Technical Session III: Example Prior Projects Conducted at Lehigh

Large Scale Testing of Existing and Innovative Floor Diaphragm Components

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University of Arizona

5 December 2016

Presentation Outline

- **Project 1: NSF GOALI (*Existing Details*)**

  Development of a Seismic Design Methodology for Precast Floor Diaphragms (DSDM)

- **Project 2: NSF NEESR (*Innovative Sys.*)**

  Development of an Inertial Force-Limiting Floor Anchorage System (IFAS)

Presentation Outline

- **Multi-University Research Projects**
- **Lehigh co-PIs and Grad Students**
- **Large Scale Sub-assemblage Testing**
- **Lehigh Testing Program used for:**
  - Component Characterization
  - Analytical Model Construction
  - Demonstration of Concept
  - Guidance for Large Scale System Tests

Project 1: NSF GOALI - DSDM

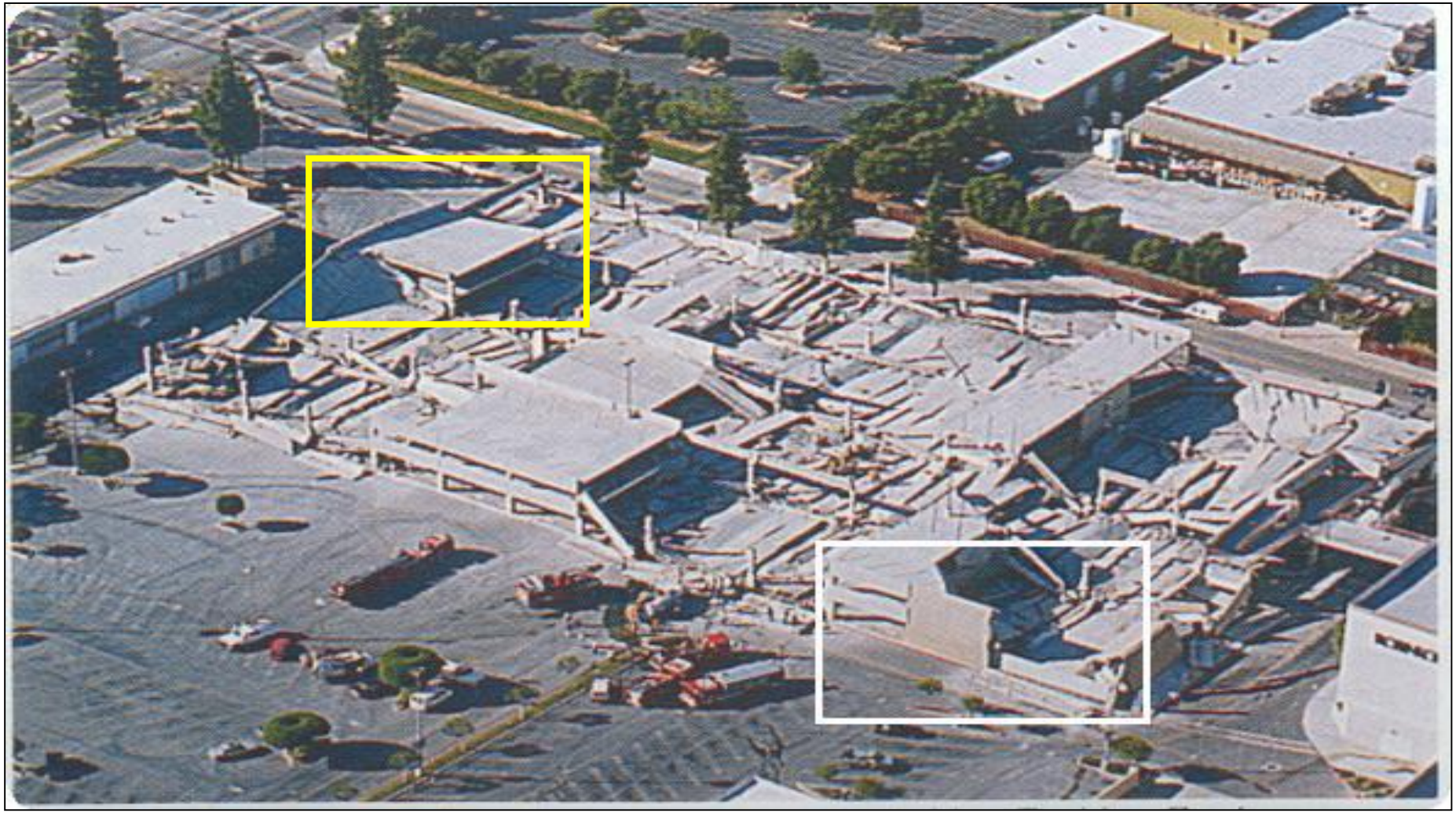
Development of a Seismic Design Methodology for Precast Floor Diaphragms (DSDM)

- **NSF GOALI (2005-07) / NEESR (2008-09)**
- **Co-funded by PCI & CPF**

Diaphragm Action

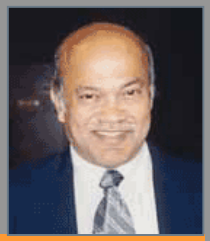
Diaphragm action carries seismic forces horizontally in the floor slab to walls and frames…

Precast Diaphragm Past Performance



DSDM Research Team

University of Arizona
Robert Fleischman
Consortium Leader



University of California
San Diego
Jose' Restrepo, PI

Lehigh University
Clay Naito, PI
Richard Sause, Co-PI

Industry Liaison
S. K. Ghosh, Co-PI
DSDM Task Group

Producer Members

Producer Members

Industry Advisory Panel

Graduate Students: Dichuan Zhang ,Ge Wan, M. Mielke, A. Mullenbach (*UA*)
Matthew Schoettler, Andrea Belleri (*UCSD*)
Ruirui Ren, Liling Cao (*LU*)

Research Flow

Structure Level (UCSD)

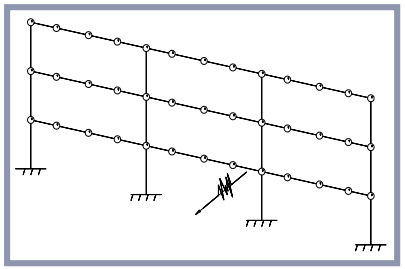
- Diaphragm Inertial Forces
- Flexible Diaphragm Structures

Diaphragm Level (UA)

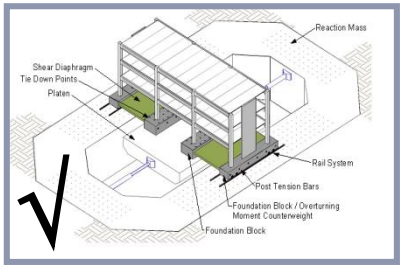
- Diaphragm Capacity
- Diagram Load Paths & Limit States

Detail Level (LU)

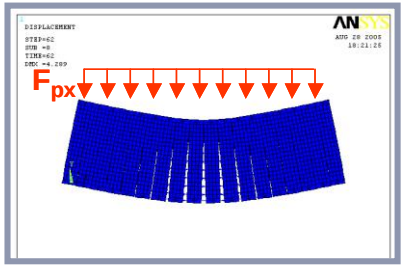
- Connector Properties
- Connector Classification



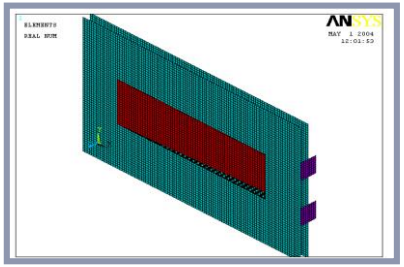
MDOF Dynamic Analysis



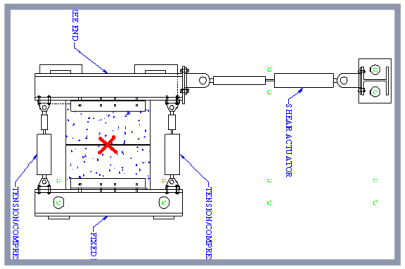
Scaled Shake Table Test



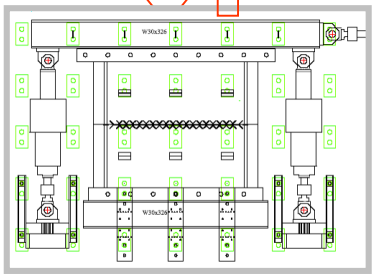
FE Pushover Analysis



3D FE Dynamic Analysis

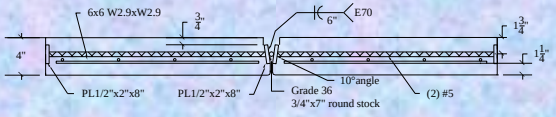


Full-Scale Detail Tests

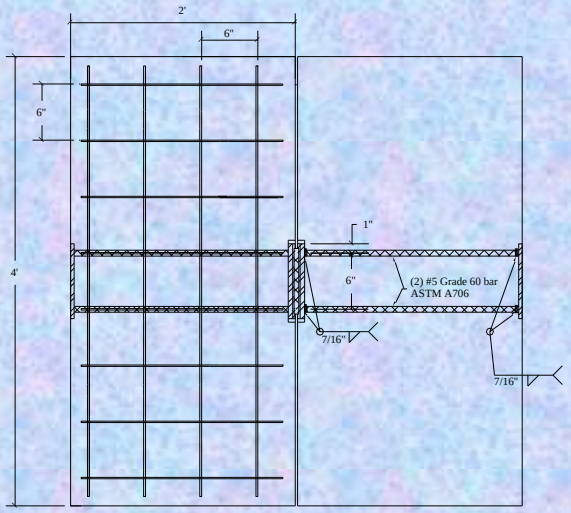


Hybrid Testing of Joints

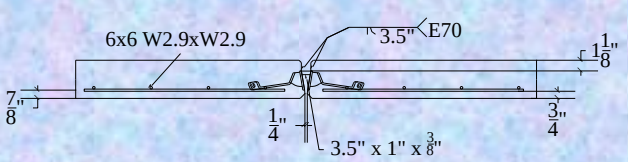
Isolated Connector Specimens



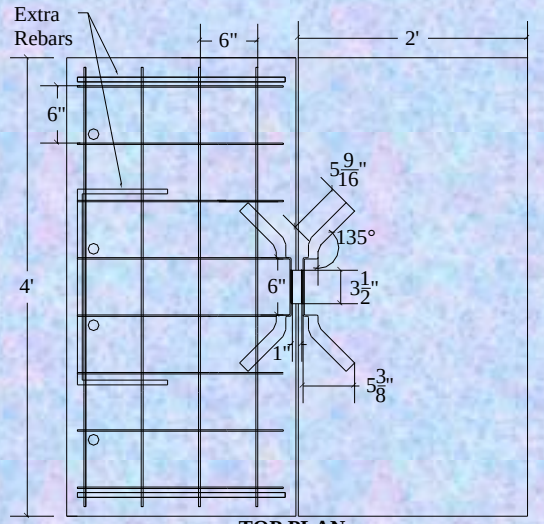
SIDE ELEVATION



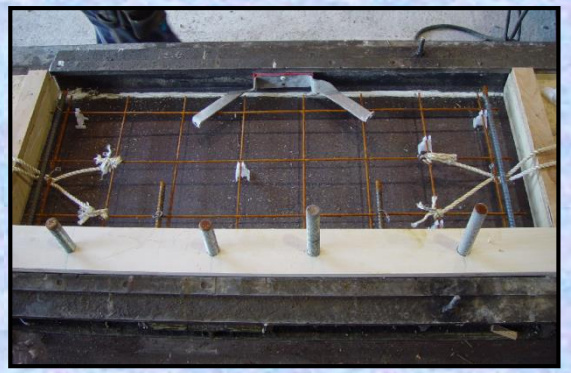
TOP PLAN
(6x6 W2.9xW2.9)



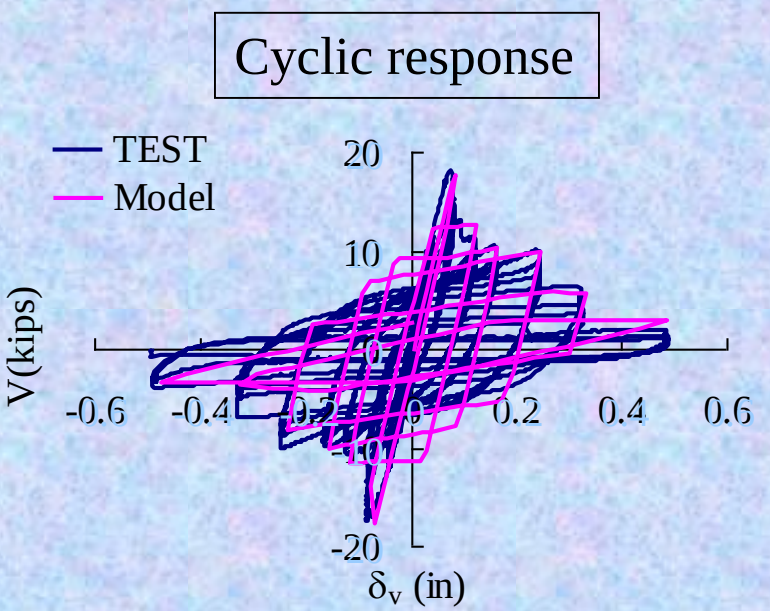
SIDE ELEVATION

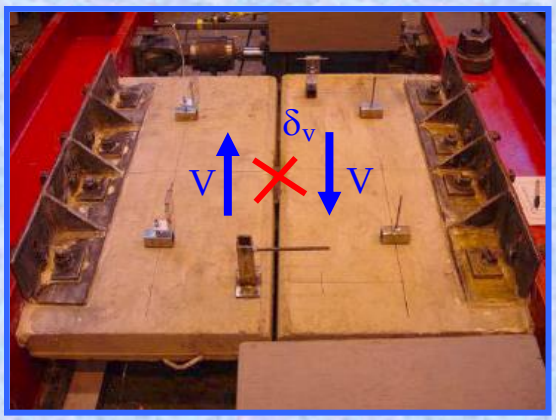


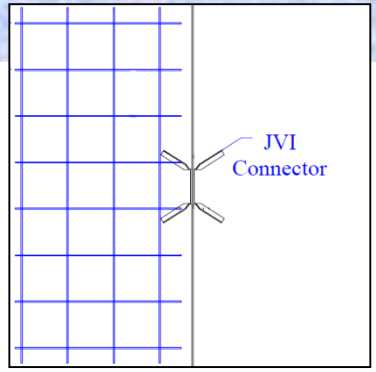
TOP PLAN
(6x6 W2.9xW2.9)



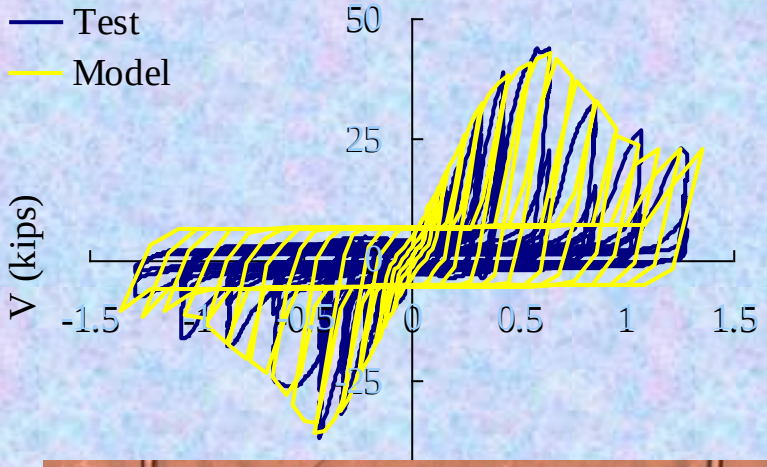
Shear Connector Model Calibration

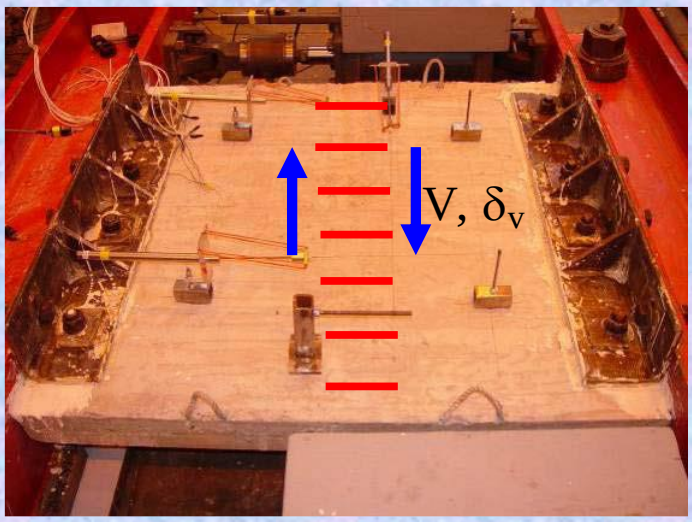


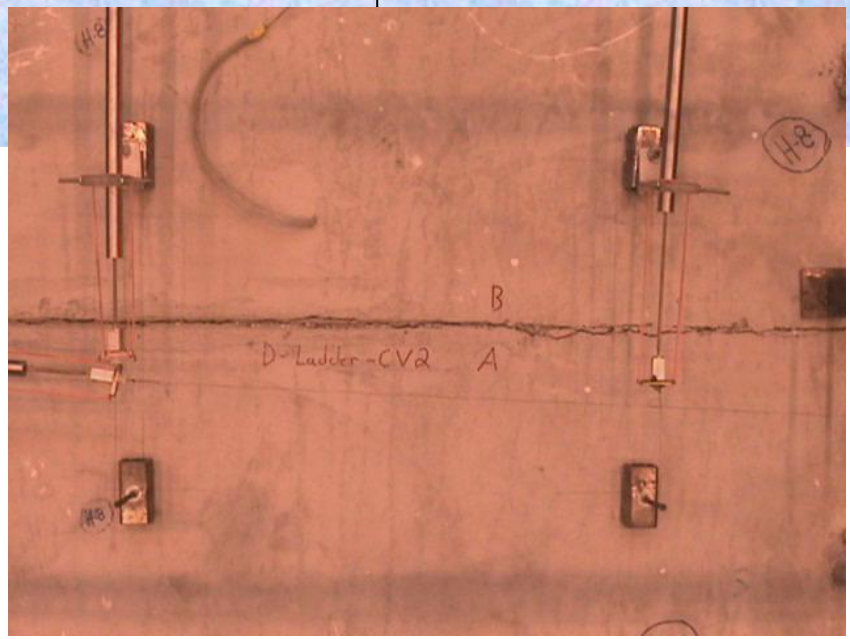


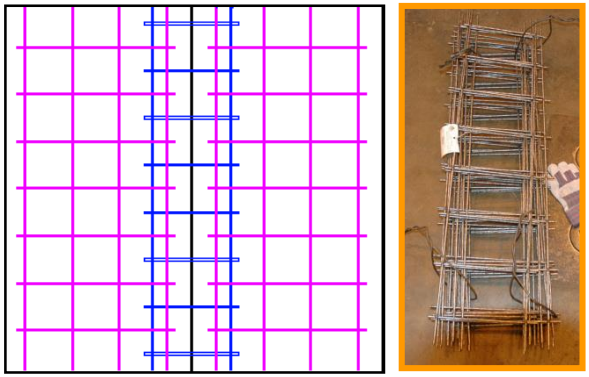


Ductile Mesh Model Calibration



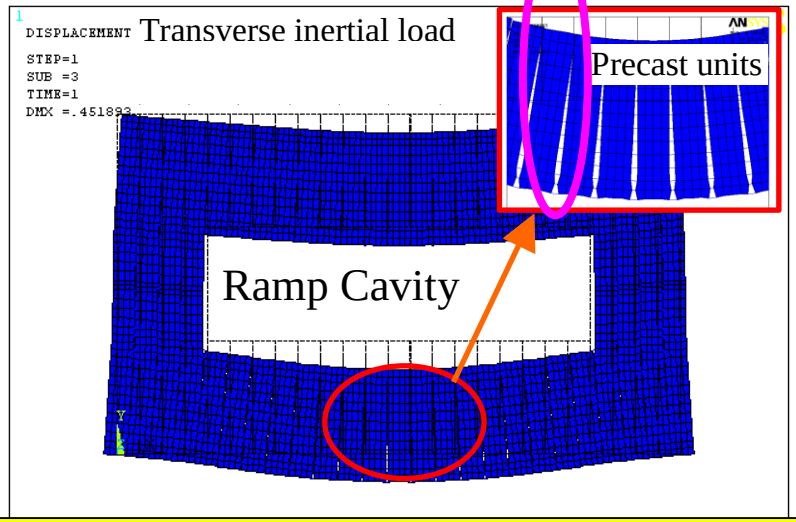


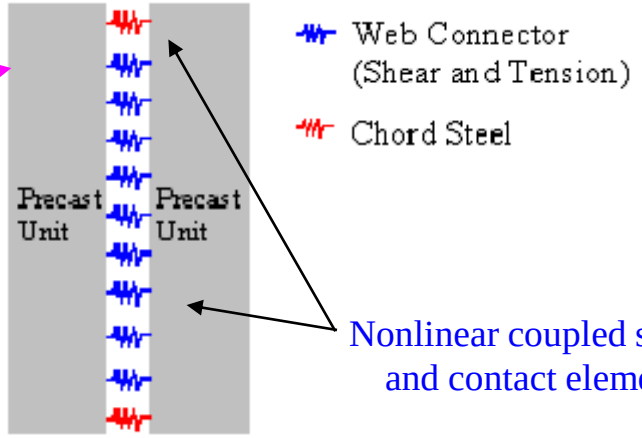




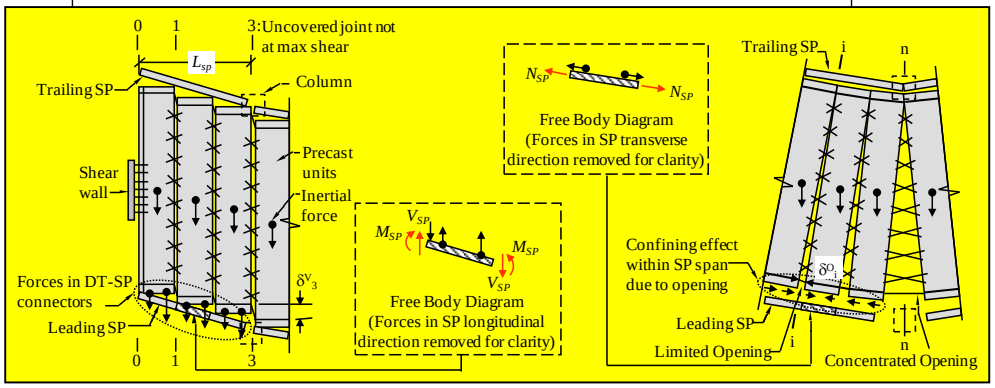
Diaphragm Analytical Models

"Discrete Connector" FE models

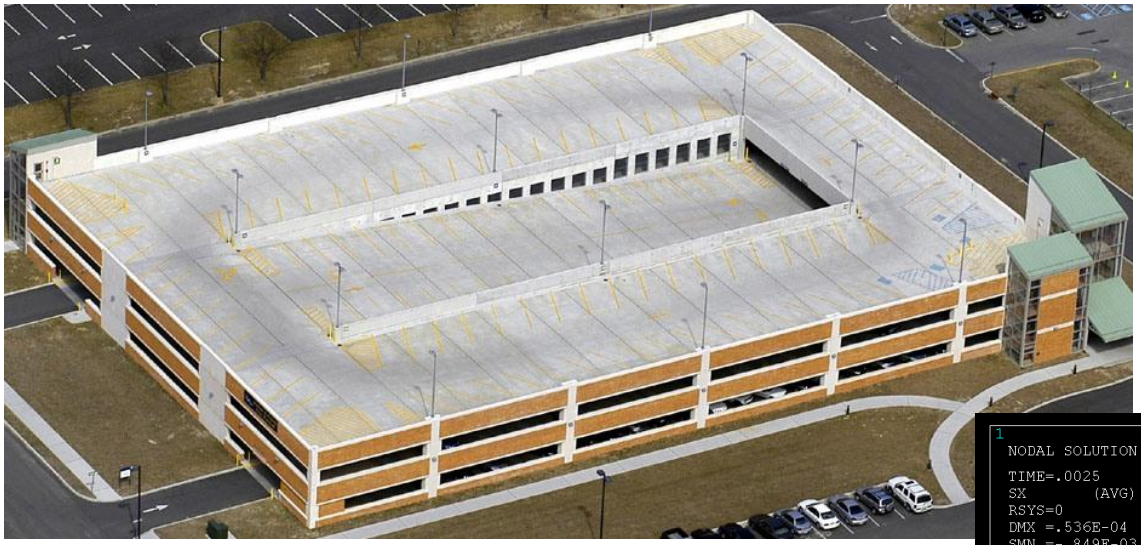


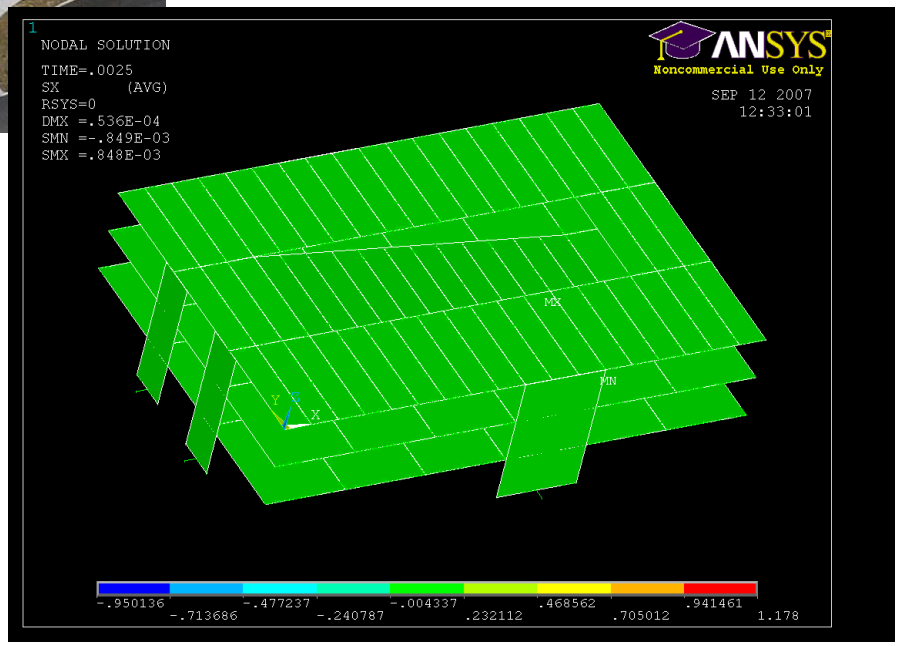


Nonlinear coupled springs and contact elements

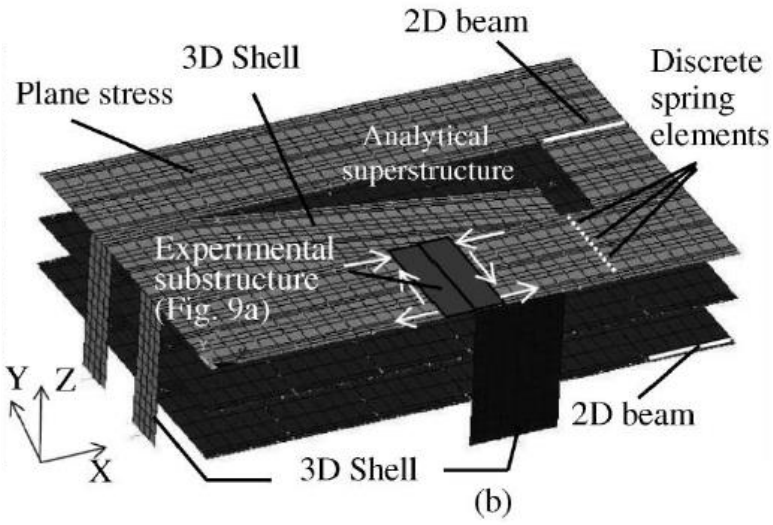


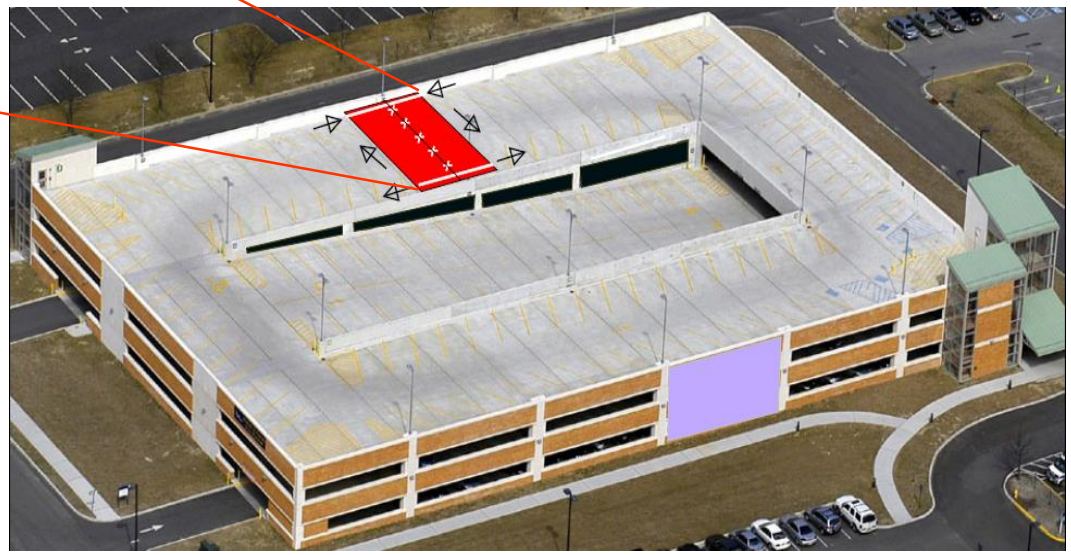
Nonlinear Dynamic Analysis



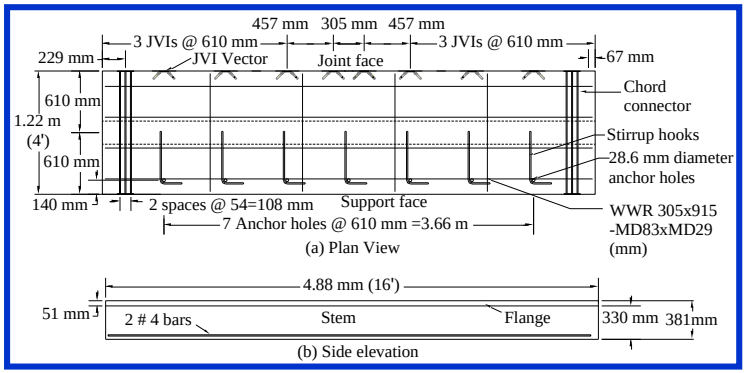


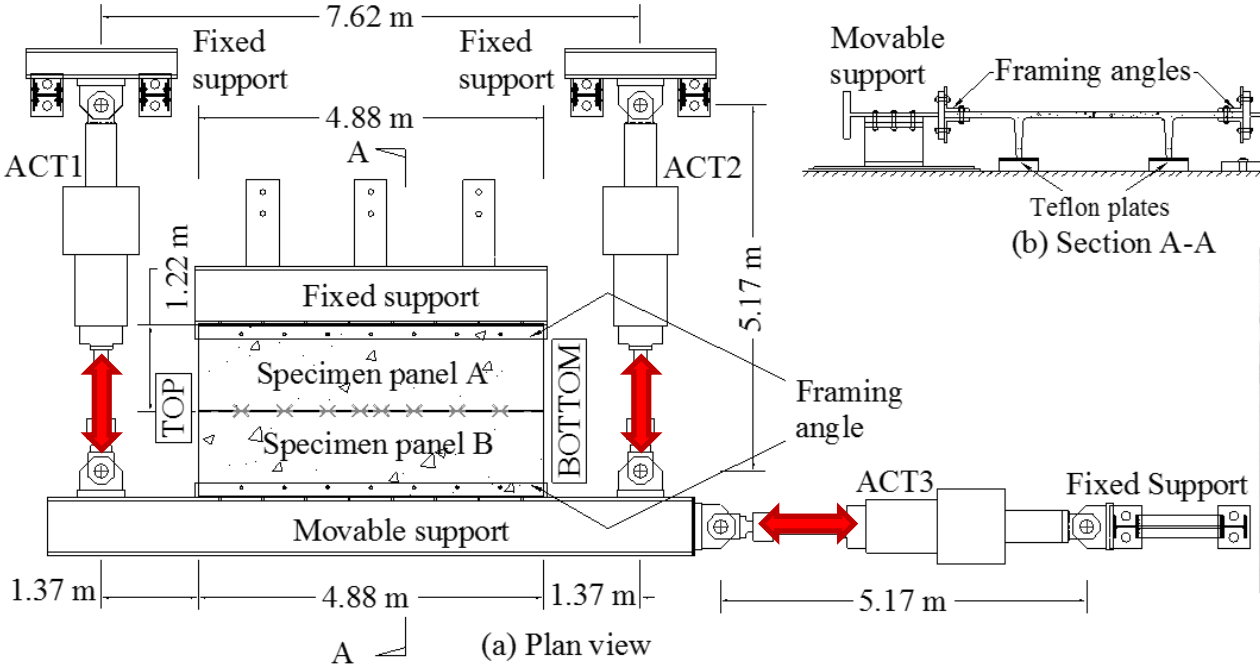
Test Substructure: Panels at Critical Joint

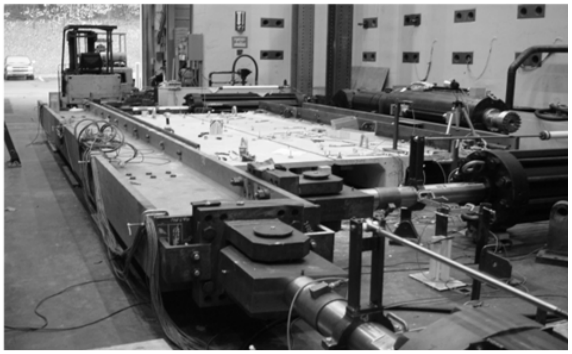




Lehigh MDOF Test Fixture







(c) Photo

Predetermined Displacement History Tests

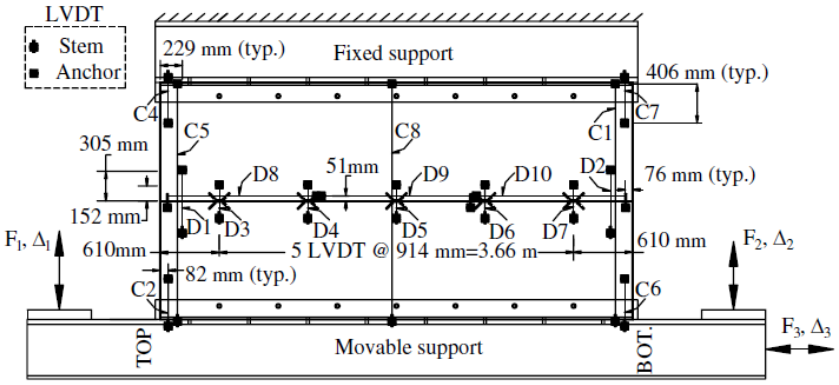


Fig. 11. Instrumentation layout

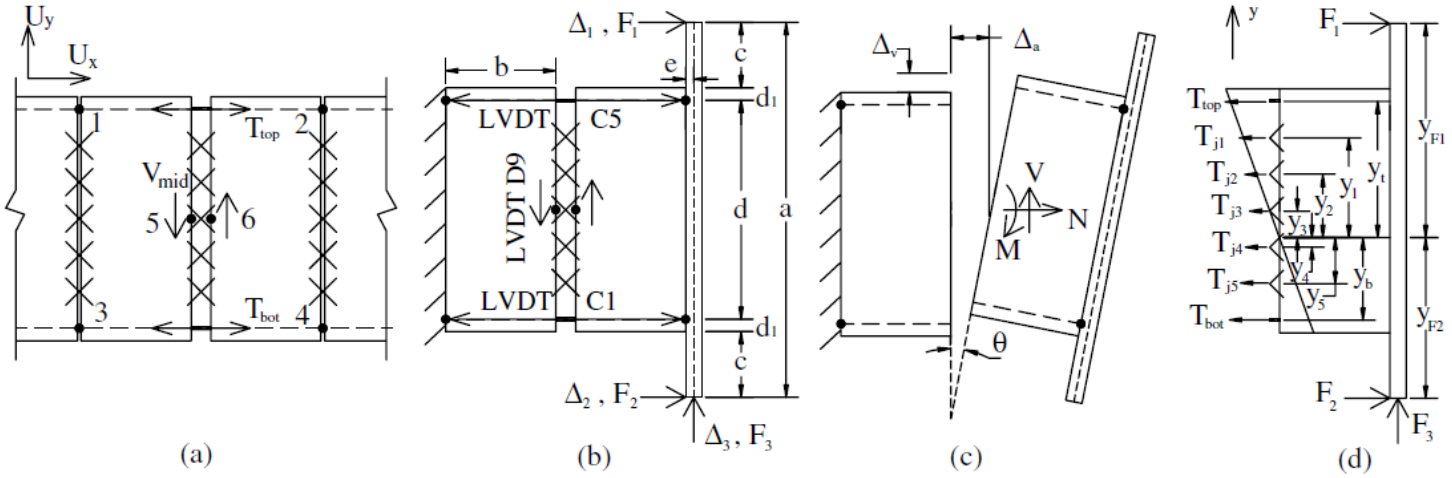
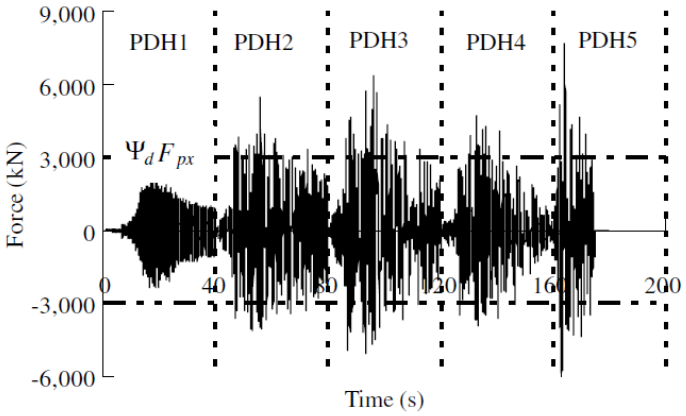


Fig. 12. DOF and force transformations: (a) FE model; (b) test specimen; (c) deformed shape; (d) free body diagram

PDH Test Predictions

Table 2. Test Sequence

Test	Earthquake	Intensity	Direction	Test panel
PDH 1	Charleston (CH)	SVC	Transverse	South
PDH 2	Charleston (CH)	DBE	Transverse	North
PDH 3	Charleston (CH)	MCE	Transverse	South
PDH 4	Charleston (CH)	DBE	Bidirection (Bi)	North
PDH 5	Berkeley (BK)	MCE	Transverse	South



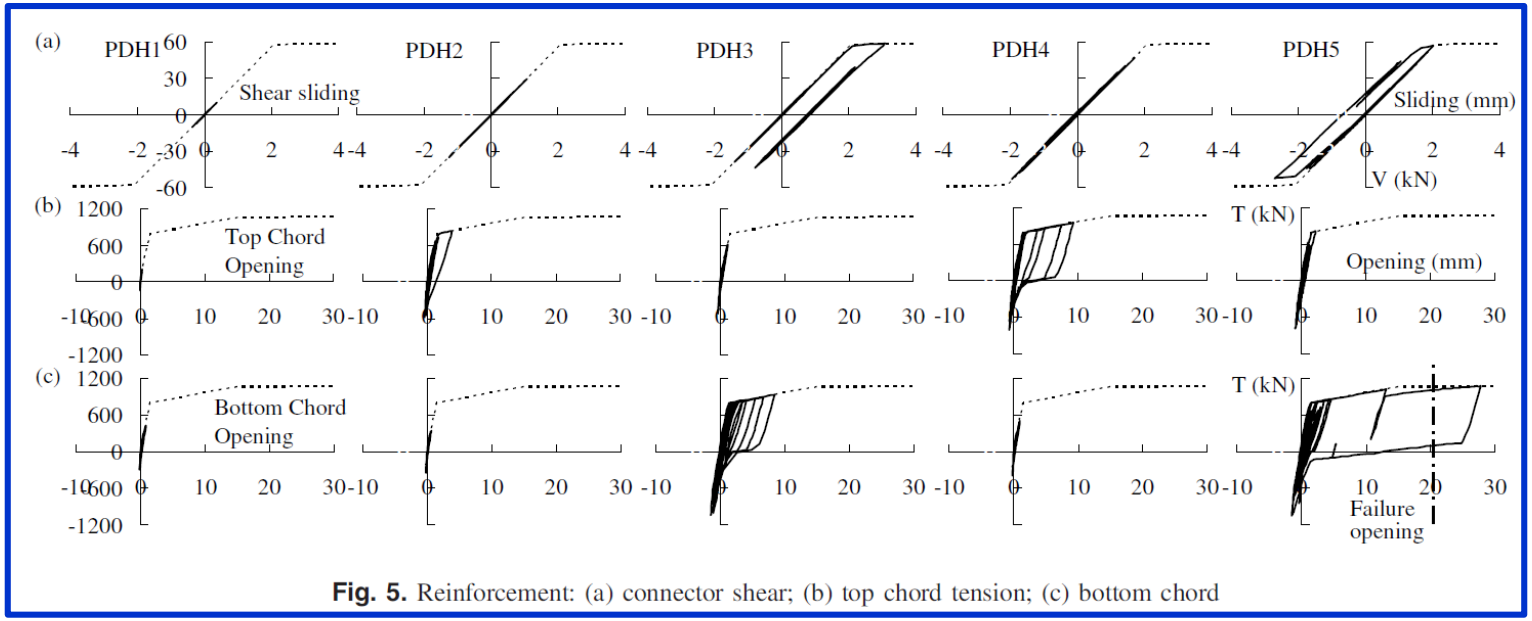
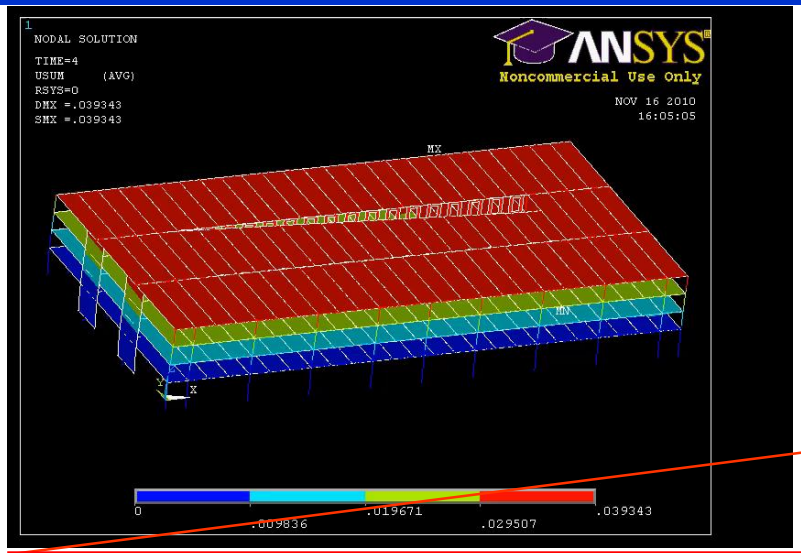
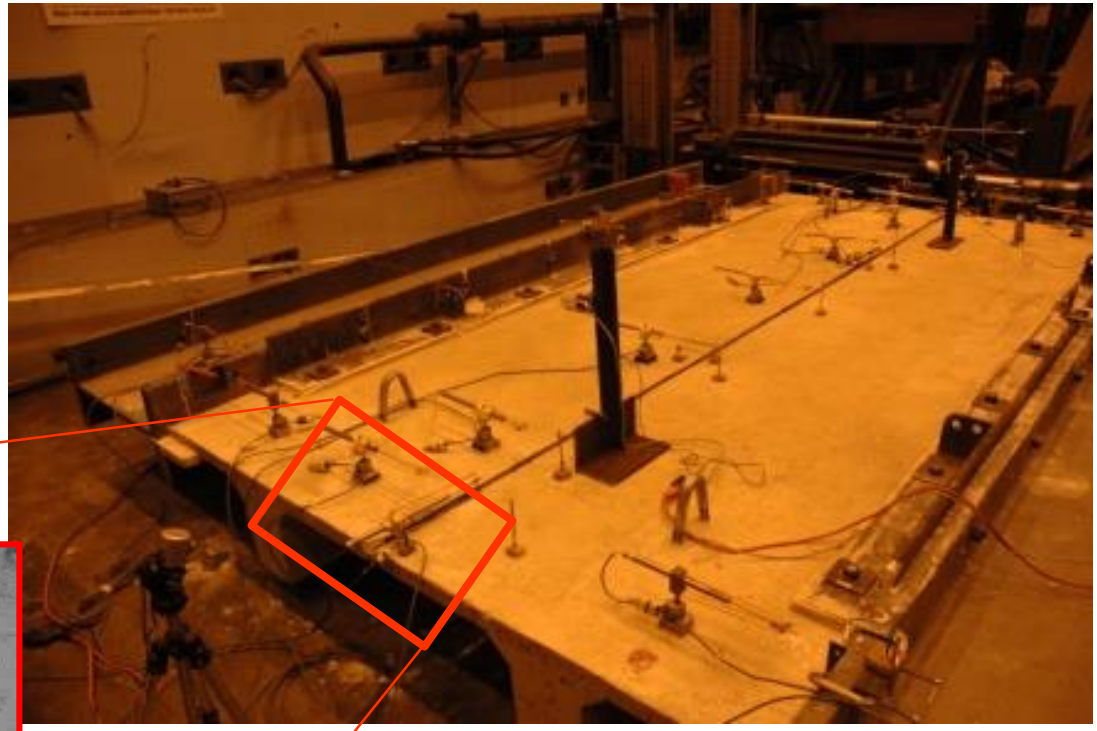


Fig. 5. Reinforcement: (a) connector shear; (b) top chord tension; (c) bottom chord

PDH Test Response





PDH Testing: Results

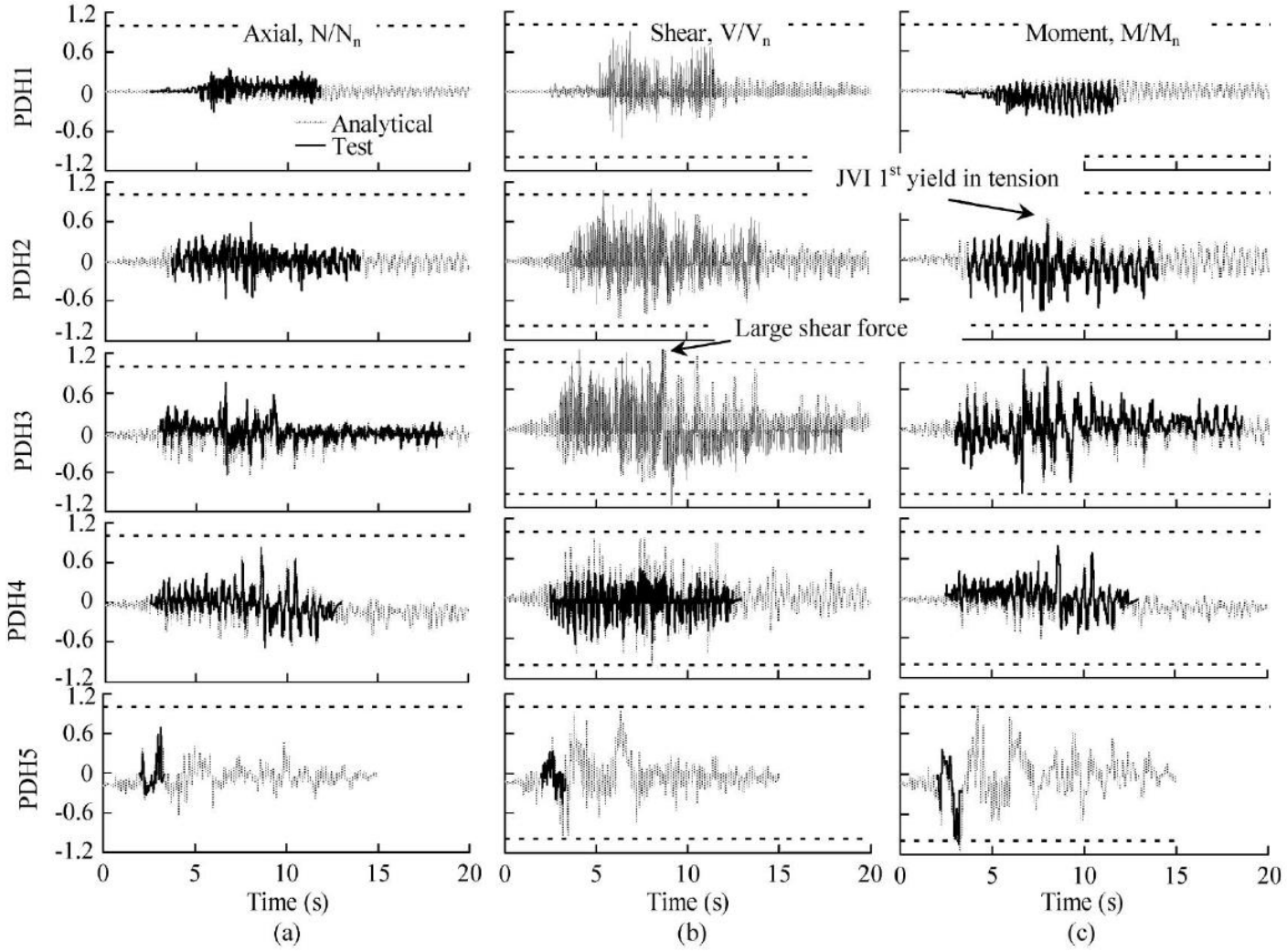
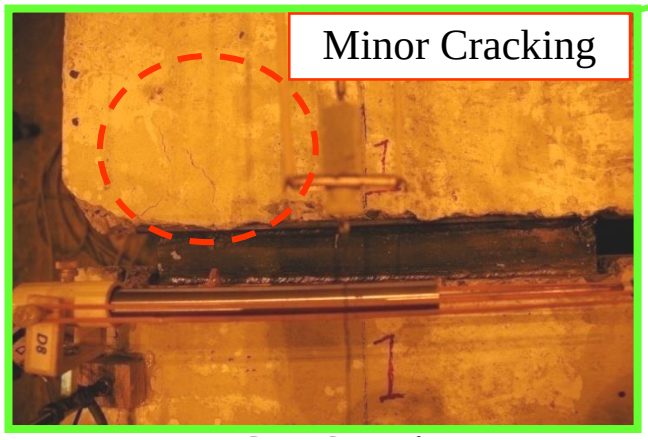
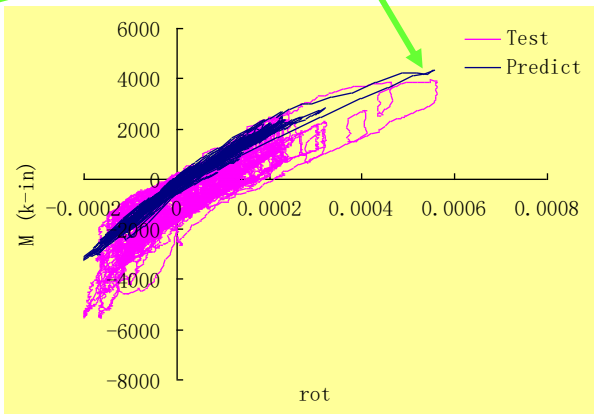


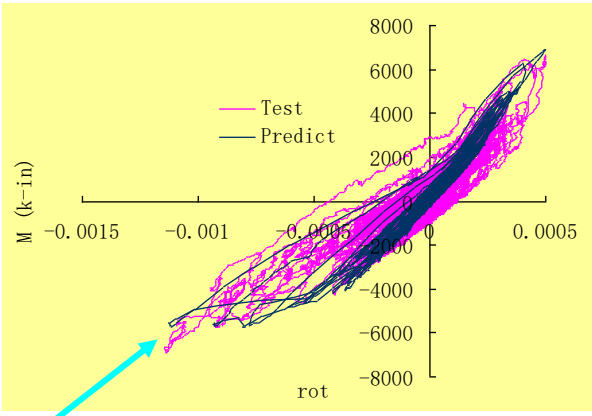
Fig. 14. Joint force: (a) axial; (b) shear; (c) moment

PDH Test Results: Flexure

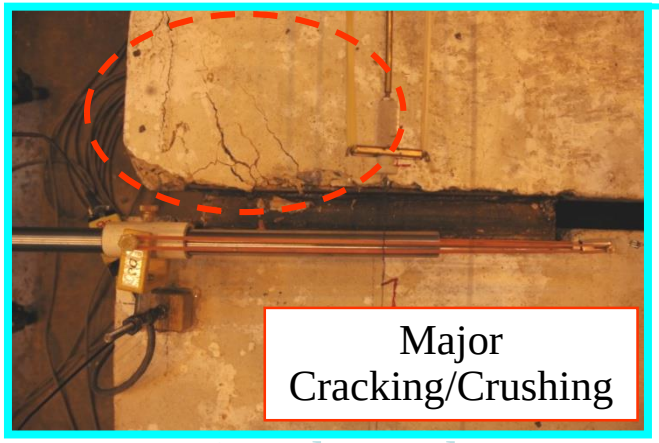


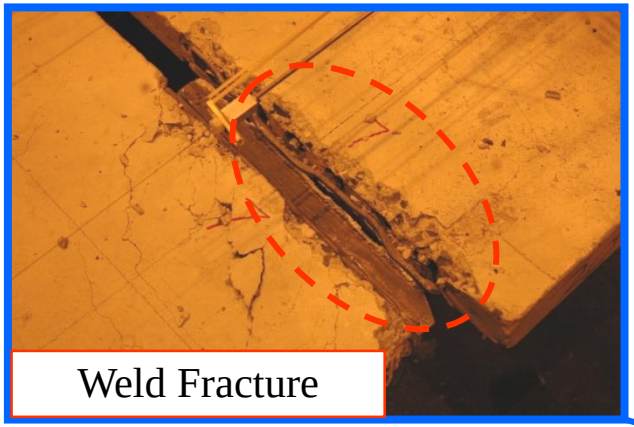


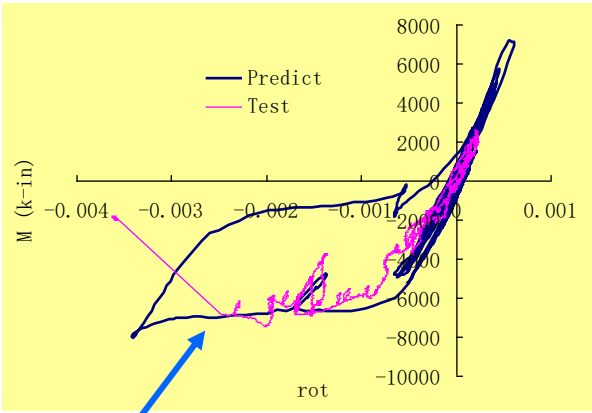
CH DBE



CH MCE

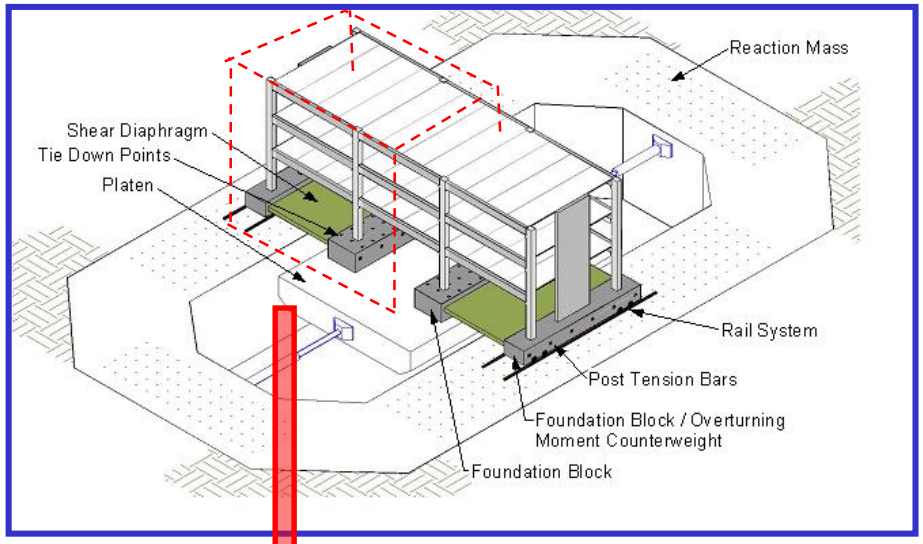


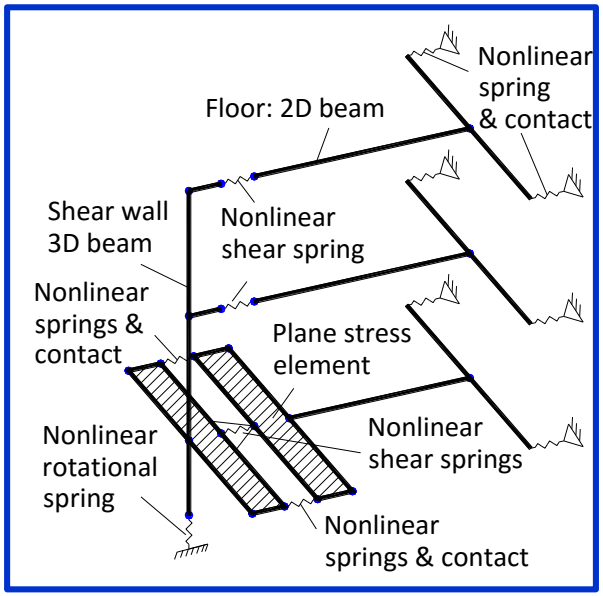


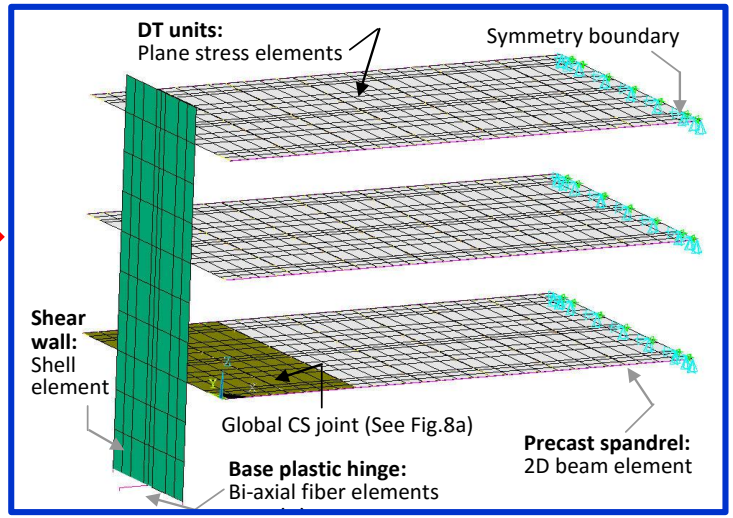


BK MCE

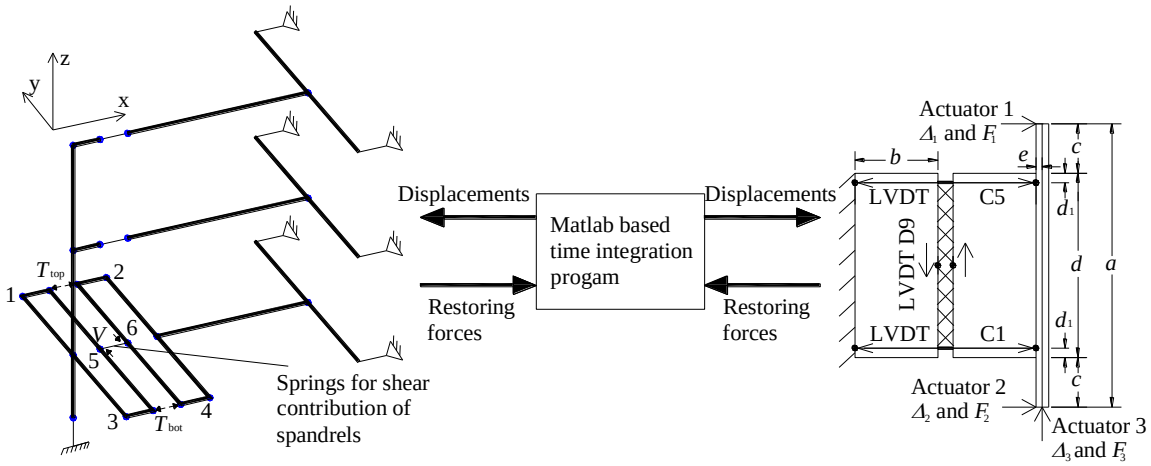
Critical Shear Joint: Hybrid Test

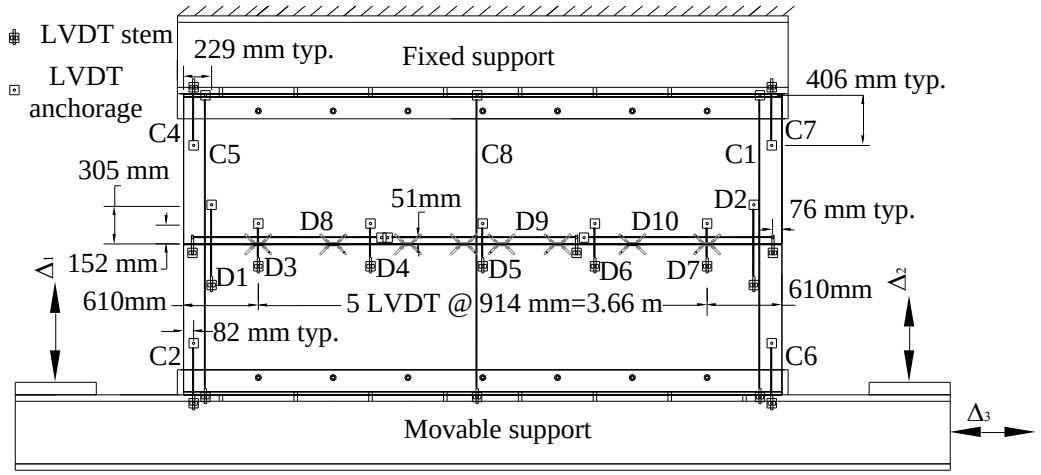






Lehigh Test Algorithms: Hybrid Testing

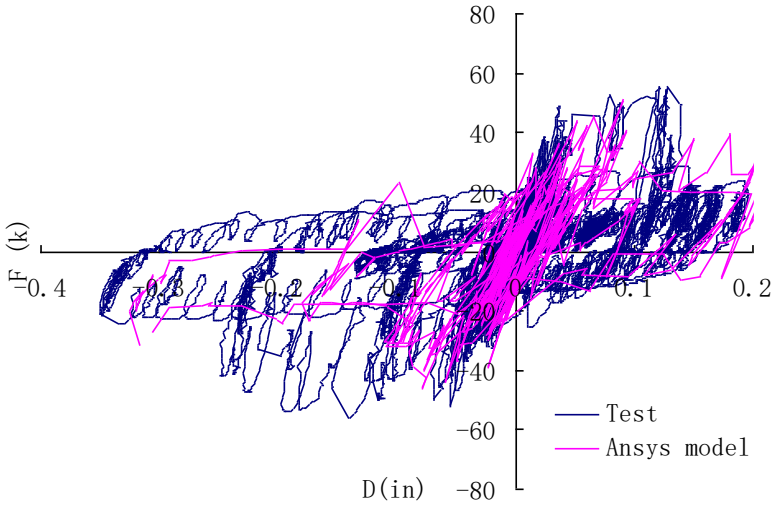


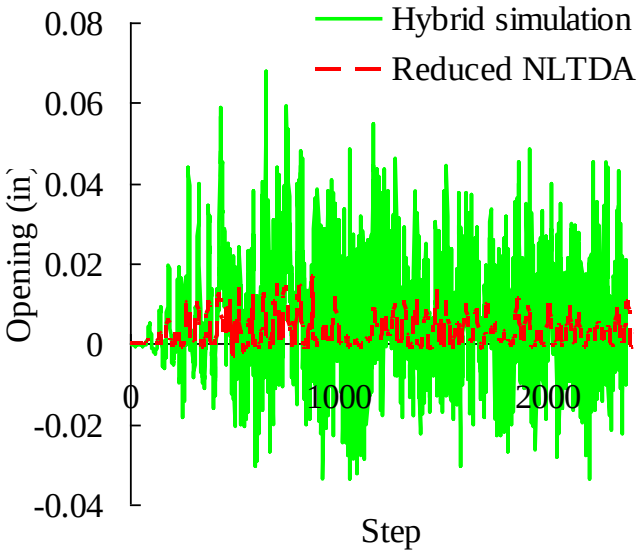


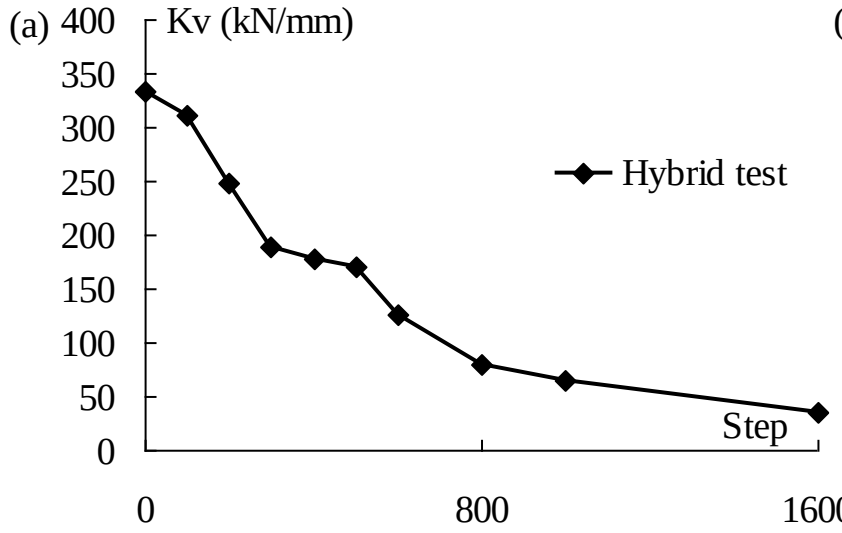
Hybrid Testing :

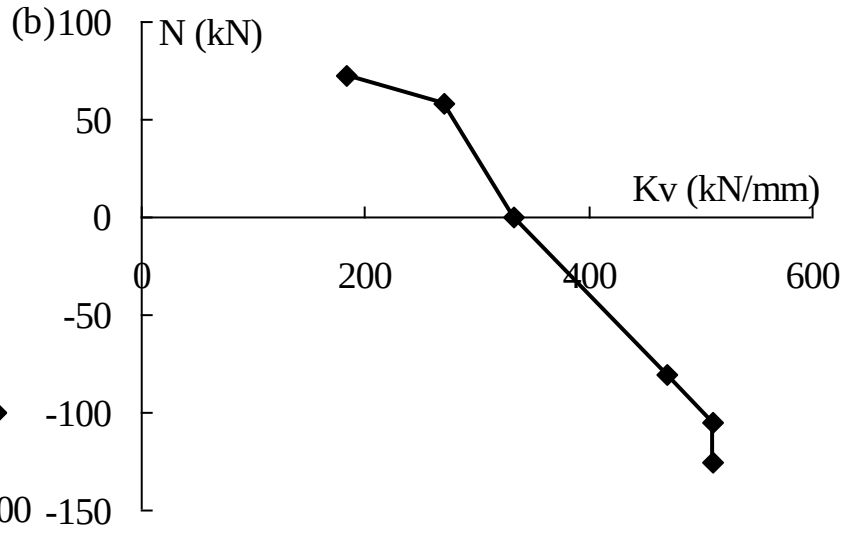
- Matlab based program
- Alpha method with fixed number of iterations (Mercan and Ricles 2005)
- Restoring force provided by RDOF Model (ANSYS)
- Actuator displacement commands (Δ_1, Δ_2, Δ_3) controlled through a multiple loop architecture
- Inner loop iterates for kinematic compensation of three actuator system

Test Results: Hybrid Testing

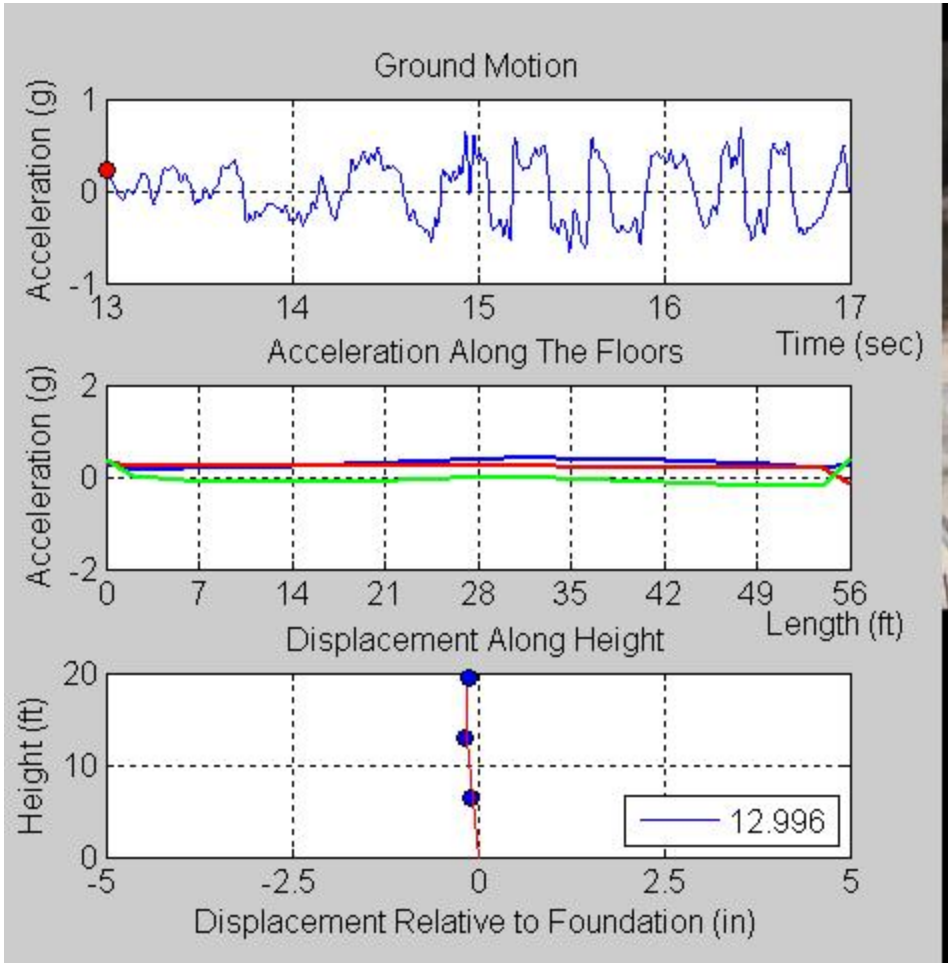


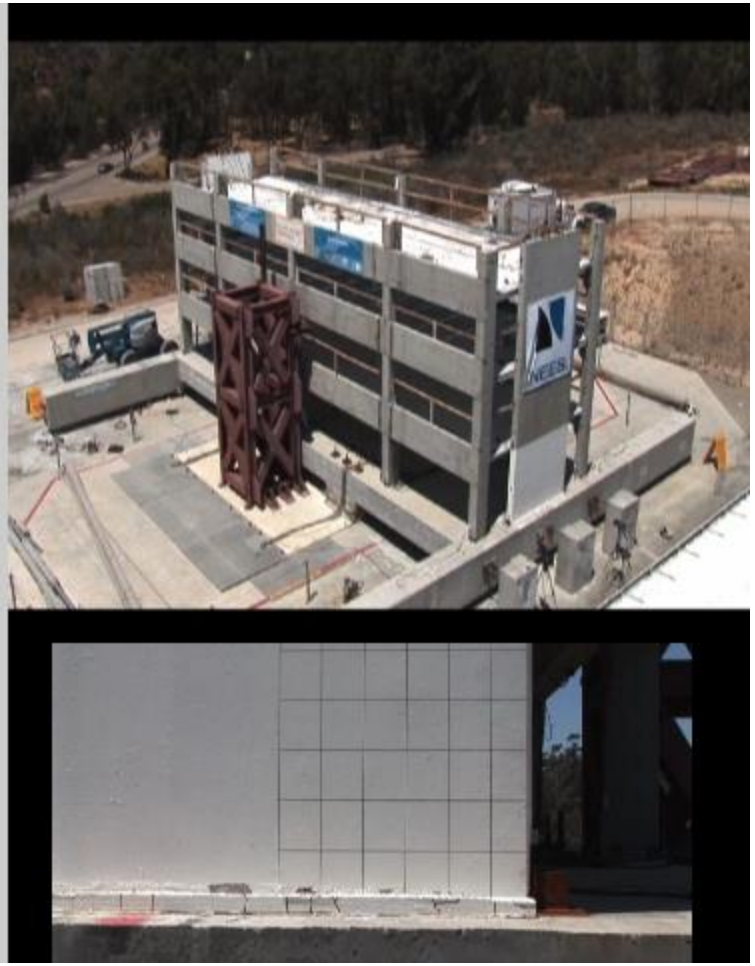




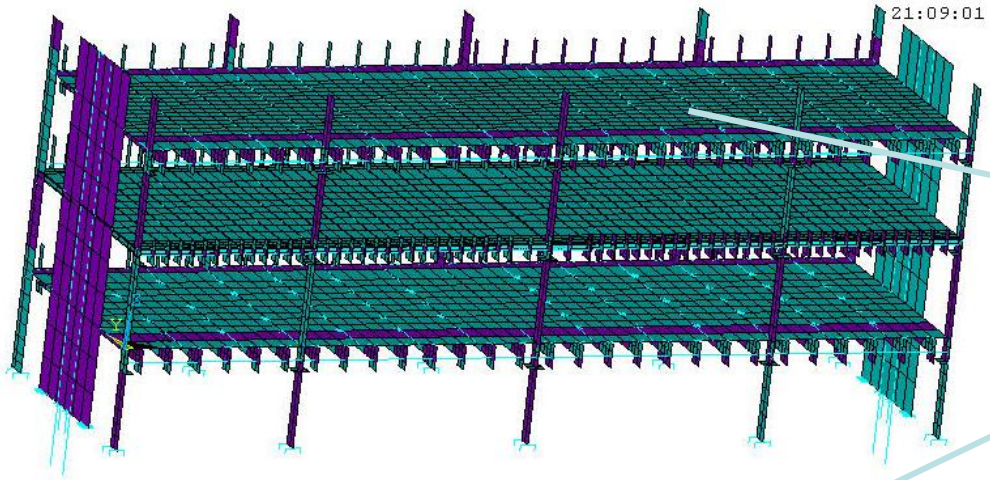


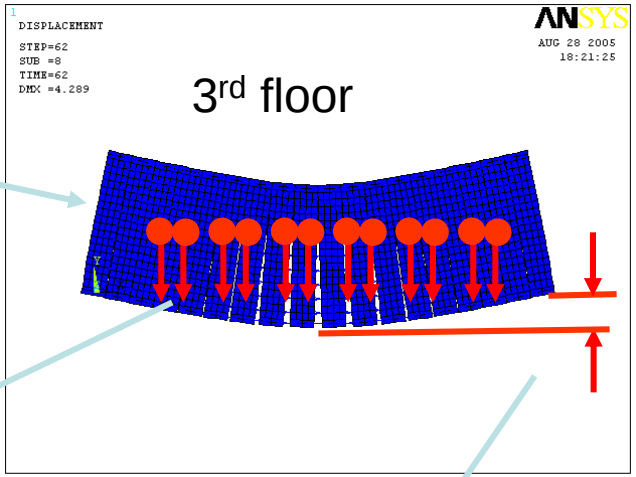
Shake Table Demonstration Test

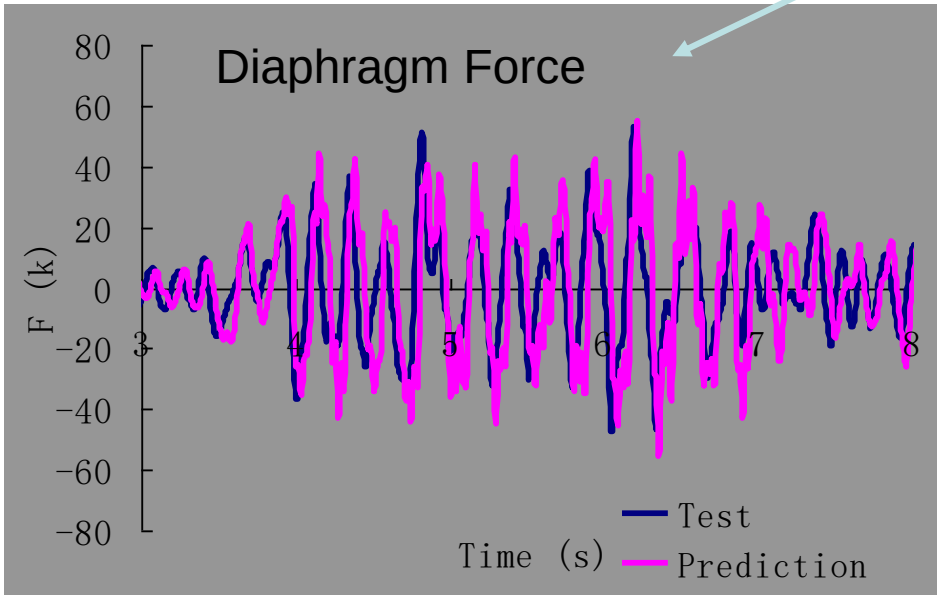


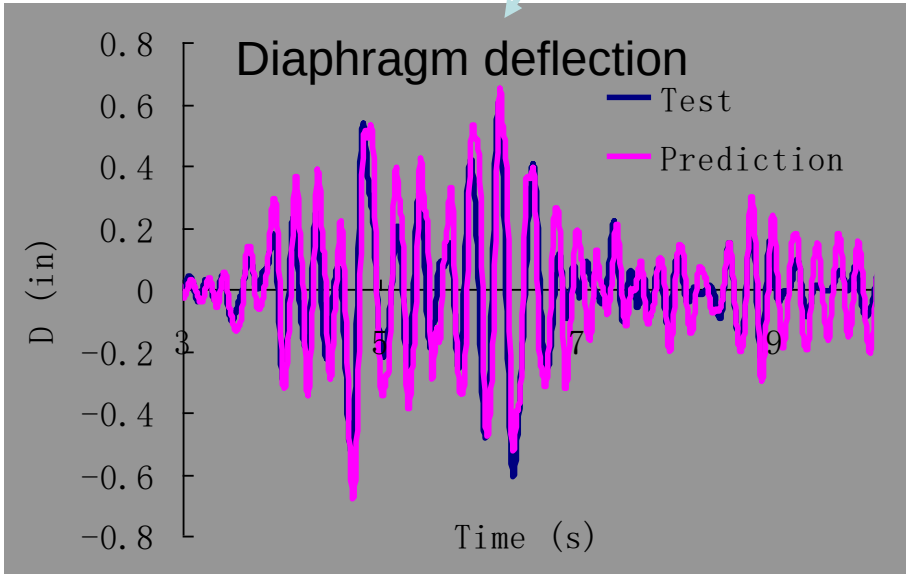


Analytical Simulation









DSDM Project Outcome

- **Deliverable**: A new seismic design methodology for precast concrete diaphragms.
- **Outcome**: New design provisions approved for inclusion in **ASCE 7-16** and Part 3 of the **2015 NEHRP Provisions**.

Project 2: NEESR IFAS

NEESR: Inertial Force-Limiting Floor Anchorage Systems for Seismic Resistant Building Structures (IFAS)

NEES @ UCSD

NEES @ Lehigh

Project Team

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Joseph Maffei

K12 partner

Utterback Middle School

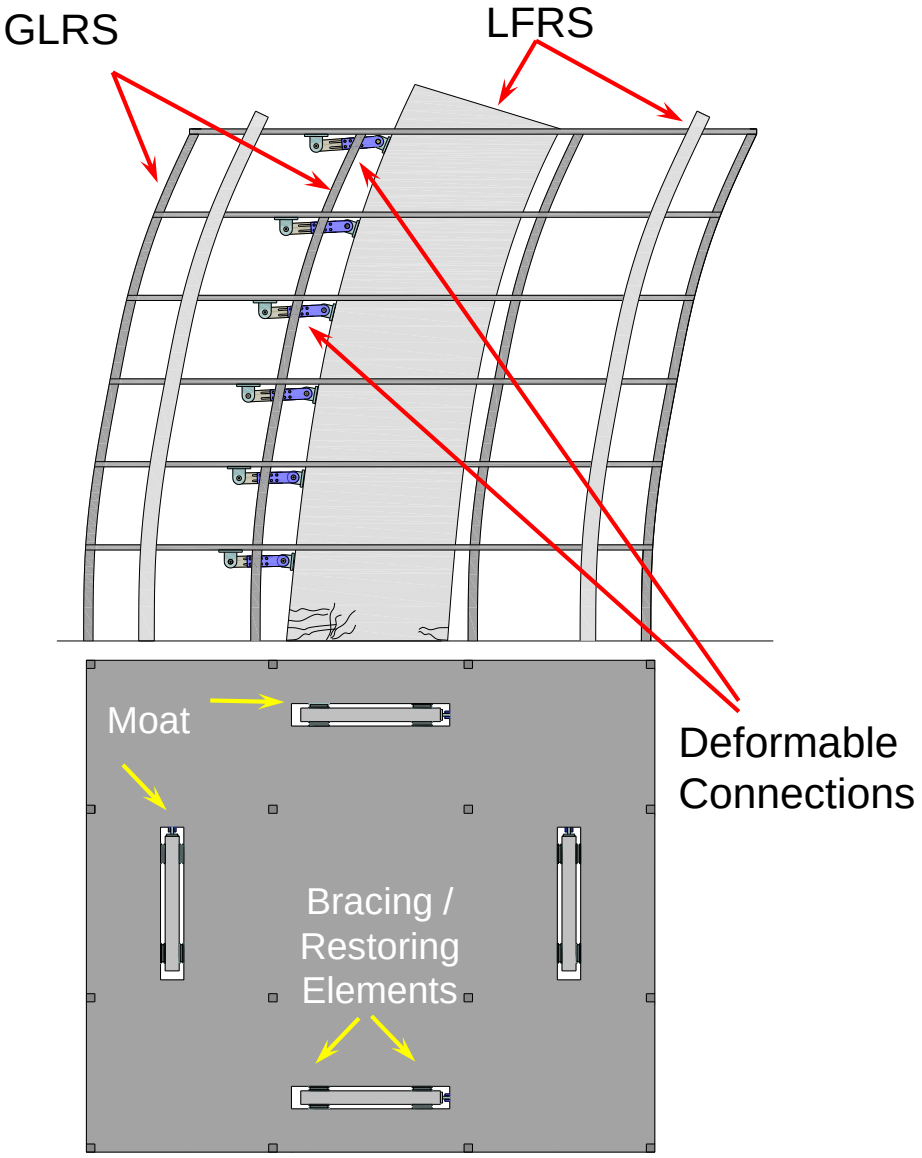
Gricelda Meraz

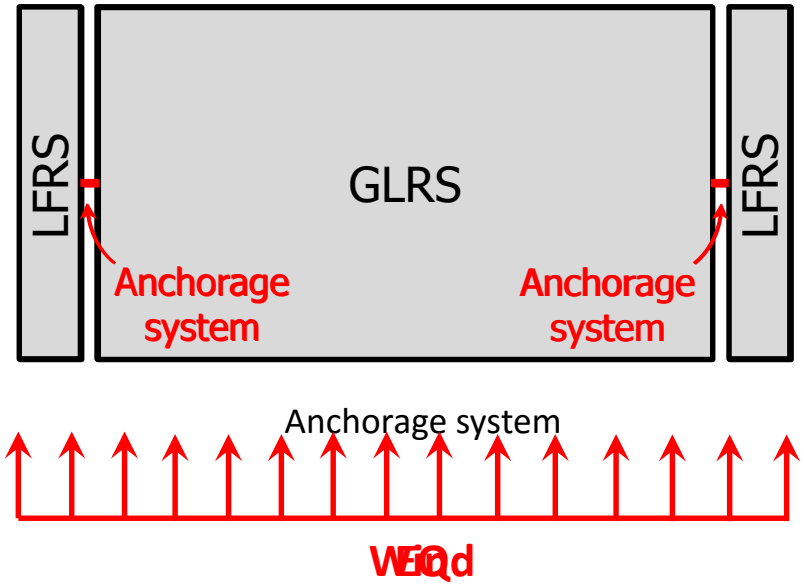
Industry Partners: NEESR Shake Table Test

Research Team

Research Meeting #3 at R&C Offices

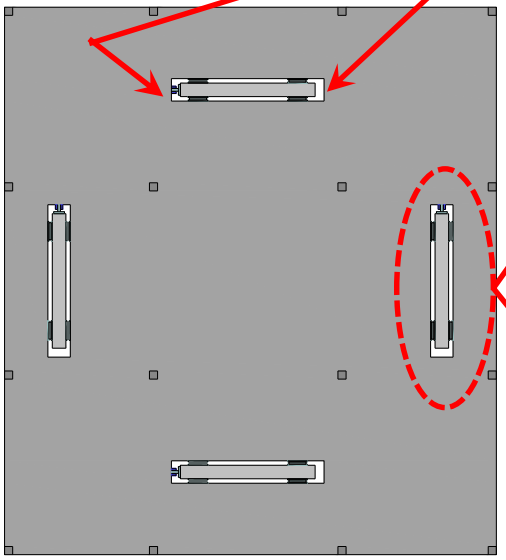
IFAS Concept

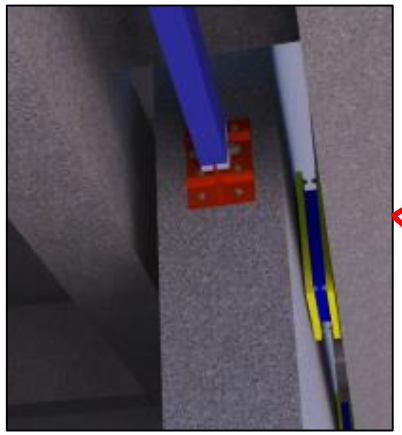




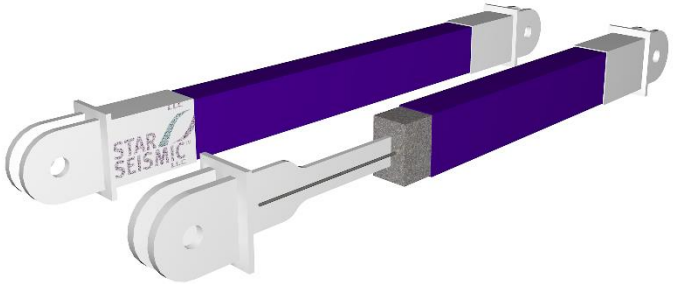
IFAS Components

Polyurethane Bumper

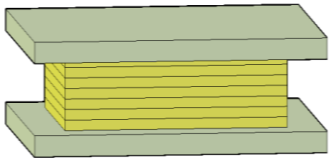




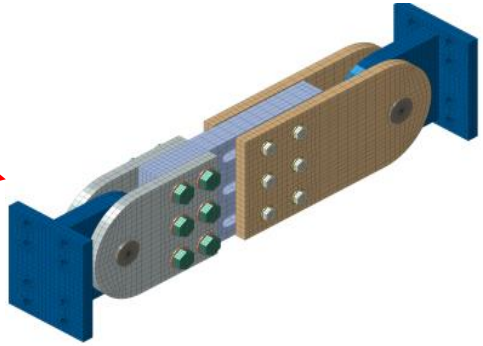
Buckling Restrained Brace (BRB)



Low Damping Rubber Bearings (RB)

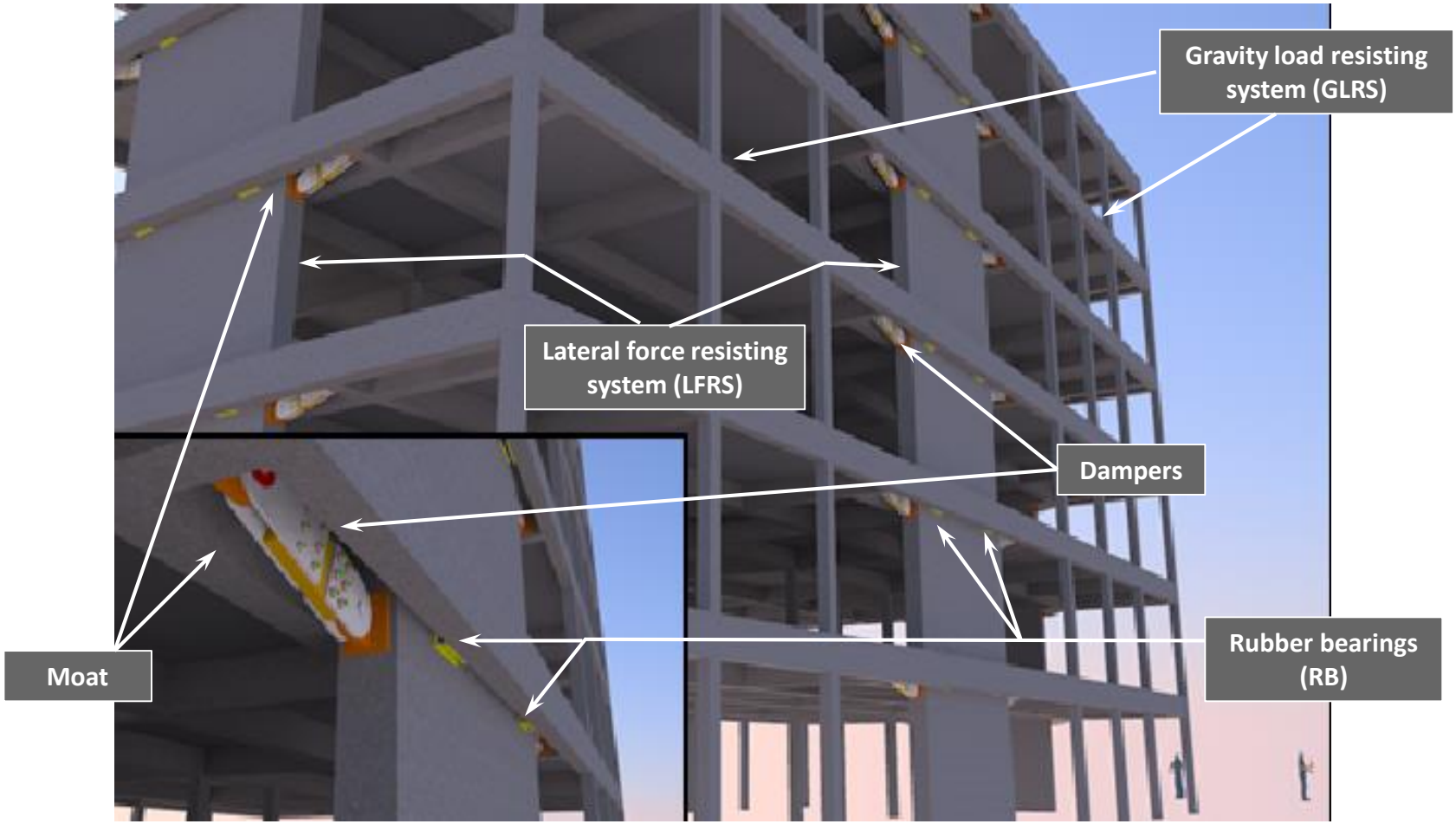


Friction Device (FD)



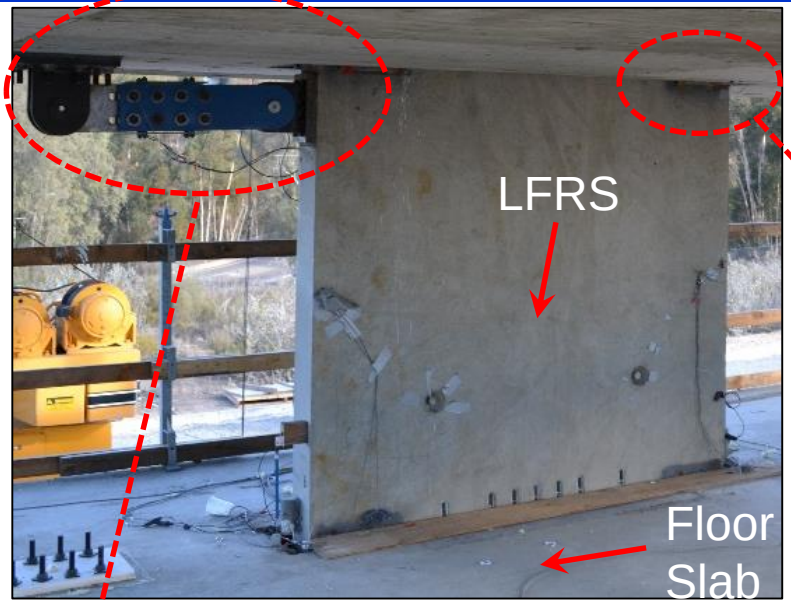
IFAS Prototype

Prototype IFAS System

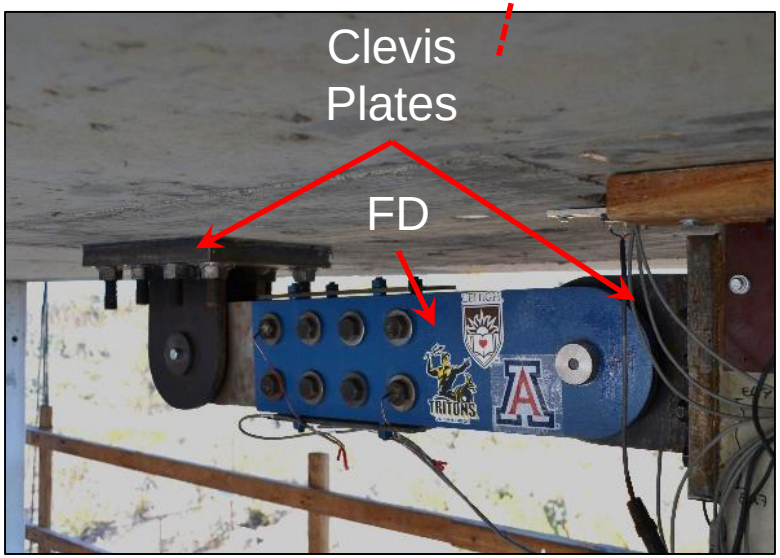


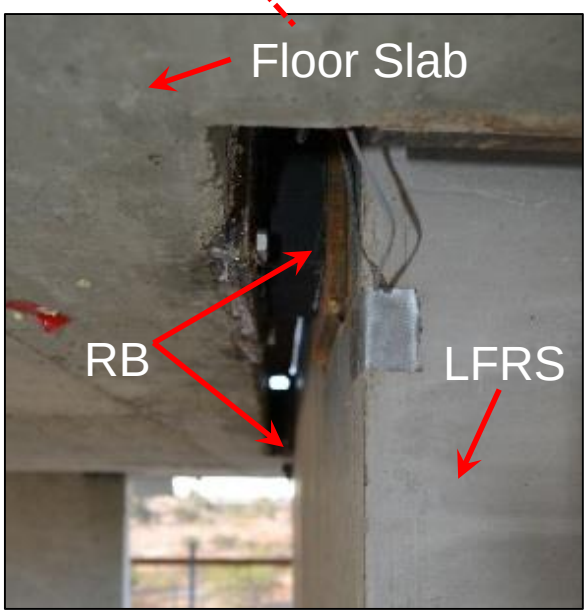
IFAS Shake Test Installation

Half-Scale 4-story Precast Rocking Shear Wall Structure

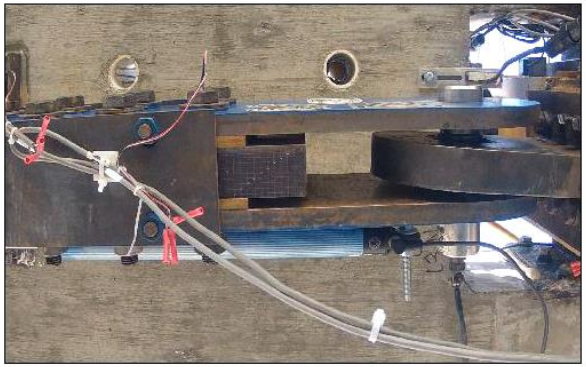


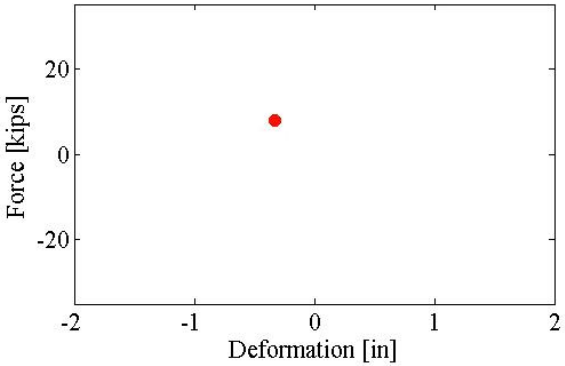
NEES @ UCSD

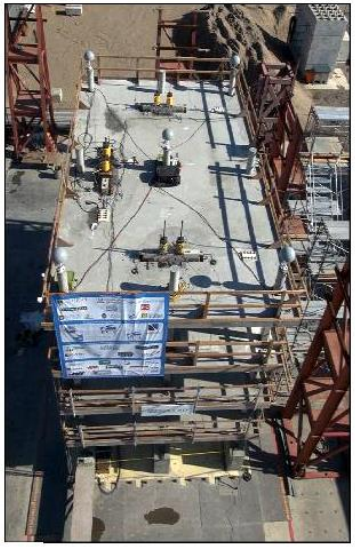




IFAS Shake Table Response: NEES@UCSD







Shake Table Testing: NEES@UCSD

LEHIGH UNIVERSITY

THE UNIVERSITY OF ARIZONA

UC San Diego

Berkeley BE05 MCE
Traditional system vs IFAS

PLAN VIEW COMPARISON

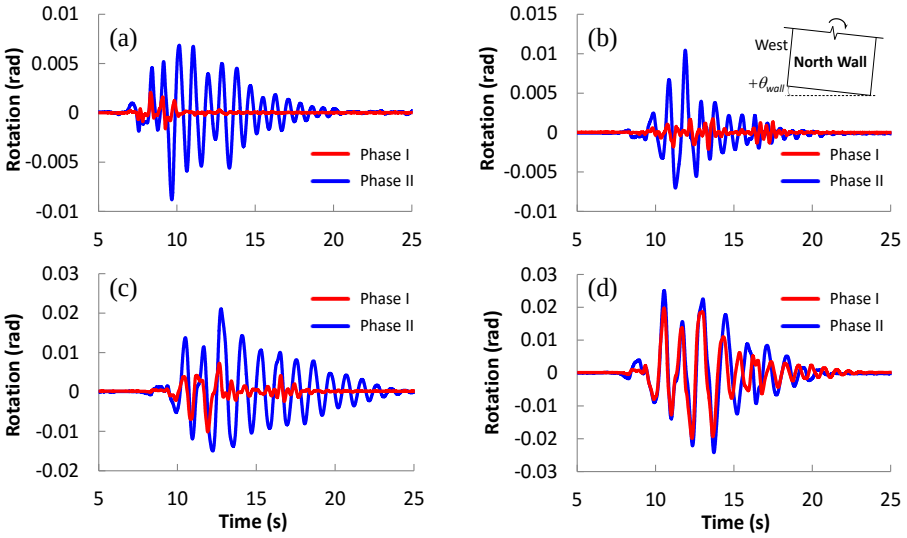
Shake Table Testing: NEES@UCSD

Shake Table test

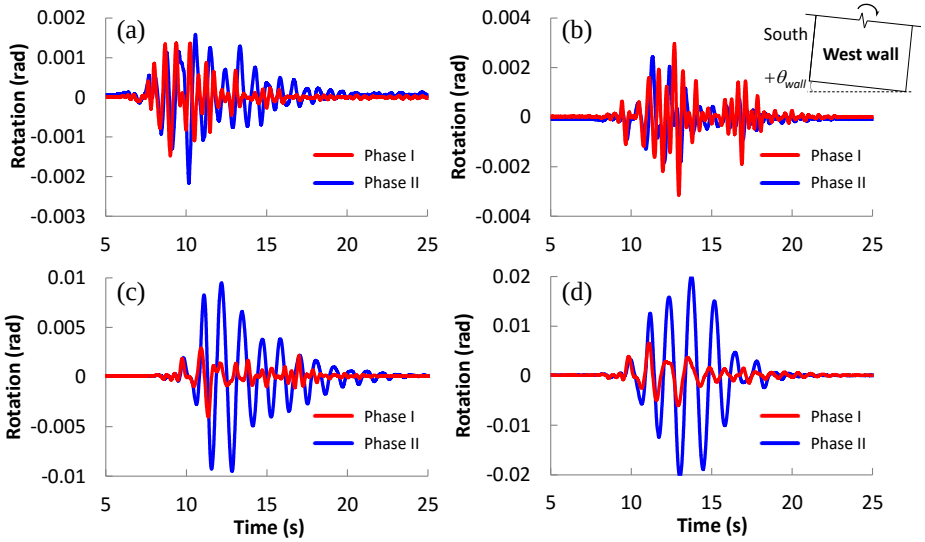
Rocking of Main(North) wall

PHASE I VS PHASE II

Shake Table Test Results: NEES@UCSD



Comparison to Traditional Structure



Subassemblage Testing: NEES@Lehigh

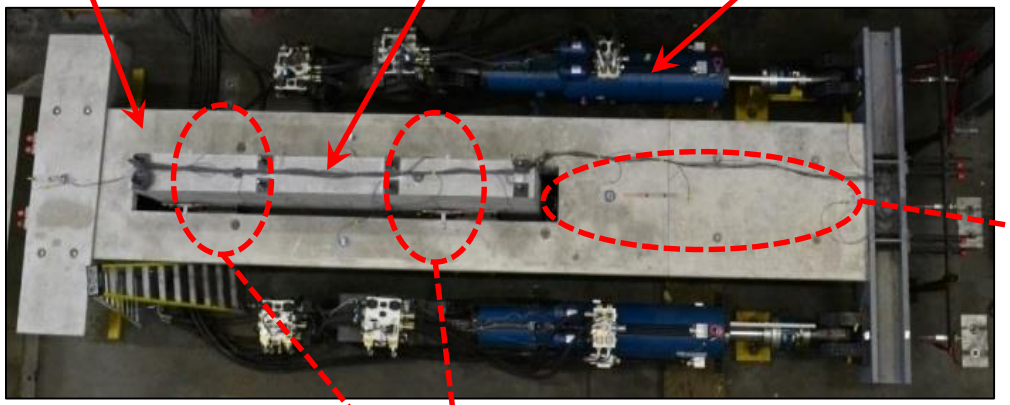
Lehigh Test Specimen

Full-Scale IFAS Testing: BRB

Floor Slab

Wall Stub

NEES Hydraulic Actuators



BRB

Steel Reinforced RB

NEES @ Lehigh

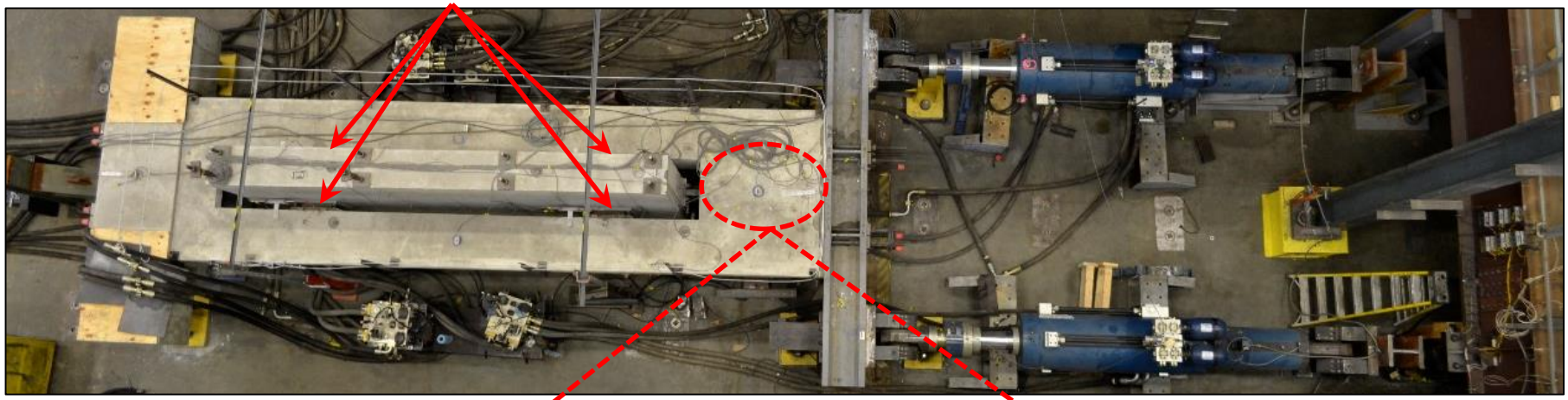
Full-Scale IFAS Testing: BRB

Full-Scale IFAS Testing: BRB

Full-Scale IFAS Testing: RB

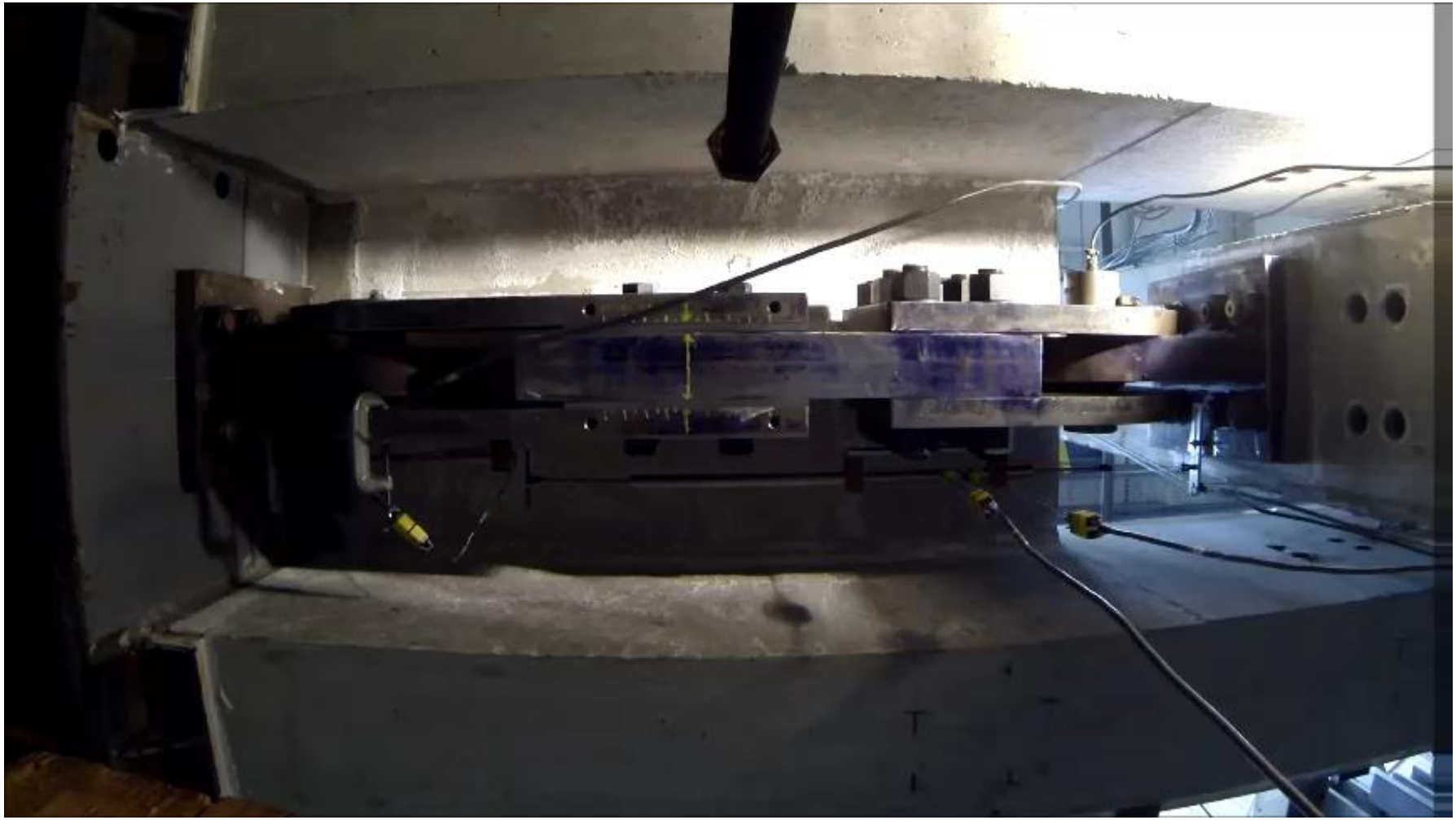
Full-Scale IFAS Testing: FD

Carbon Fiber Reinforced RB

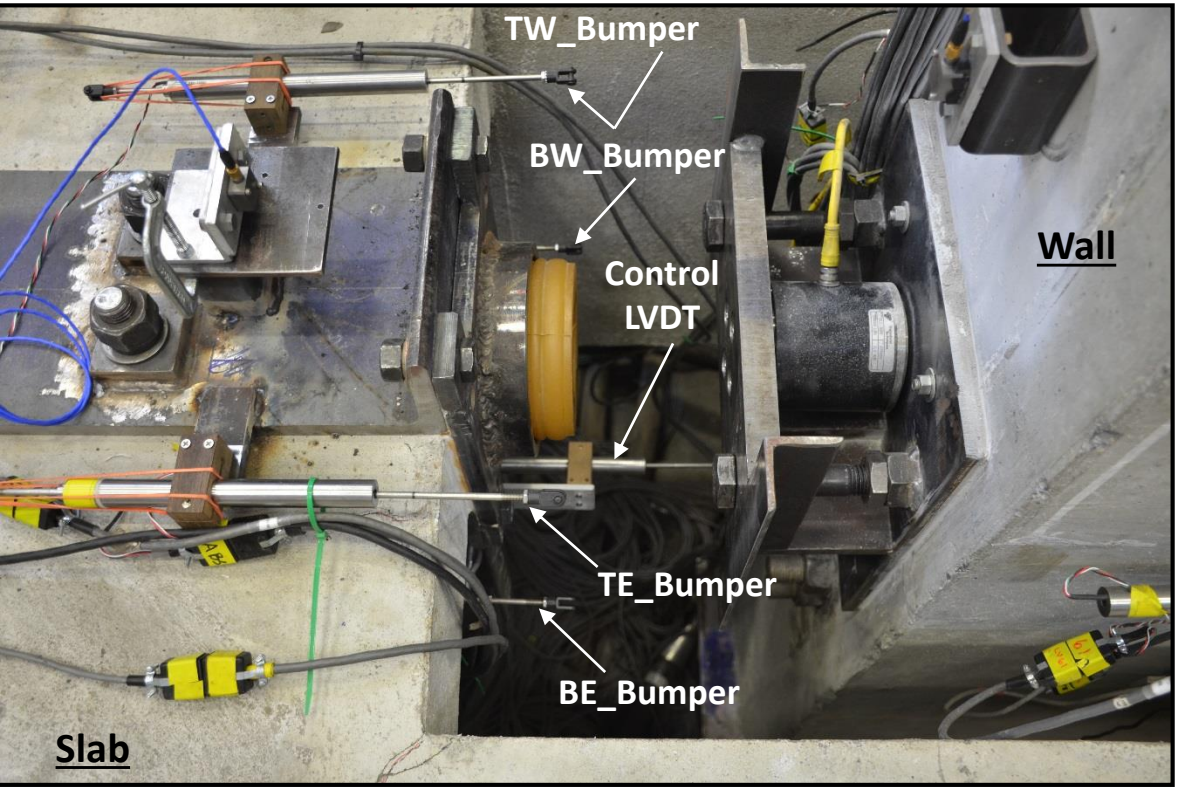


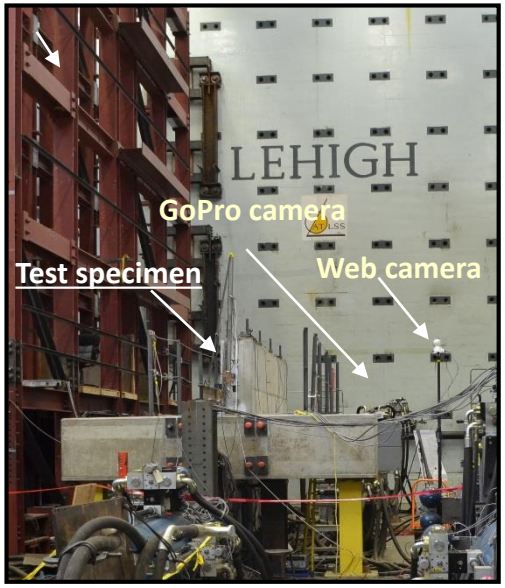
FD

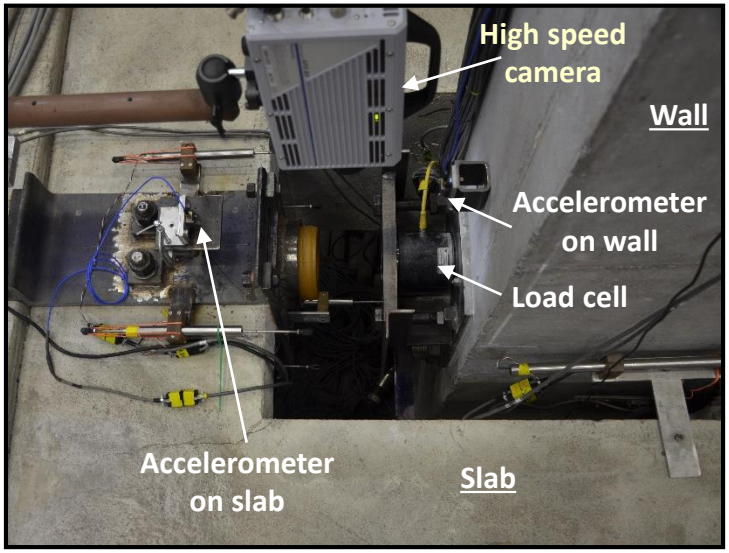
Full-Scale IFAS Testing: FD



Bumper Impact Tests: NHERI@Lehigh



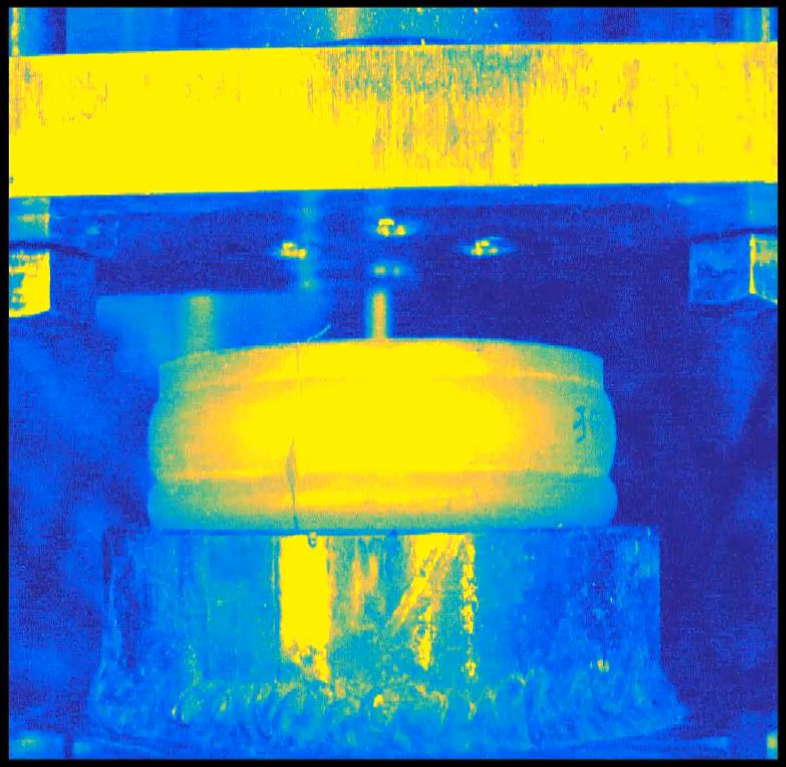


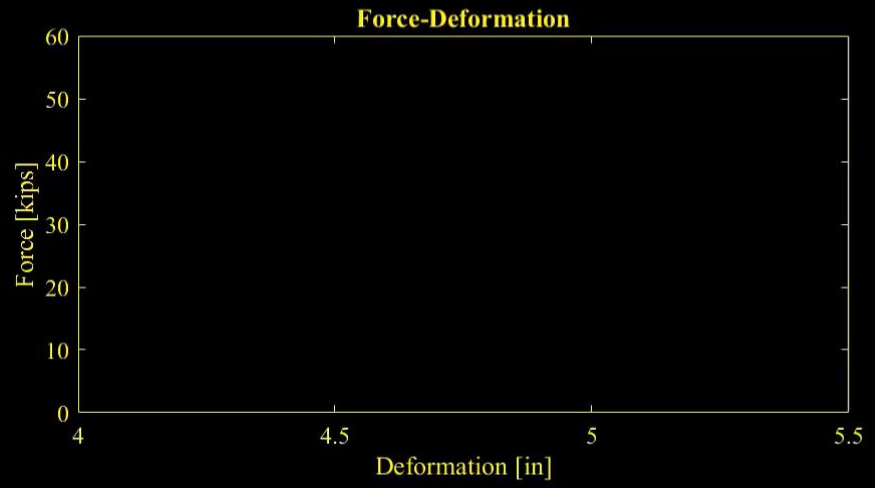


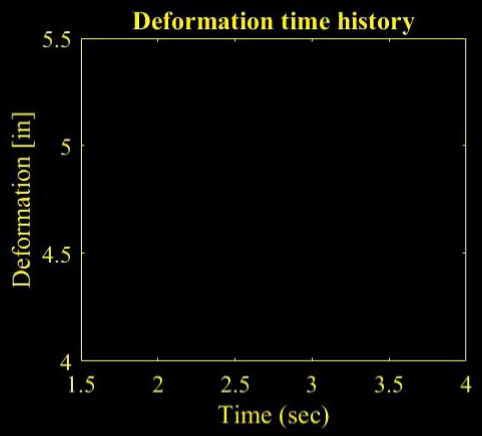
Bumper Impact Tests: NHERI@Lehigh

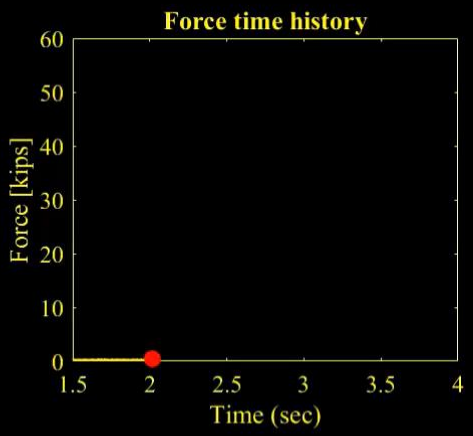
Bumper Impact Tests: NHERI@Lehigh

Bumper Test (1-22)

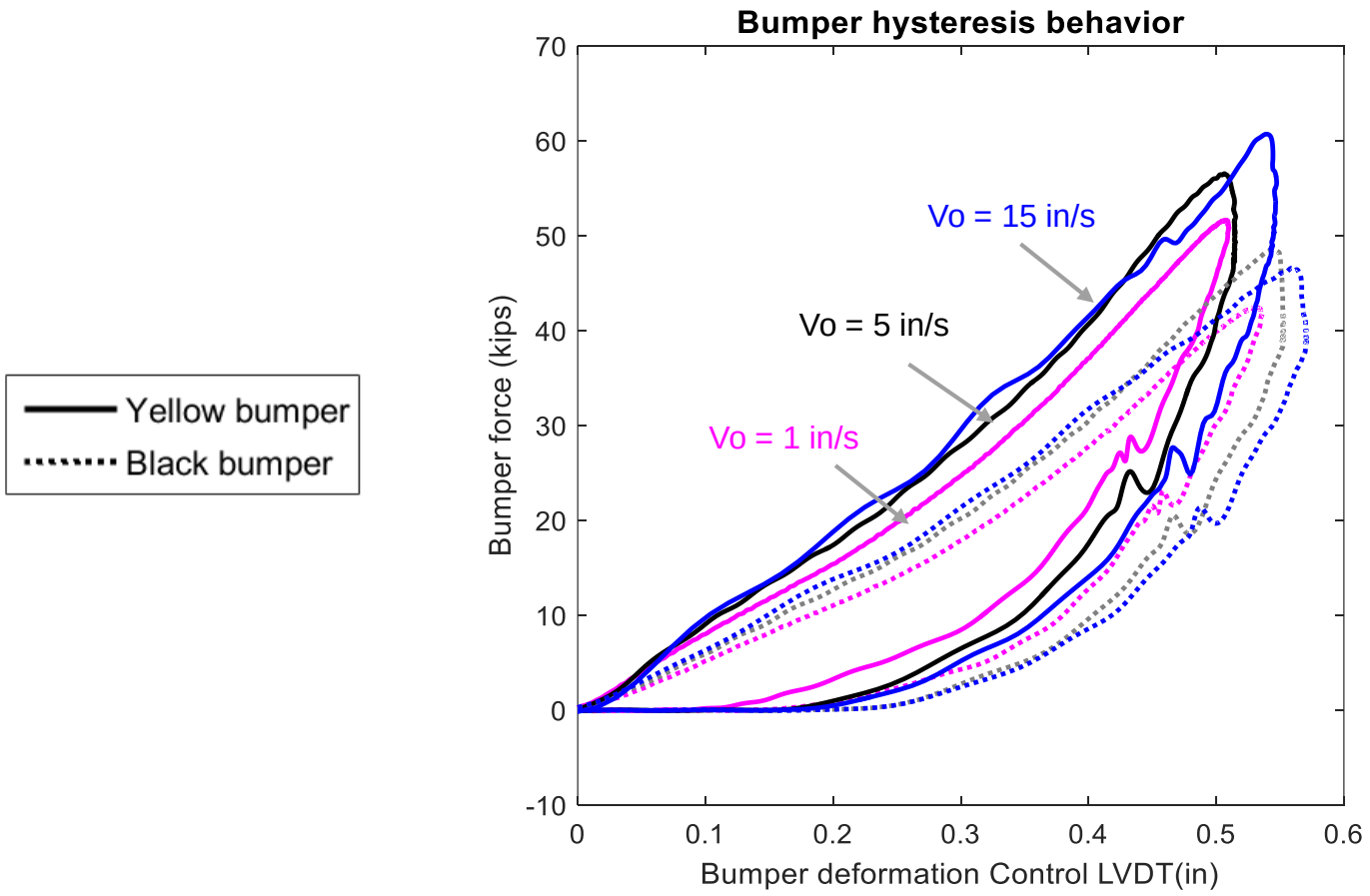








Bumper Test Results: NHERI@Lehigh



Thank You !