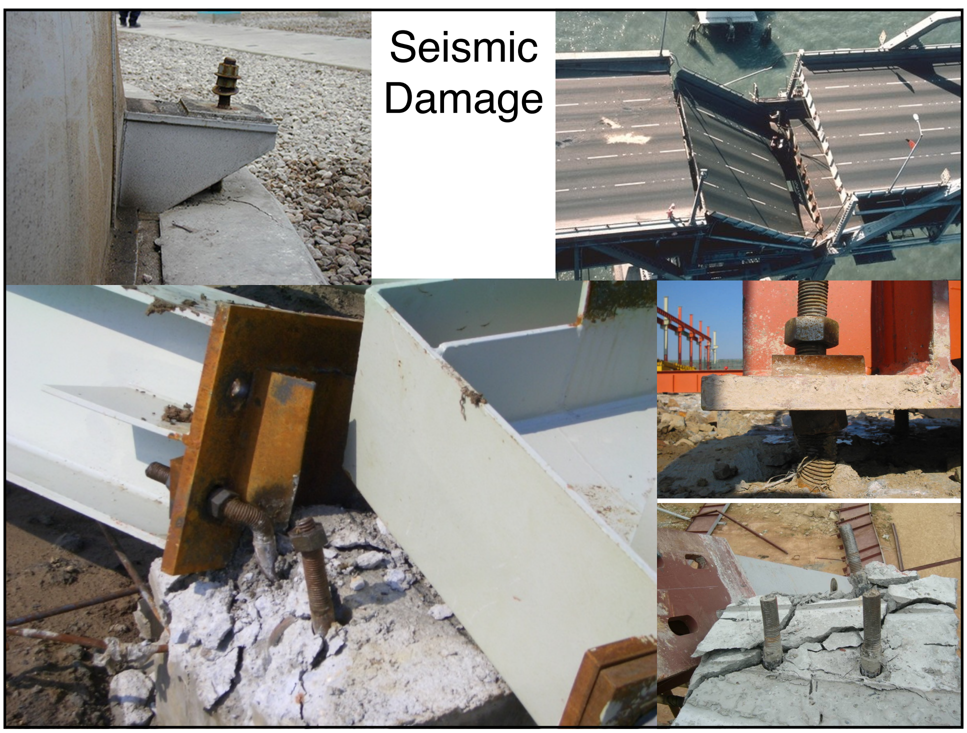
Fastening to Concrete

2. Seismic Behavior in Plain Concrete

Dr. Jian Zhao
University of Wisconsin, Milwaukee



Seismic Provisions

- – Seismic Design Category C, D, E & F
- – No anchors in plastic hinge
- – PI anchors must pass Simulated Seismic Test
- – Design strength reduced by 25%
- – Ductile steel failure of anchors shall control,

or...

- – Ductile yielding of attachment,

or...

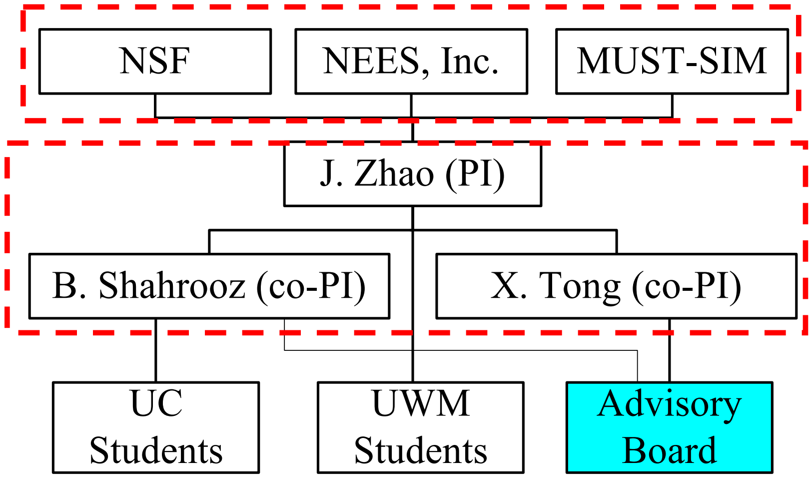
- – Anchor capacity reduced by 60%

3

NEES-Anchor Project Objectives

- Obtain detailed experimental data for cast-in-place anchors/studs under simulated seismic loadings.
- Focus the tests on cyclic shear and combined tension-shear.
- Evaluate the current seismic anchor design provisions and improve the design practices.
- Verify the proposed design methods and details by testing anchor connections: steel column-concrete foundation and girder-wall.

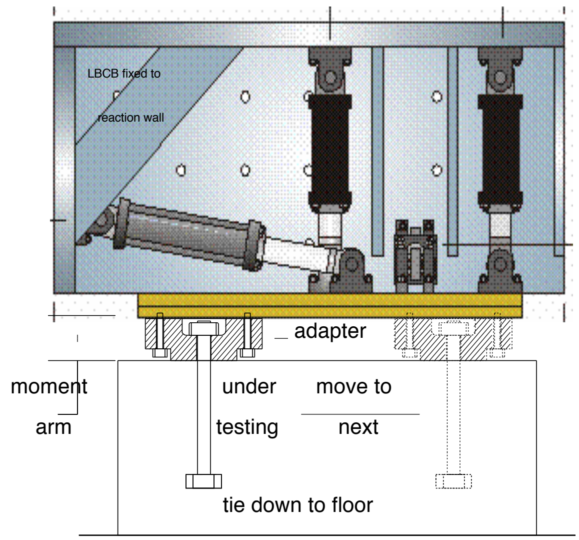
Project Team



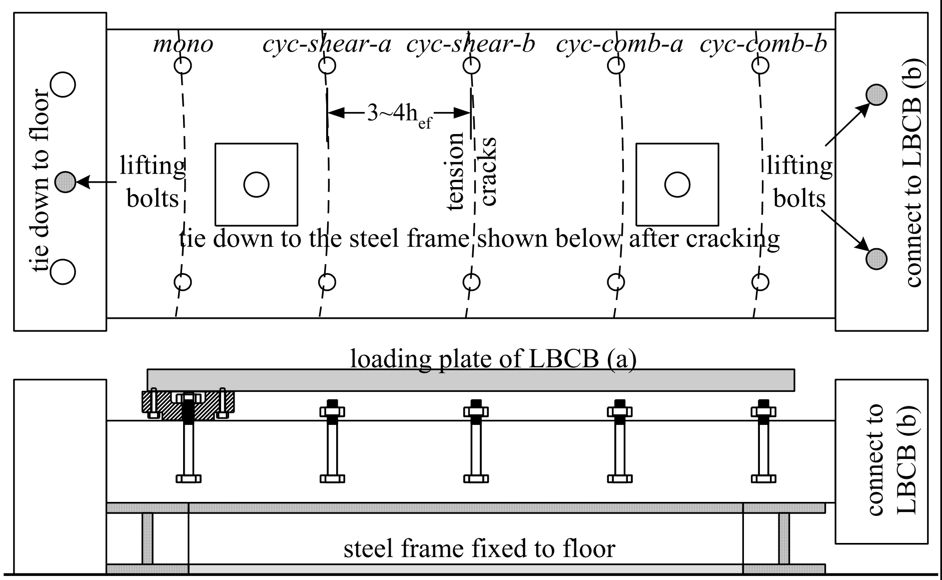
Experimental Program (Original)

- 1/5 scale tests
- Single anchor tests: uncracked concrete
- Single anchor tests: cracked Concrete
- Anchor connection tests

Single Anchors Tests



Cracked Concrete



NEES-Anchor Tests (Actual Plan)

- 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)

NEES-Anchor Project

Jian Zhao, University of Wisconsin, Milwaukee (UWM)

Bahram Shahrooz, University of Cincinnati (UC)

Xiangdong Tong, Jinhuan Manufacturing Group

Derek Petersen, UWM graduate student

Zhibin Lin, UWM Post-doc

Luke Butler, UC graduate student

16 undergraduate students

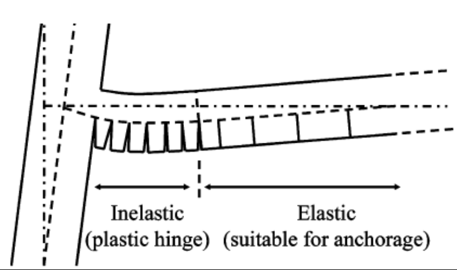
Review of Previous Studies

11

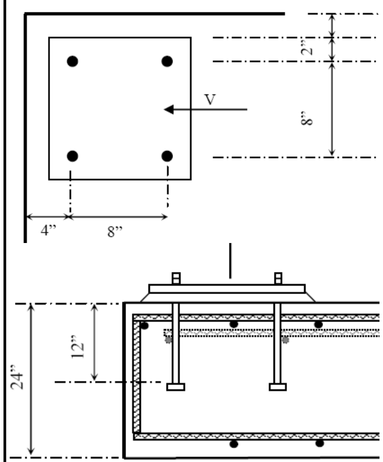
Code for Seismic Design

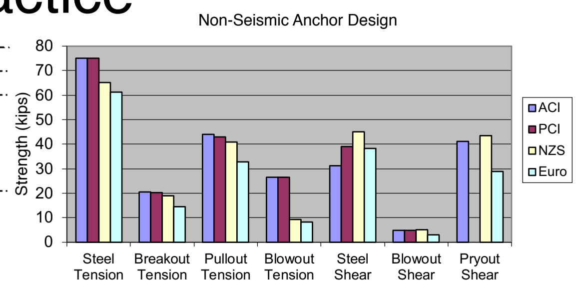
- ACI provisions do not apply to the design of anchors in plastic hinge zones.
- A 0.75 factor is applied on the design strength ϕN_n and ϕV_n for concrete failure modes
- Design shall target at ductile steel failure
- Capacity design permitted that member fails before the anchor connection
- More conservative for concrete failure modes

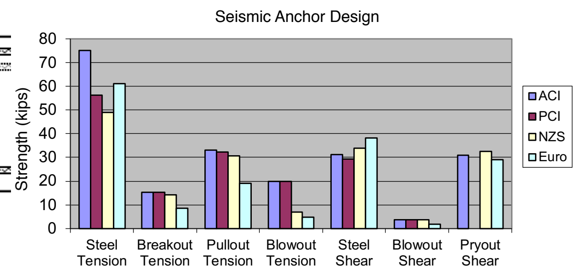
Hoehler (2001)



Current Practice







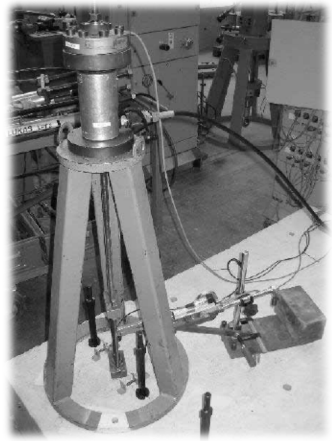
Strength Reduction Factors

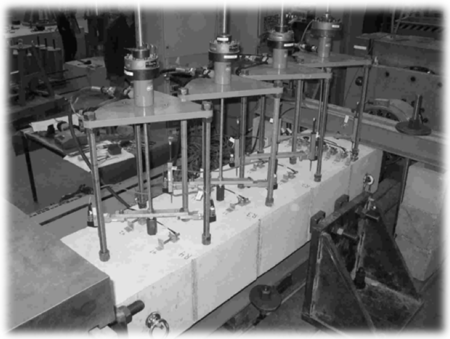
- Strength Reduction Factors for Concrete Breakout in Tension

	ACI 318-08	CEB 1997	NZS 3101 2006	PCI 6th Edition
Strength Reduction	.7	.555	.65	.7

Cyclic Tension

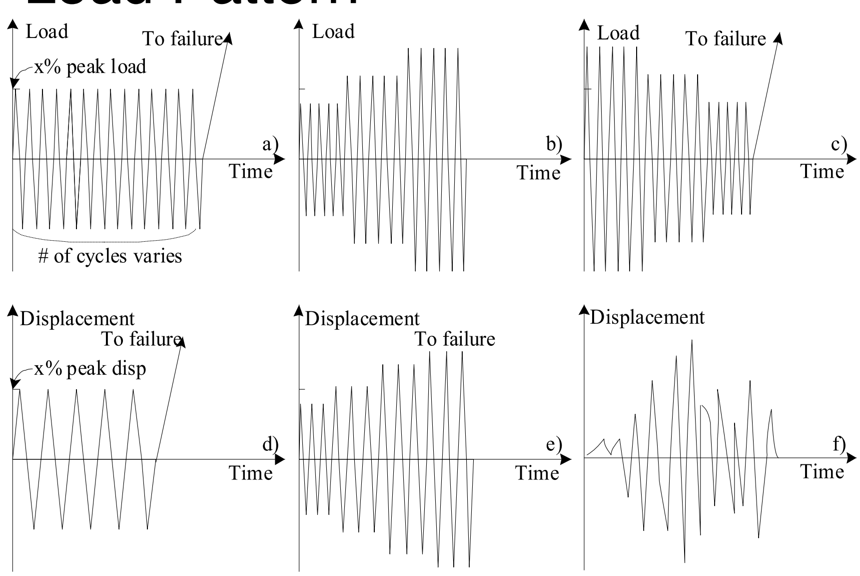
- Cyclic Tests on Cracked and Uncracked Concrete





Hoehler, Rodriguez, and Eligehausen

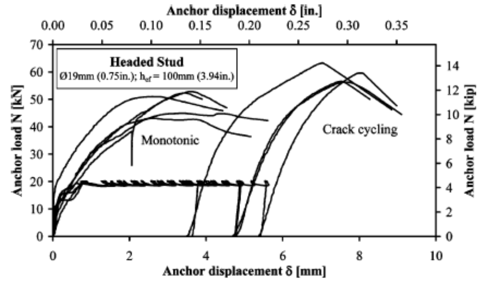
Load Pattern



Cyclic Tension

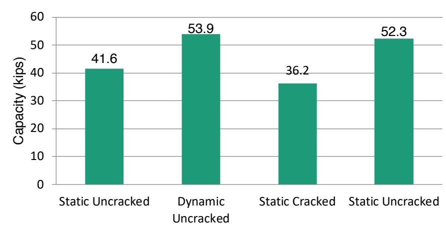
- Minimal Change Between Monotonic and Cyclic Loading

  (Hoehler 2001)

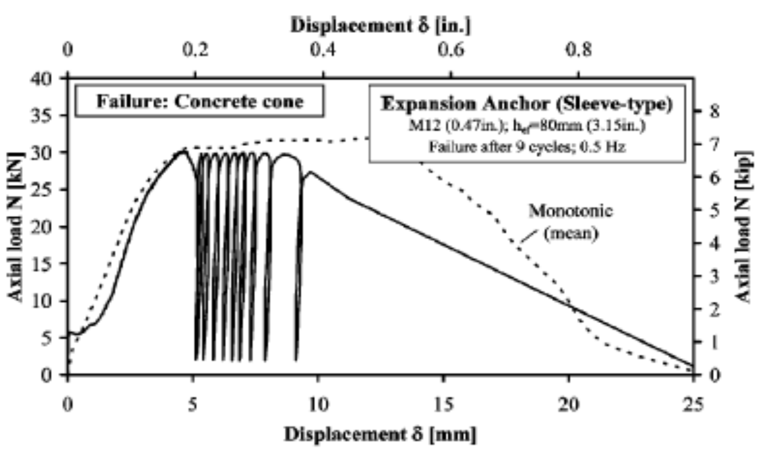


- Dynamic Capacities can be 30% Higher for CIP, Undercut, Sleeve, and Grouted Anchors (Rodriguez 2001)

Effect of Load Type on Tensile Capacity of Cast-in-Place Anchors



Cyclic Tension



Tension Cycling (100%)

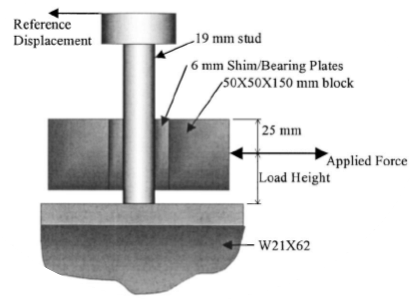
Hoehler and Eligehausen (2008)

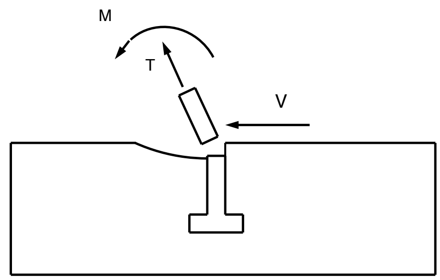
Cyclic Shear

- Steel Strength Reduction of 10 – 20%

- Reversed Cyclic Loading Resulted in almost 40% Reduction in Shear Capacity Compared to Static Capacities

Civjan and Singh (2003)





Tension-Shear Interaction

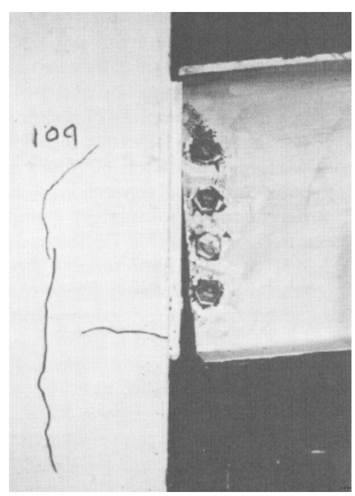
- 23% Reduction in Capacity When Subjected to Reversed Cyclic Loading

- 7.16 Degrees Maximum Cyclic Rotation

- 6.46 Degrees Maximum Static Rotation

- Concrete Cone Failure Under Cyclic Loading

- Ductile Steel Failure Under Static Loading



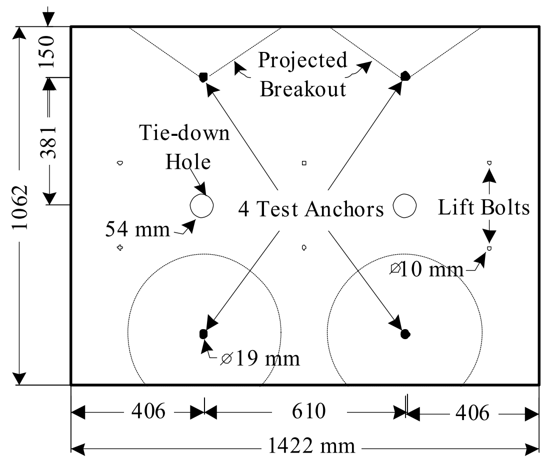
Roeder and Hawkins (2003)

Phase I

Unreinforced single anchors subjected to cyclic loading

Test No.	H_{ef} mm (in)	C_{a1} mm (in)	Load Type	Failure Load (kips)	Failure Mode
Shear					
2222010	100 (4)	100 (4)	M	14.18	Cone
2232010	100 (4)	100 (4)	M	14.46	Cone
3162010	100 (4)	100 (4)	UC	13.44	Cone
3172010	100 (4)	100 (4)	UC	14.28	Cone
9032010	100 (4)	100 (4)	RC	14.13	Cone
9032010_2	100 (4)	100 (4)	RC	14.76	Cone
1132010	150 (6)	100 (4)	M	13.41	Cone
3012010	150 (6)	100 (4)	M	15.82	Cone
3022010	150 (6)	100 (4)	UC	14.84	Cone
3052010	150 (6)	100 (4)	UC	15.18	Cone
4092010	150 (6)	100 (4)	RC	14.33	Cone
6162010	150 (6)	100 (4)	RC	14.57	Cone
3092010	150 (6)	150 (6)	M	16.11	Steel
3102010	150 (6)	150 (6)	M	17.74	Steel
3222010	150 (6)	150 (6)	M	16.84	Steel
3232010	150 (6)	150 (6)	M	16.17	Steel
3122010	150 (6)	150 (6)	UC	16.14	Steel
3222010	150 (6)	150 (6)	UC	16.57	Steel
3242010	150 (6)	150 (6)	RC	15.40	Steel
Tension					
2052010	100 (4)	100 (4)	M	19.66	Cone
2122010	100 (4)	100 (4)	M	21.22	Cone
3252010	100 (4)	100 (4)	UC	18.44	Cone
3252010_2	100 (4)	100 (4)	UC	17.96	Cone
3252010	150 (6)	100 (4)	M	28.30	Cone
3302010	150 (6)	100 (4)	M	25.20	Cone
3312010	150 (6)	100 (4)	UC	28.14	Steel
4062010	150 (6)	100 (4)	UC	27.80	Steel
1292010	150 (6)	150 (6)	M	28.37	Steel

Specimens

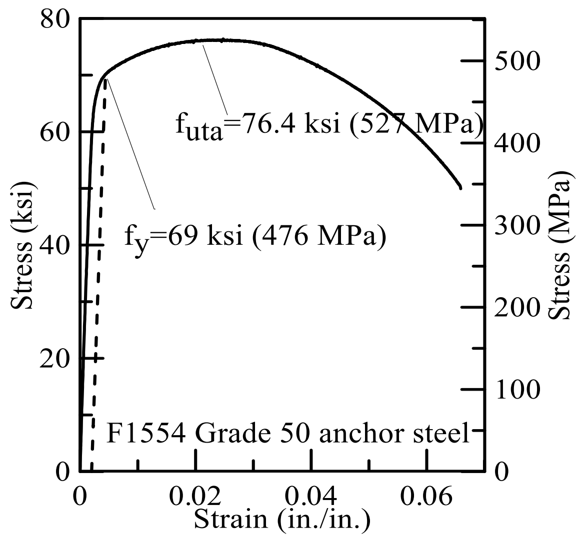


23

Upcoming Project Deadlines

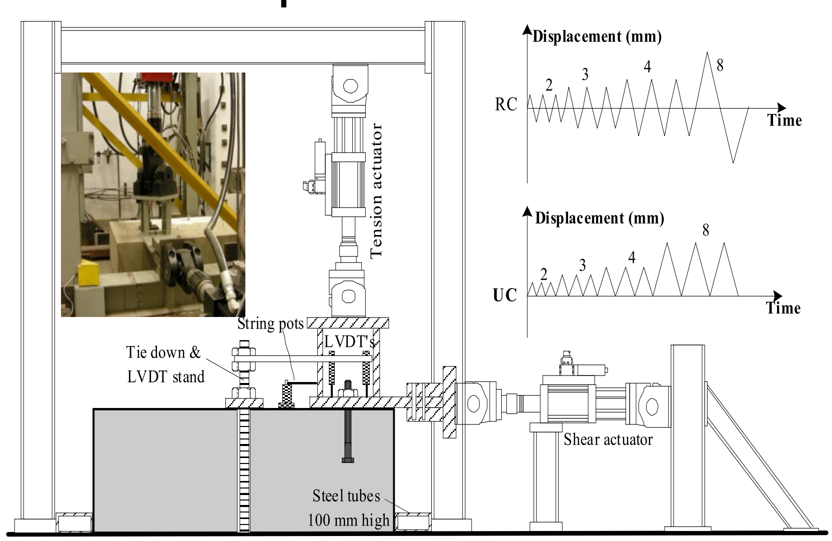
- 11/1/08: First Set of Specimens Poured
- 12/1/08: Load Frame Completed
- 1/1/09: Complete Monotonic Tension Tests
- 2/1/09: Second Set of Specimens Poured
- 3/1/09: Complete Monotonic Tension/Shear, and Cyclic Tension Tests

Specimens



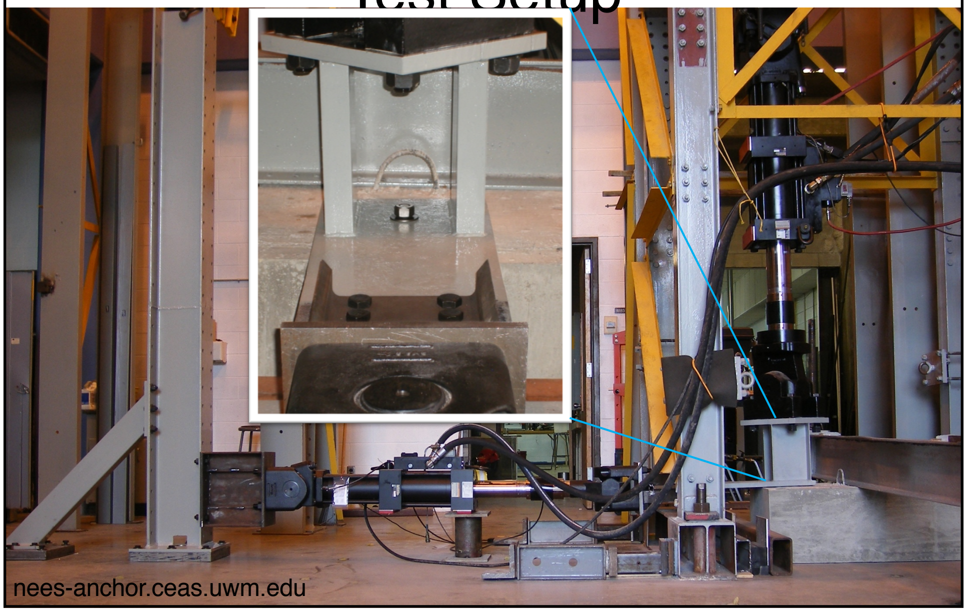
25

Test Setup



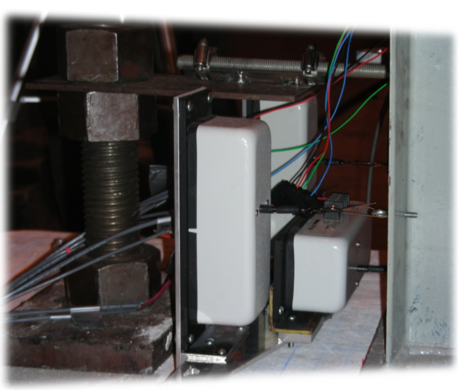
26

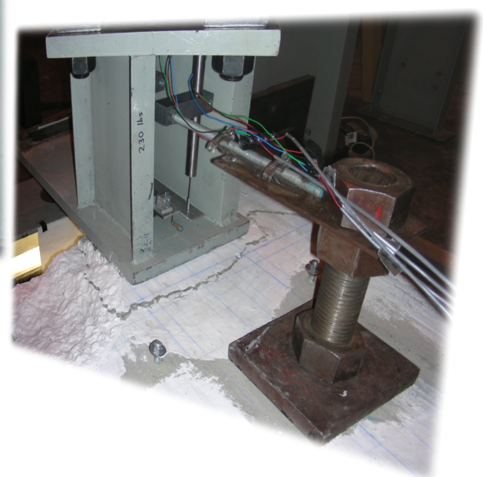
Test Setup



nees-anchor.ceas.uwm.edu

Instrumentation

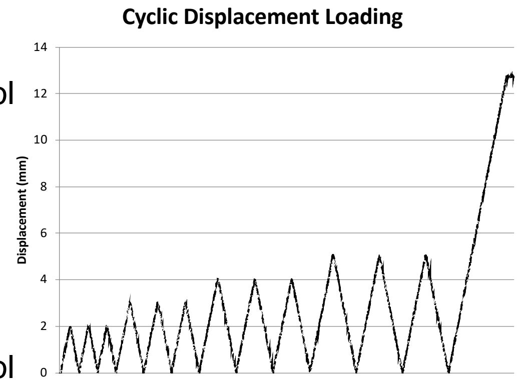




nees-anchor.ceas.uwm.edu

Tension Loading Protocol

- Monotonic Loading:
  - Displacement control
  - 1mm/min load rate



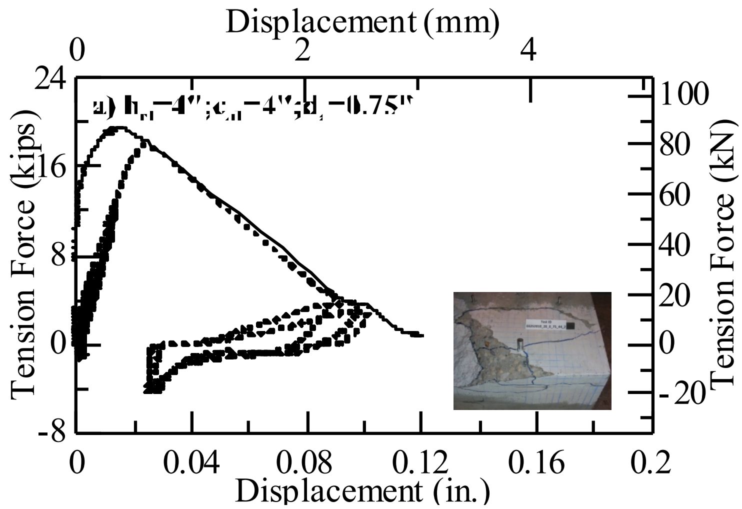
- Cyclic Loading
  - Displacement control
  - 2mm/min load rate
  - Displacement intervals of 1mm

nees-anchor.ceas.uwm.edu

Monotonic Tension Loading

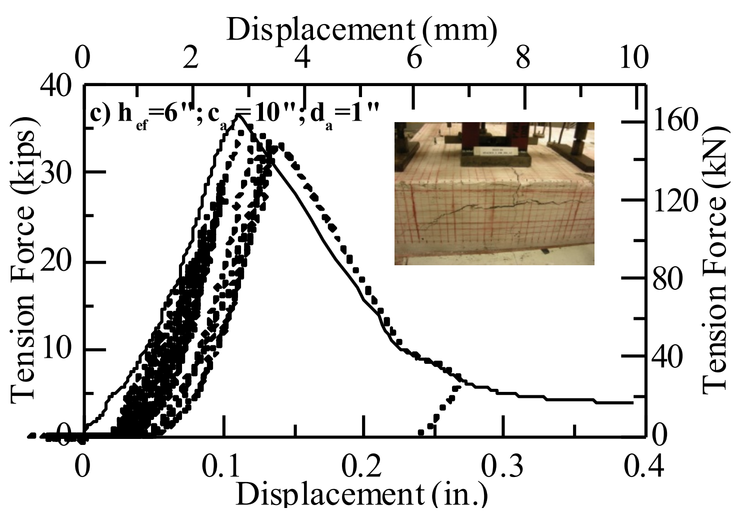
nees-anchor.ceas.uwm.edu

Concrete Breakout in Tension



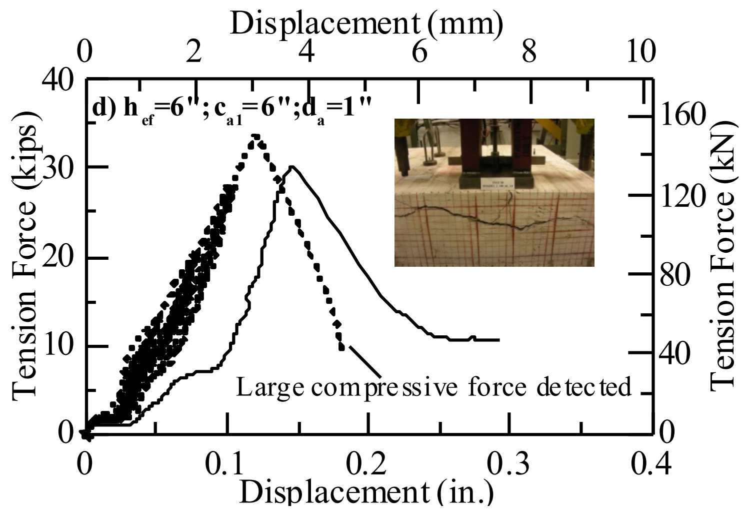
31

Concrete Breakout in Tension



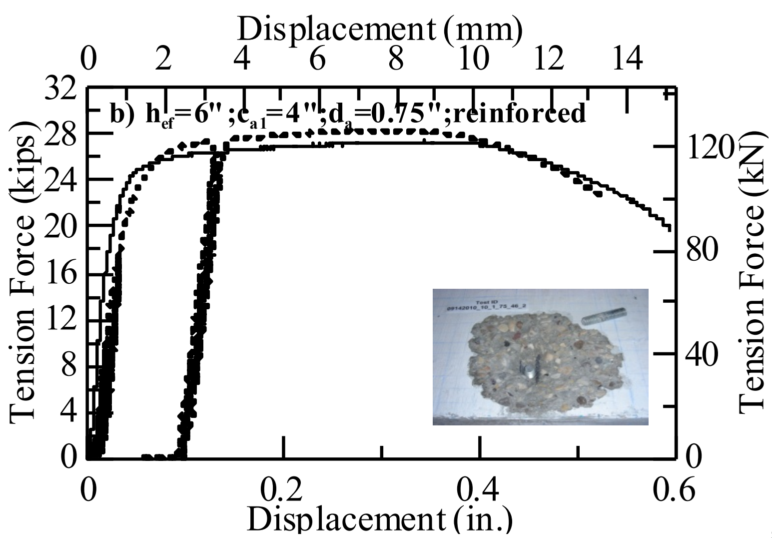
32

Concrete Breakout in Tension



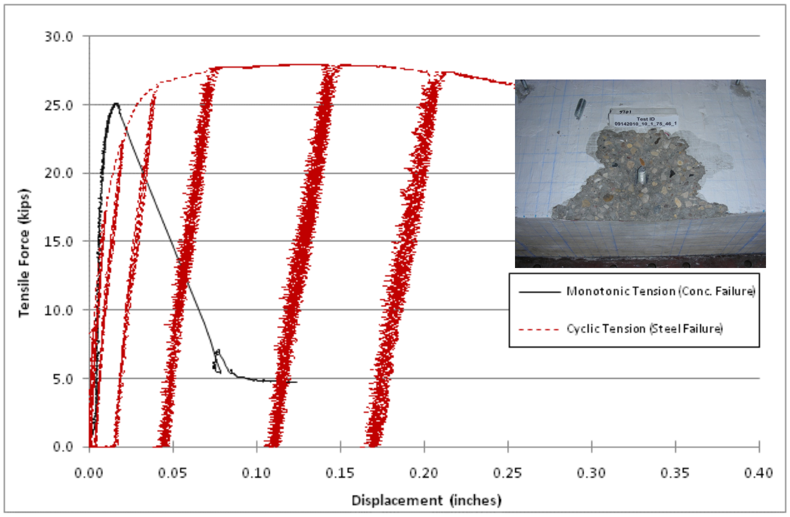
33

Steel Fracture in Tension



34

Steel Fracture in Tension

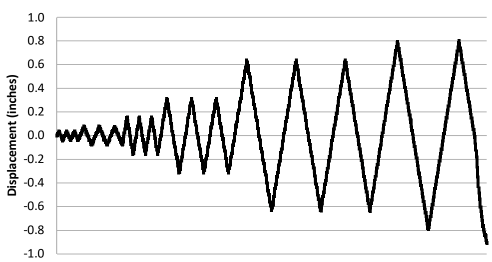


35

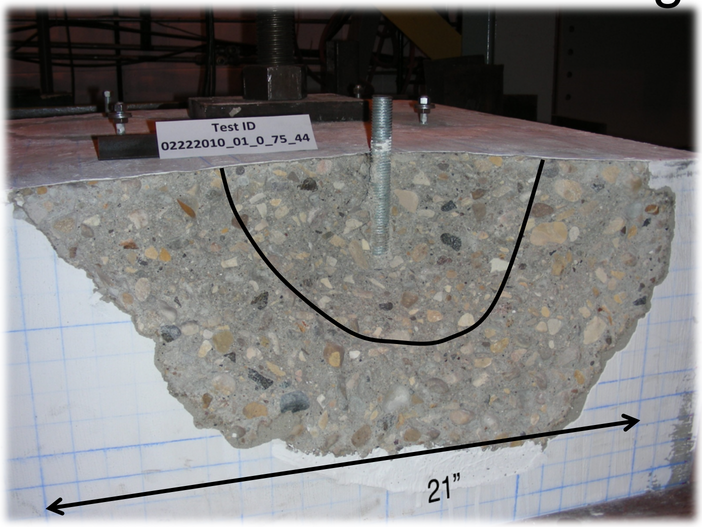
Shear Loading Pr

- Computer Controlled Hydraulic Actuators
- Displacement Controlled Loading
  - Capture Post Peak Behavior
- Load Cycle Limits of Displacement
  - Shows Capacity Degradation in Progressive Cycles

Cyclic Shear Displacment

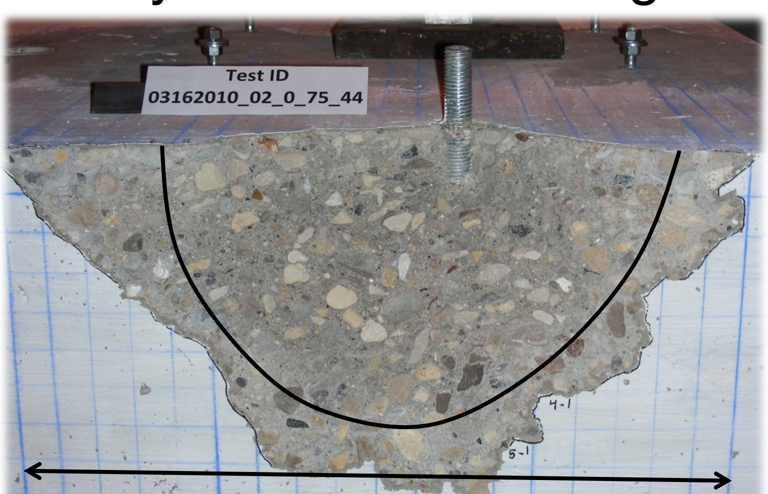


Monotonic Shear Loading



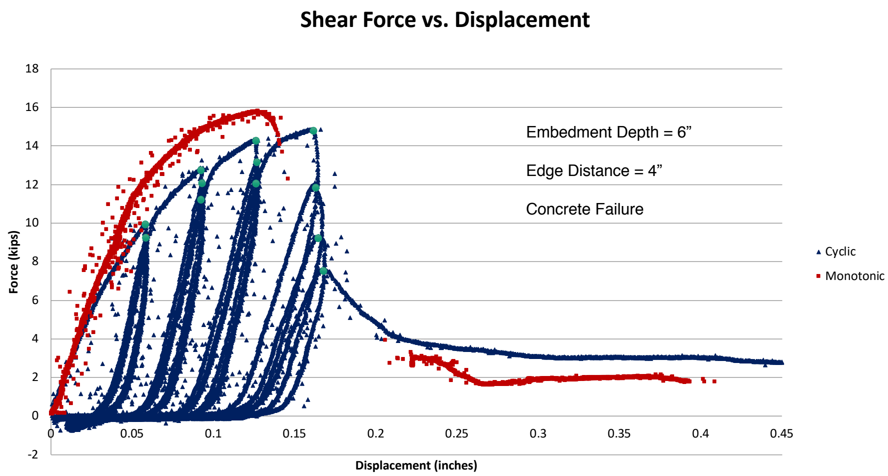
nees-anchor.ceas.uwm.edu

Cyclic Shear Loading



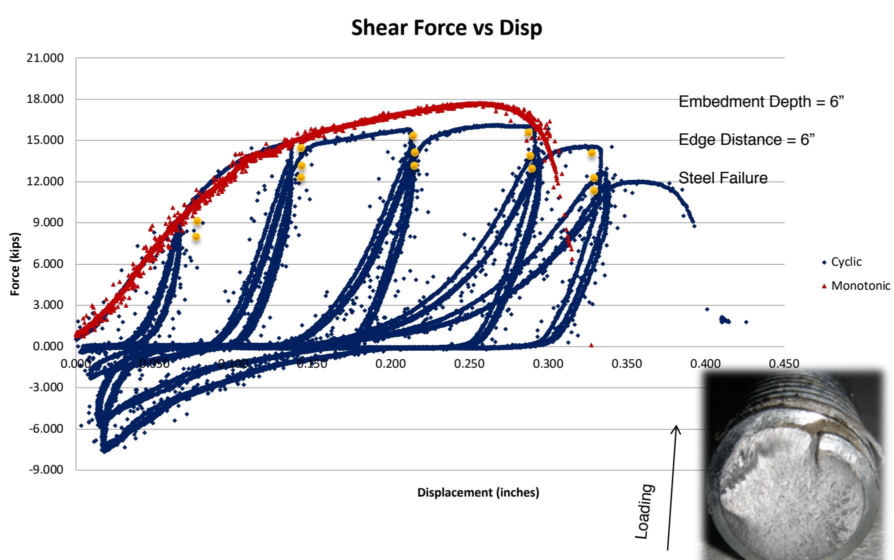
nees-anchor.ceas.uwm.edu

Test Data



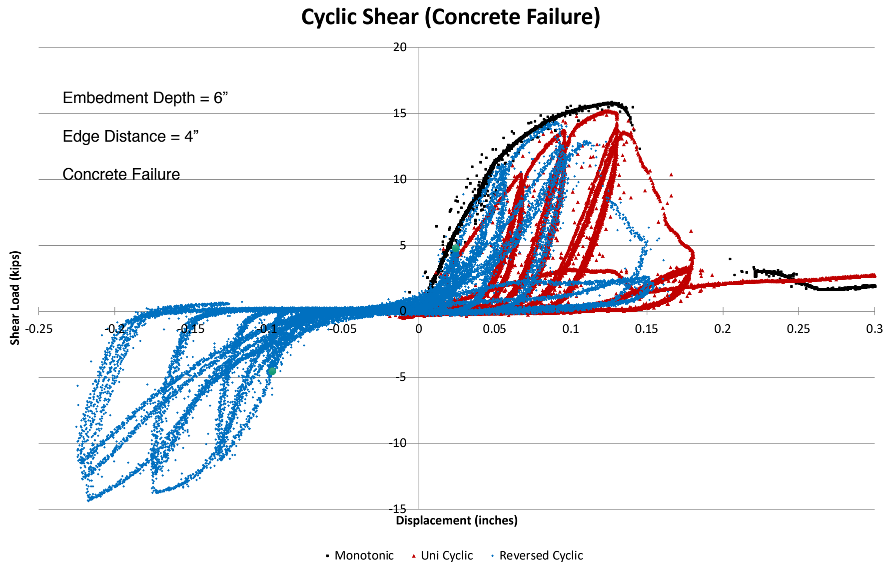
nees-anchor.ceas.uwm.edu

Test Data

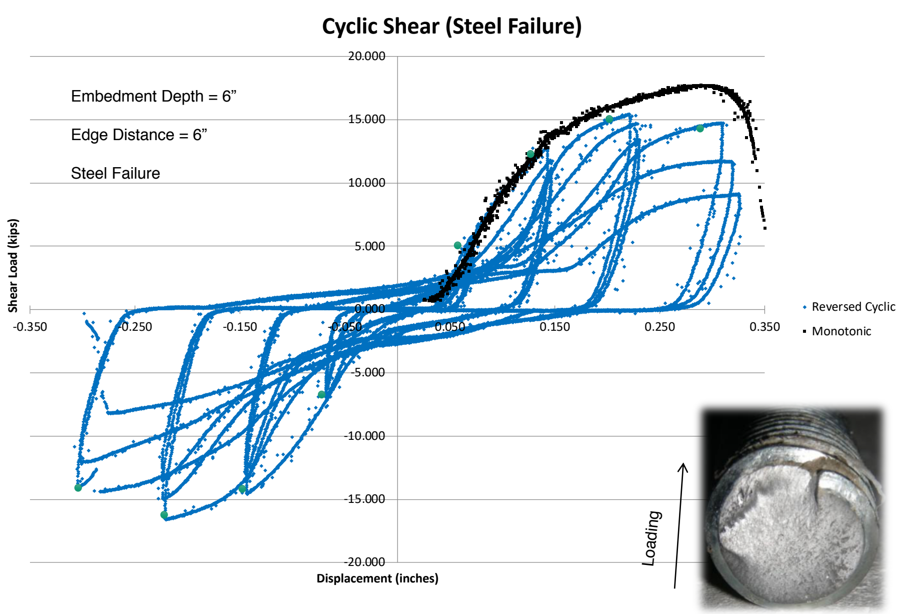


nees-anchor.ceas.uwm.edu

Unreinforced Test Data



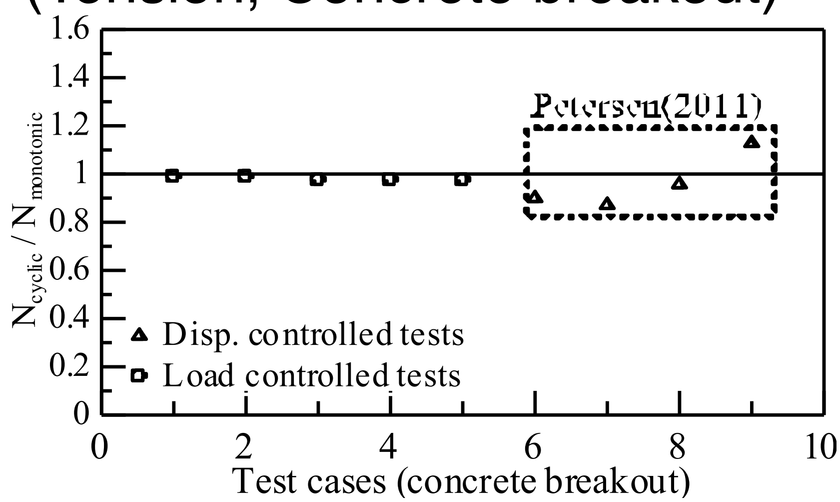
Unreinforced Test Data



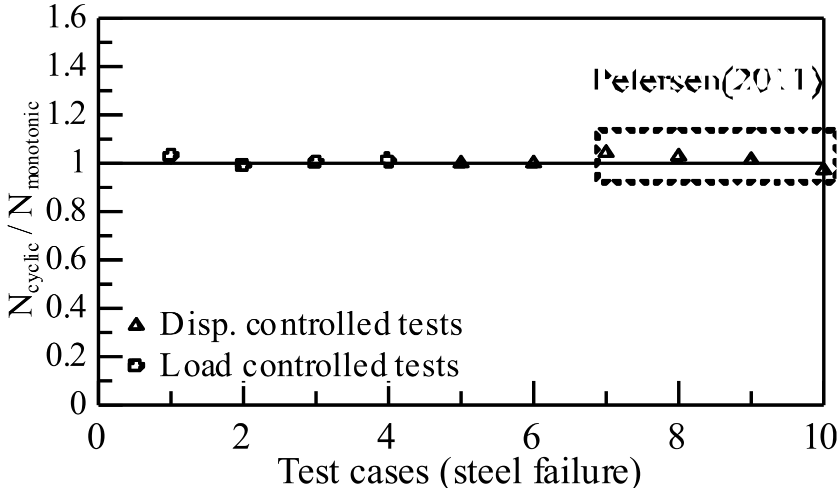
Cyclic Tests in the Literature

References	Specimen	Tension tests	Shear tests	Loading type
Hasselwander et al. (1974)	Single anchor	2 (s:2)		Cyclic load
Swirsky et al. (1978)	Single anchor		10 (s:2 c:8)	Reversed load
Bischof (1978)	Pushout-2		2 (c:2)	Cyclic load
Klingner et al. (1982)	Single anchor		3 (s:3)	Reversed load
Hawkins and Mitchell (1984)	Pushout-4		9 (s:6 c:3)	Reversed load
Nakajima et al. (1996)	Pushout-4		2 (s:2)	Reversed load
Gattesco and Giuriani (1996)	Single anchor		2 (s:2)	Cyclic load
Taplin and Grundy (1997)	Pushout-8		2 (s:2)	Cyclic load
Bursi and Gramola (1999)	Pushout-8		5 (s:5)	Reversed Disp.
Nakashima (1999)	Single anchor		12 (s:6 c:6)	Reversed load
Nakashima (2000)	Single anchor	2 (s:2)	4 (s:4)	Reversed load

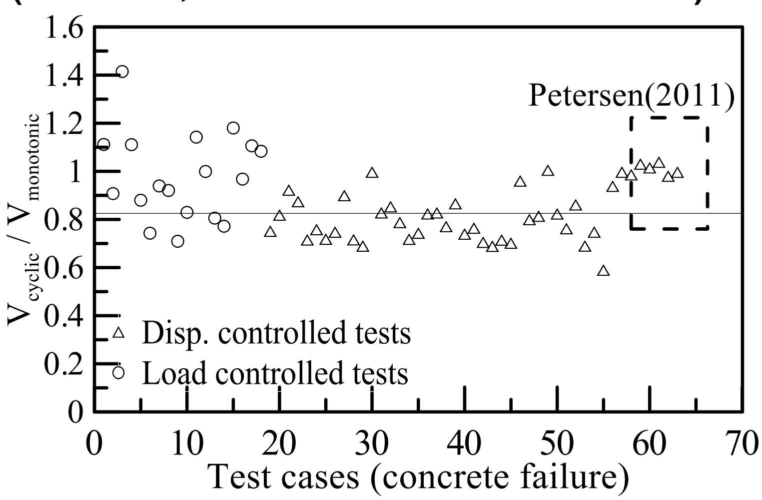
Seismic Reduction Factors (Tension, Concrete breakout)



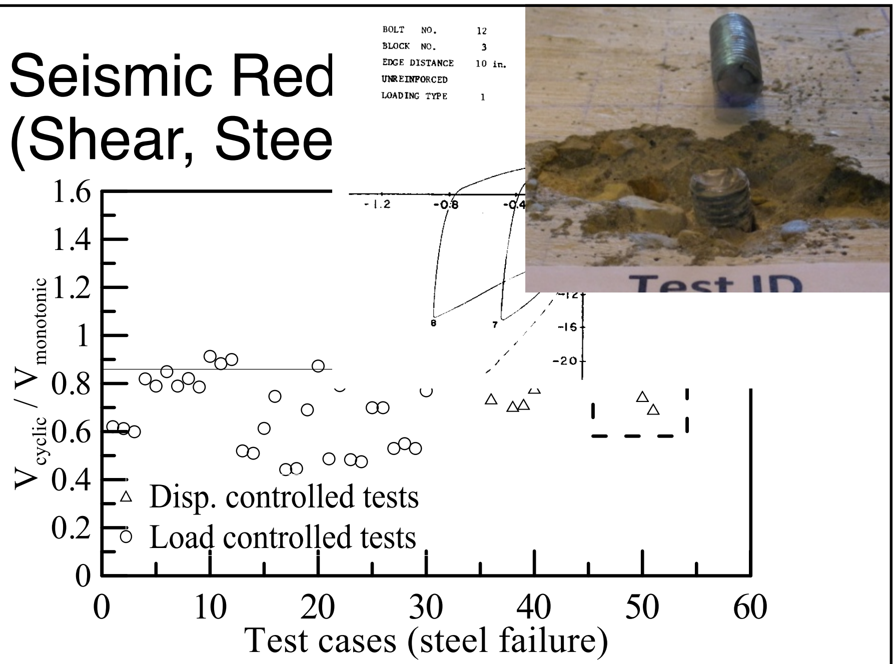
Seismic Reduction Factors (Tension, Steel fracture)



Seismic Reduction Factors (Shear, Concrete breakout)

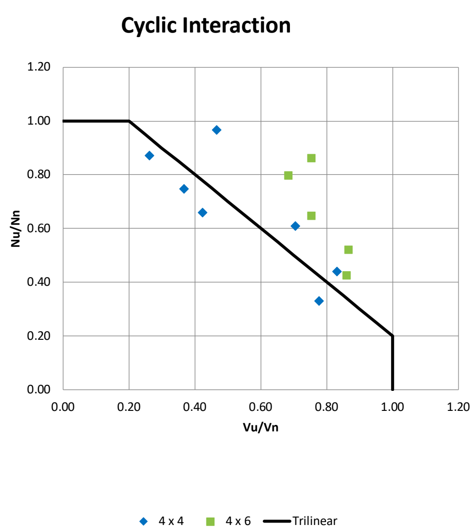


Seismic Red (Shear, Stee



Tension/Shear Interaction

- **Vn & Nn Based on Cyclic Test Results**
- **Concrete Shear Cone Failure Occurred First in all Tests**
- **6" Embedment Moves Tension Resistance Away from Concrete Shear Cone Formation**



Conclusions from Phase I Tests

Under quasi-static cyclic loading

- Low-cycle fatigue is significant for concrete breakout capacity → reduction factor = 0.8 (shear and tension)
- Anchor rod in shear is subjected to combined bending and shear → reduction factor = 0.8 or detailed equations needed
- Anchor rod in tension: Low-cycle fatigue is not significant → reduction factor = 1.0
- Tests needed for other failure modes
- Combined loading not included