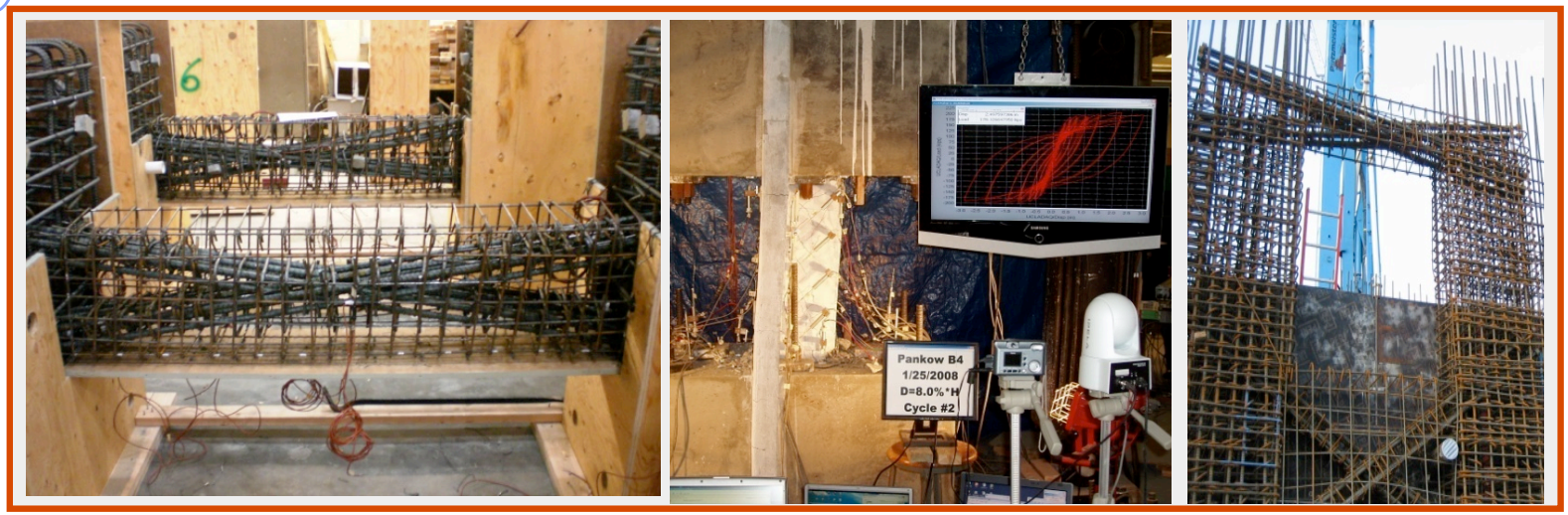
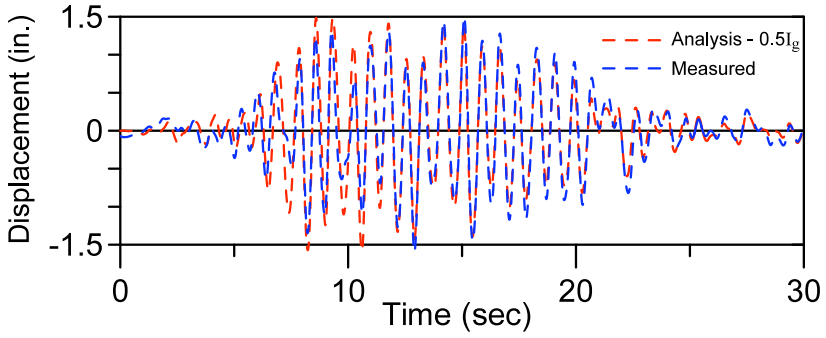
RC Core Walls – Testing and Modeling of Coupling Beams

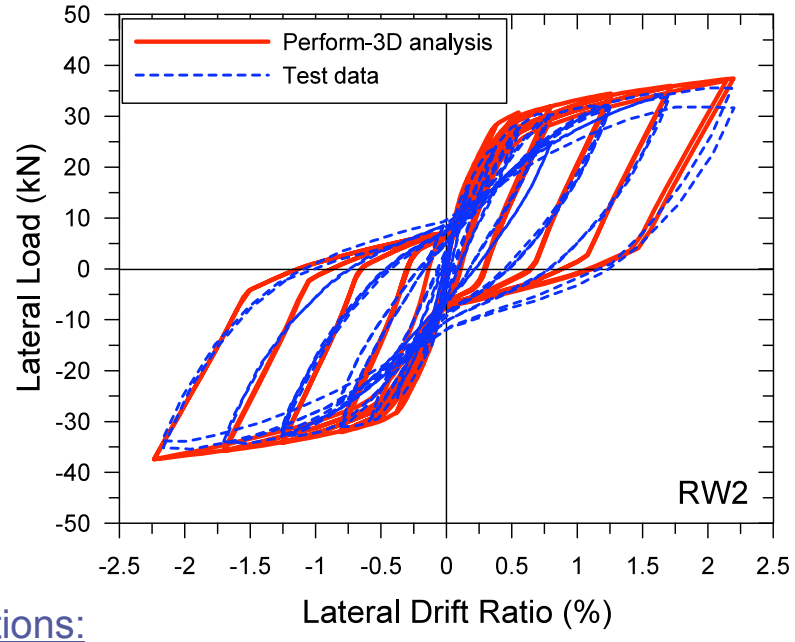


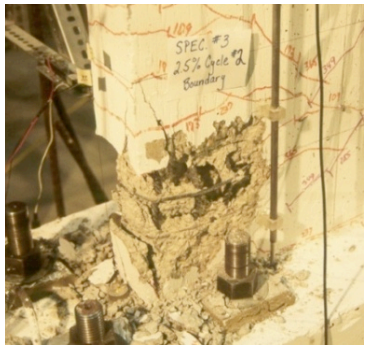
John Wallace and David Naish, UCLA
Andy Fry and Ron Klemencic, MKA

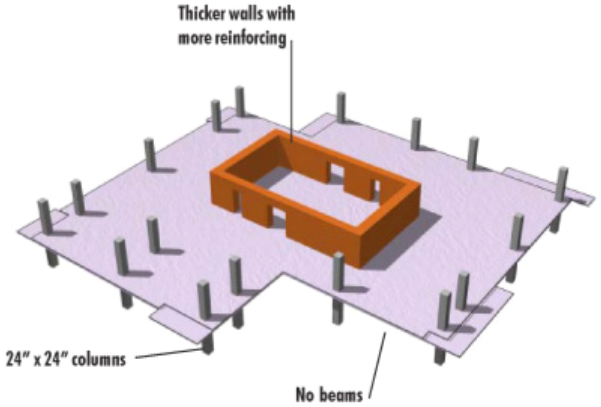
PEER Center Annual Meeting – October 2009
Tall Buildings Initiative Session

Tall Buildings – Modeling









Publications:

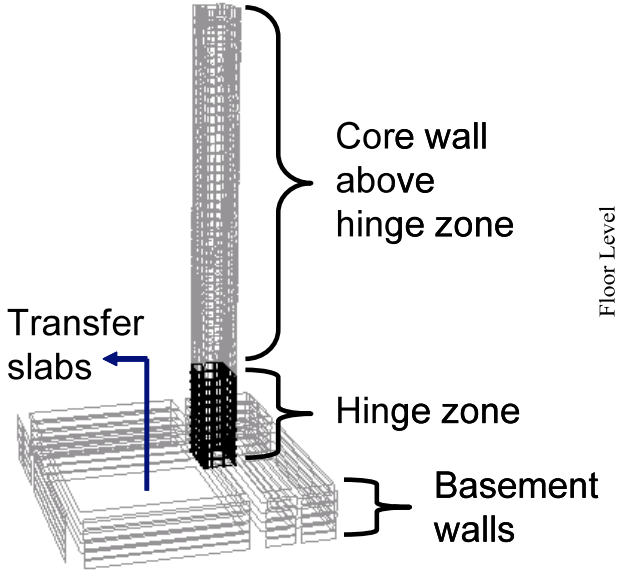
Thomsen and Wallace, ASCE JSE, April 2004

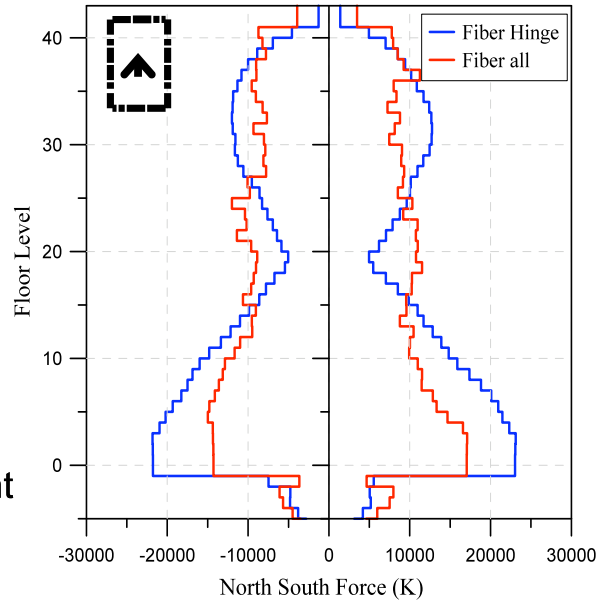
Orakcal and Wallace, ACI SJ, Oct 2004, March 2006

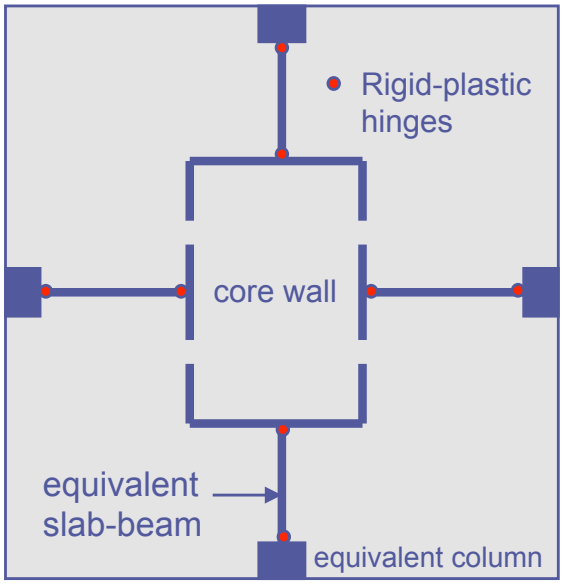
Wallace, Tall & Special Buildings, Dec. 2007

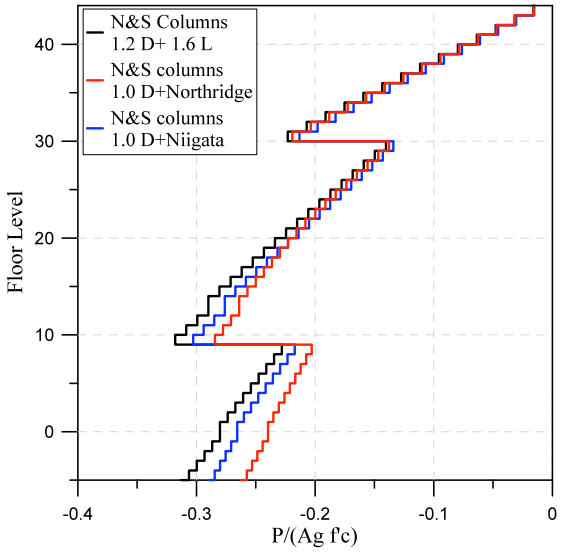
ATC 72 Report (PEER TBI)

Tall Buildings – System Modeling









Publications:

Wallace JW
Tall & Special Buildings
Dec. 2007

Salas Marisol
MS Thesis, UCLA
June 2008

ATC 72 Report
Modeling & Acceptance Criteria (PEER TBI)

Tall Buildings - Coupling Beams

- Background
- Test Program
  - Aspect ratio
  - Transverse reinforcement
  - Slab (RC and PT)
- Test Results
  - Effective stiffness
  - Deformation capacity
- Modeling
  - Shear hinge
- Conclusions

Core Wall Coupling Beams

Project Motivation

- Aspect ratio, l_n/h
  - 2.4 & 3.33
- f'c
- Residual strength
- Effect of slab
  - RC
  - PT
- Detailing
  - Ash and 1/2Ash

Project Motivation

- Aspect ratio, l_n/h
  - 2.4 & 3.33
- f'c
- Residual strength
- Effect of slab
  - RC
  - PT
- Detailing
  - Ash and 1/2Ash

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Project Motivation

- Aspect ratio, l_n/h
  - 2.4 & 3.33
- f'c
- **Residual strength**
- Effect of slab
  - RC
  - PT
- Detailing
  - Ash and 1/2Ash

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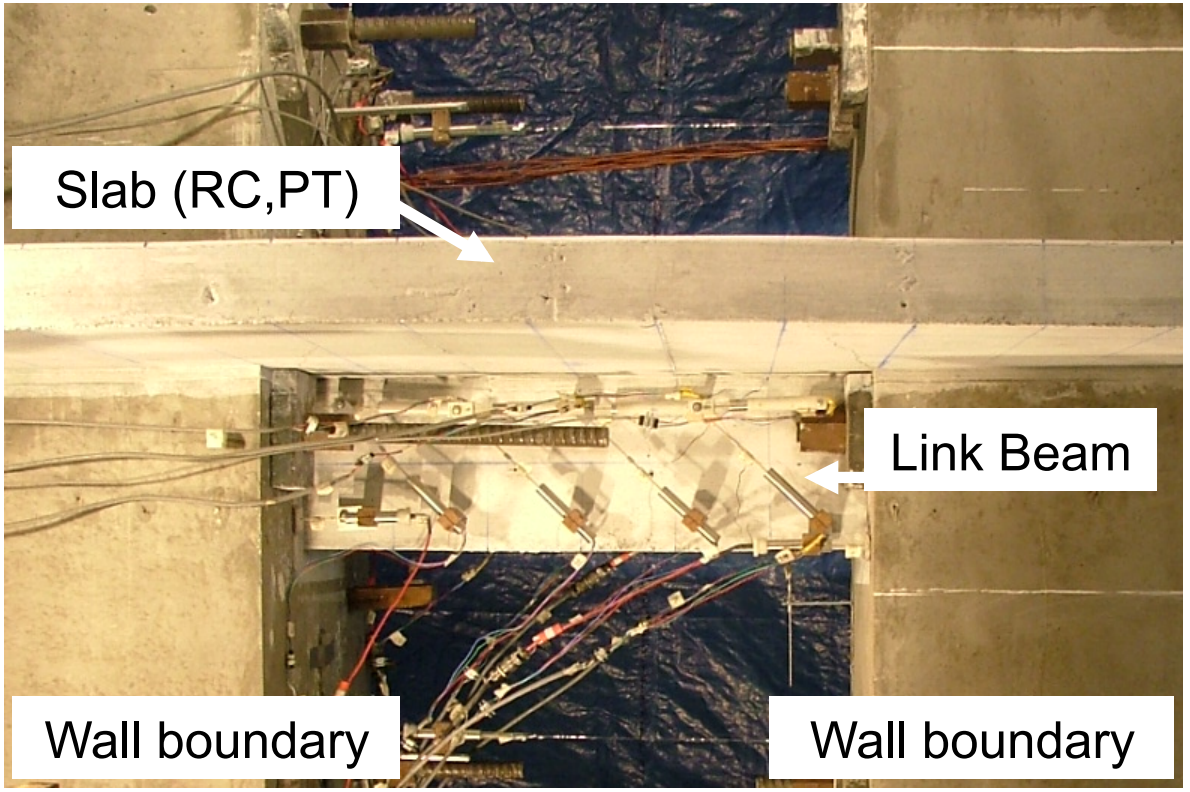
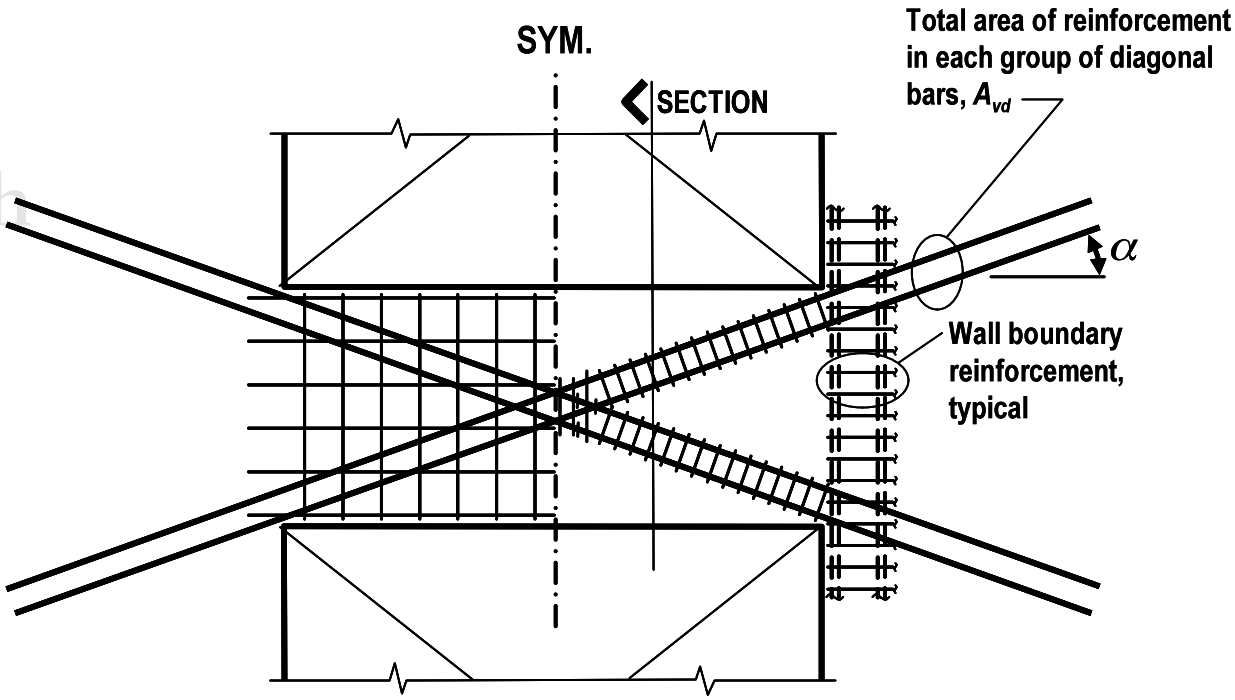
Project Motivation

- Aspect ratio, l_n/h
  - 2.4 & 3.33
- f'c
- Residual strength
- **Effect of slab**
  - **RC**
  - **PT**
- Detailing
  - Ash and 1/2Ash



Project Motivation

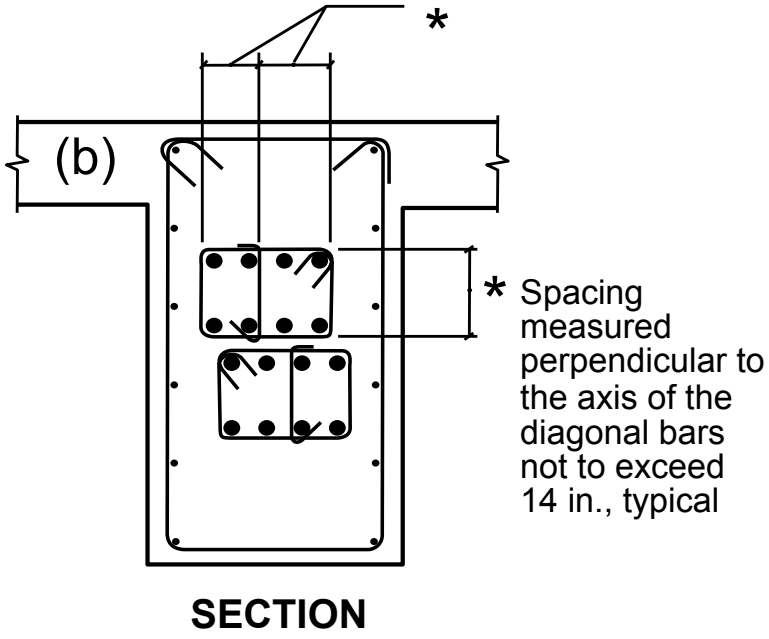
- Aspect ratio, l_n/h
  - 2.4 & 3.33
- f'_c
- Residual strength
- Effect of slab
  - RC
  - PT
- **Detailing**
  - A_{sh} and $\frac{1}{2}*A_{sh}$



ACI 318 Code Provisions

ACI 318-05 S21.7.7

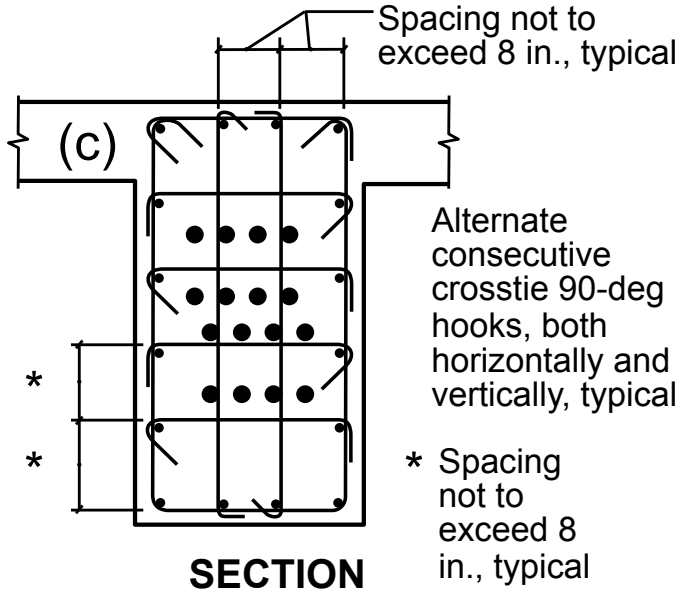
- Must have diagonal bars enclosed in transverse reinforcement.



Diagonal Confinement

ACI 318-08 S21.9.7

- Option to enclose entire beam cross-section with transverse reinforcement



Full Section Confinement

Specimen	l_n/h	α (°)	*Transverse Reinforcement*		f'_c, psi	f_y, psi	f_w, psi	*Description*
			Entire Section	*Diagonals*				
CB24F			#3 @ 3"	N.A.	6850			Full section confinement (ACI 318-08)
CB24D			#2 @ 2.5"	#3 @ 2.5"	6850			Diagonal confinement (ACI 318-05)
CB24F-RC	2.4	15.7	#3 @ 3"	N.A.	7305			Full section conf. w/ RC slab (ACI 318-08)
CB24F-PT			#3 @ 3"	N.A.	7242	70000	90000	Full section conf. w/ PT slab (ACI 318-08)
CB24F-1/2-PT			#3 @ 6"	N.A.	6990			Full section conf. (reduced) w/ PT slab (ACI 318-08)
CB33F	3.33	12.3	#3 @ 3"	N.A.	6850			Full section confinement (ACI 318-08)
CB33D			#2 @ 2.5"	#3 @ 2.5"	6850			Diagonal confinement (ACI 318-05)

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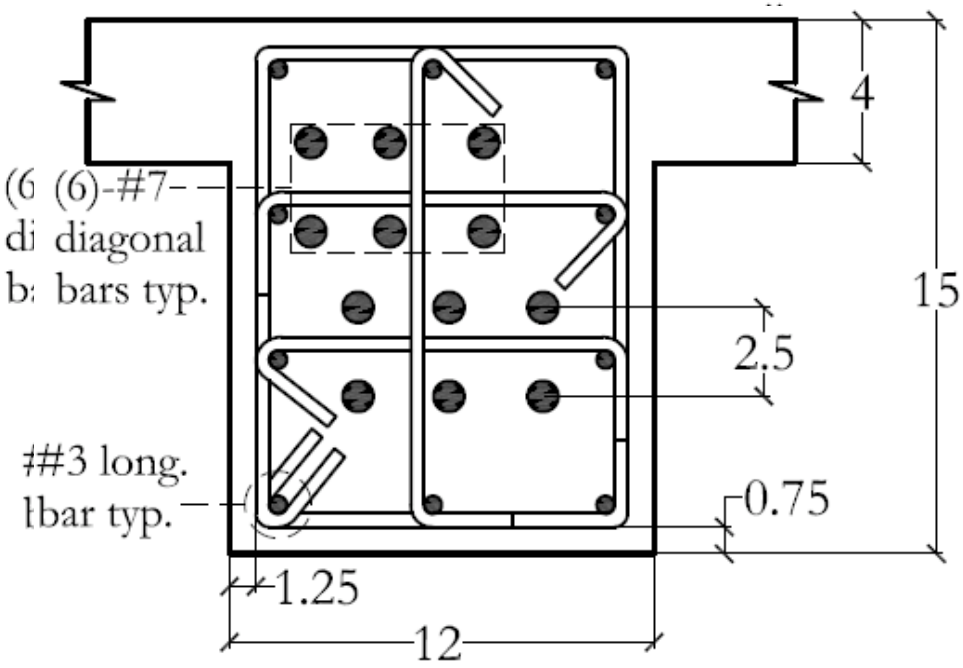
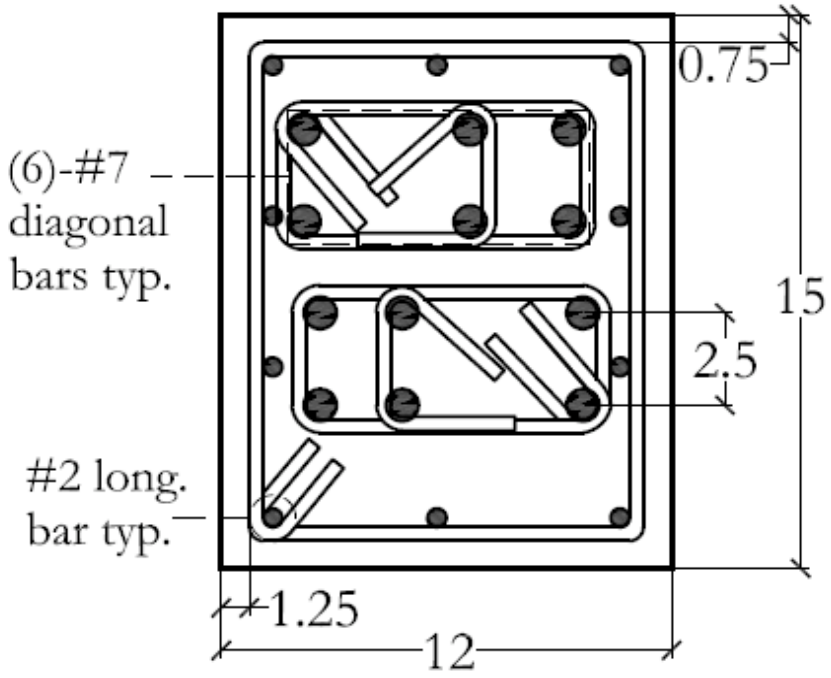
Test Beams: $l_n/h = 2.4$

- **CB24F (-RC,PT)**
  - ACI 318-08 (full)
  - Shear stress =
- **CB24D**
  - ACI 318-08 (diag.)
  - Shear stress =

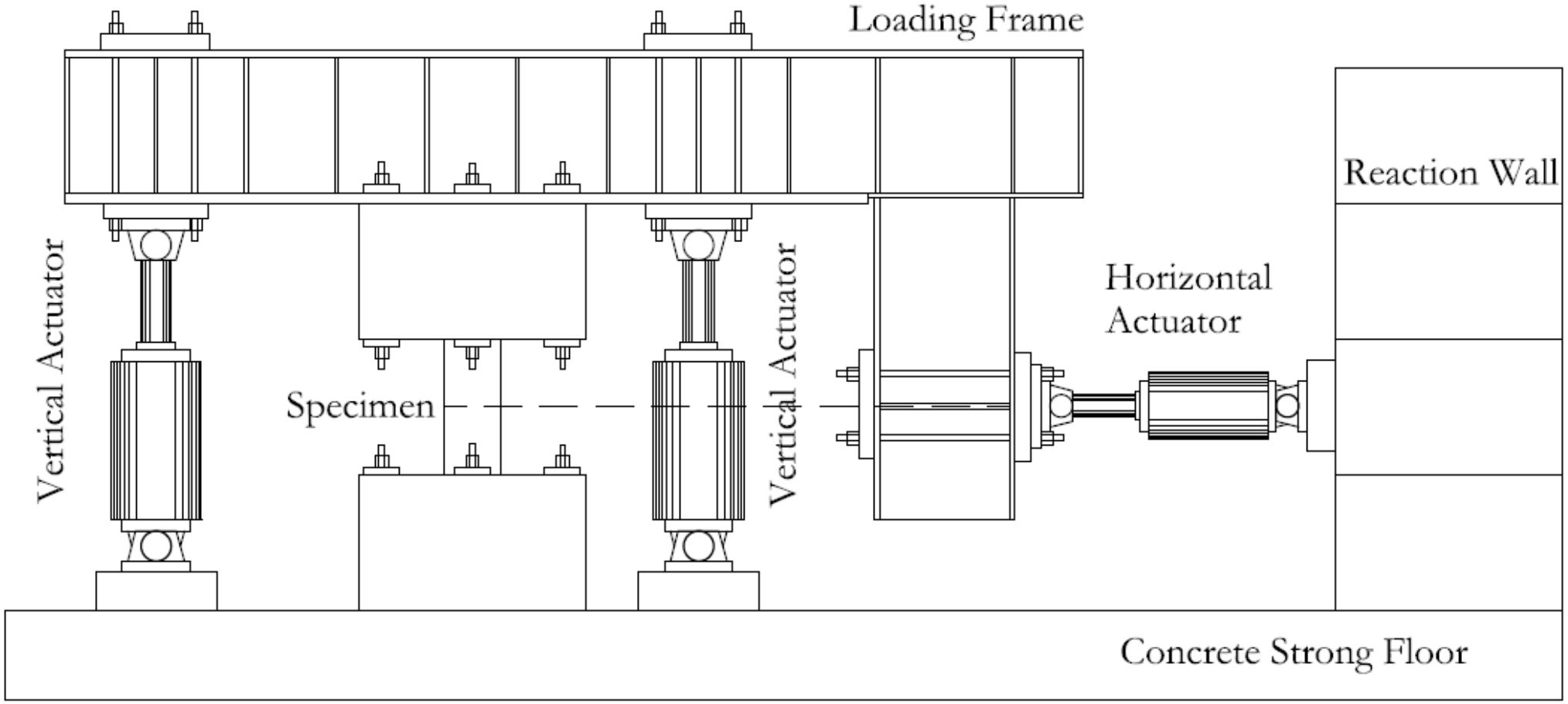


Section A-A



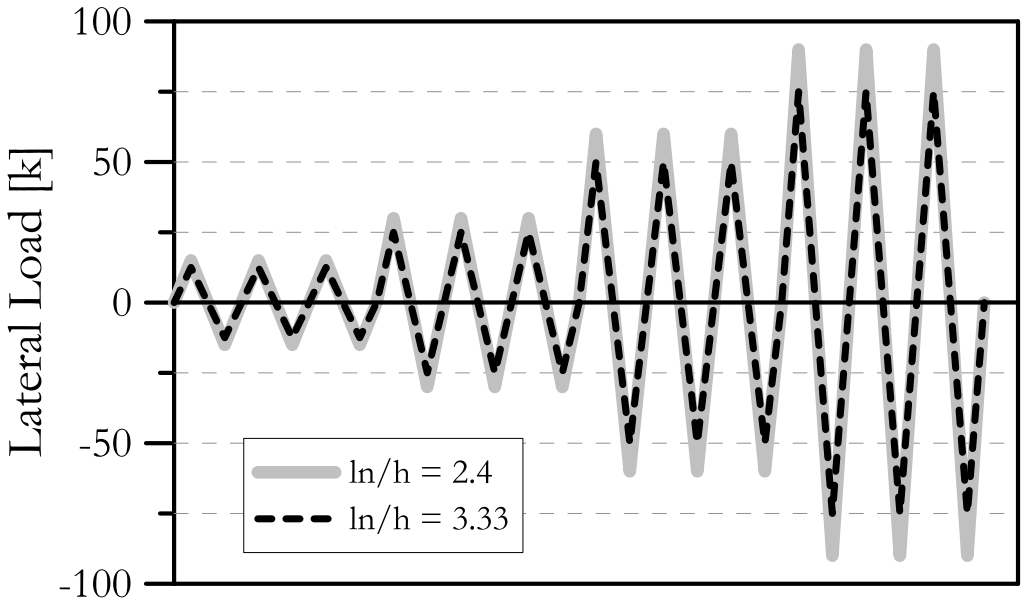
Section B-B

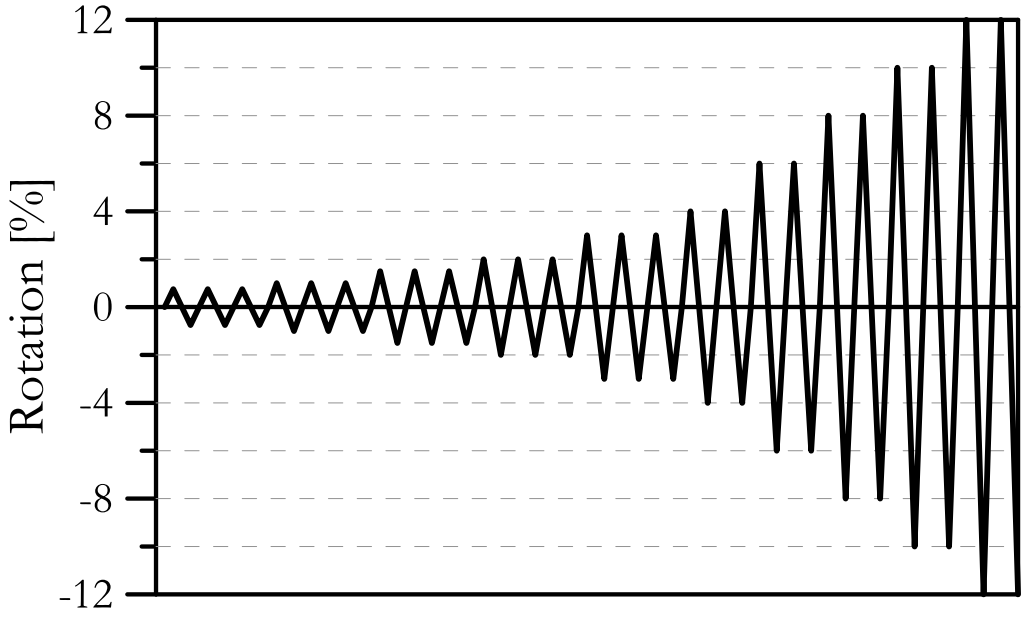
Laboratory test setup



Loading Protocol

- Estimate for V_y based on M-φ analysis
- Load-controlled testing
  - 3 cycles each
  - V_{lat} = 1/8*V_y, 1/4*V_y, 1/2*V_y, and 3/4*V_y





- Displacement-controlled testing
  - 3 cycles each ($\Delta/l_n = \theta$)
  - θ = 0.75%, 1.0%, 1.5%, 2.0%, and 3.0%
  - 2 cycles each (Δ/l_n > CP for FEMA 356)
  - θ = 4.0%, 6. 0%, 8.0%, 10.0%, and 12.0%

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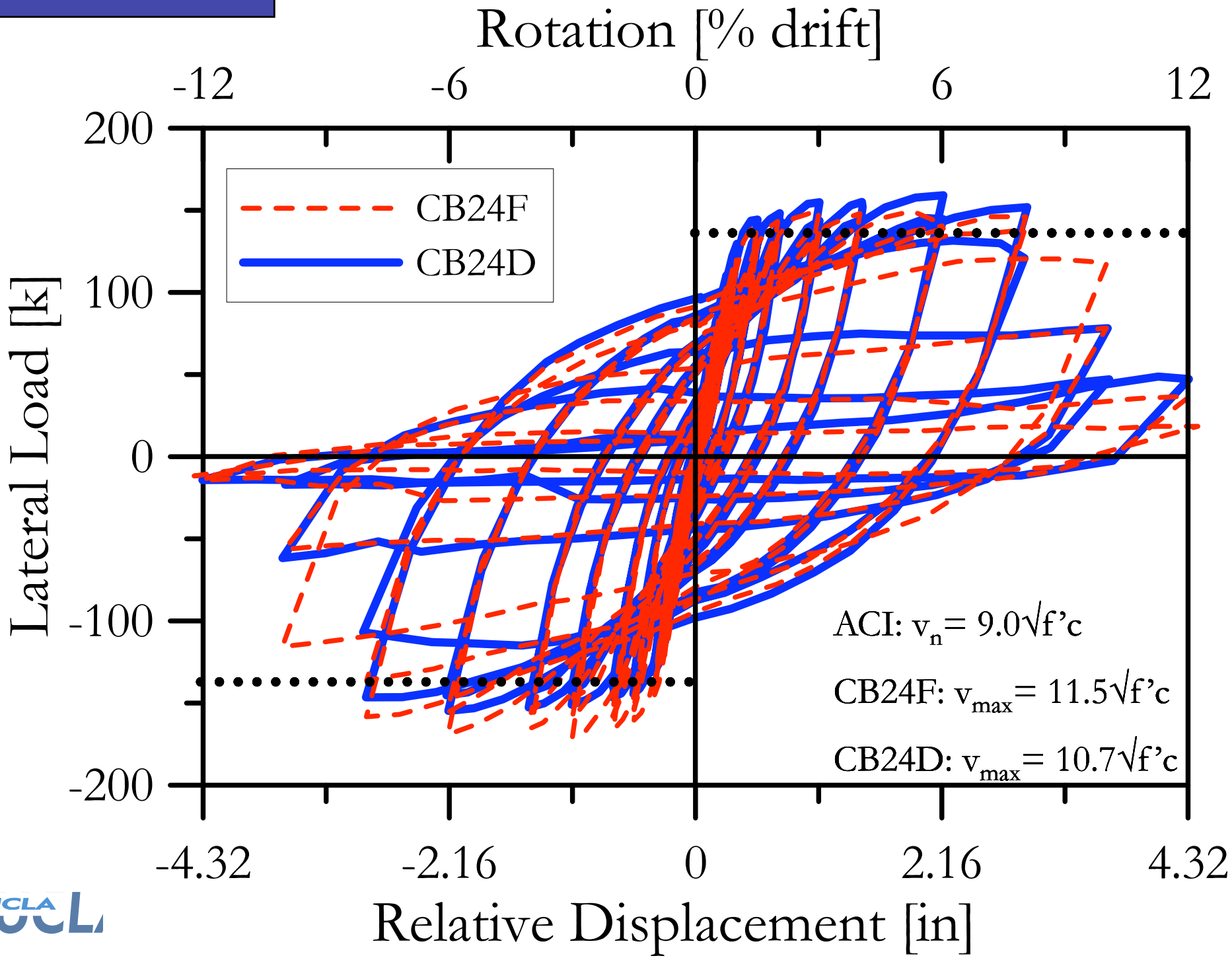
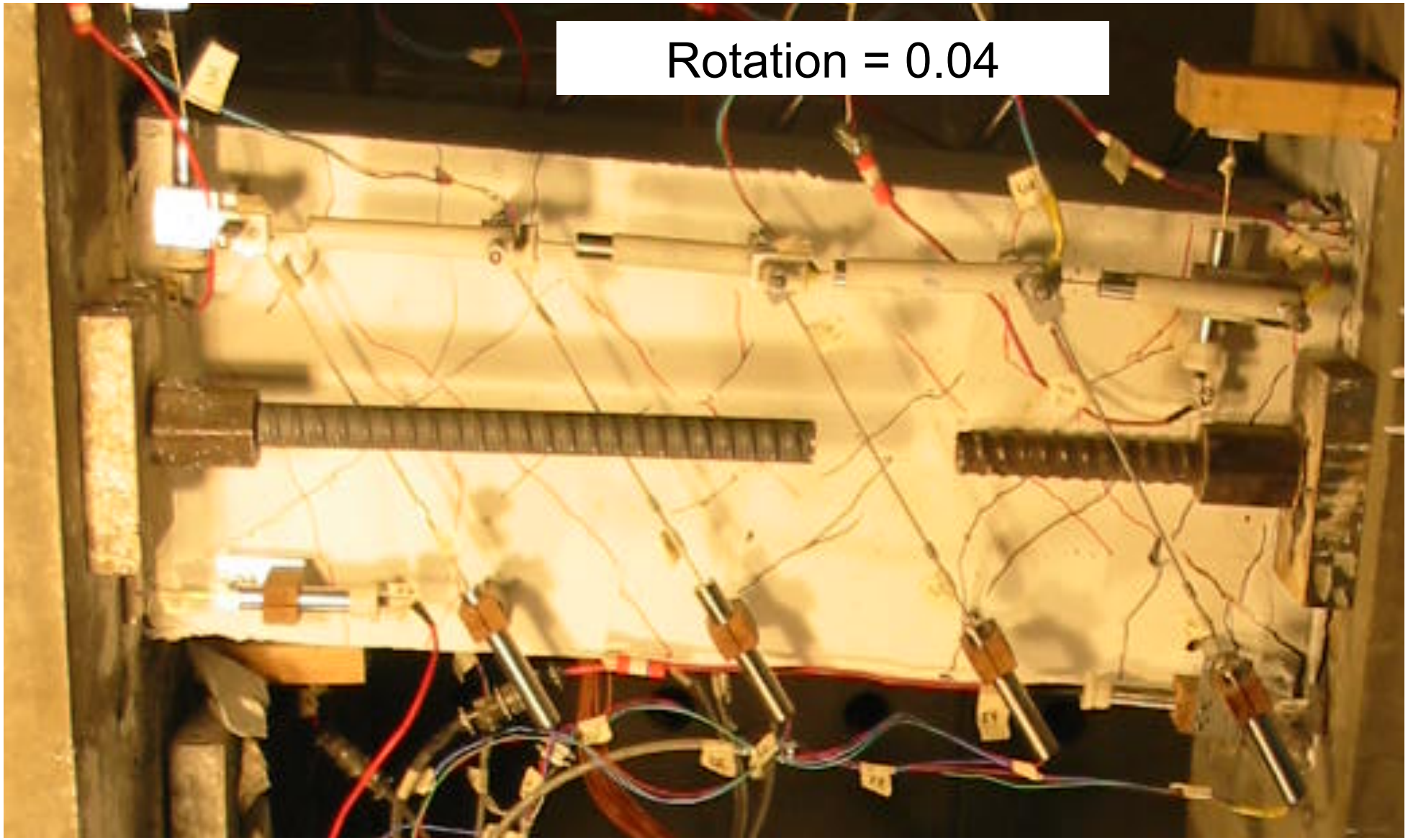
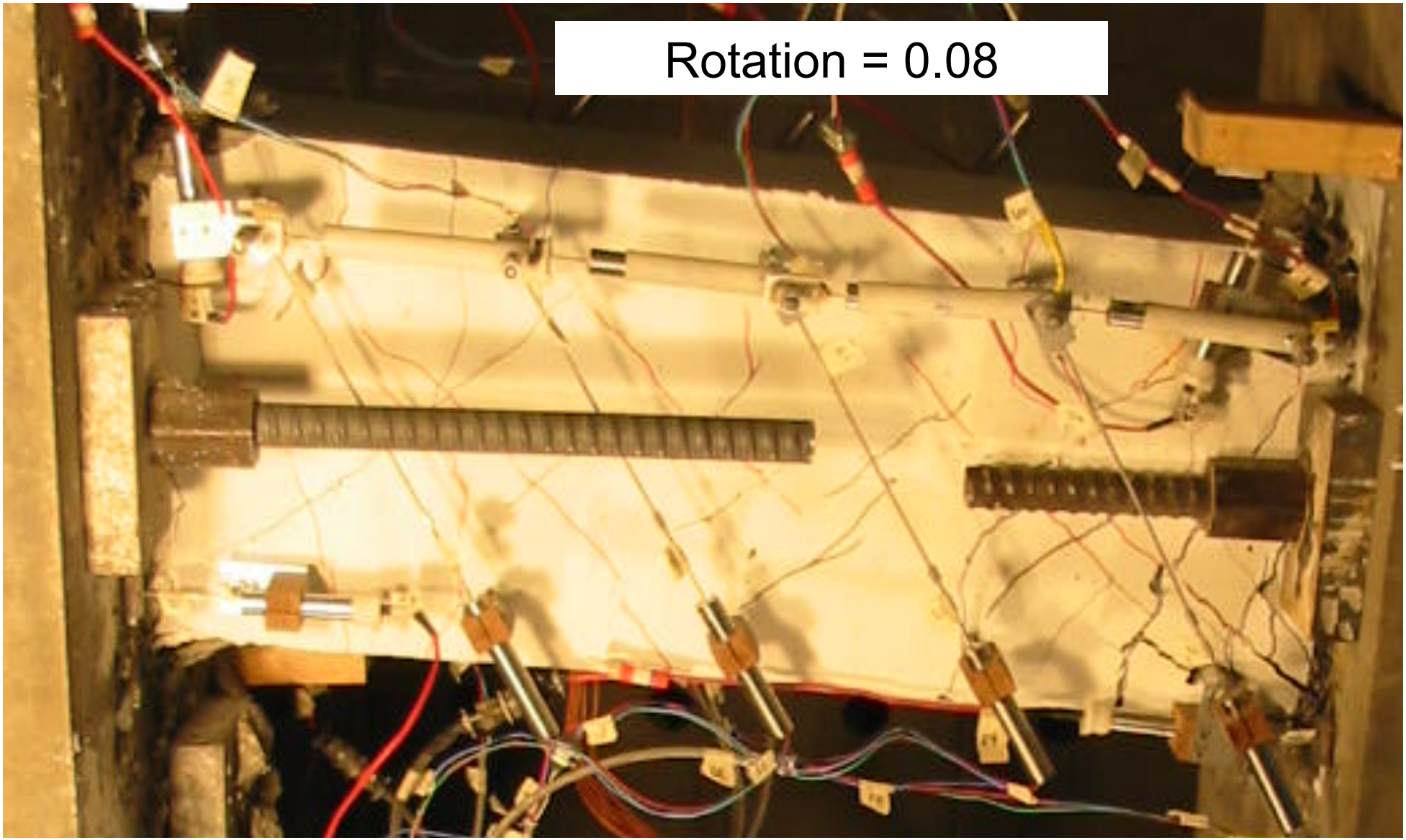
Load-Deformation



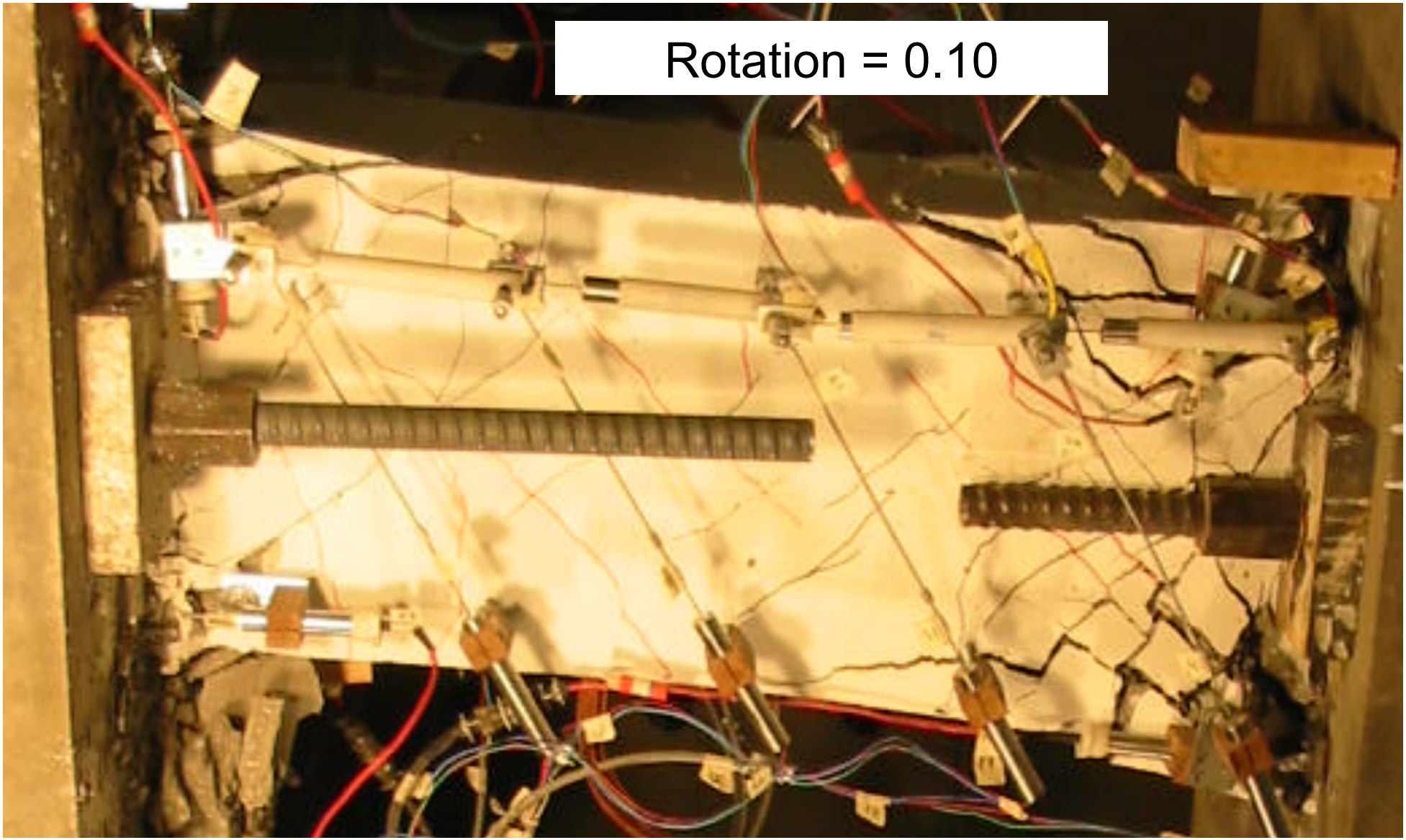
CB24F



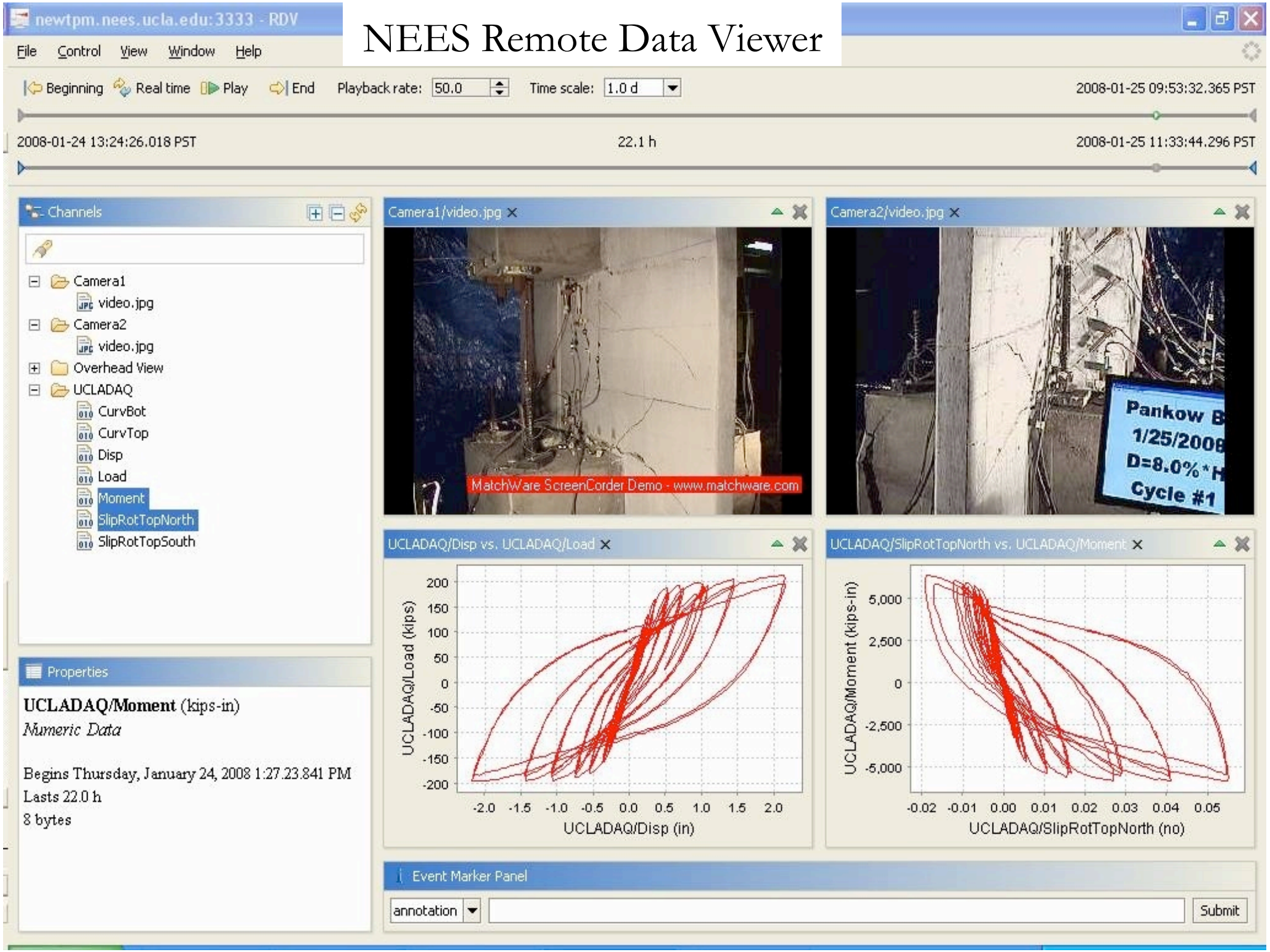
CB24F



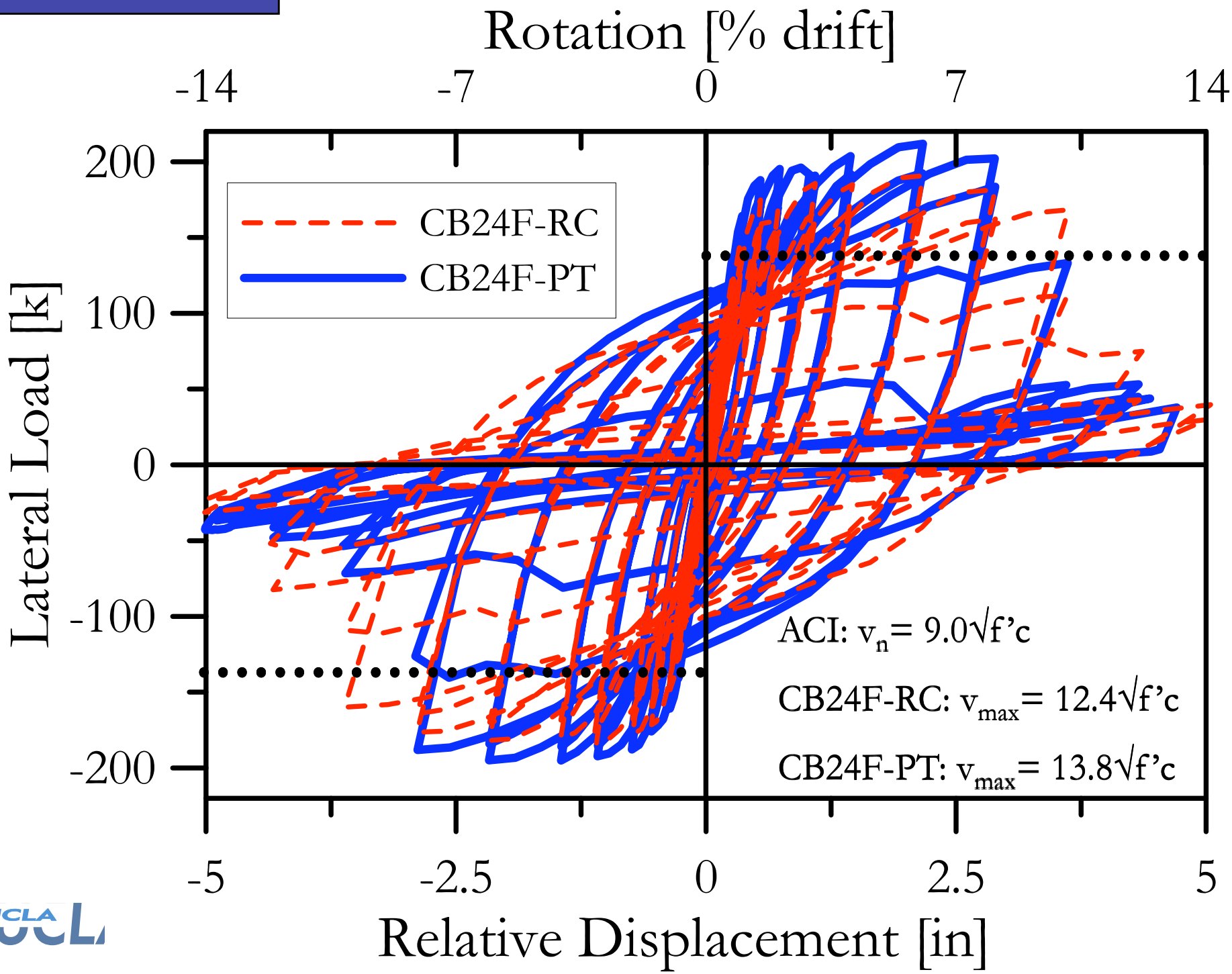
CB24F



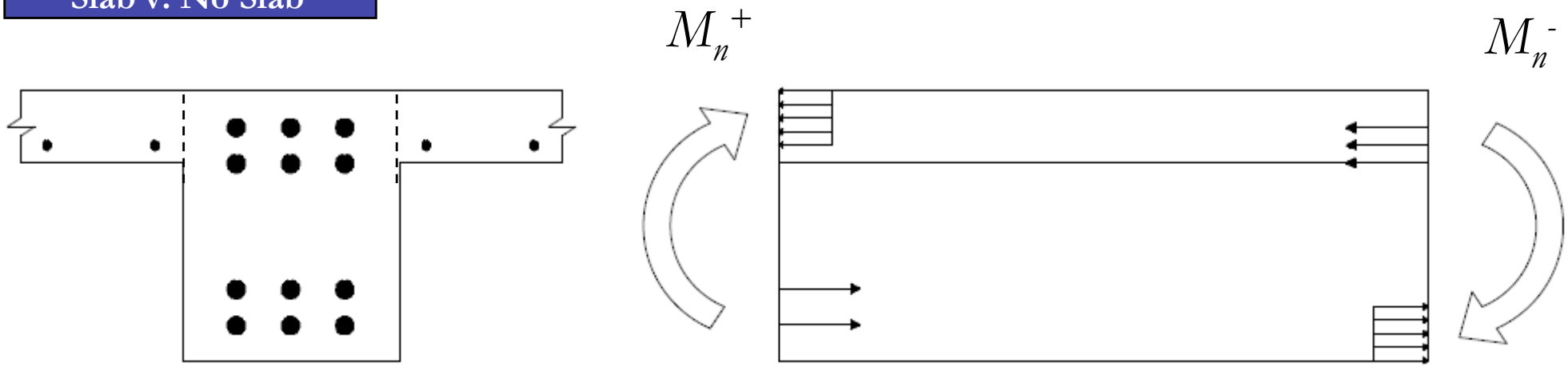
NEES Remote Data Viewer



Load-Deformation



Moment-Curv. Slab v. No Slab

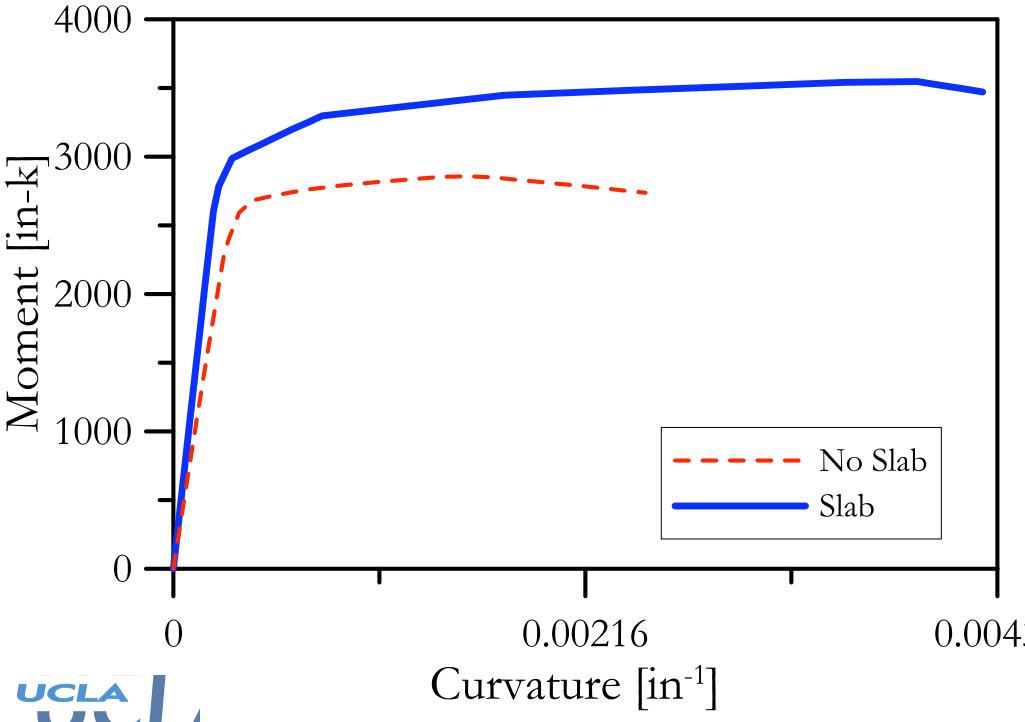


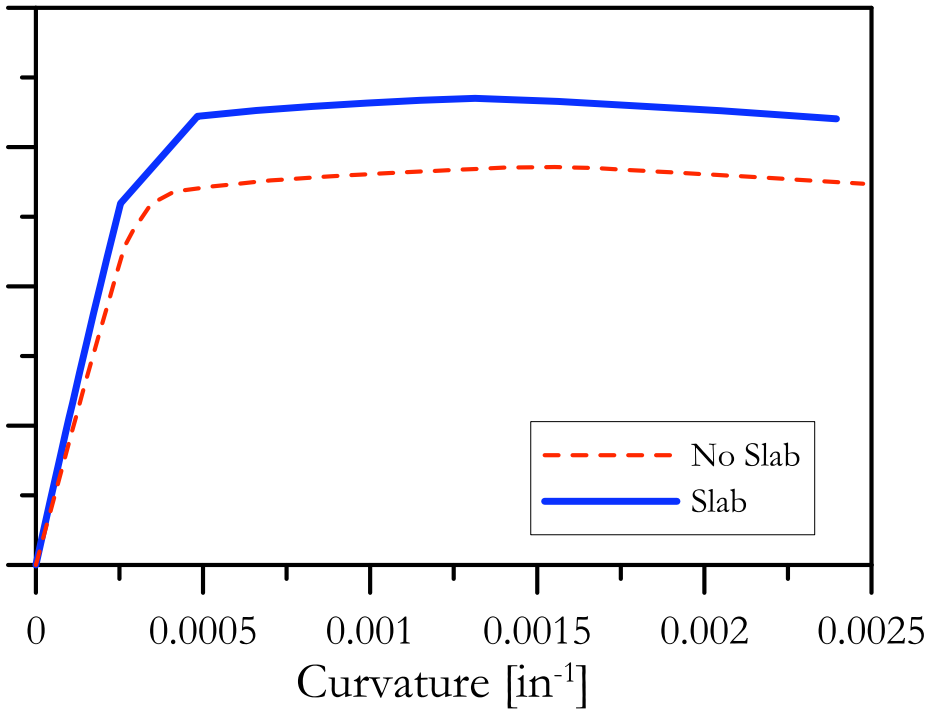
M_n^+ (slab) = 3550 in-k

M_n^- (slab) = 3350 in-k

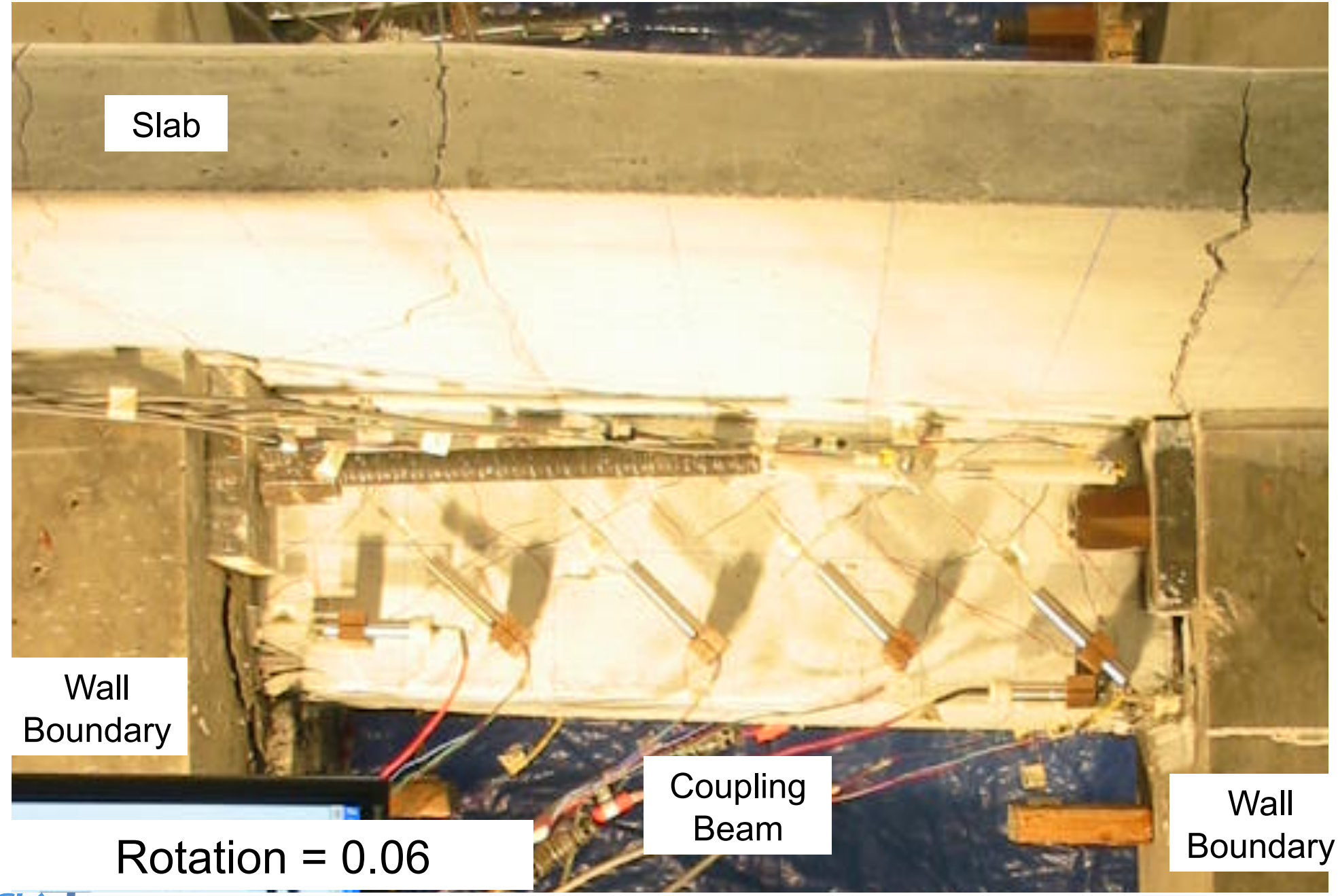
M_n^+(no slab) = 2850 in-k

M_n^-(no slab) = 2850 in-k



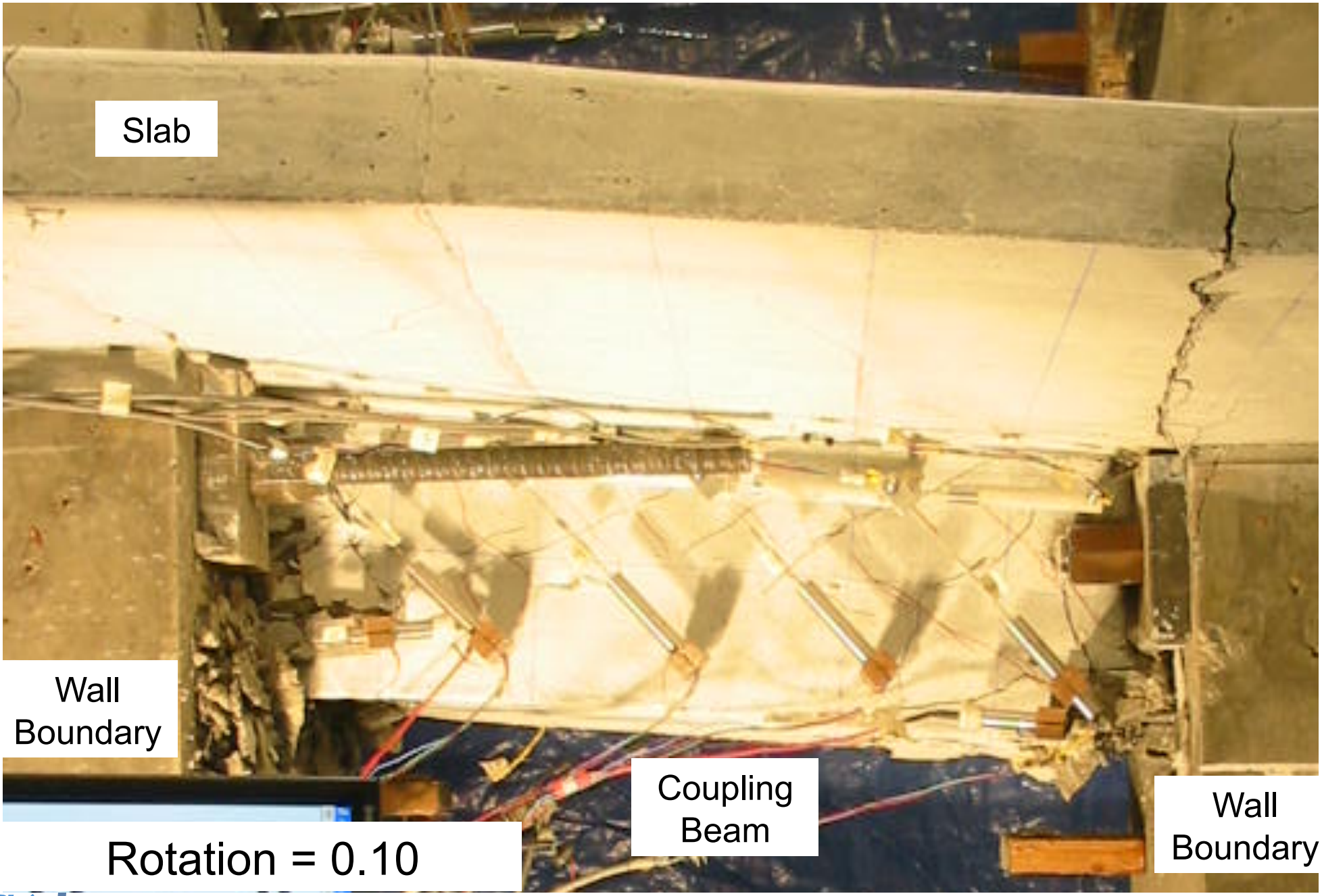


CB24F-PT



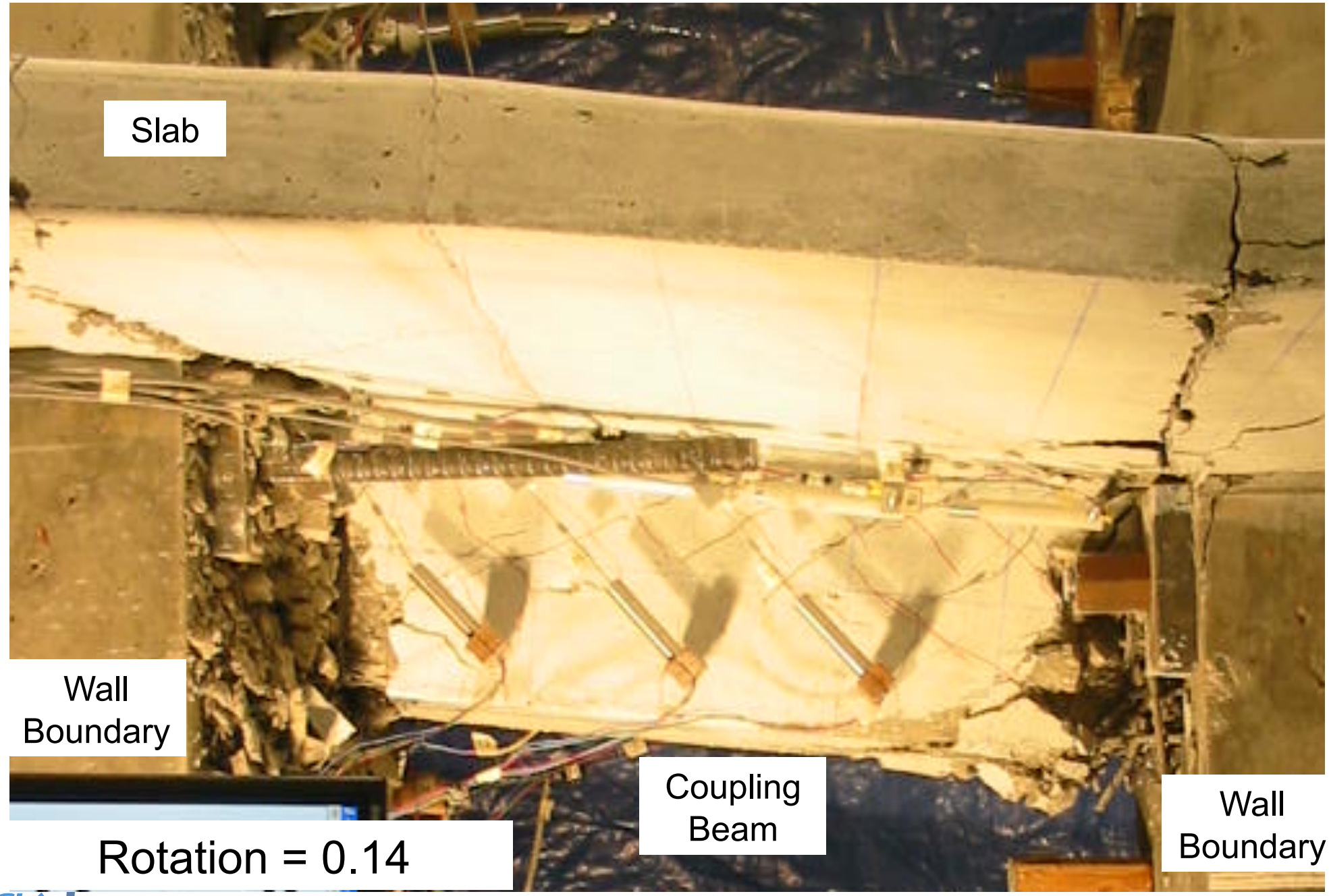
Rotation = 0.06

CB24F-PT

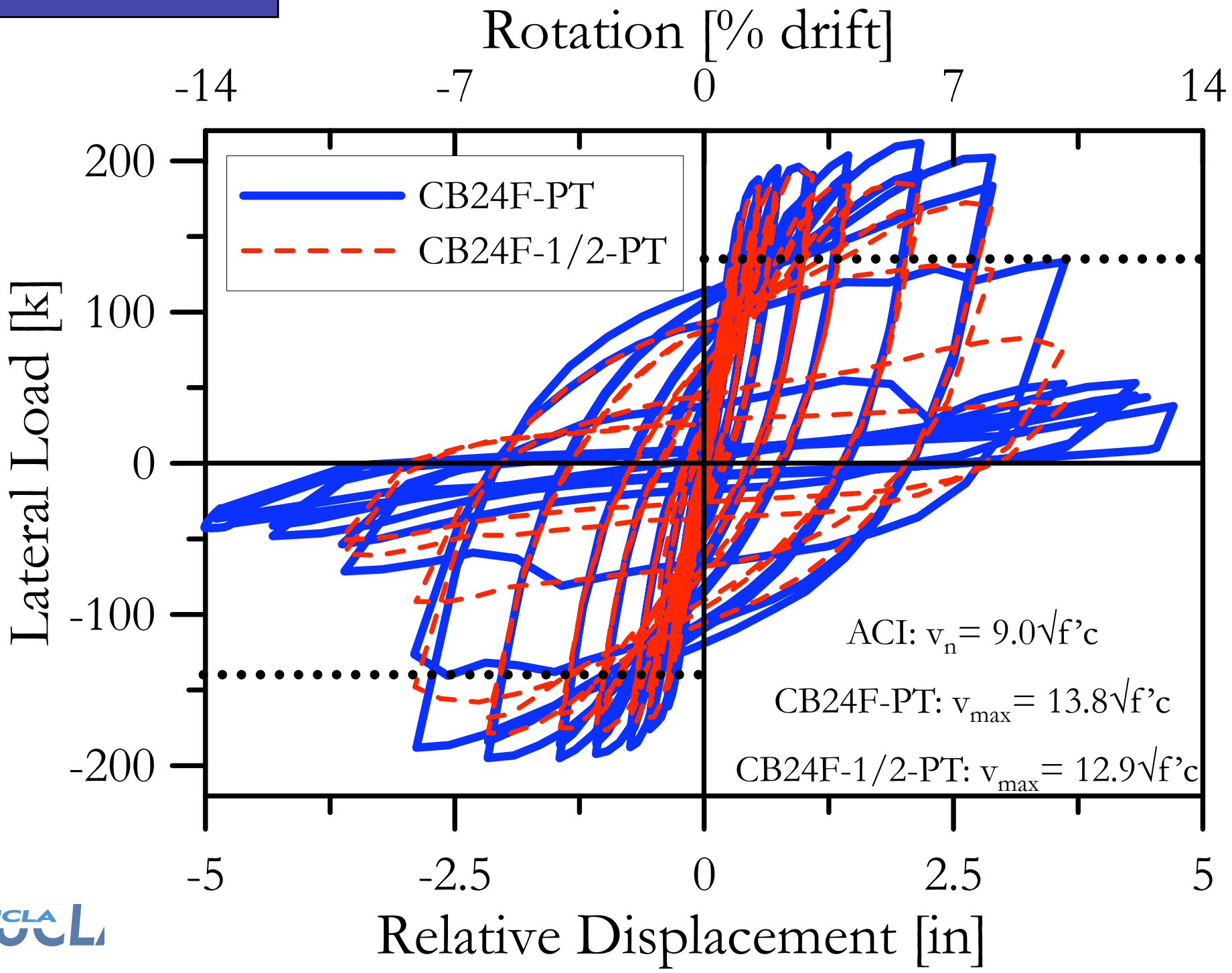


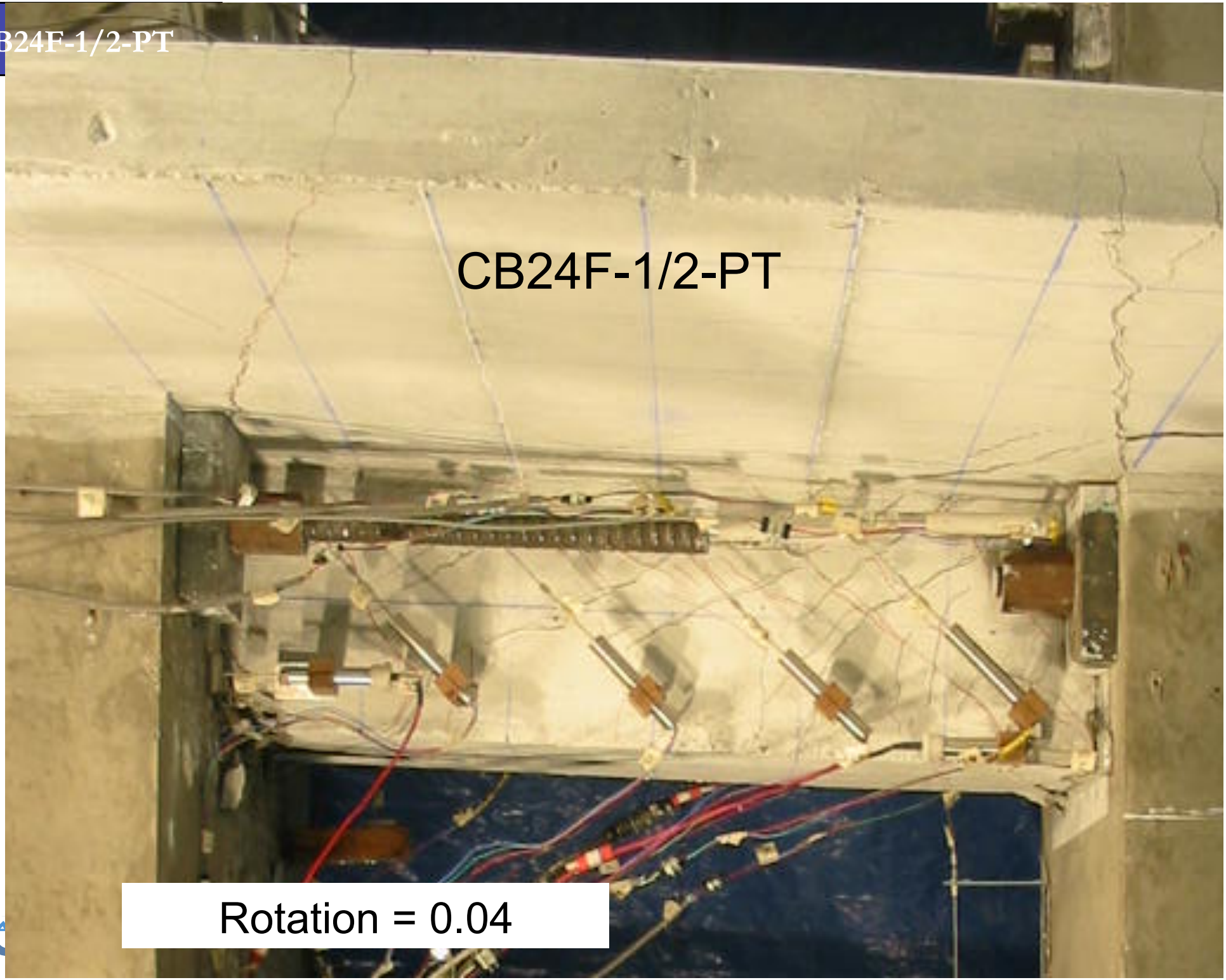
Rotation = 0.10

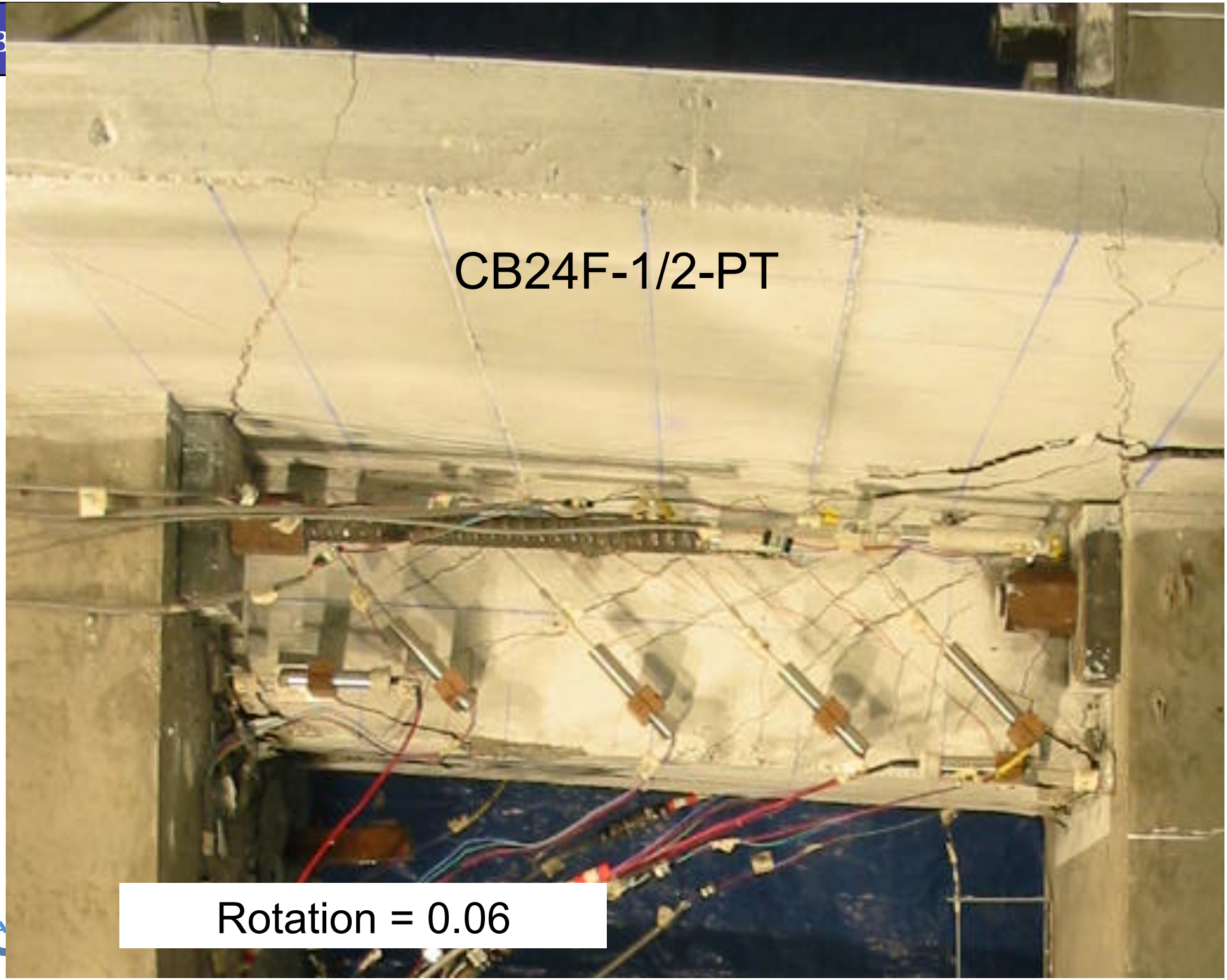
CB24F-PT

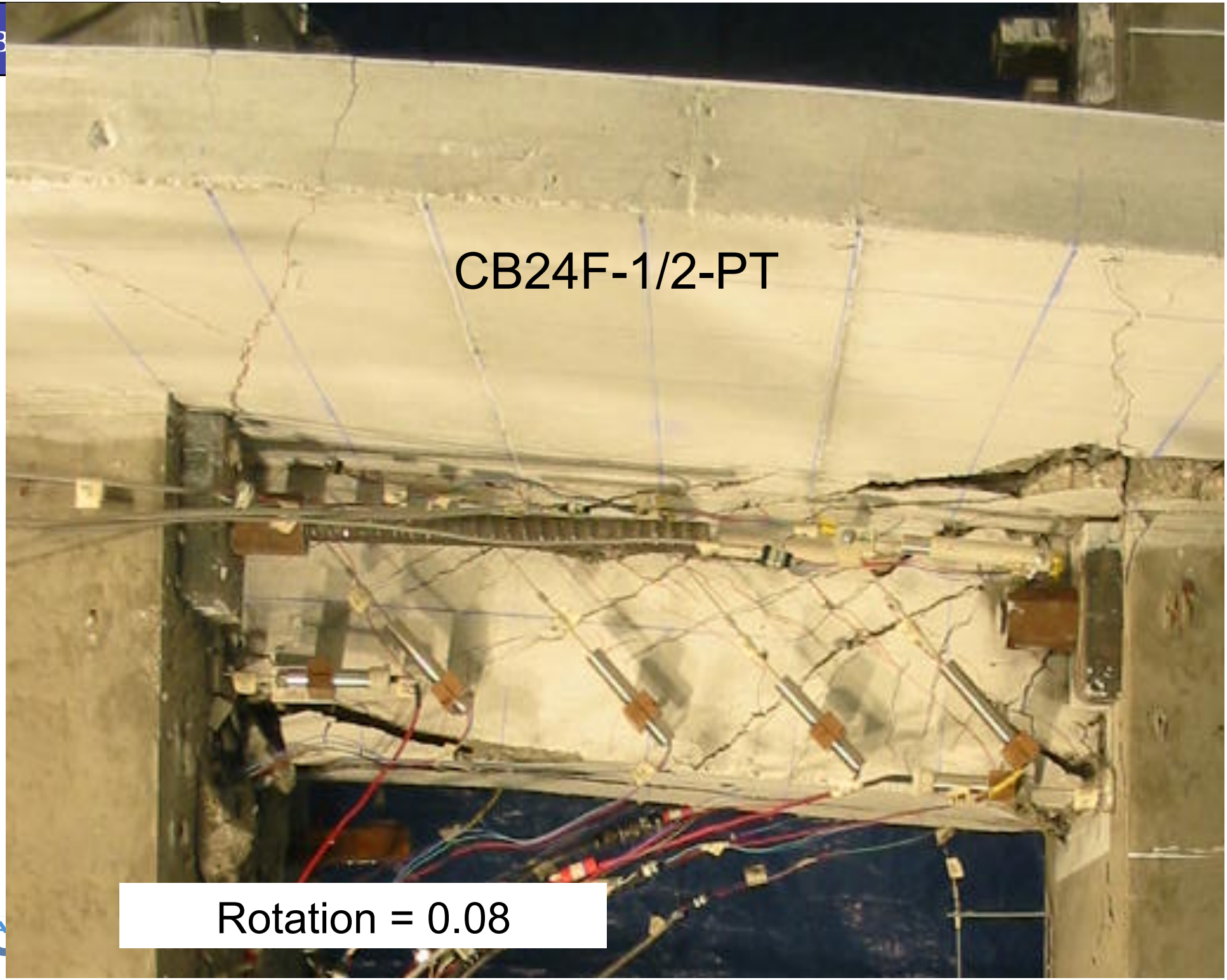

Slab
Wall Boundary
Coupling Beam
Wall Boundary
Rotation = 0.14

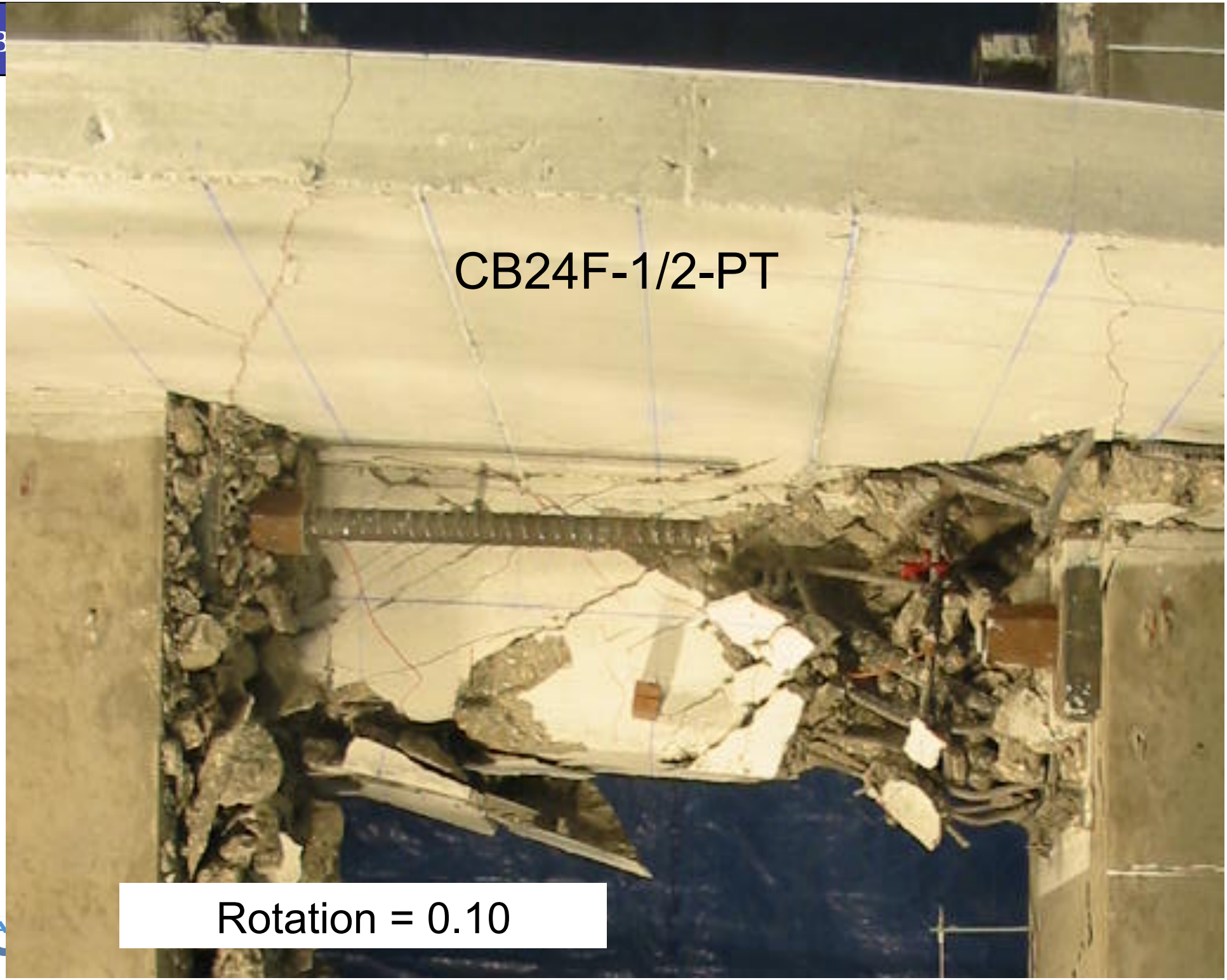
Load-Deformation



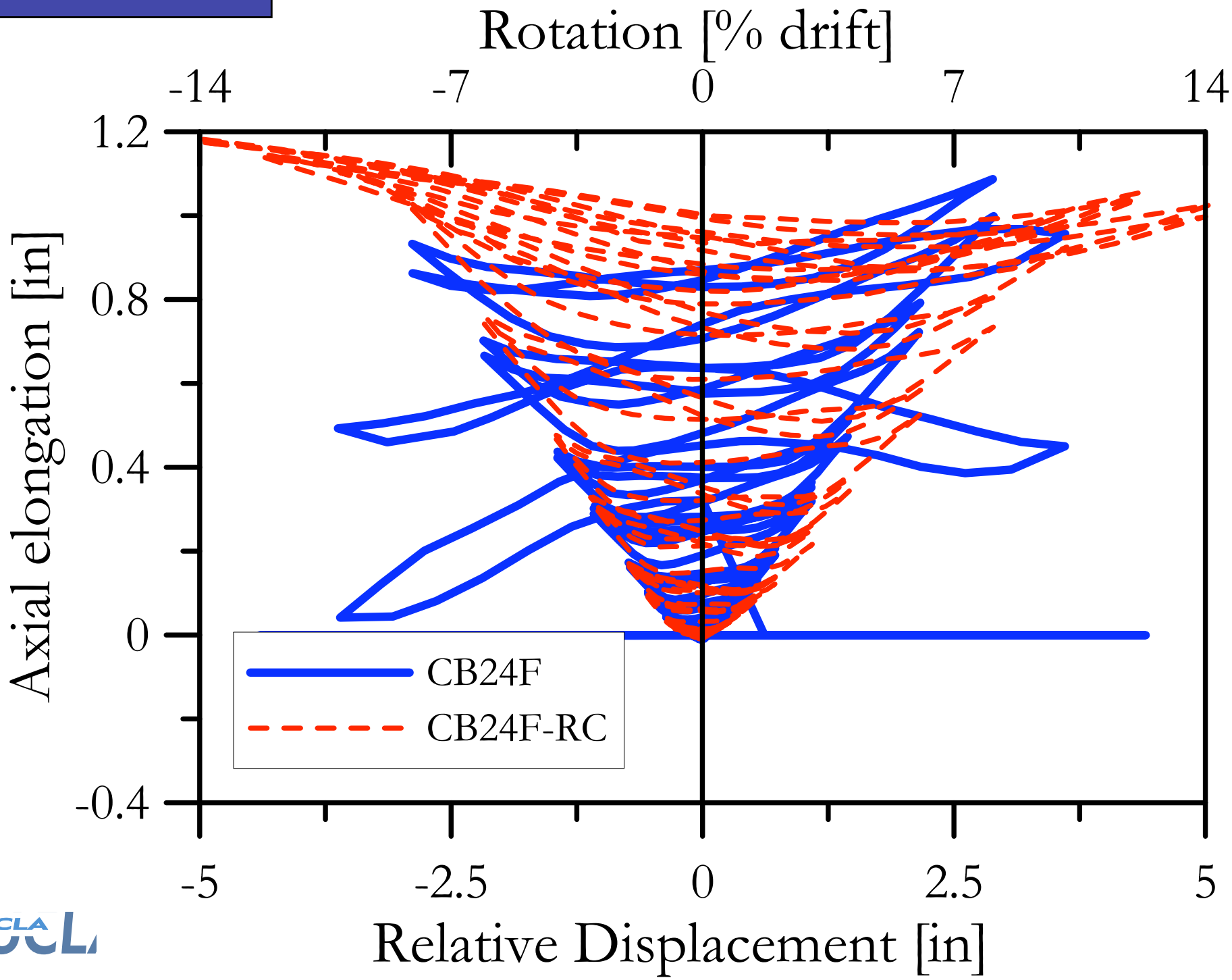

CB24F-1/2-PT
Rotation = 0.04


CB24F-1/2-PT
Rotation = 0.06

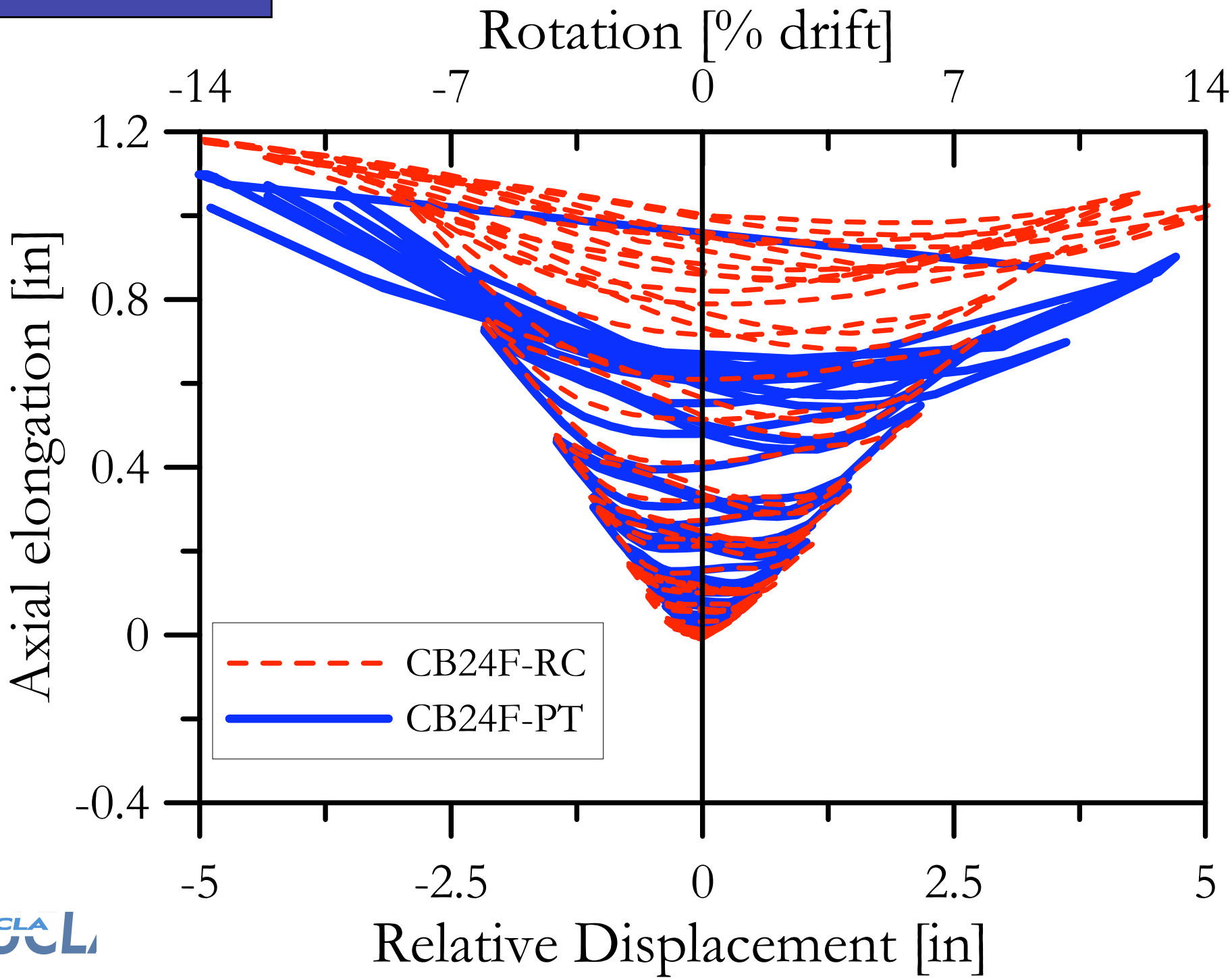

CB24F-1/2-PT
Rotation = 0.08


CB24F-1/2-PT
Rotation = 0.10

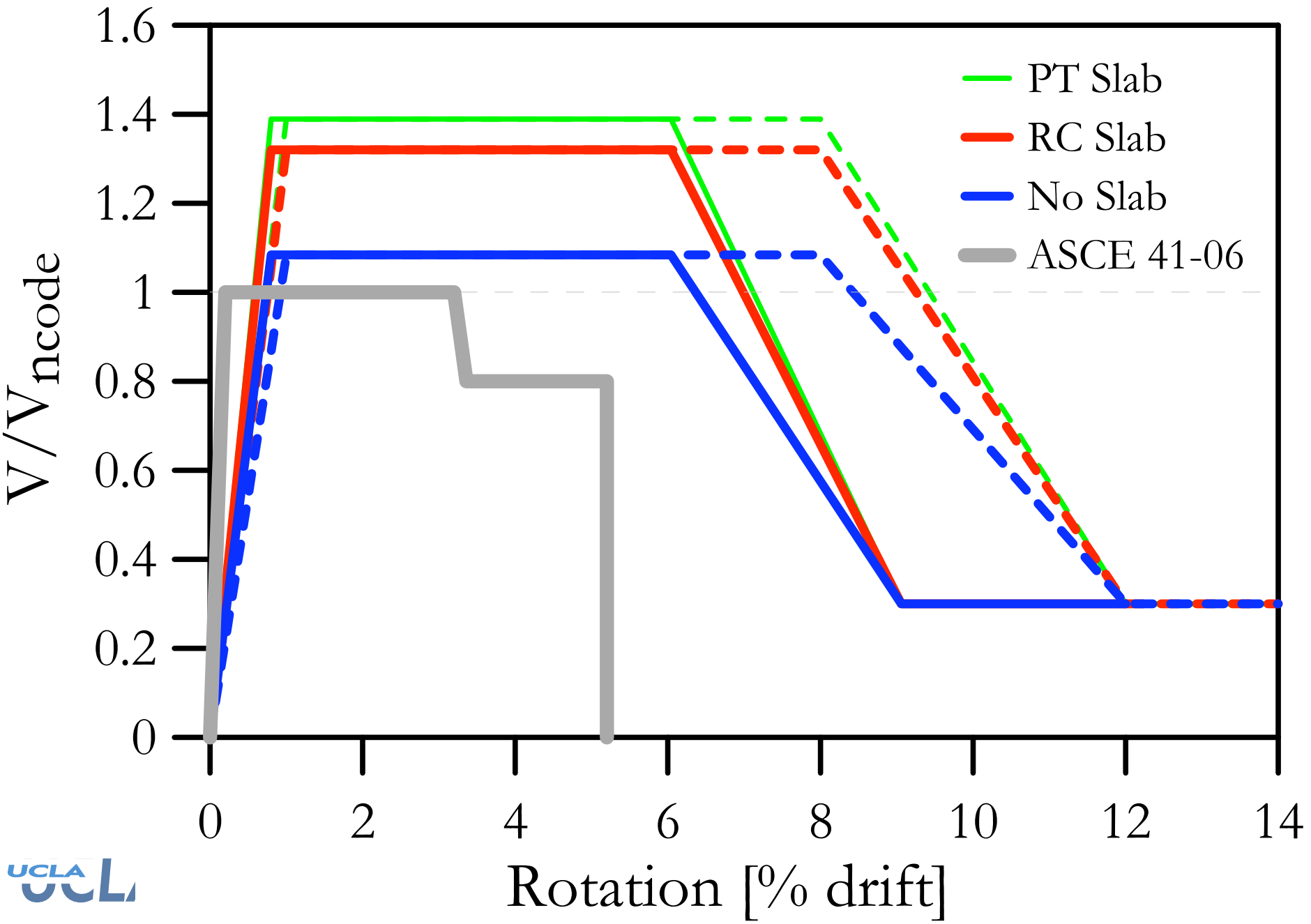
Axial Growth



Axial Growth



Load-Deformation Backbone



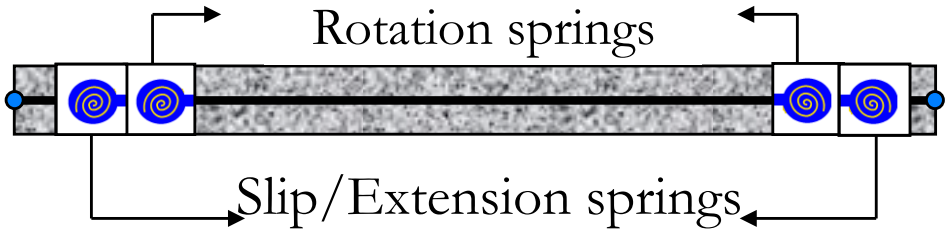
Modeling – Perform 3D

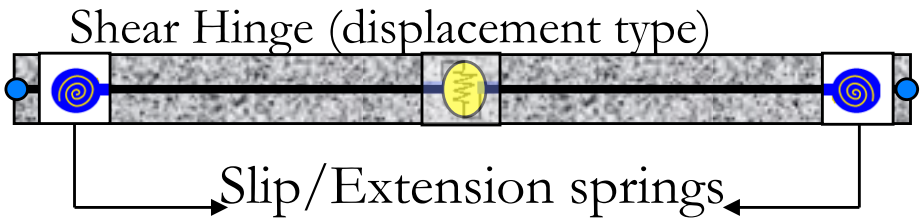
Frame Model

- Elastic beam concrete cross-section (EI_{eff} = 0.5*EI_g)
- Concentrated plastic M_n-θ hinges
- **Slip hinges:** Based on Alsiwat and Saatcioglu (1992)

Shear Hinge Model

- Elastic beam concrete cross-section (EI_{eff} = 0.5*EI_g)
- Plastic V_n-δ hinge
- **Slip hinges:** Based on Alsiwat and Saatcioglu (1992)



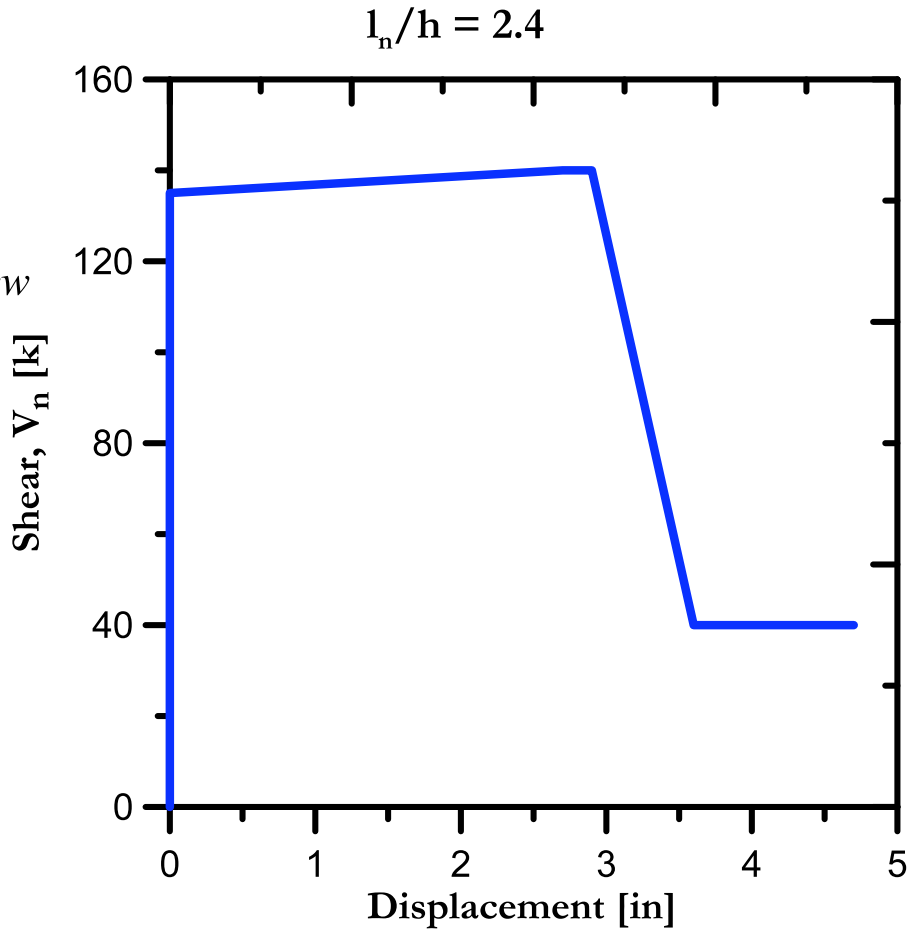


Modeling Parameters

- V_n-δ hinge
- V_n ACI 318-08 Eq 21-9

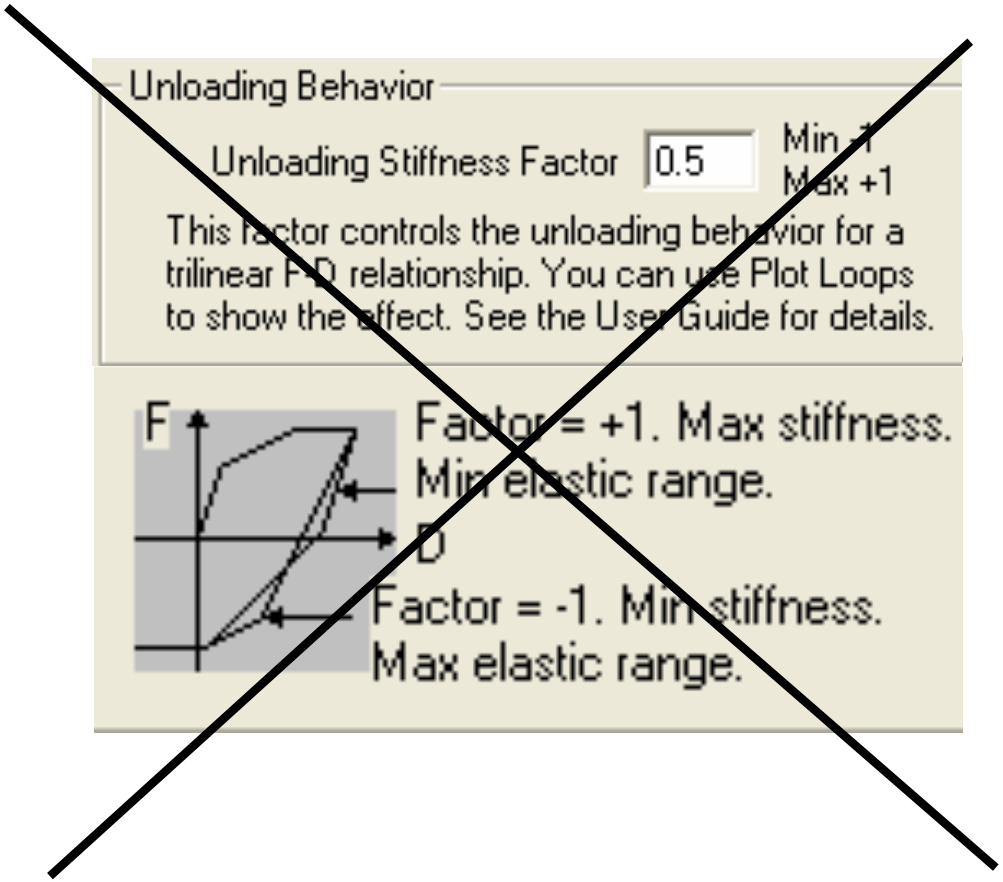
$$V_n = 2A_{vd} f_y \sin\alpha \le 10\sqrt{f'_c} A_{cw}$$

- **Displacement δ**
  - based on test results (Backbone)
  - Rigid – no elastic stiffness



Modeling Parameters

- Cyclic energy dissipation factors V_n-δ hinge
- DY – 0.5
- DU – 0.45
- DL – 0.4
- DR – 0.35
- DX – 0.35



Slip Hinge Calculations

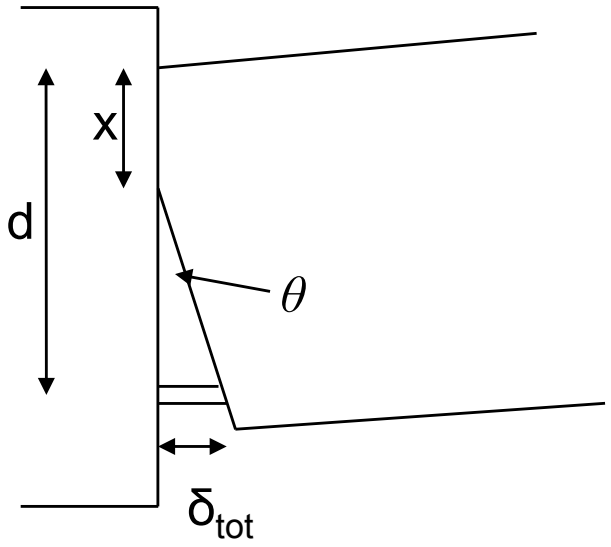
$M - \theta_{@\delta_{tot}}$

At yield of tension reinforcement:

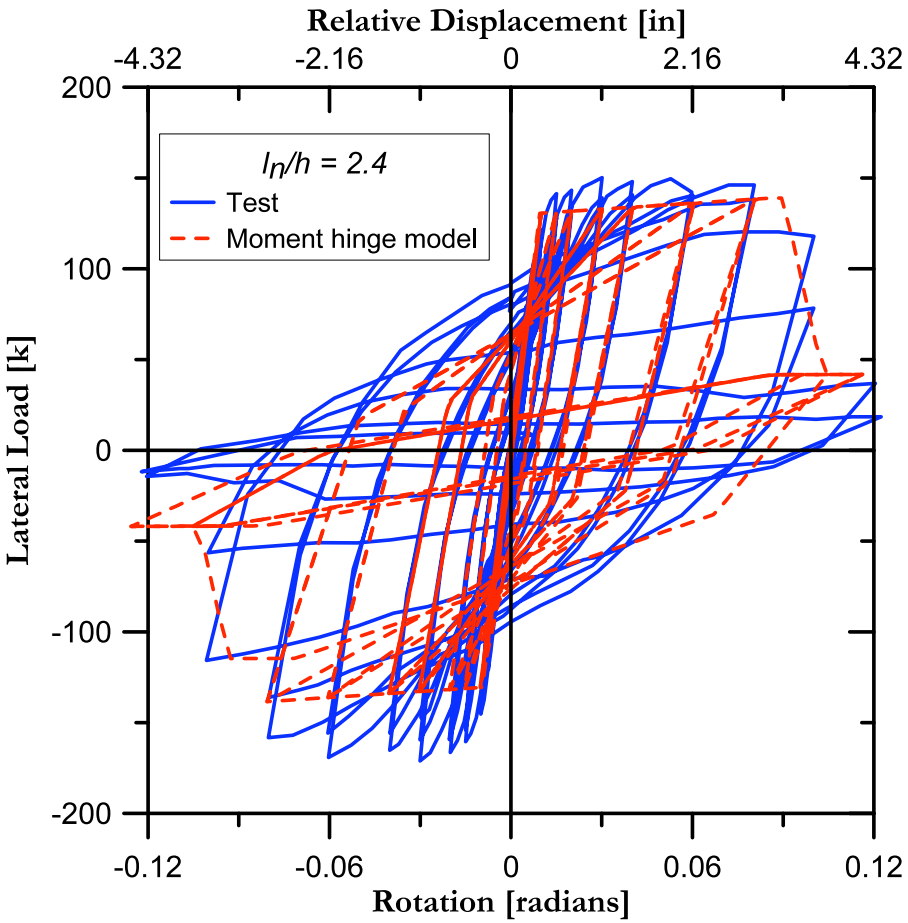
$$\theta_{@\delta_{tot}} = \frac{\delta_{tot}}{d - x} = \frac{0.0417"}{12.625" - 5"} = 0.00547$$

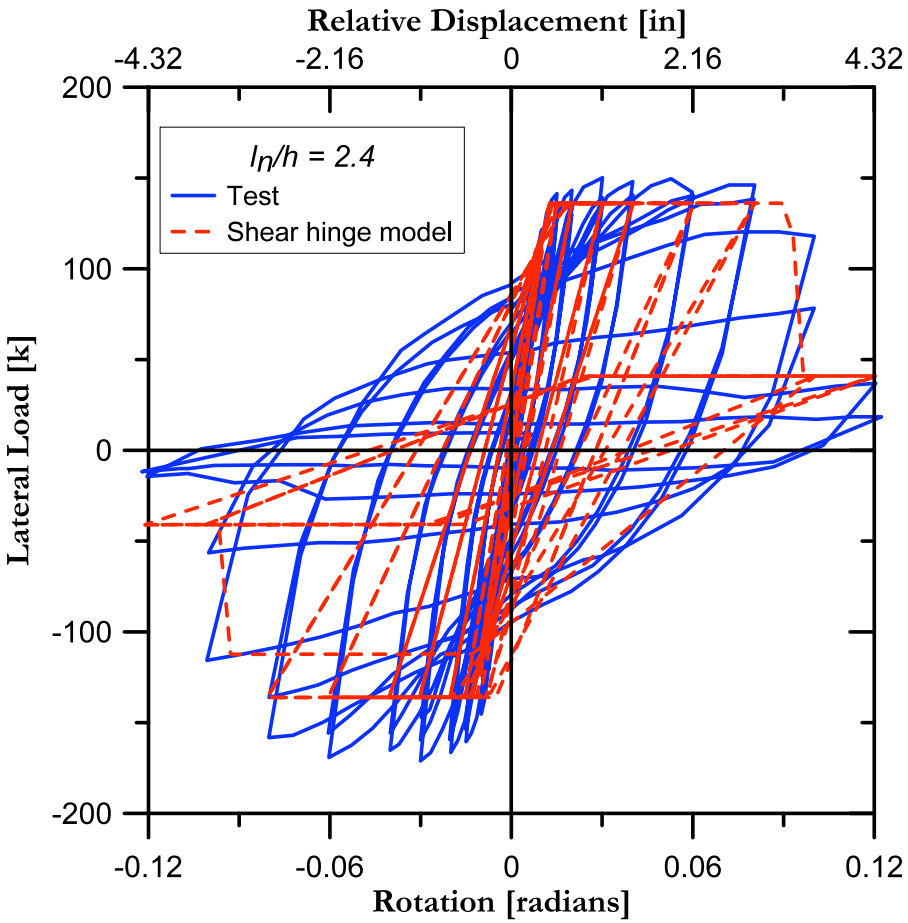
$$M_y = 2200in - k$$

$$K = M_y / \theta = 2200 / 0.0054 = 402200$$



Modeling Results: Perform 3D





Concluding Remarks

- Coupling beam load-displacement response is similar for the two detailing options included in ACI 318-08
- Slab provides for modest increase in strength, but has little impact on ductility
- Effective elastic stiffness ~0.15*EI_g
- Simple nonlinear models can accurately capture load-deformation response
- New project to investigate SRC coupling beams [steel W-section, Steel plate]

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Acknowledgements

- Charles Pankow Foundation
- Webcor Concrete
- Materials – Catalina Pacific, Hanson, SureLock
- Lab Technicians (NEES staff) – Steve Keowen, Alberto Salamanca, Steve Kang
- Brian Morgen (MKA)
- Lab Assistants – Joy Park, Nolan Lenahan, Cameron Sanford
- A. Lemnitzer, D. Skolnik, S. Taylor-Lange, M. Salas

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http://nees.ucla.edu
http://nees.ucla.edu/wallace