

RC Core Walls – Testing and Modeling of Coupling Beams



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

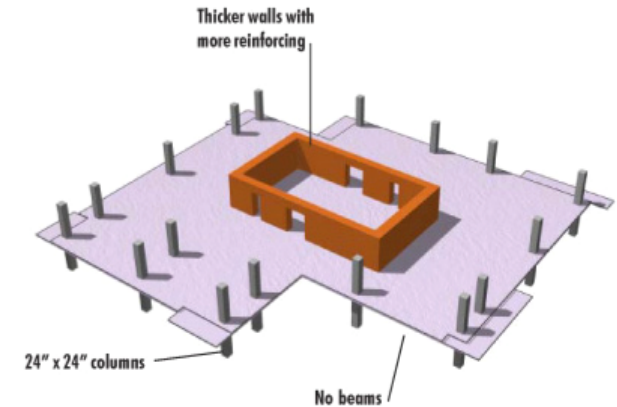
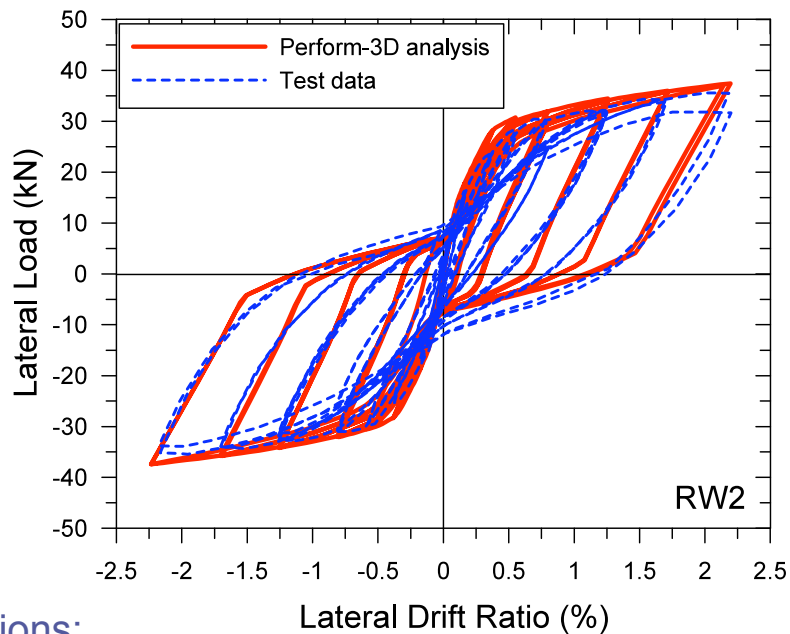
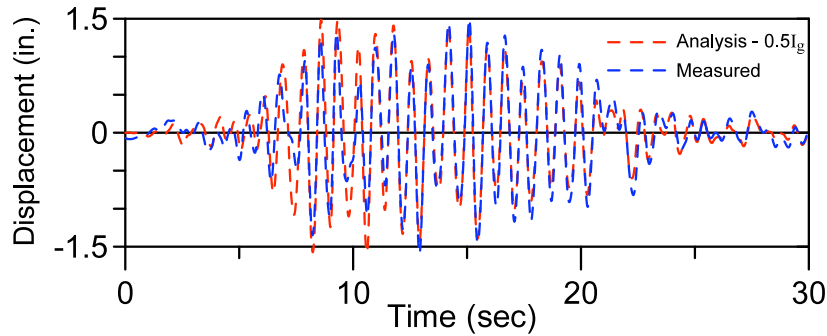
PEER Center Annual Meeting – October 2009
Tall Buildings Initiative Session

nees@UCLA

The George E. Brown, Jr. Network for Earthquake Engineering Simulation



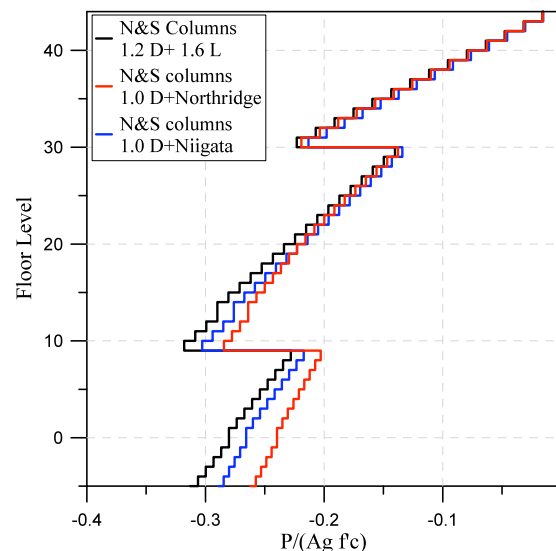
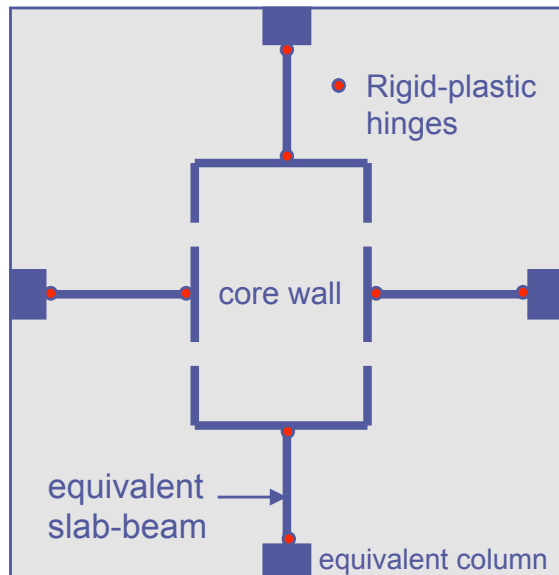
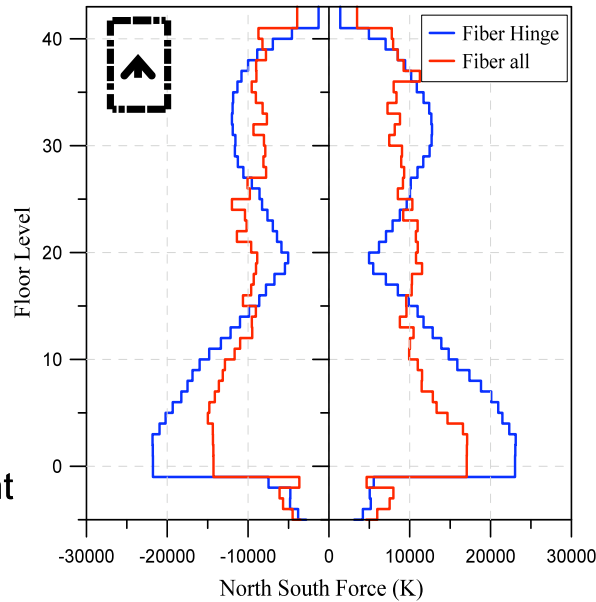
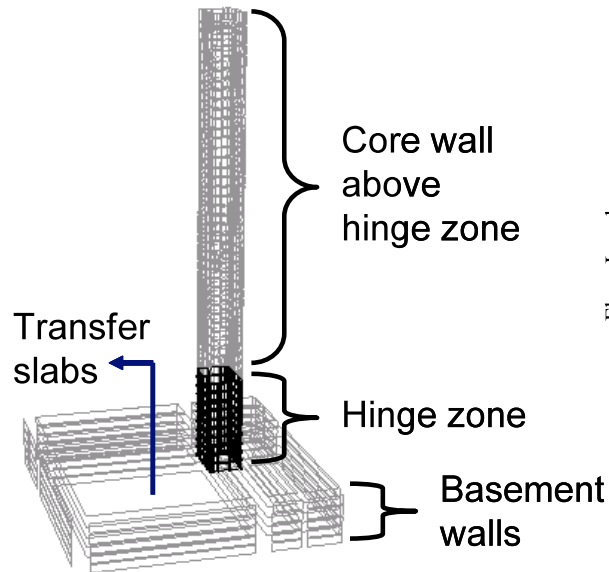
Tall Buildings – Modeling



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



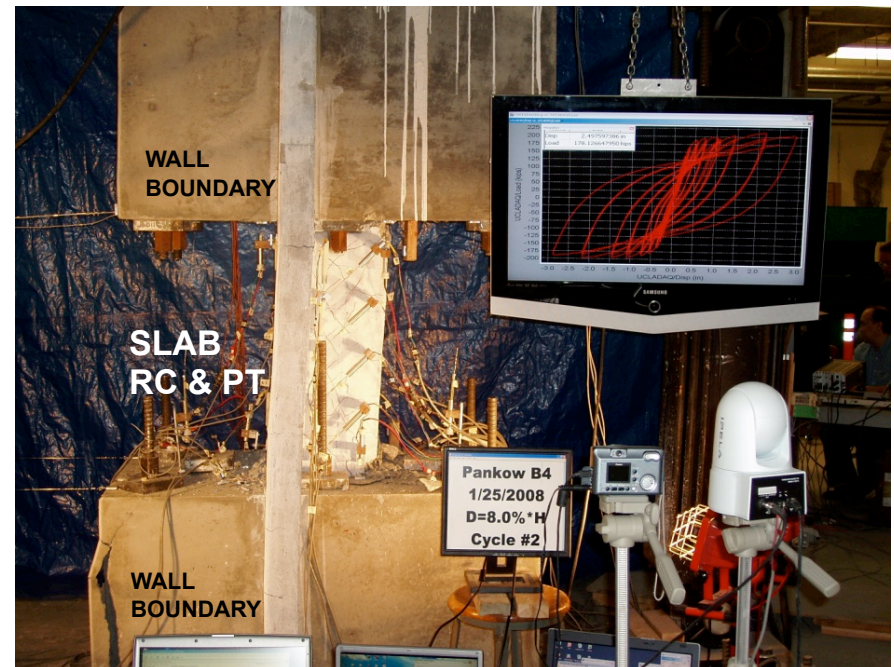
Publications:
Wallace JW
Tall & Special Buildings
Dec. 2007

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



Link 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

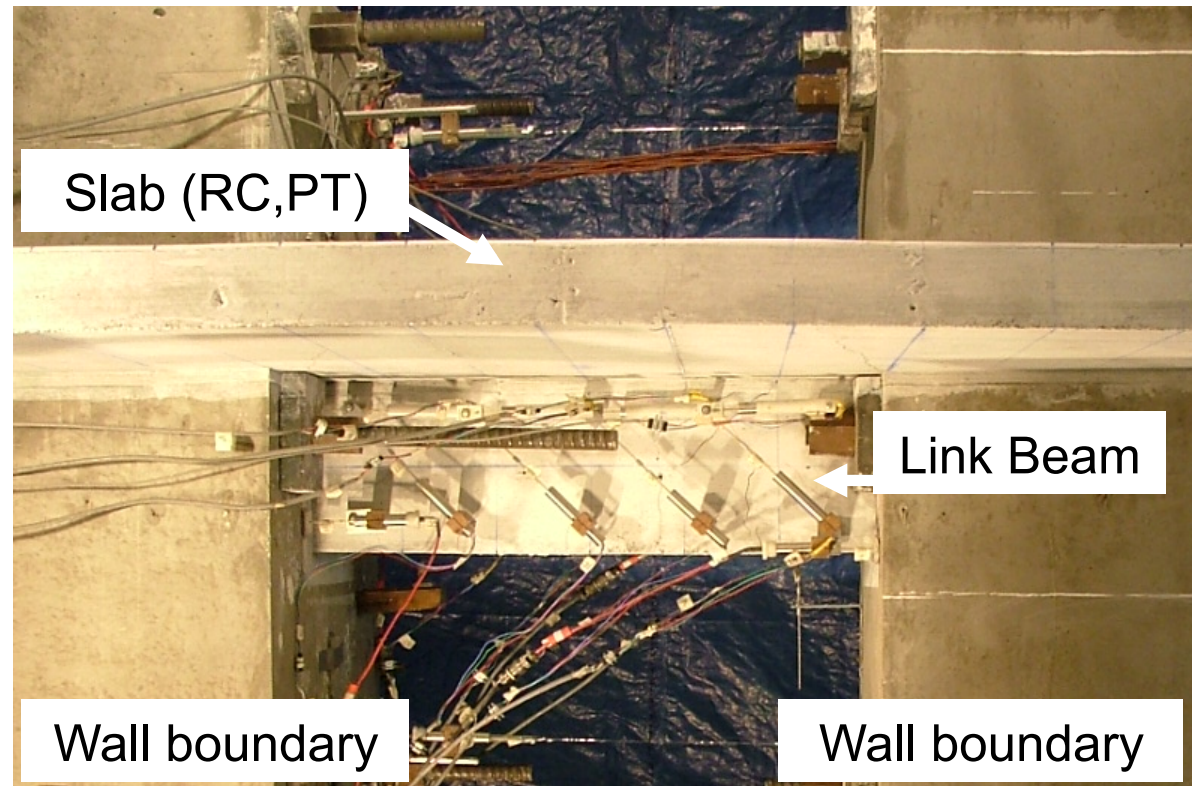
- Aspect ratio, l_n/h
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Project Motivation

- Aspect ratio, l_n/h

- 2.4 & 3.33

- f'_c

- Residual strength

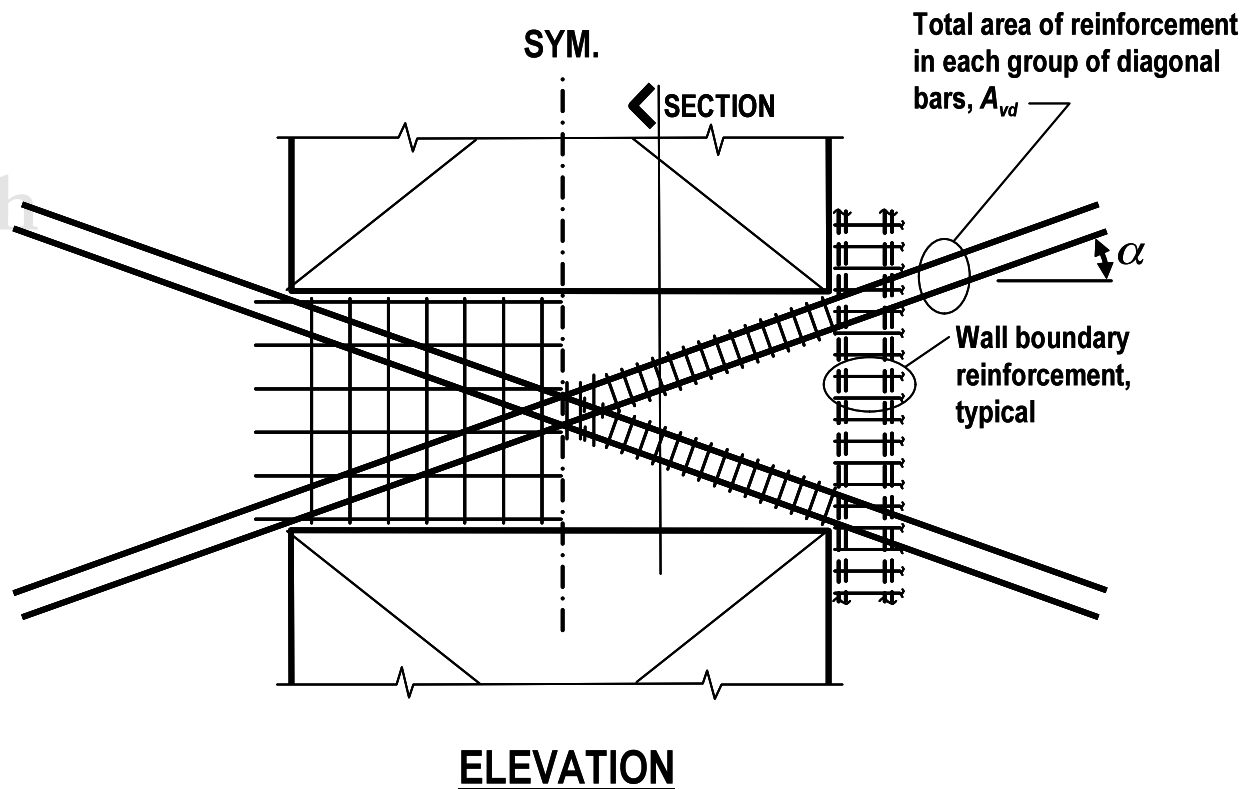
- Effect of slab

- RC

- PT

- Detailing

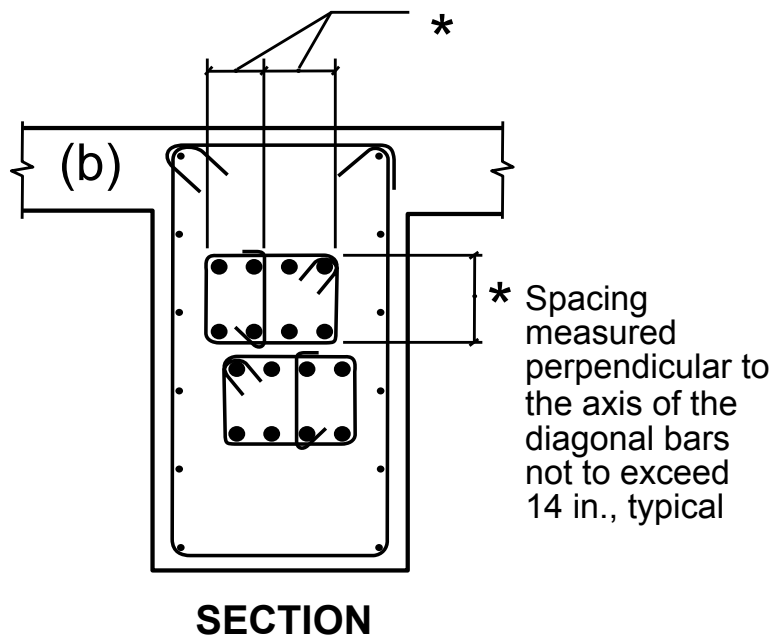
- A_{sh} and $1/2 * A_{sh}$



ACI 318 Code Provisions

■ ACI 318-05 S21.7.7

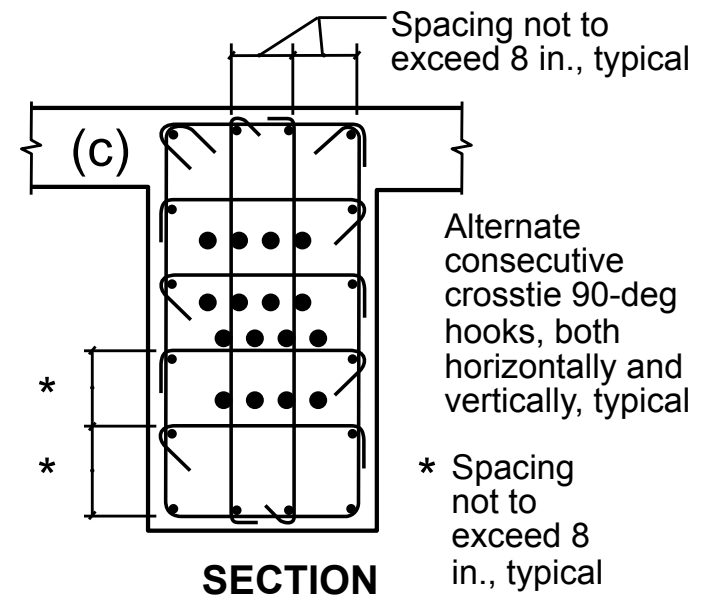
- Must have diagonal bars enclosed in transverse reinforcement.



Diagonal Confinement

■ ACI 318-08 S21.9.7

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



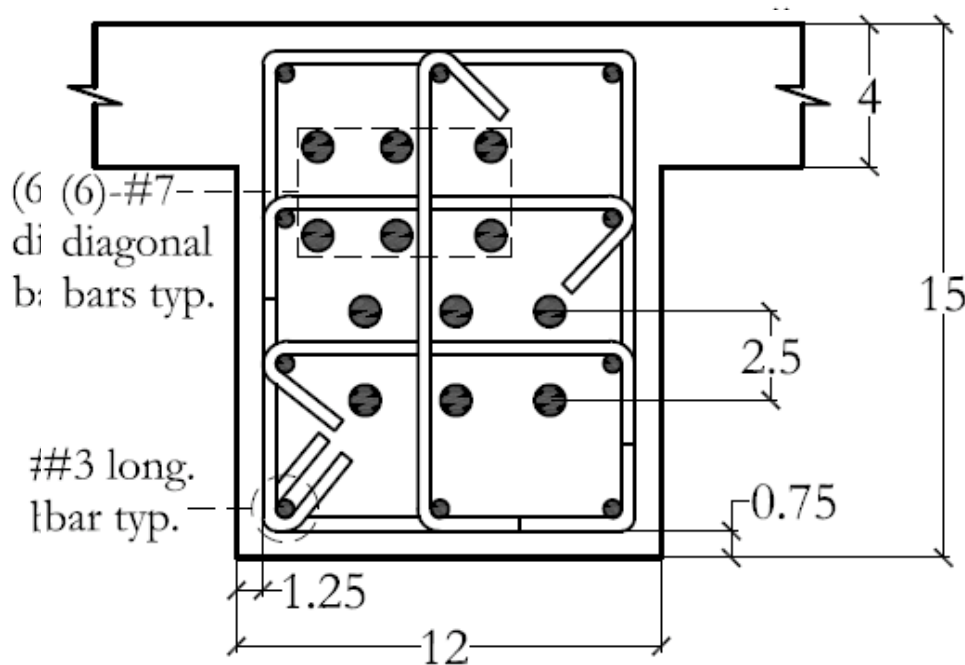
Full Section Confinement

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 @ 3"	N.A.	6850			Full section confinement (ACI 318-08)
CB33D	3.33	12.3	#2 @ 2.5"	#3 @ 2.5"	6850			Diagonal confinement (ACI 318-05)

Test Beams: $l_n/b = 2.4$

■ CB24F (-RC,PT)

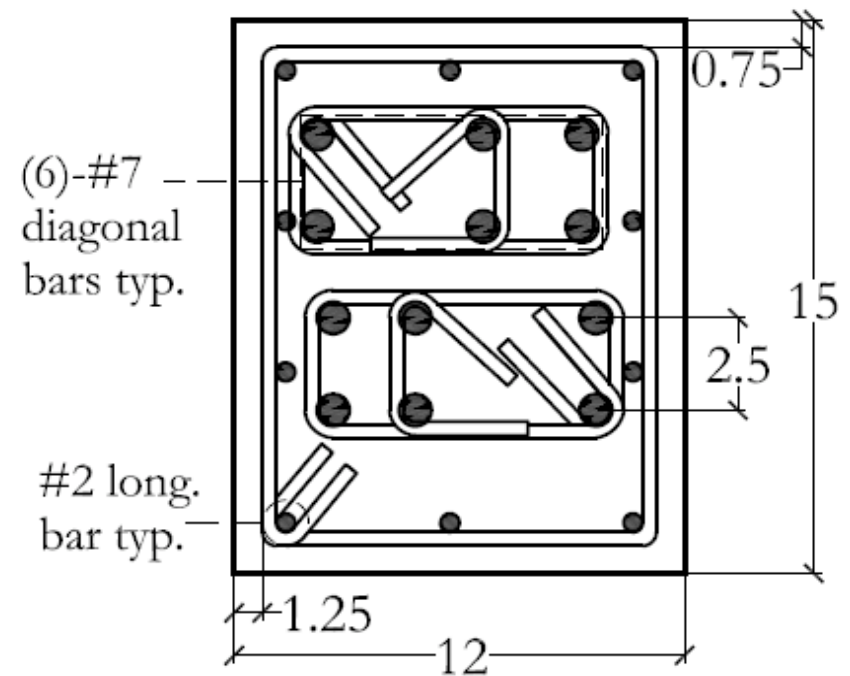
- ACI 318-08 (full)
- Shear stress =



Section AAA

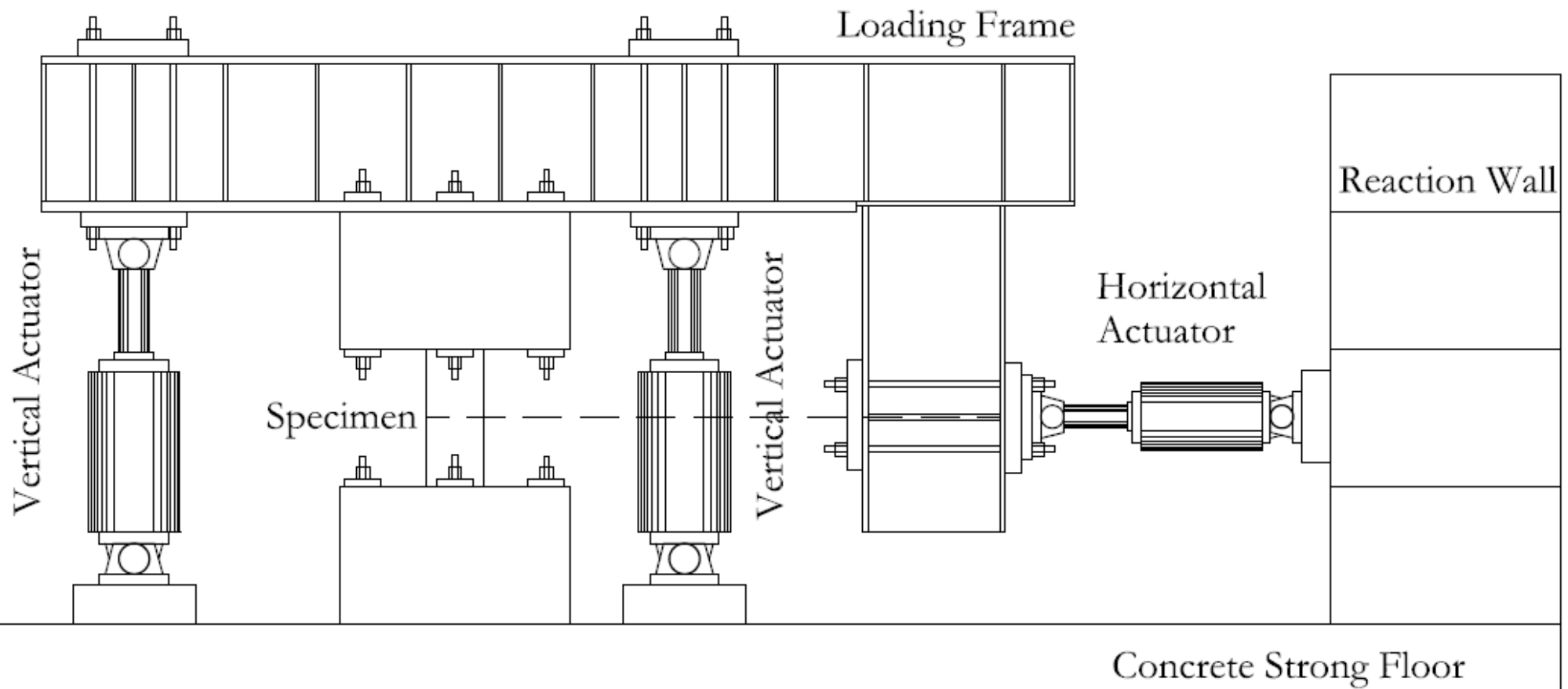
■ CB24D

- ACI 318-08 (diag.)
- Shear stress =



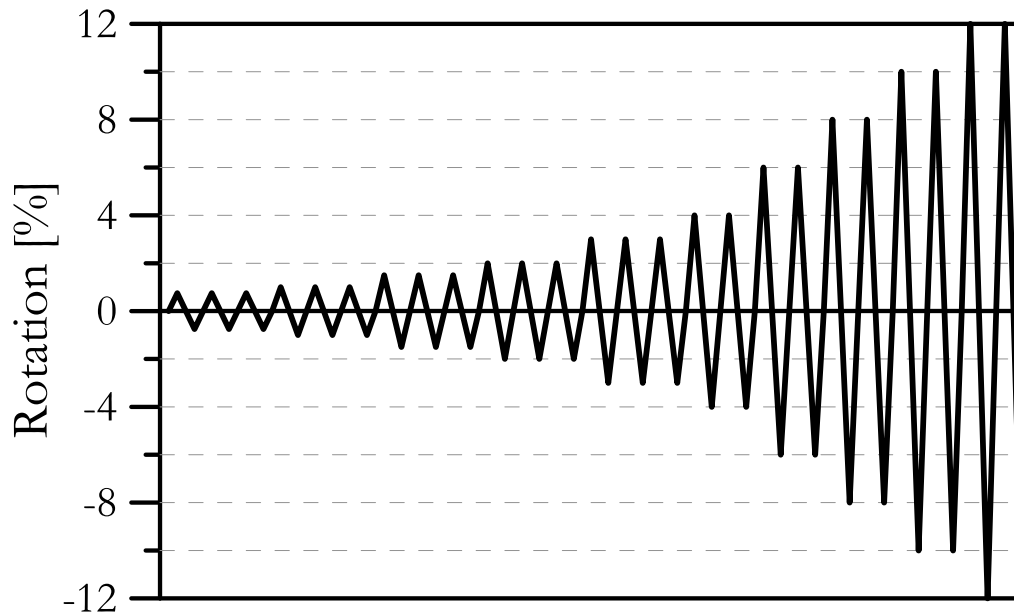
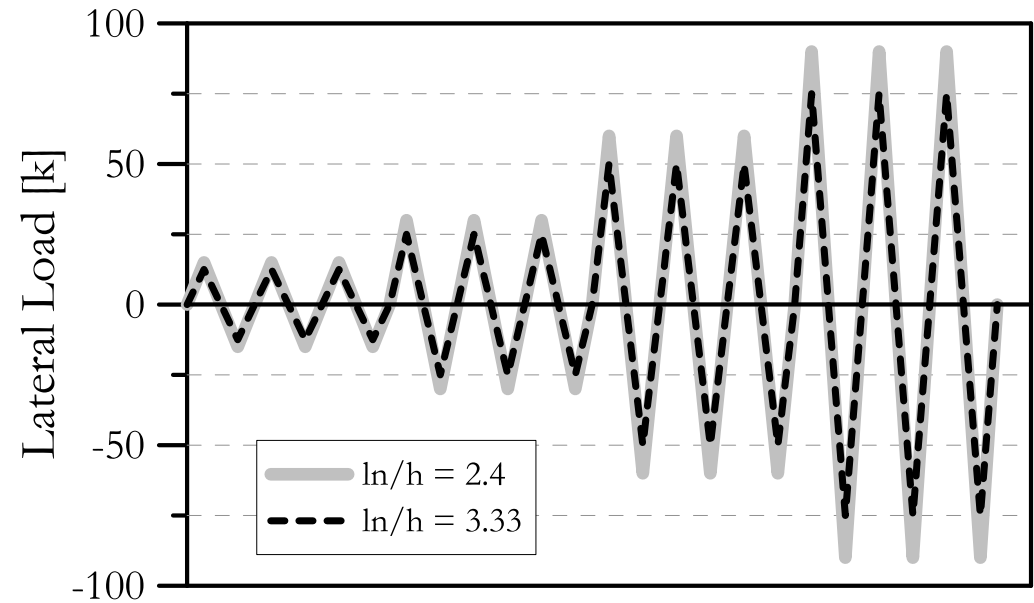
Section B-B

Laboratory test setup



Loading Protocol

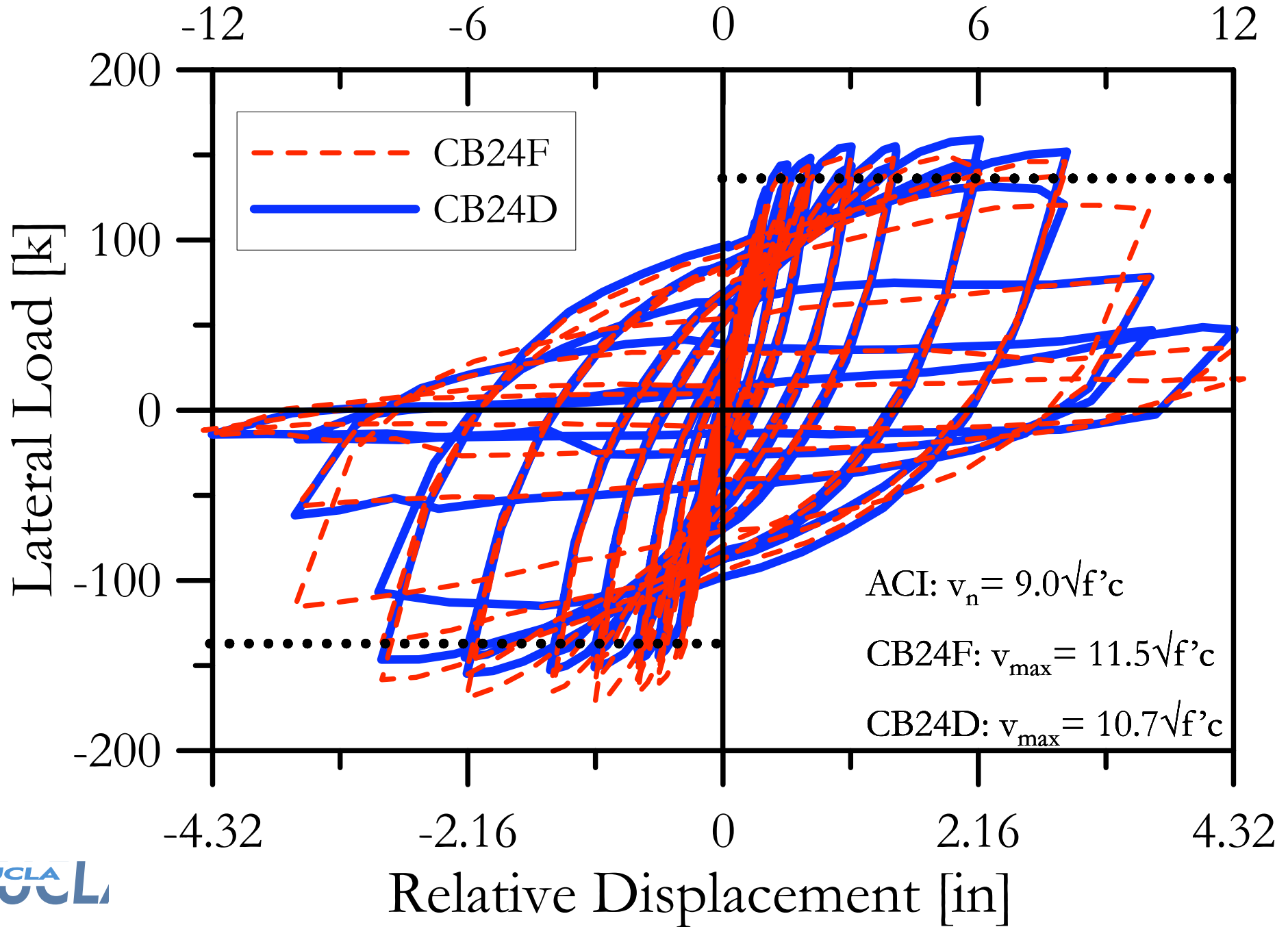
- Estimate for V_y based on $M-\phi$ analysis
- Load-controlled testing
 - 3 cycles each
 - $V_{lat} = 1/8*V_y, 1/4*V_y, 1/2*V_y,$ and $3/4*V_y$



- Displacement-controlled testing
 - 3 cycles each ($\Delta/l_n = \theta$)
 - $\theta = 0.75\%, 1.0\%, 1.5\%, 2.0\%,$ and 3.0%
 - 2 cycles each ($\Delta/l_n > CP$ for FEMA 356)
 - $\theta = 4.0\%, 6.0\%, 8.0\%, 10.0\%,$ and 12.0%

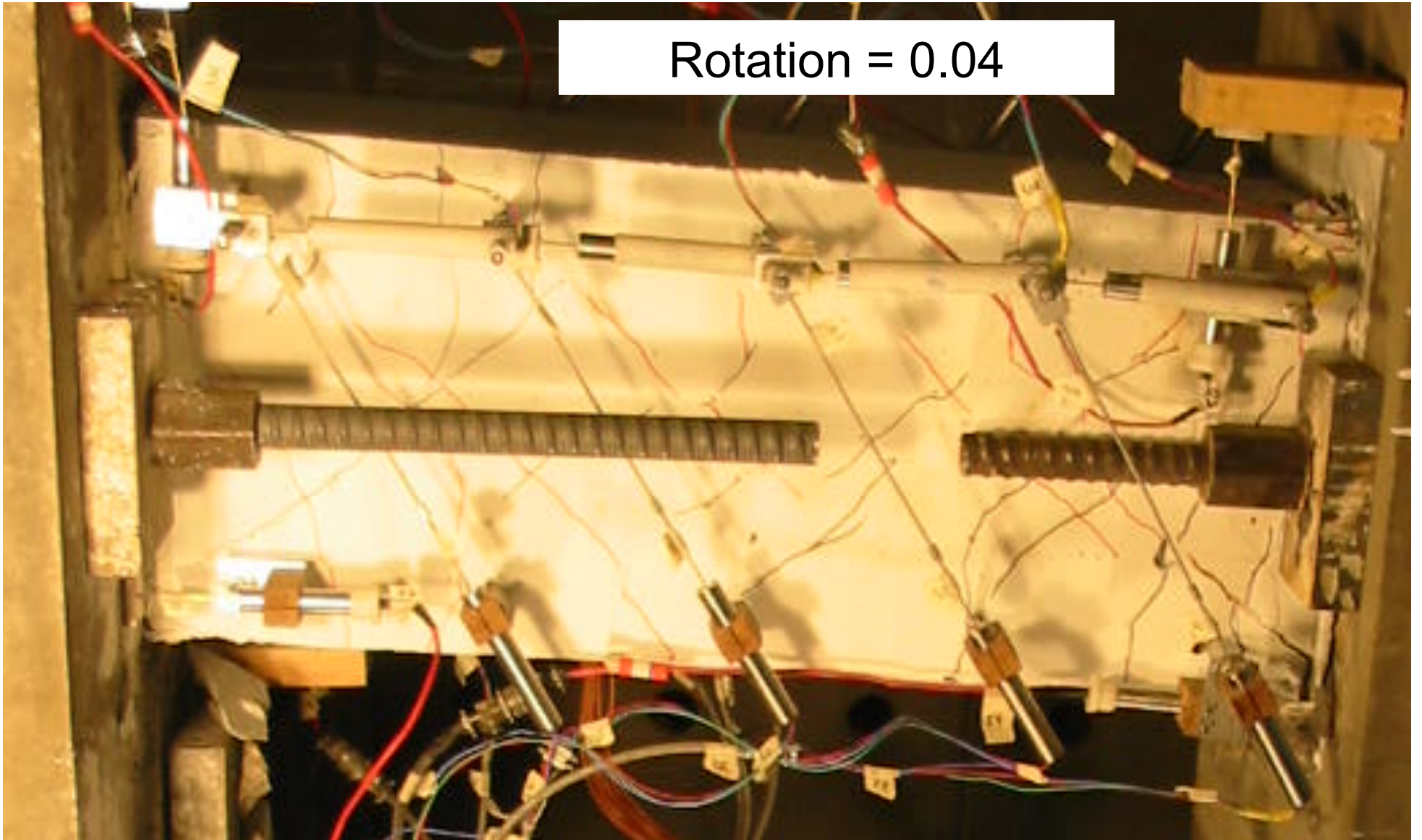
Load-Deformation

Rotation [% drift]



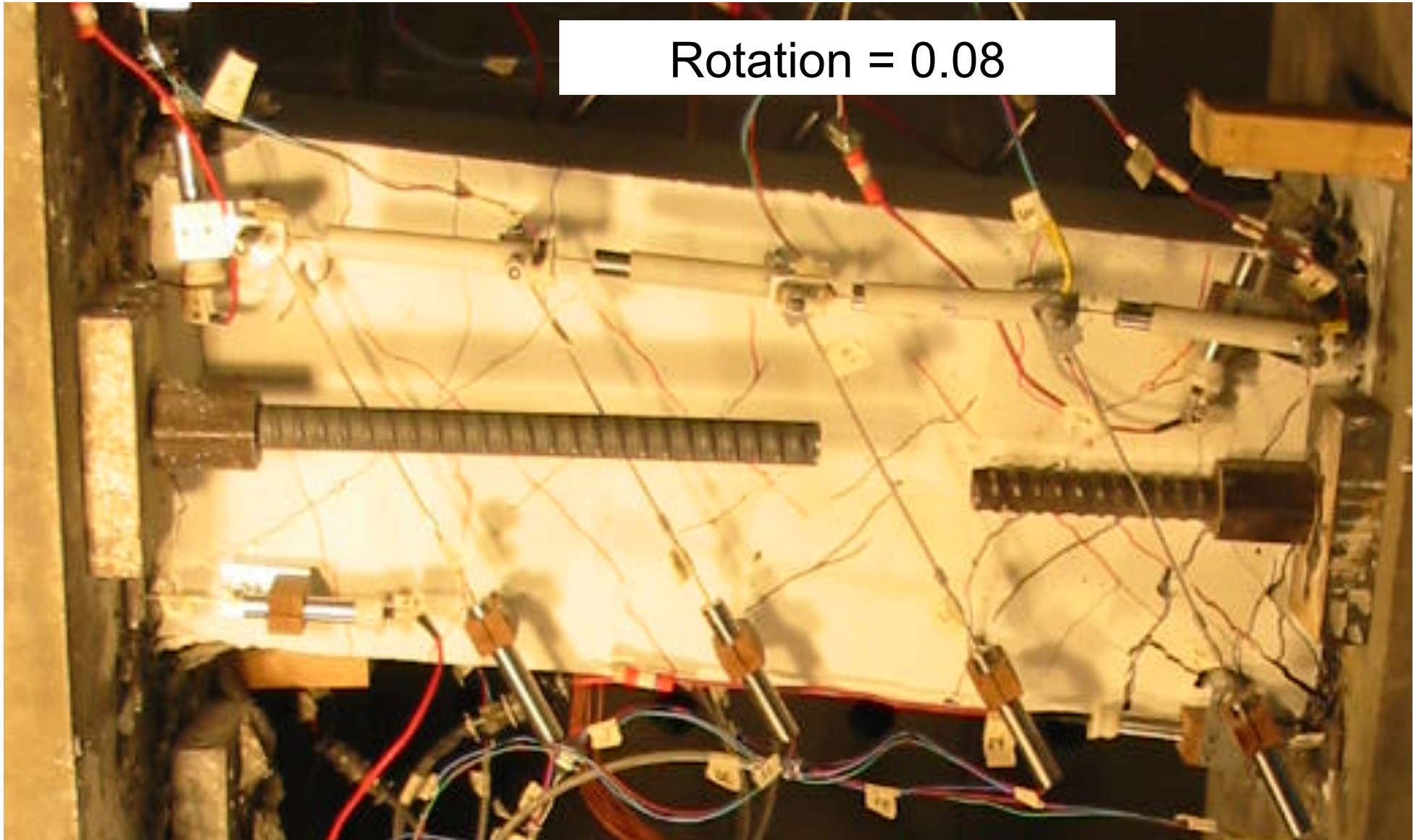
CB24F

Rotation = 0.04



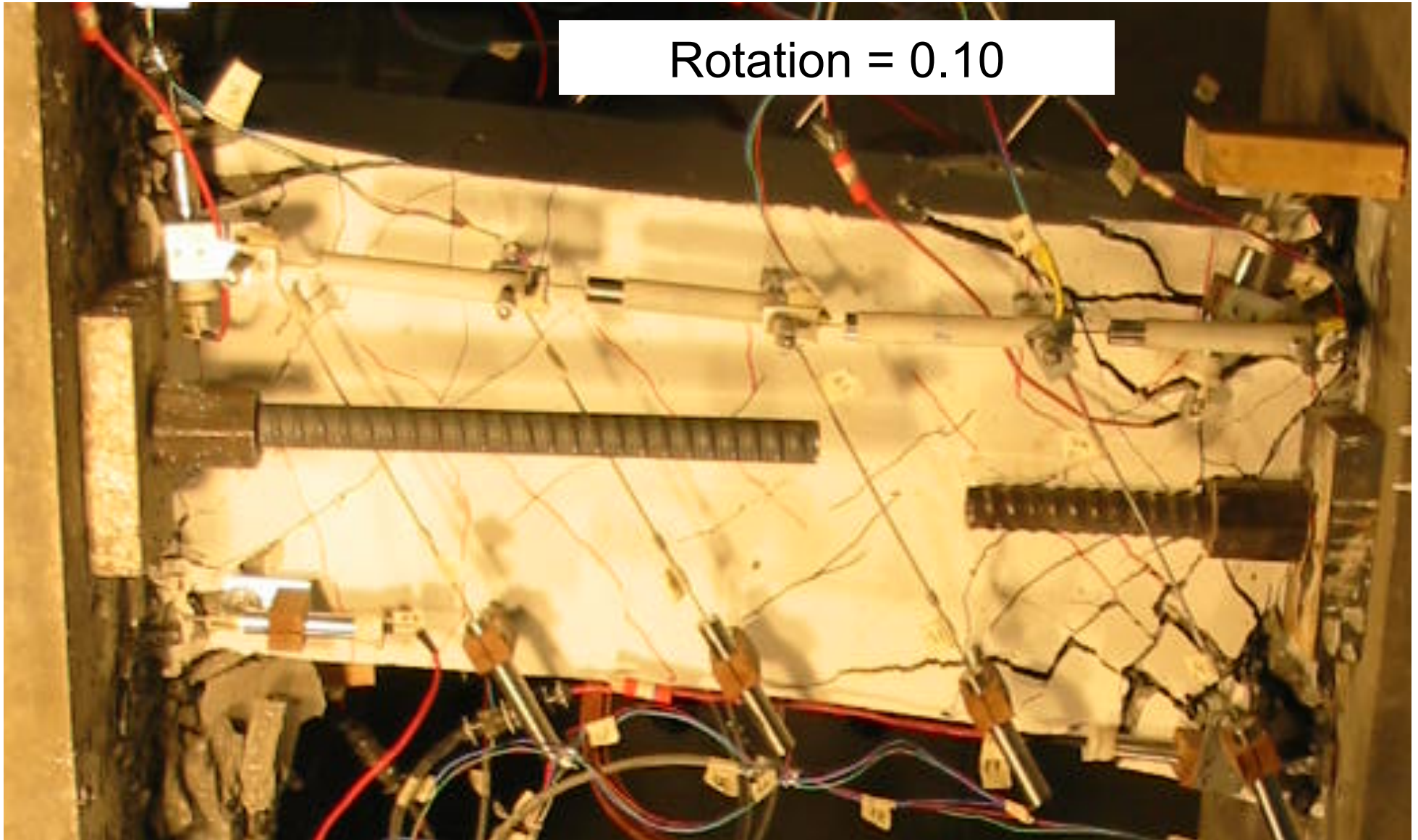
CB24F

Rotation = 0.08



CB24F

Rotation = 0.10



NEES Remote Data Viewer

File Control View Window Help

Beginning Real time Play End Playback rate: 50.0 Time scale: 1.0 d

2008-01-25 09:53:32.365 PST

2008-01-24 13:24:26.018 PST

22.1 h

2008-01-25 11:33:44.296 PST

Channels

- Camera1
 - video.jpg
- Camera2
 - video.jpg
- Overhead View
- UCLADAQ
 - CurvBot
 - CurvTop
 - Disp
 - Load
 - Moment
 - SlipRotTopNorth
 - SlipRotTopSouth

Properties

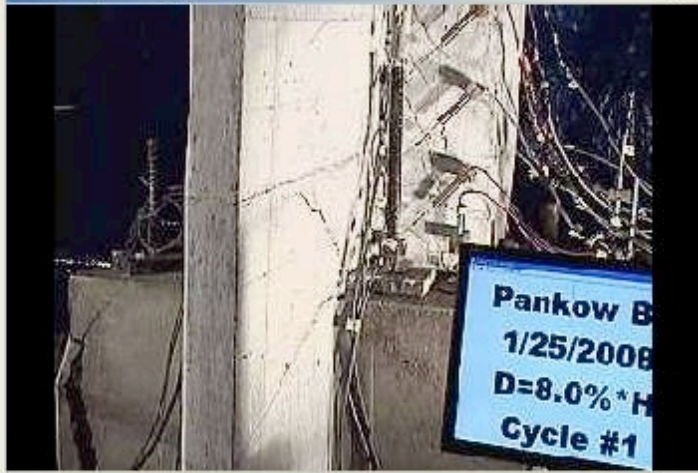
UCLADAQ/Moment (kips-in)
Numeric Data

Begins Thursday, January 24, 2008 1:27:23.841 PM
 Lasts 22.0 h
 8 bytes

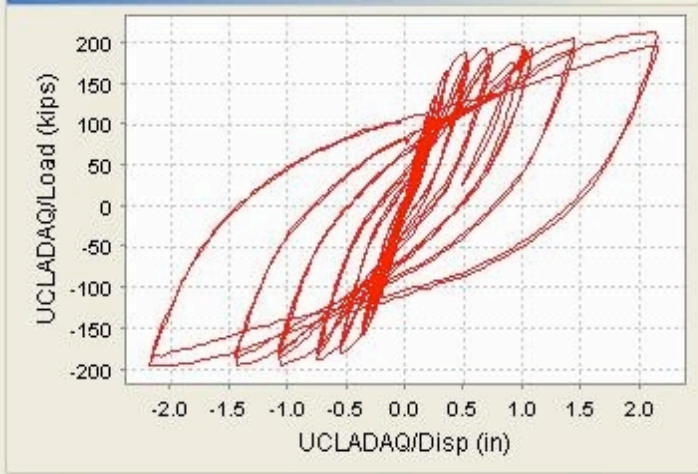
Camera1/video.jpg



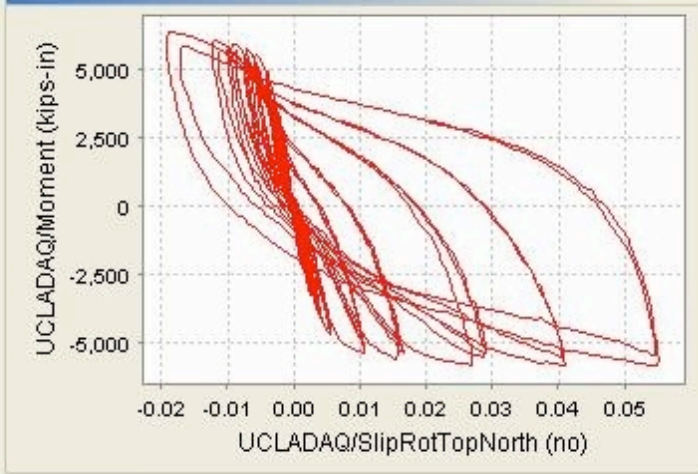
Camera2/video.jpg



UCLADAQ/Disp vs. UCLADAQ/Load

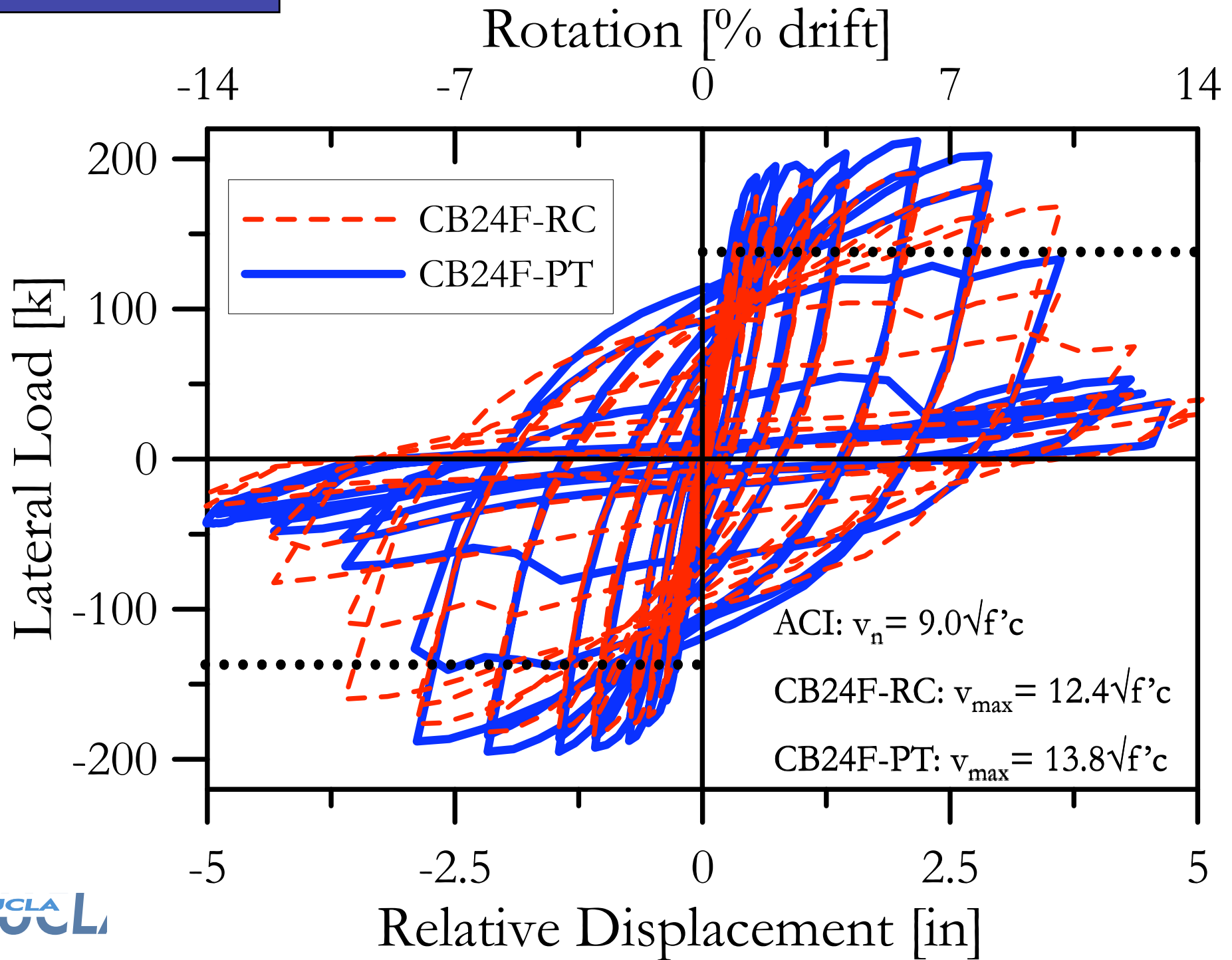


UCLADAQ/SlipRotTopNorth vs. UCLADAQ/Moment

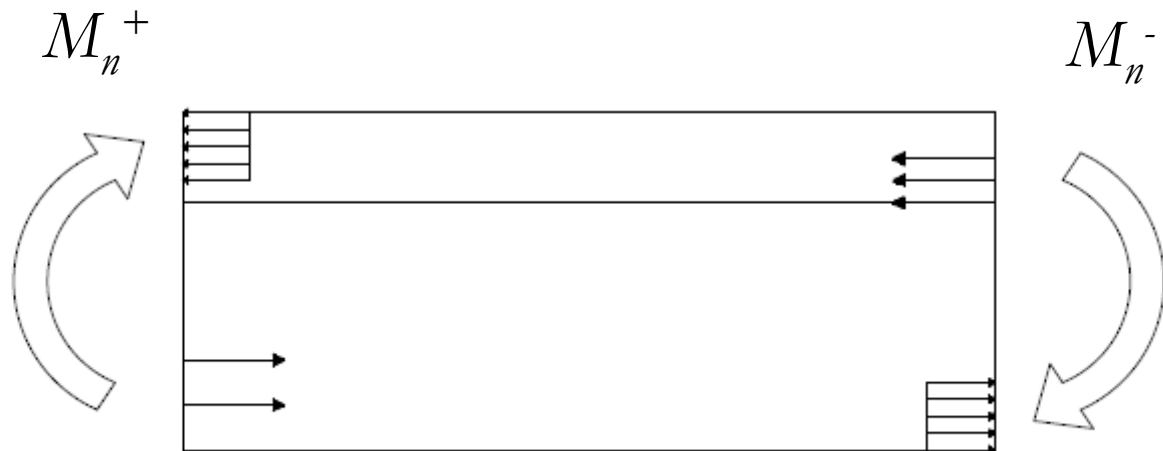
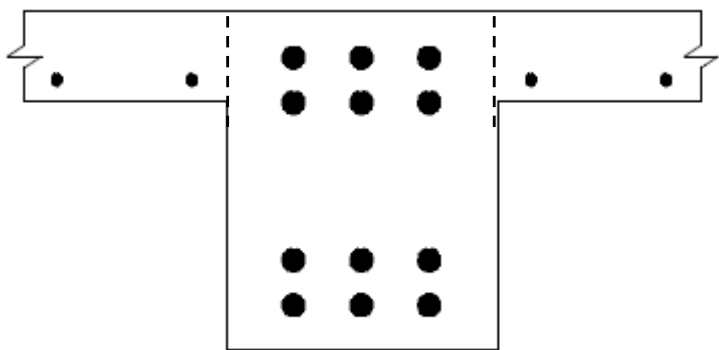


Event Marker Panel

annotation Submit



**Moment-Curv.
Slab v. No Slab**

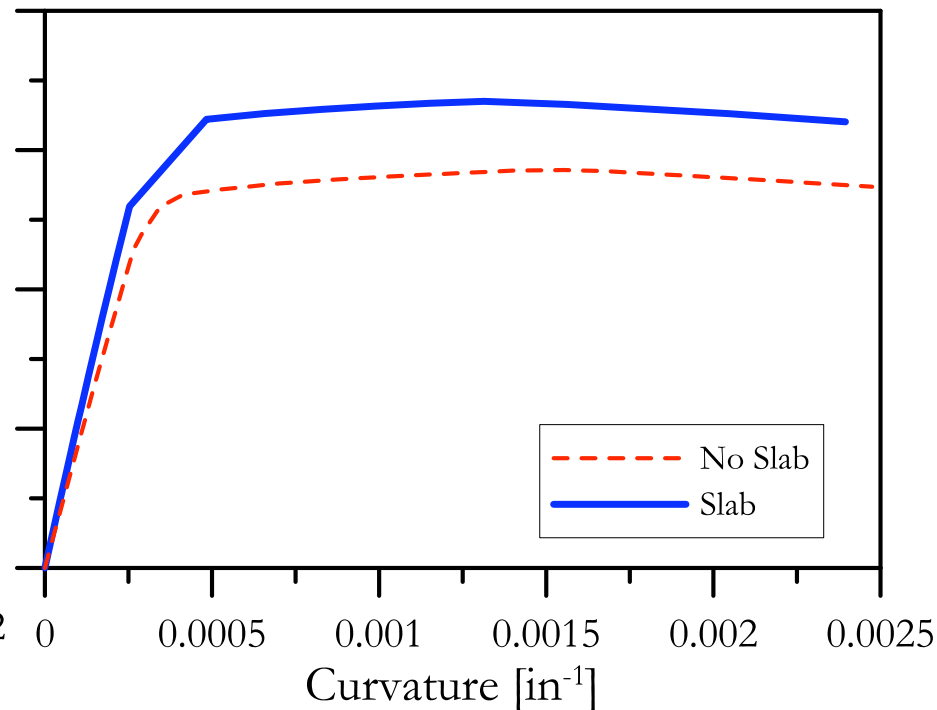
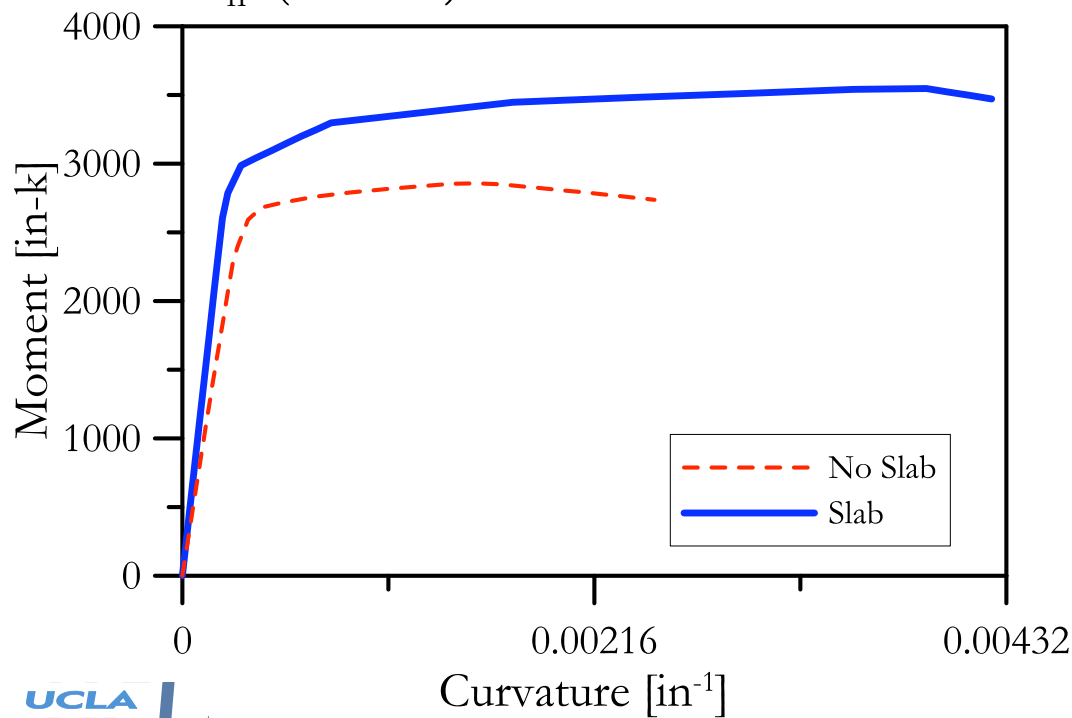


$$M_n^+ (\text{slab}) = 3550 \text{ in-k}$$

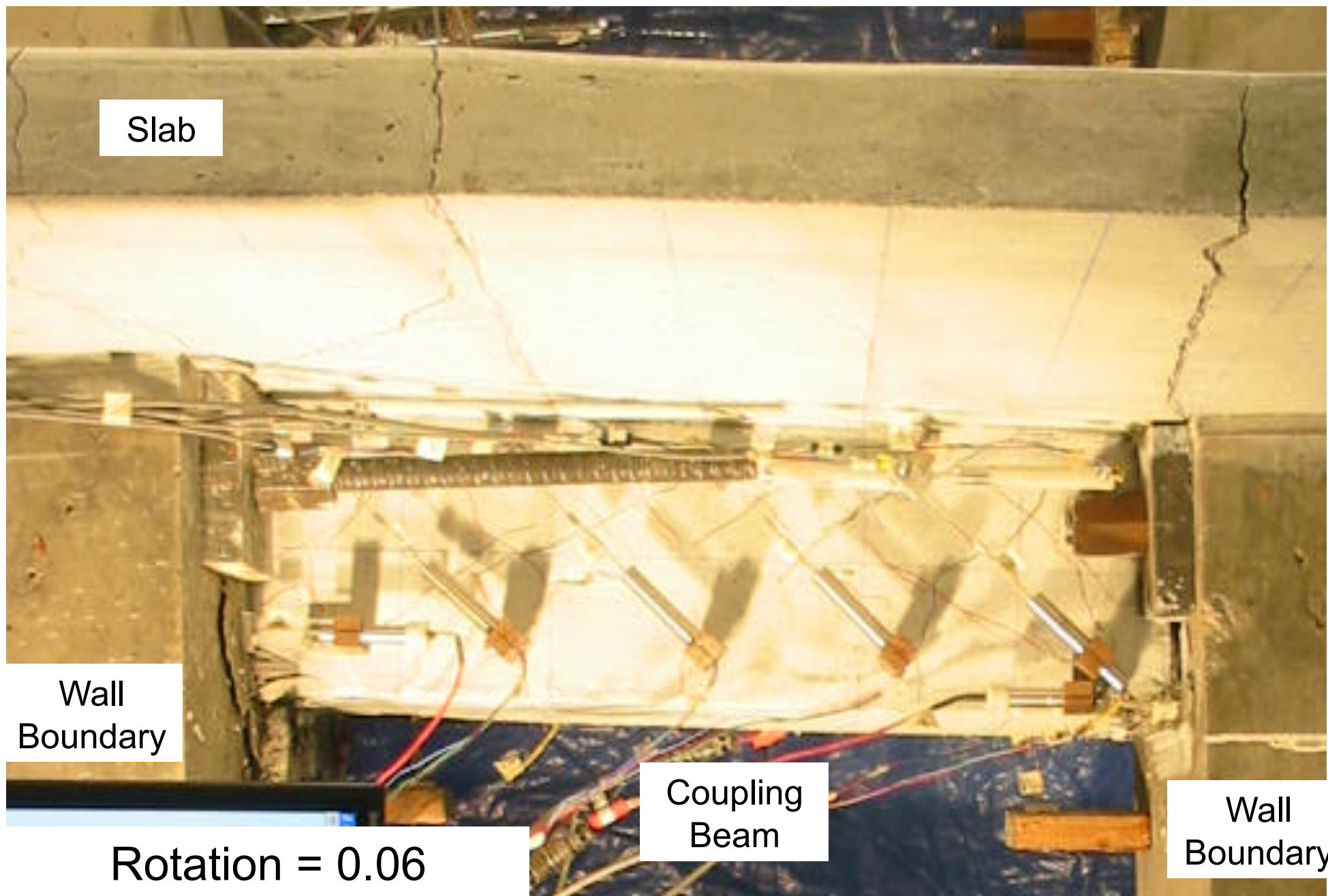
$$M_n^- (\text{slab}) = 3350 \text{ in-k}$$

$$M_n^+ (\text{no slab}) = 2850 \text{ in-k}$$

$$M_n^- (\text{no slab}) = 2850 \text{ in-k}$$



CB24F-PT



Slab

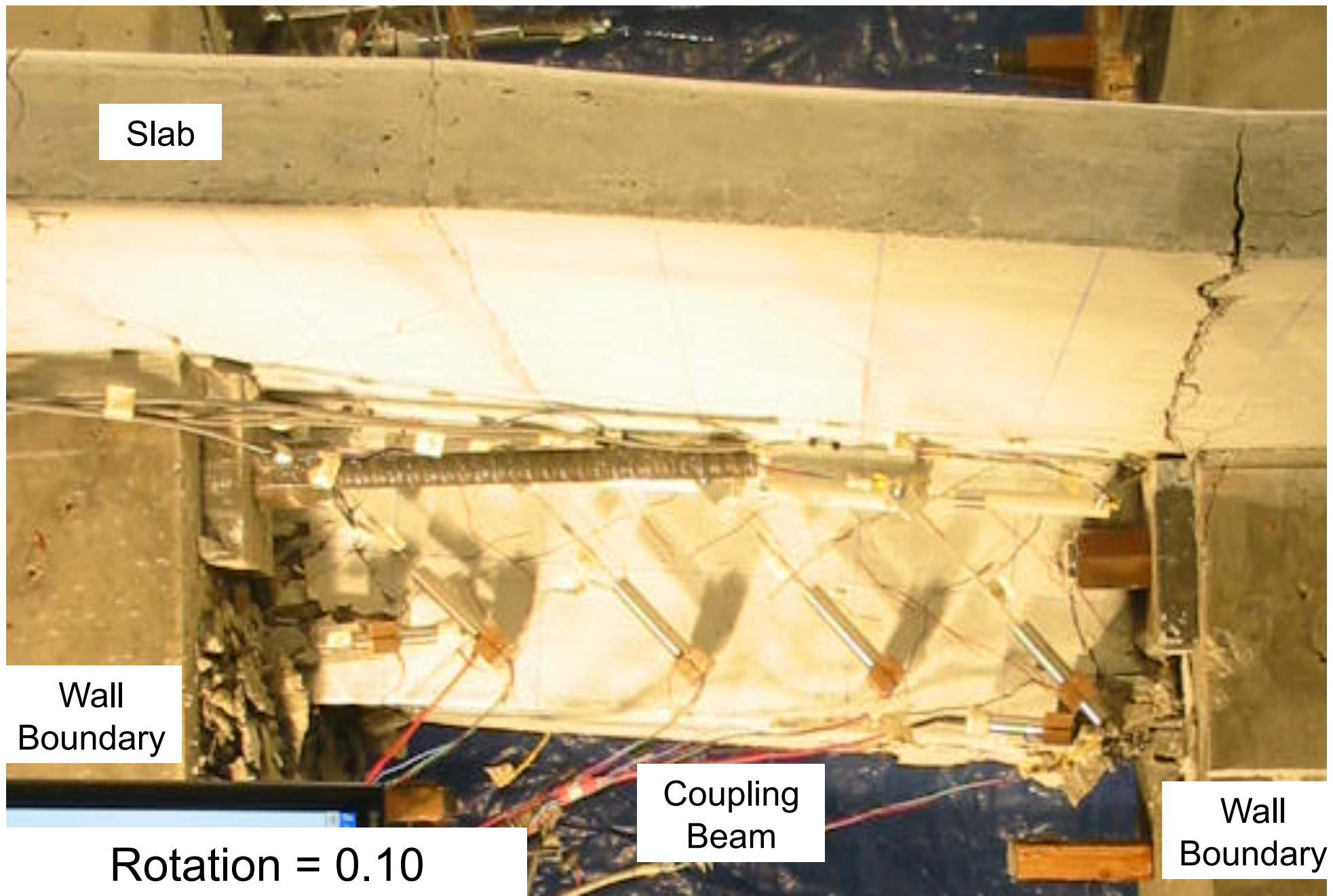
Wall
Boundary

Coupling
Beam

Wall
Boundary

Rotation = 0.06

CB24F-PT



CB24F-PT

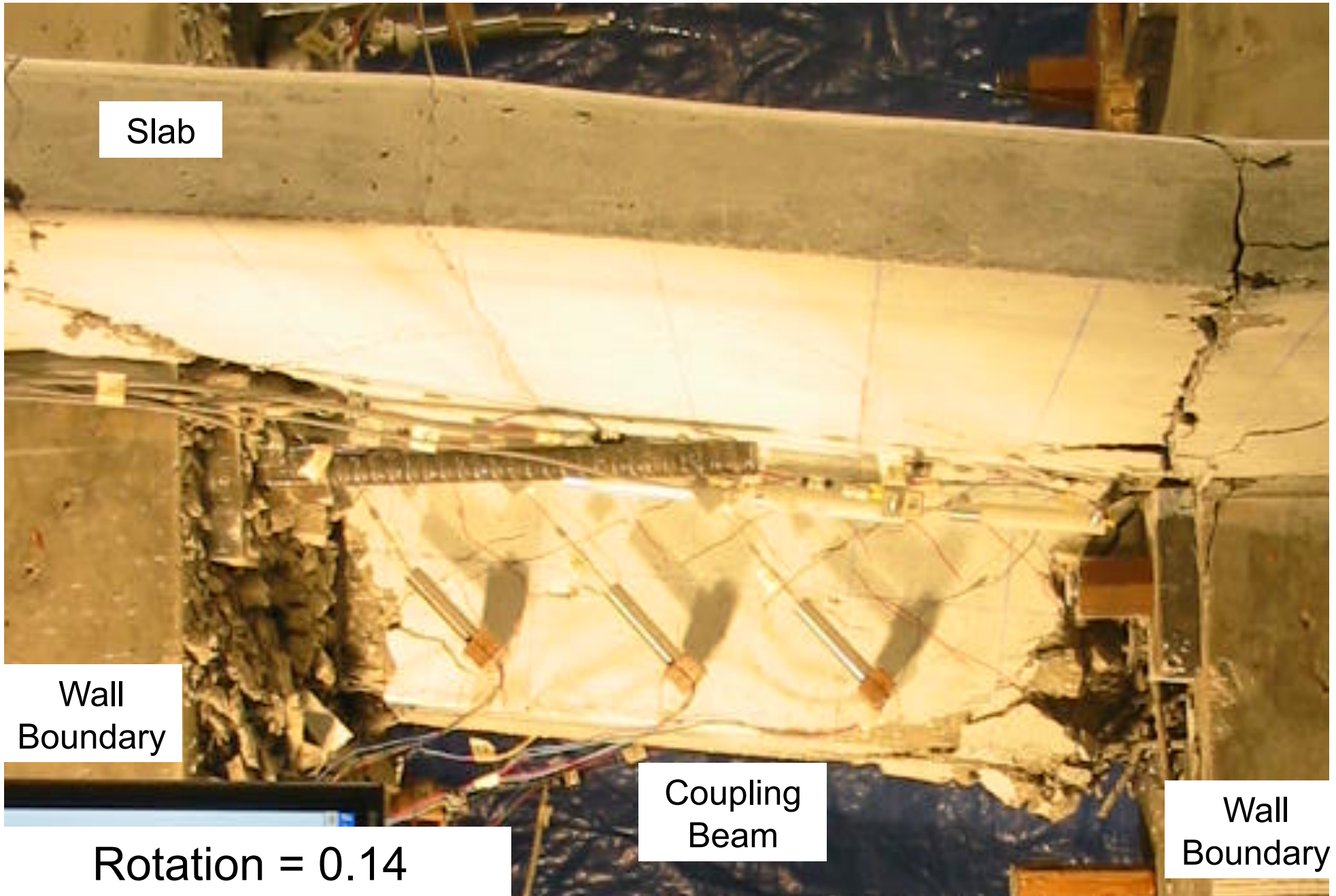
Slab

Wall
Boundary

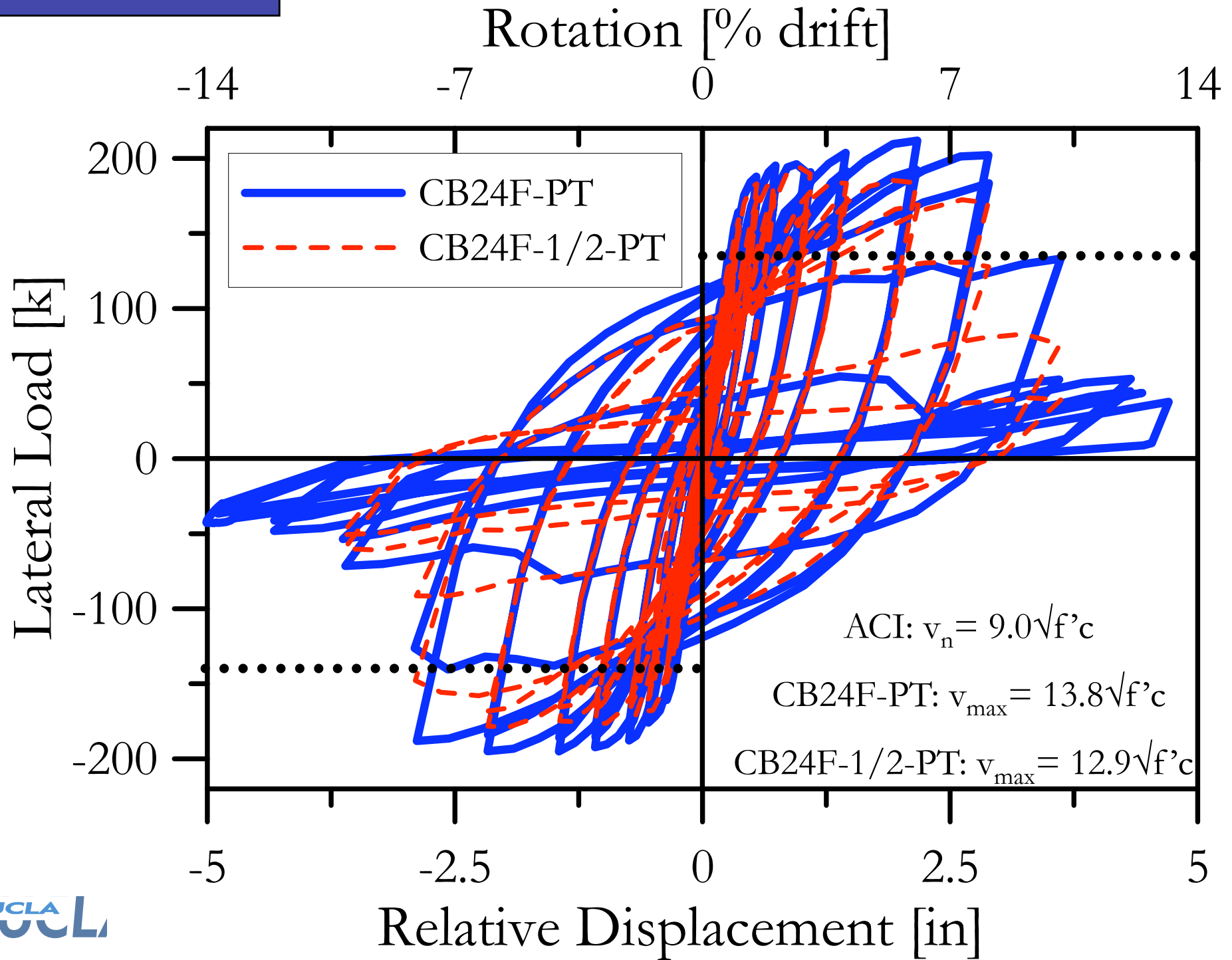
Coupling
Beam

Wall
Boundary

Rotation = 0.14



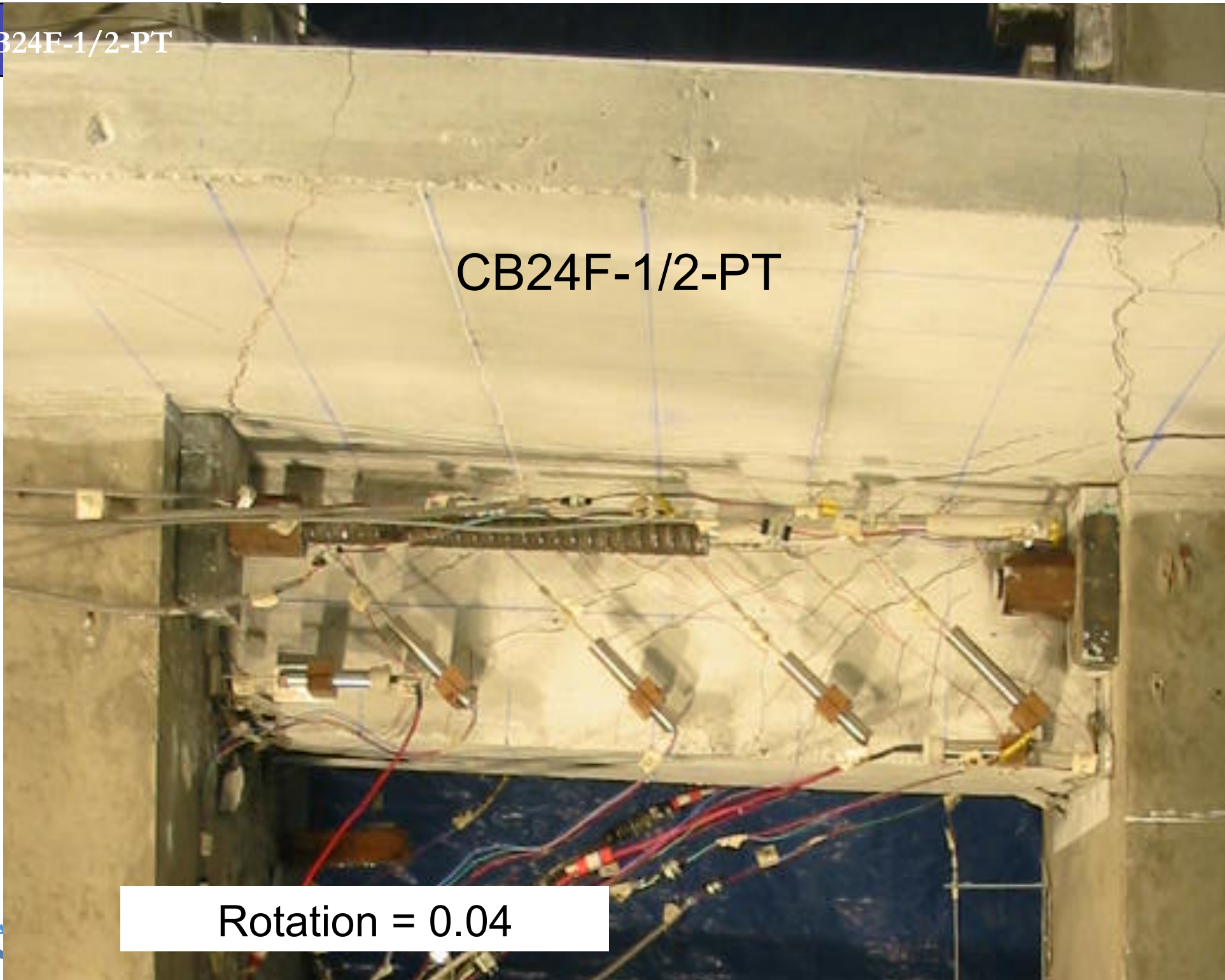
Load-Deformation



CB24F-1/2-PT

CB24F-1/2-PT

Rotation = 0.04



CB24F-1/2-PT

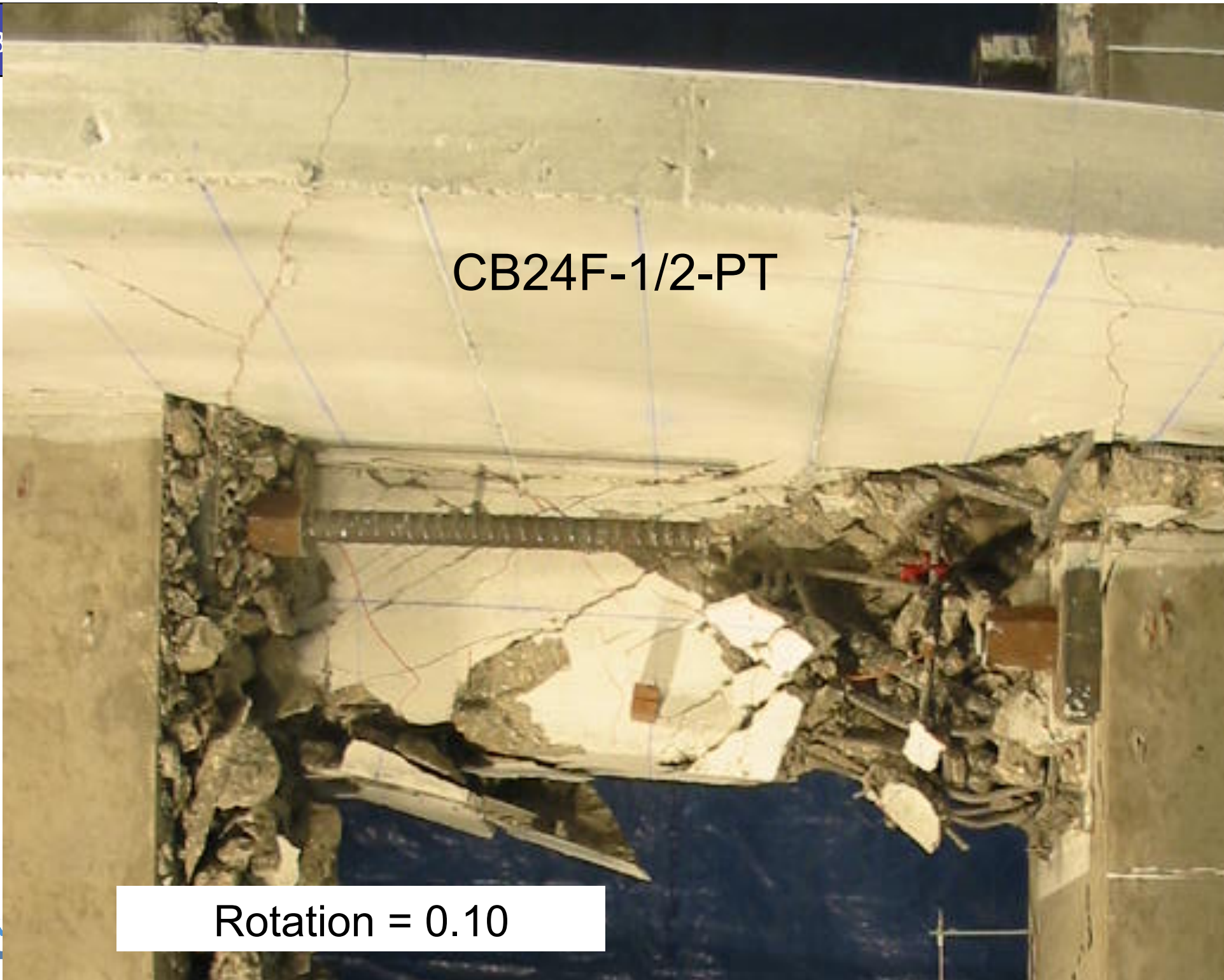
Rotation = 0.06

CB24F-1/2-PT

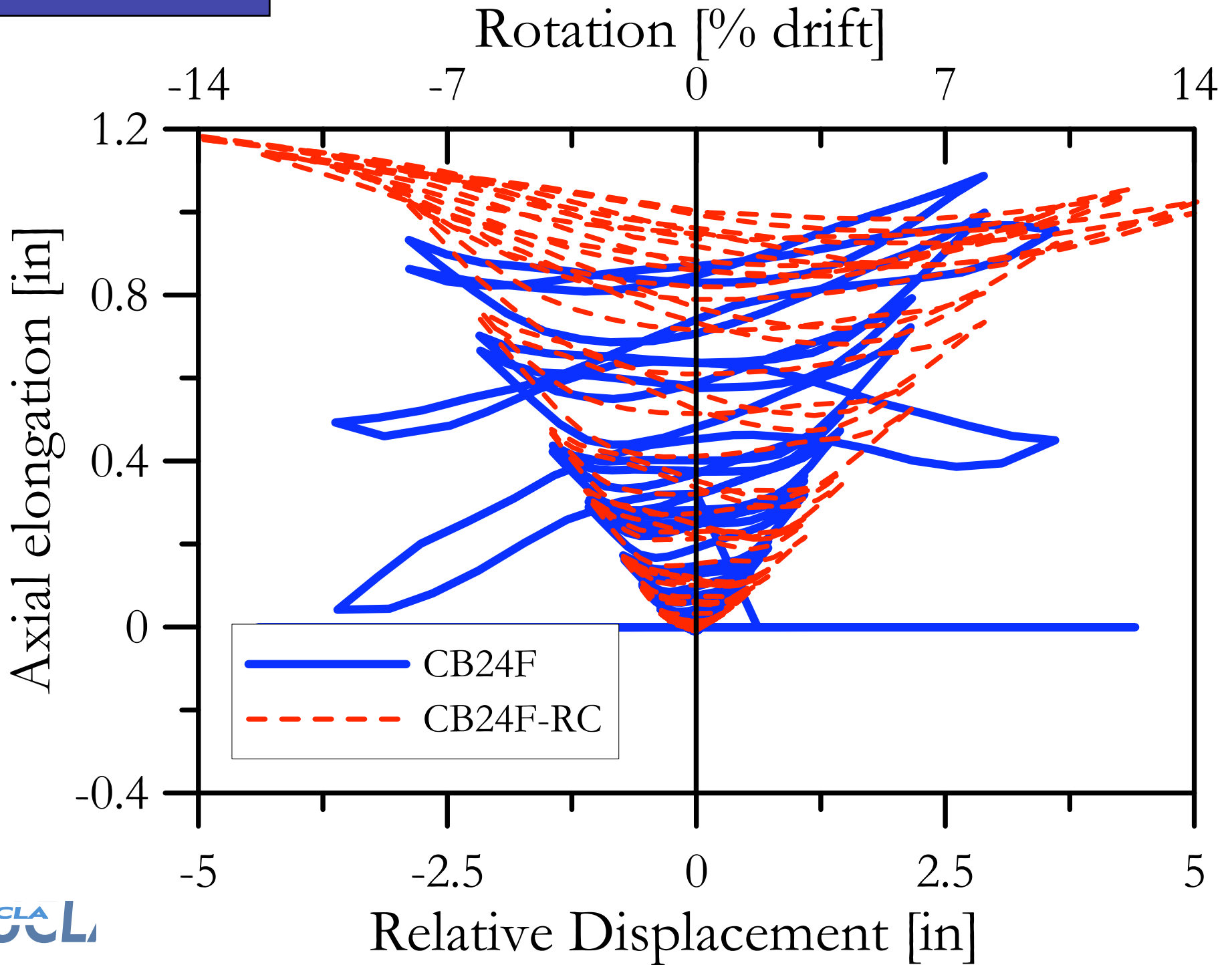
Rotation = 0.08

CB24F-1/2-PT

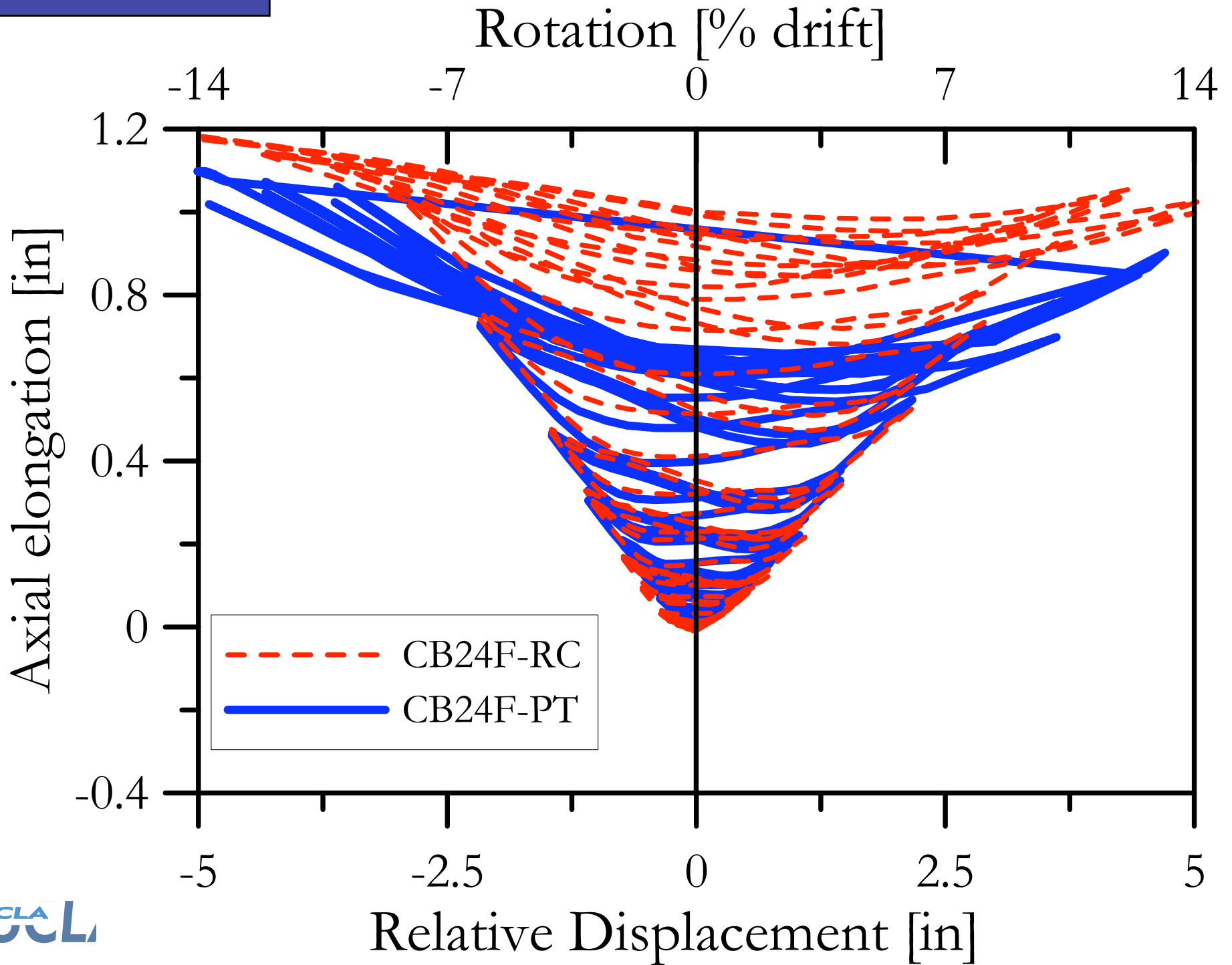
Rotation = 0.10



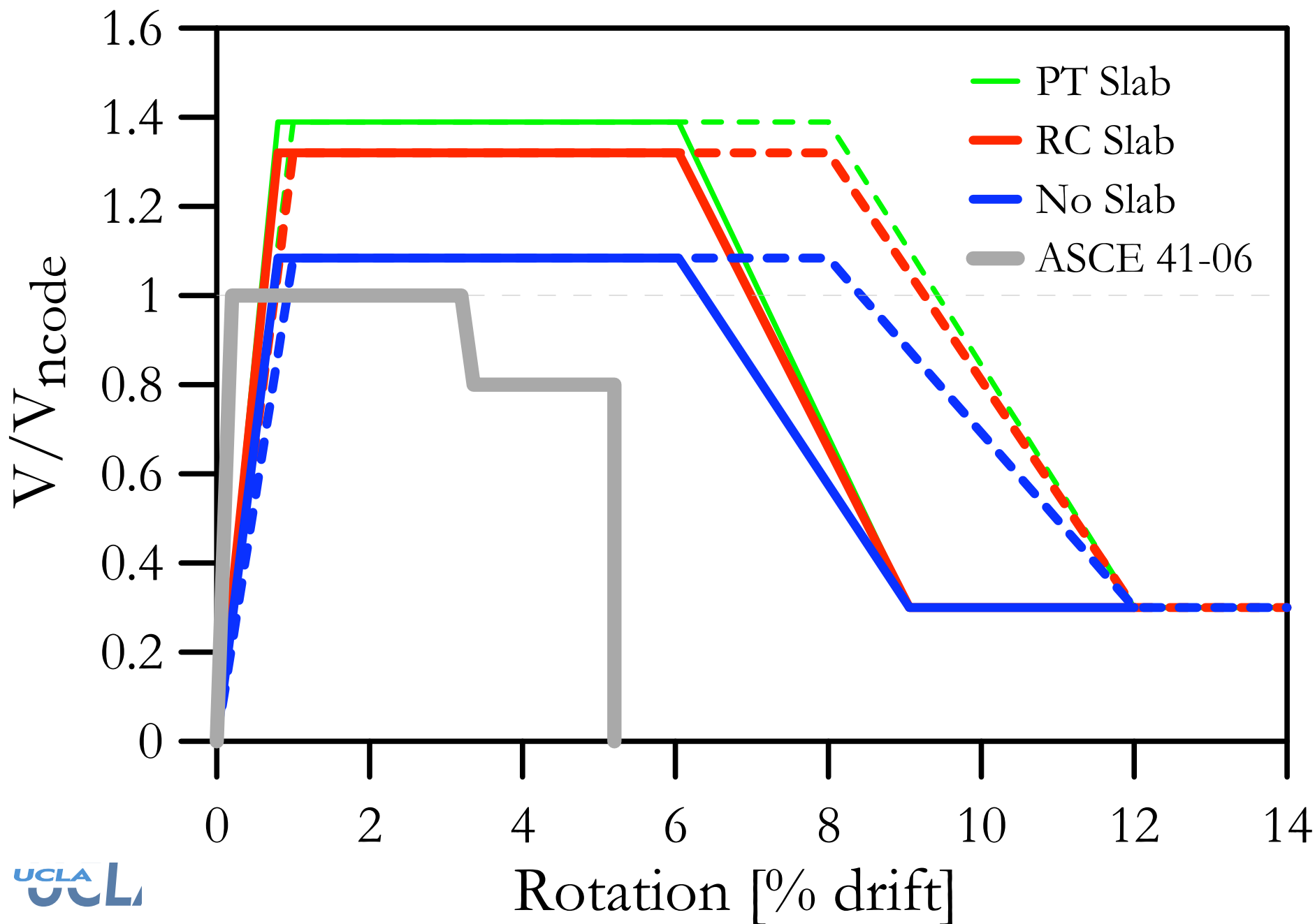
Axial Growth



Axial Growth



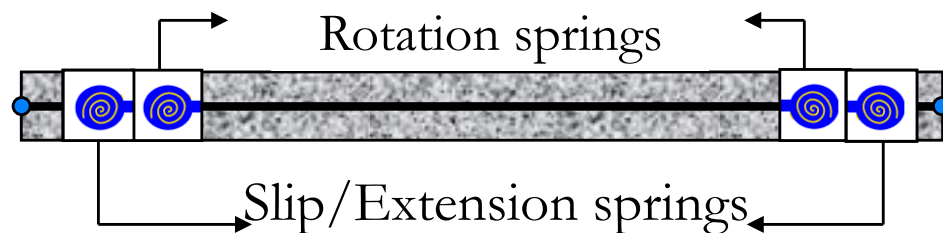
Load-Deformation
Backbone



Modeling – Perform 3D

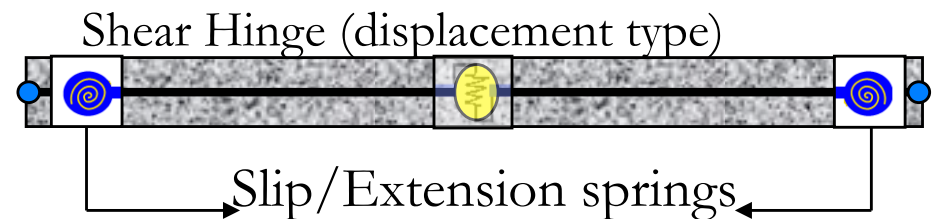
■ Frame Model

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



■ Shear Hinge Model

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



Modeling Parameters

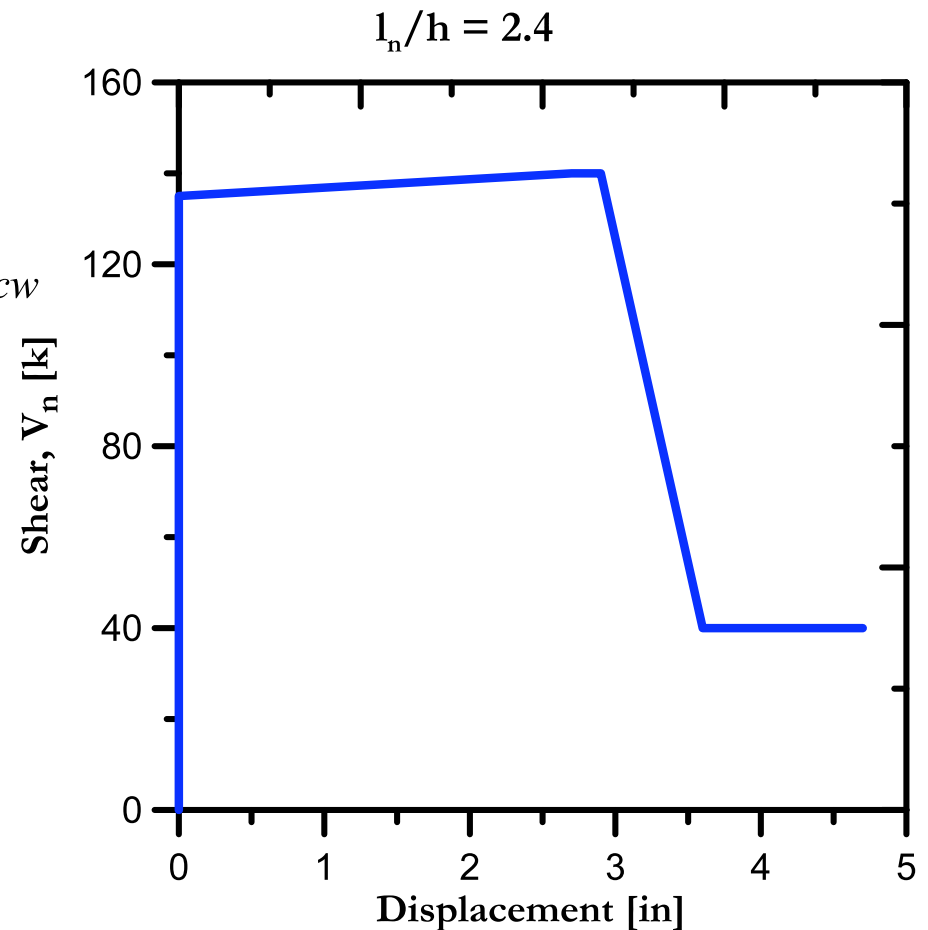
■ V_n - δ hinge

■ V_n ACI 318-08 Eq 21-9

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

■ 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

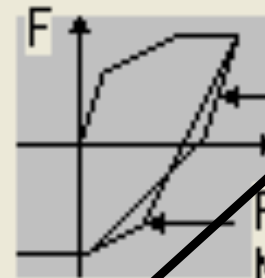
■ DR – 0.35

■ DX – 0.35

Unloading Behavior

Unloading Stiffness Factor Min -1
Max +1

This factor controls the unloading behavior for a trilinear F-D relationship. You can use Plot Loops to show the effect. See the User Guide for details.



Factor = +1. Max stiffness.
Min elastic range.

Factor = -1. Min stiffness.
Max elastic range.

Slip Hinge Calculations

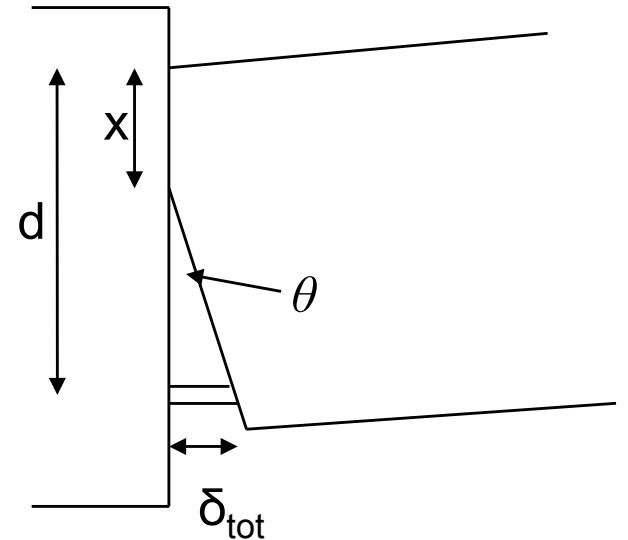
$$M - \theta_{@ \delta_{tot}}$$

At yield of tension reinforcement:

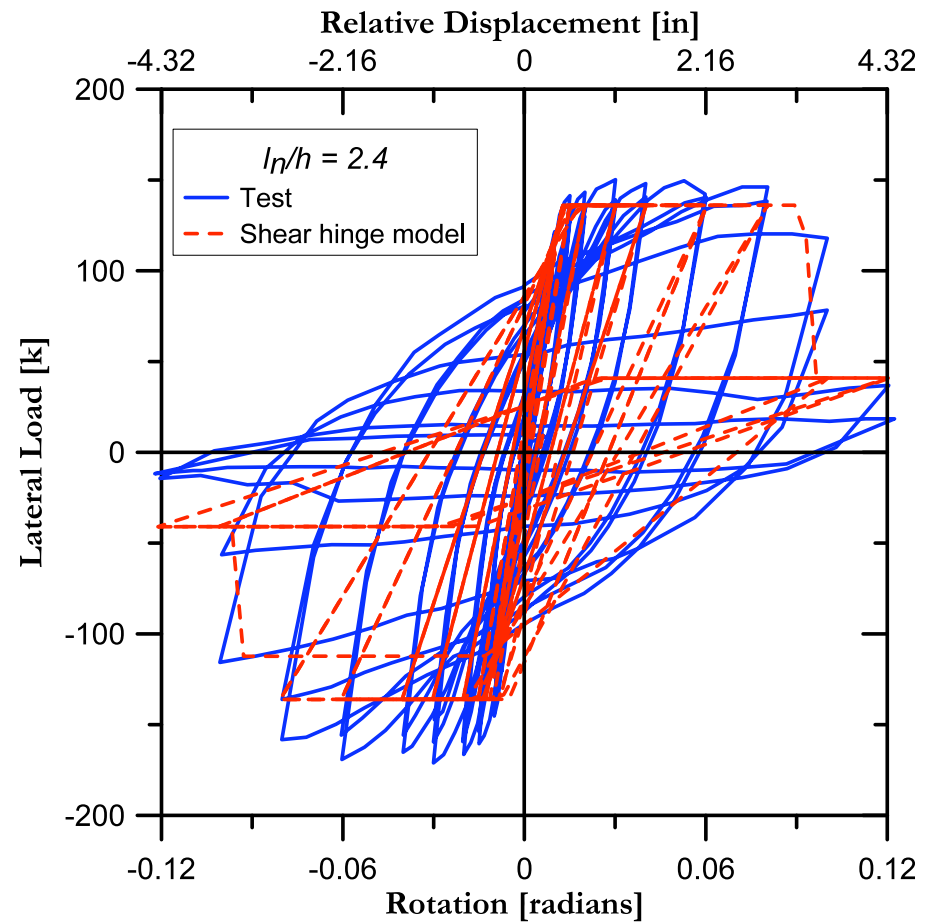
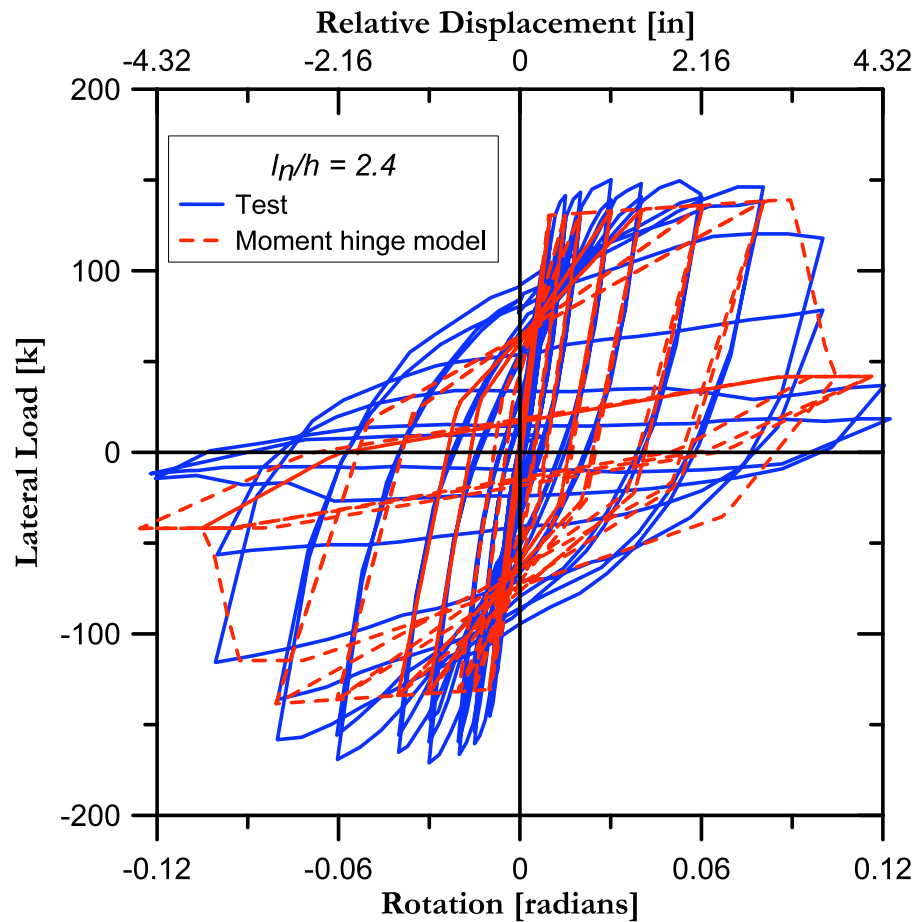
$$\theta_{@ \delta_{tot}} = \frac{\delta_{tot}}{d - x} = \frac{0.0417''}{12.625'' - 5''} = 0.00547$$

$$M_y = 2200in - k$$

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



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 $\sim 0.15 * EI_g$
- Simple nonlinear models can accurately capture load-deformation response
- New project to investigate SRC coupling beams [steel W-section, Steel plate]

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

<http://nees.ucla.edu>

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



EXPERIMENTAL EVALUATION AND
ANALYTICAL MODELING OF ACI 318-05/08
REINFORCED CONCRETE COUPLING BEAMS
SUBJECTED TO REVERSED CYCLIC LOADING

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