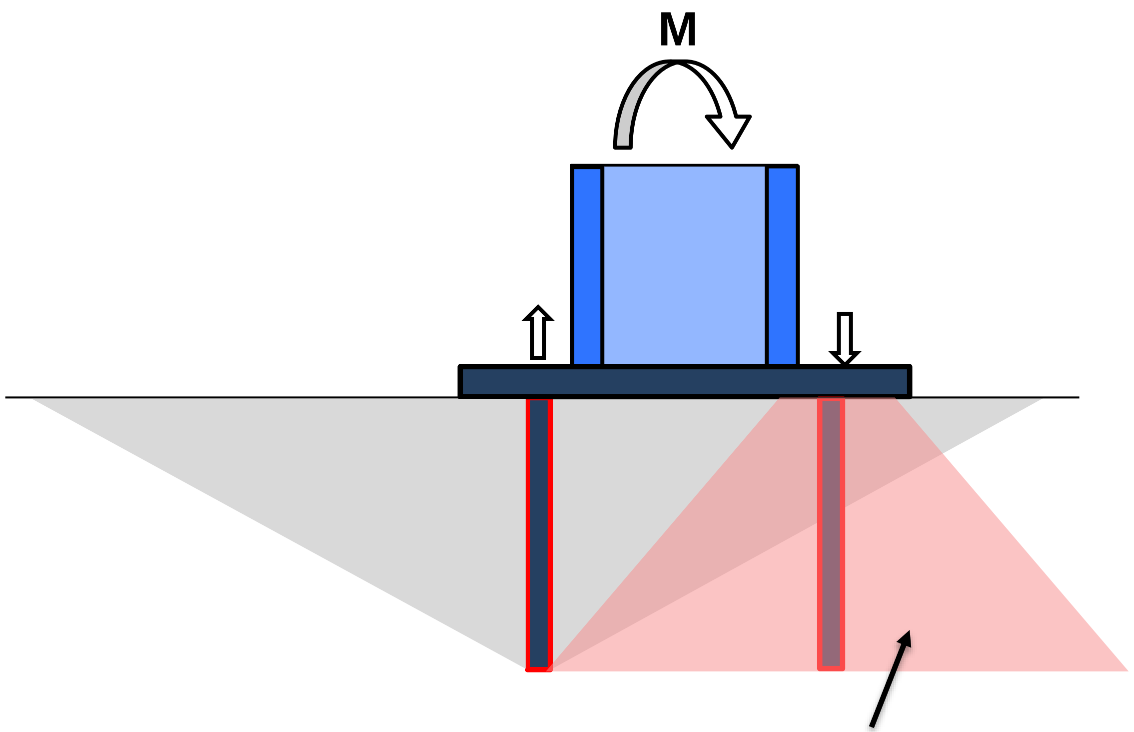
Tension Loading

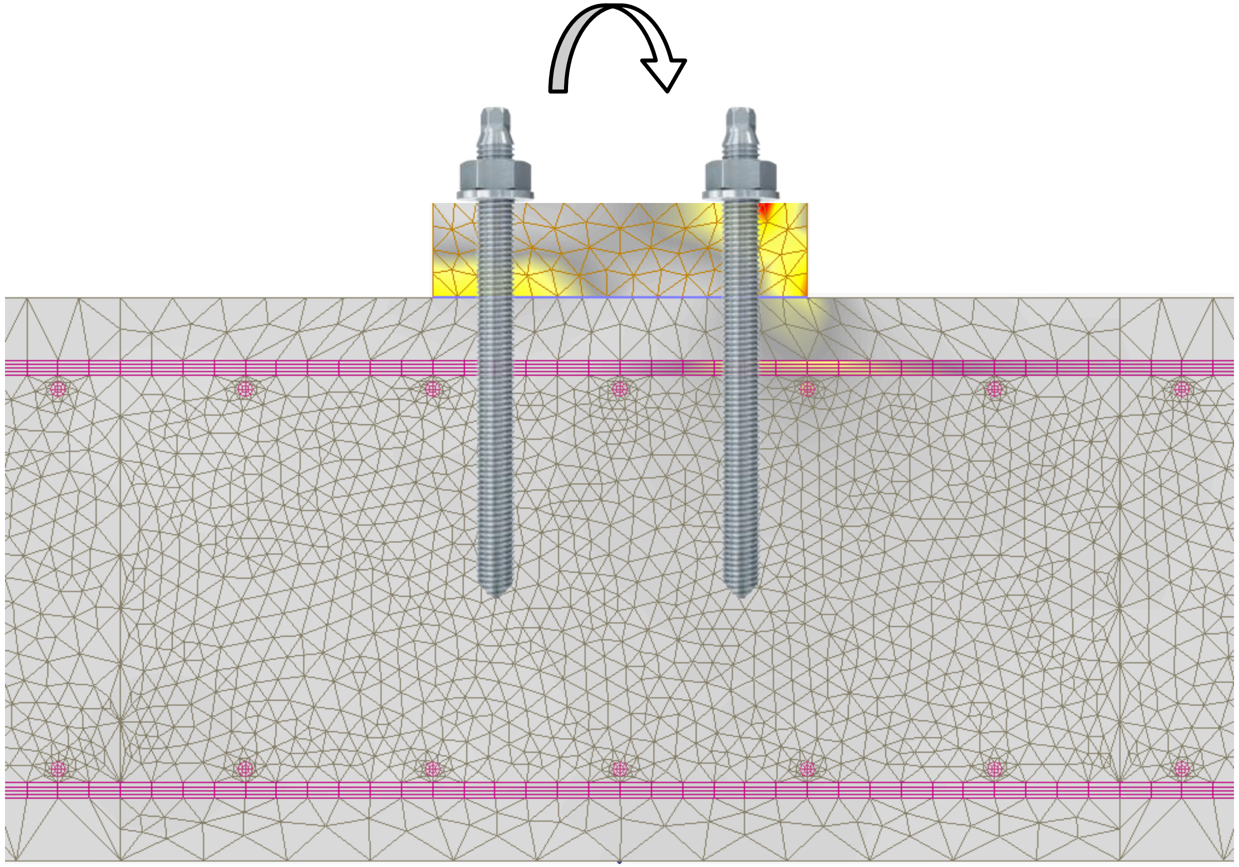


CC+PO cracks



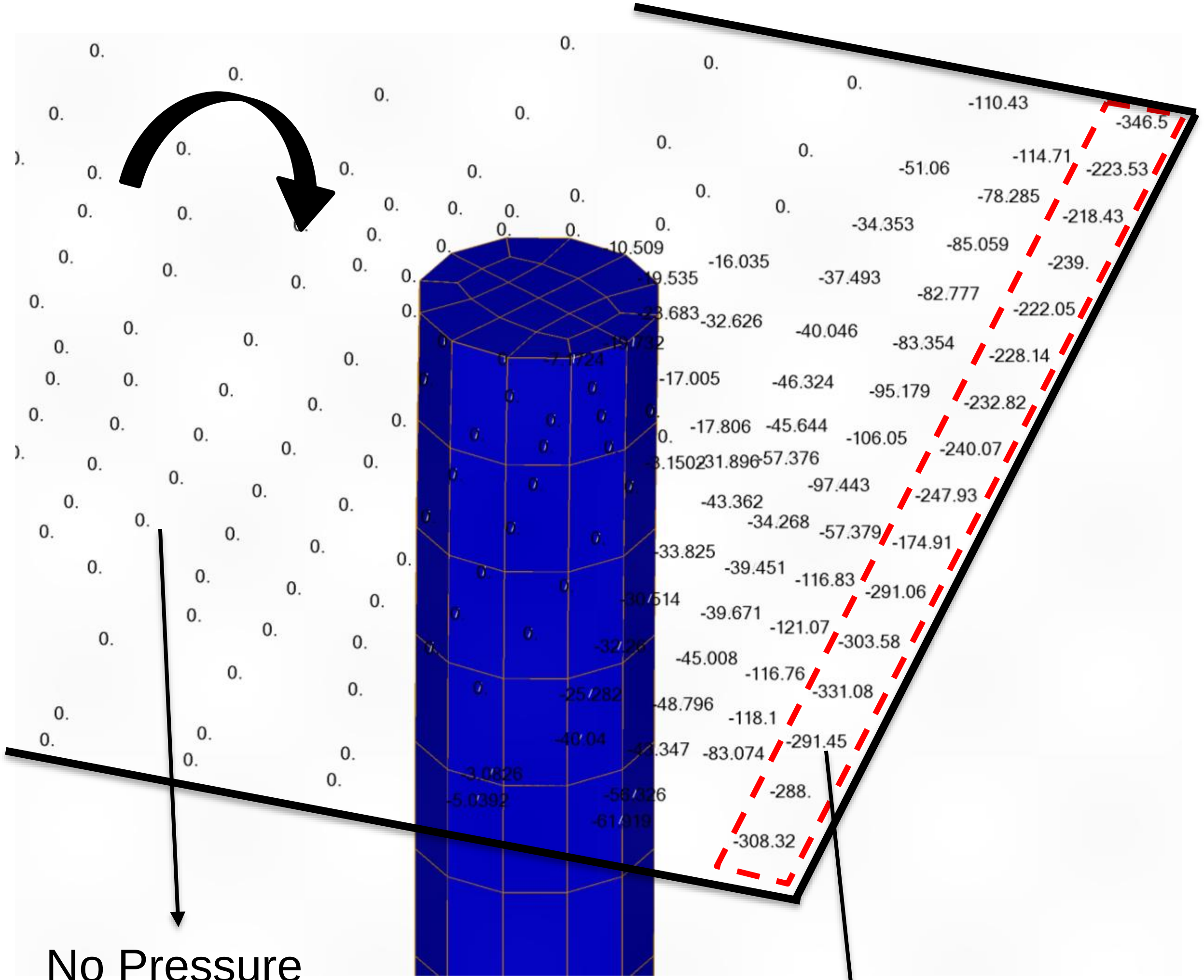
Compressive Stresses





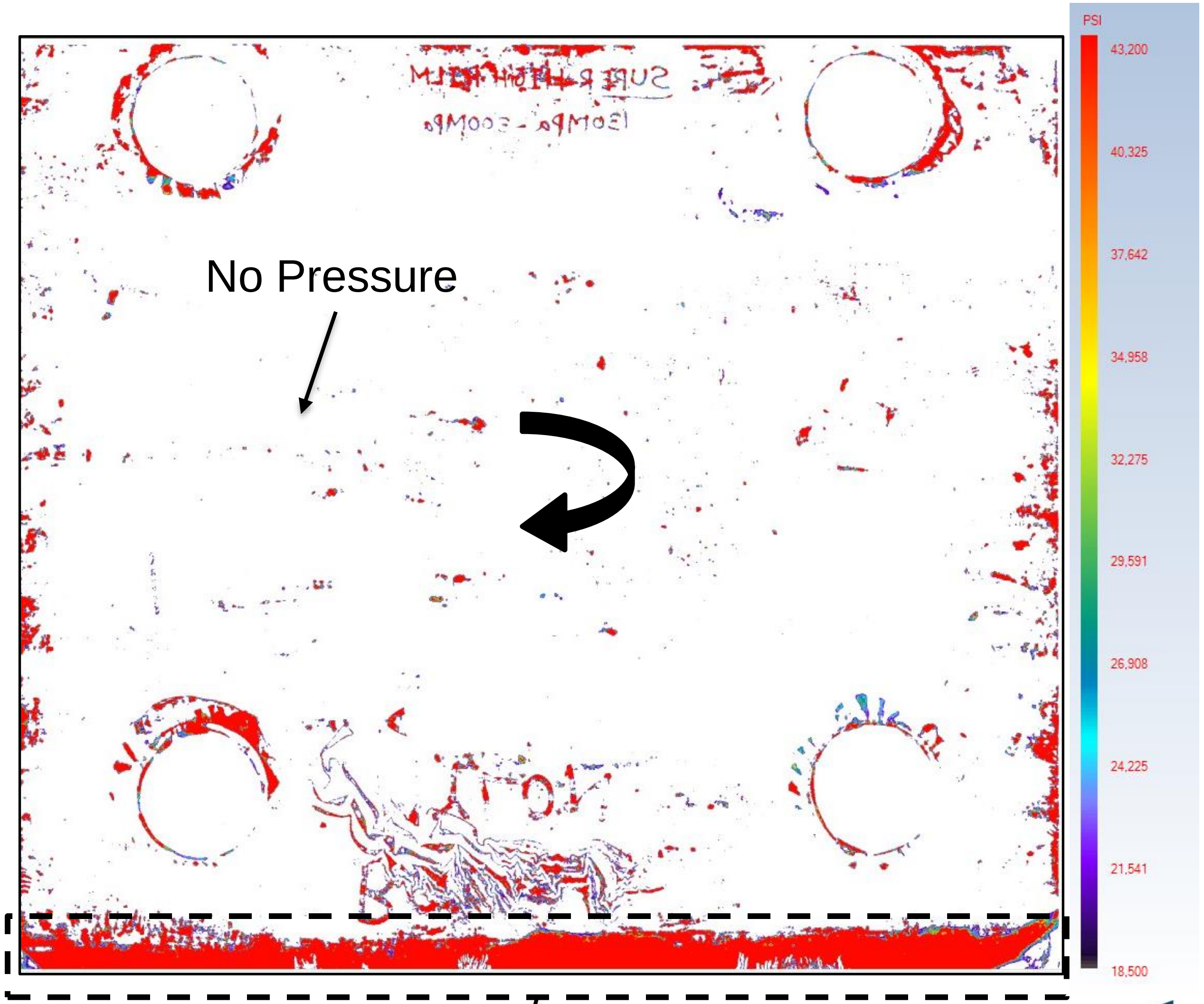
Compression stresses go from the compression point to the end of anchorage (i.e. the end of tie)

Validation of Compressive Stresses



No Pressure

Pressure ≈ 45 ksi



No Pressure

Pressure ≈ 43 ksi

Conclusions

- Positive influence of baseplate compression is valid for monotonically loaded anchor groups failing in combined pullout and concrete cone (CC+PO) failure mode
- Positive influence of baseplate compression is valid when the anchor group is located near the edge and loaded monotonically in either direction (towards the edge or away from the edge)

Thank You!

Questions/Suggestions?