Advanced Simulation for Natural Hazard Engineering
& Grand Challenges for Multi-Hazard Engineering

Seismic Structural Components

LEHIGH JOINT RESEARCHER WORKSHOP
UC SAN DIEGO & SIMCENTER
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Presentation Outline

- Grand Challenges in Earthquake Engineering Structural Research
- Approaches for Integrating Physical Experiments & Computer Simulation using NHERI resources
- Example Projects: Seismic Design of Horizontal Elements
  - Case Study 1: **NSF GOALI: Development of a Seismic Design Methodology for Precast Floor Diaphragms (DSDM)**
  - Case Study 2: **NSF NEES: Inertial Force-Limiting Anchorage Systems (IFAS)**
  - Case Study 3: **NSF ENH: Development of New Knowledge for Steel Seismic Floor and Roof Collectors**

Grand Challenges in Earthquake Engineering Structural Research

NHERI Five Year Science Plan

The NHERI Five-Year Science Plan identifies three Grand Challenges:

Three Grand Challenges

- Identify and *quantify the characteristics of earthquake*, windstorm, and associated *hazards* — including tsunamis, storm surge, and waves — that are **damaging to civil infrastructure** and disruptive to communities.

- Evaluate the **physical vulnerability of civil infrastructure** and the *social vulnerability of populations* in communities exposed to earthquakes, windstorms, and associated hazards.

- Create the **technologies and engineering tools to design**, **construct, retrofit,** and operate a multi-hazard **resilient and sustainable infrastructure** for the nation.

2019 NHERI INTERNATIONAL WORKSHOP Report

Grand Challenges in Earthquake Engineering

1. **Community Resilience Framework:** interactive comprehensive framework for measuring, monitoring, and evaluating community resilience at different scales
2. **Decision Making:** decisions based on a clear understanding of the built environment, simulation-based decision-making strategies. state-of-the-art decision-making tools for more efficient resource allocation based on comparing different strategies for earthquake mitigation
3. **Simulation:** knowledge of the inventory of infrastructure, scalable tools. Powerful simulation technologies to model the time and spatial impacts of a seismic event from the component to the regional scale
4. **Mitigation:** strategies to measure, monitor, and model community vulnerability to establish mitigation strategies. Better approaches for retrofit of the built environment's most vulnerable sectors
5. **Design Tools:** emerging sustainable materials and innovative structural concepts to significantly change the way infrastructure is designed and constructed, integrated with design tools that could dramatically improve earthquake resilience. Harness the power of performance-based earthquake engineering (PBEE).

National Research Council. 2011. *Grand Challenges in Earthquake Engineering Research: A Community Workshop Report*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13167.

Grand Challenges in Earthquake Engineering

Dimension (Breakout Group)	Grand Challenge Problem	OVERARCHING GRAND CHALLENGES: Community Resilience Framework	Decision Making	Simulation	Mitigation	Design Tools
Community Resilience	1. Framework for Measuring, Monitoring, and Evaluating Community Resilience	√	√	√	√	√
	2. Motivating Action to Enhance Community Resilience	√	√	√	√	
Pre-event Prediction and Planning	3. Develop a National Built Environment Inventory	√	√	√	√	
	4. Multi-Scale Seismic Simulation of the Built Environment	√		√	√	
	5. Integrated Seismic Decision Support	√	√	√		
	6. Risk Assessment and Mitigation of Vulnerable Infrastructure	√	√	√	√	√
	7. Protect Coastal Communities	√	√	√	√	
Design of Infrastructure	8. Regional Disaster Simulator	√	√	√	√	
	9. High Fidelity Simulation	√		√	√	
	10. New Sustainable Materials and Systems for Earthquake Resilience	√		√	√	√
	11. Harnessing the Power of Performance Based Earthquake Engineering (PBEE) to Achieve Resilient Communities	√		√	√	√
Post-event Response and Recovery	12. Rapid Post-Earthquake Assessment Reconstruction and Recovery	√	√	√	√	

National Research Council. 2011. *Grand Challenges in Earthquake Engineering Research: A Community Workshop Report*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13167.

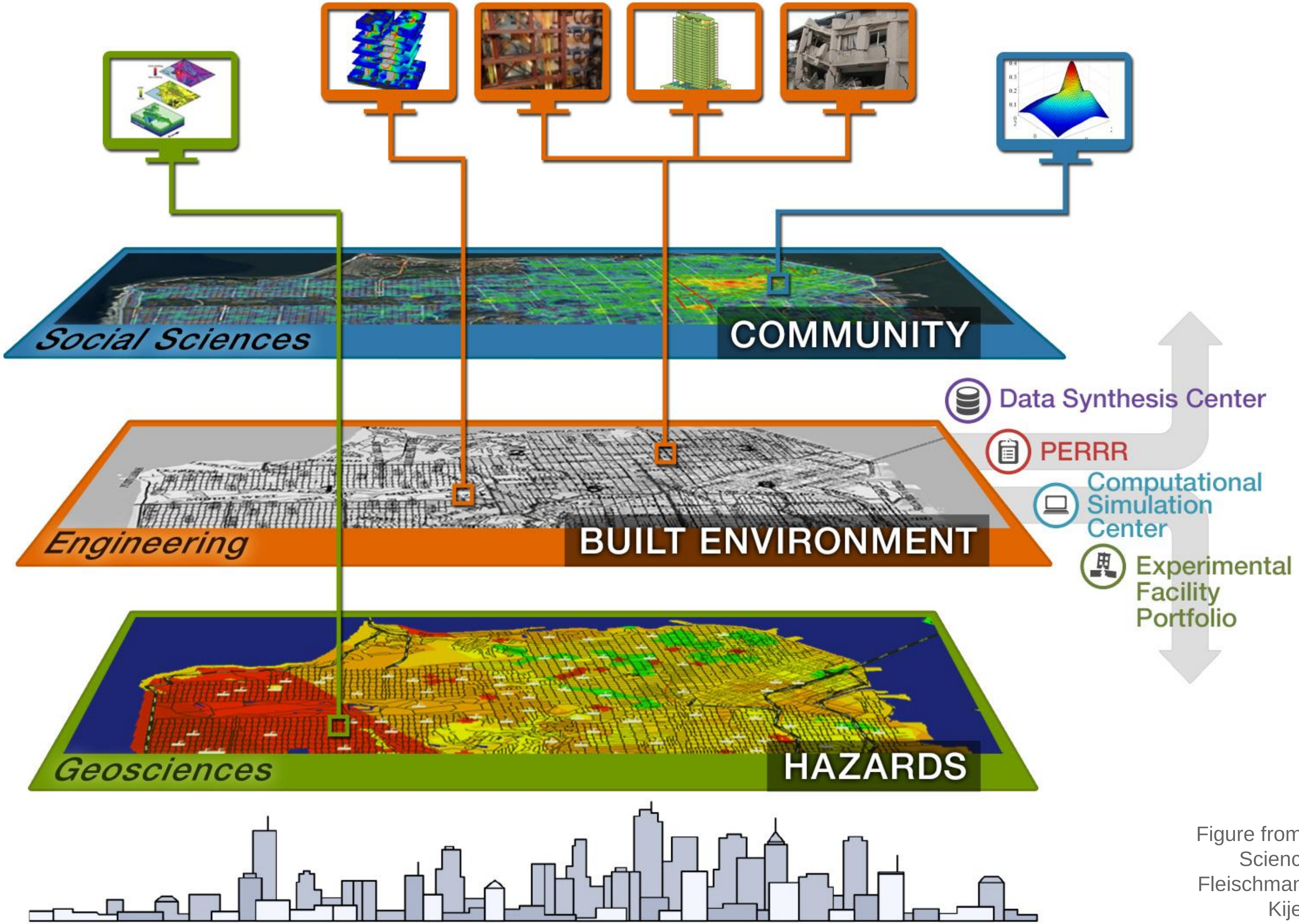


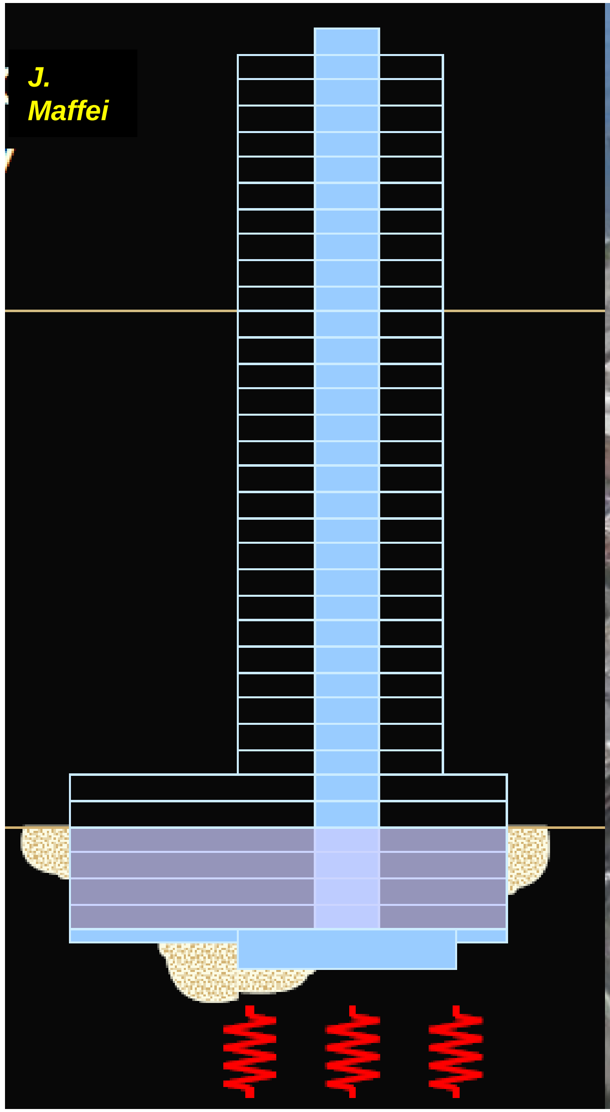
Figure from Proposed NEES2 Science Plan, 2015-2019 Fleischman, Deierlein, Mahin, Kijewski, Leon, Frost .

Grand Challenges

- Experimental research in earthquake engineering has shifted from isolated characterization testing of existing structural components:
    - System Behavior & System Interactions
    - Vulnerable or Poorly Understood Systems
    - New Materials and Processes
    - Low Damage, Protective and Smart Systems
    - Non Structural Components and Contents
    - Sensors and Monitoring
    - Risk Assessment and Hazard Mitigation
    - Multi-Hazard, Multi Scale Investigations
    - Special Structures

System Behavior and System Interactions

- **Complex System Behaviors:**
  - Tall Buildings
  - Discontinuities (e.g. Transfer Conditions)
  - Diaphragm action, Tie Structures
  - Structural Irregularity in Plan, Vertical Offsets



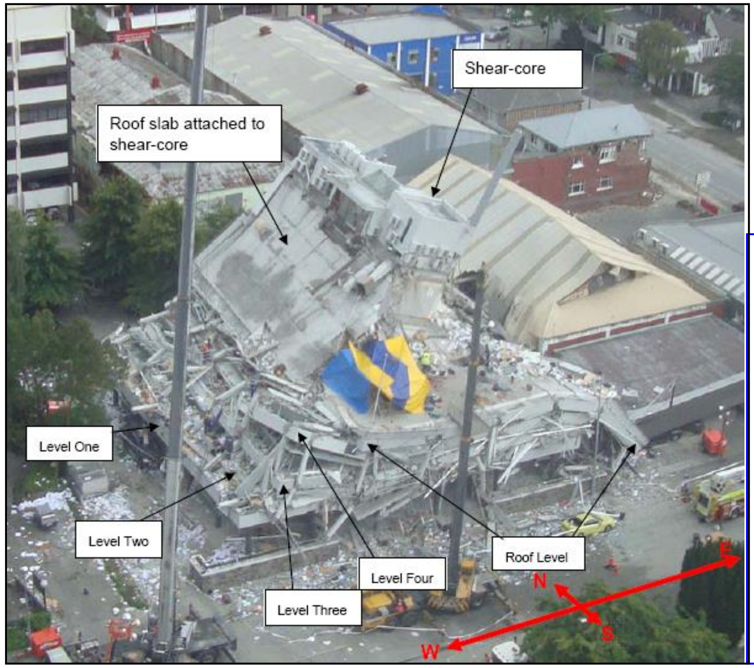
System Behavior and System Interactions

- **System Interactions**:
  - Seismic Force Resisting System (SFRS) – Gravity Load Resisting System (GLRS) coupling
  - Soil-Structure-Foundation Interaction
  - Axial Force Interactions:
    - ✓ Gravity Load,
    - ✓ Overturning
    - ✓ Vertical Acceleration

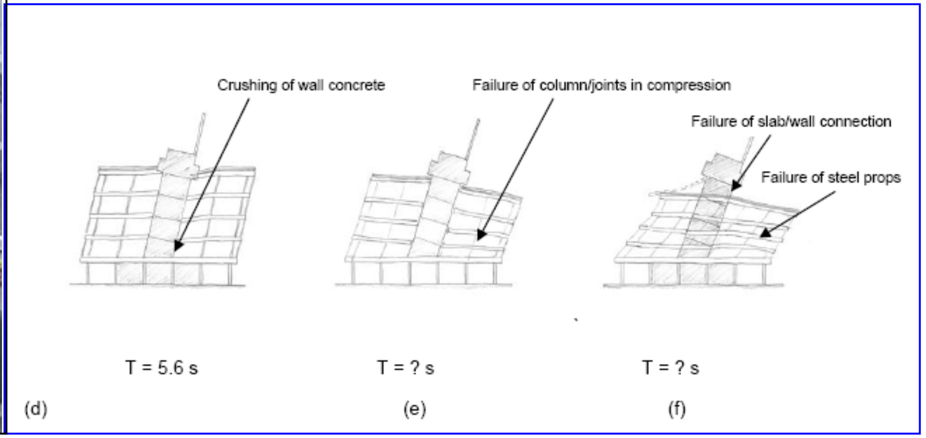
(EERI 2011)
Photo: Sritharan
(Elwood 2011)

Vulnerable or Poorly Understood Systems

- **Vulnerable/Poorly Understood Systems**
  - Near Collapse Behavior
  - Identifying "Killer" Buildings
  - Underdesigned or Failure Critical
  - Complex Response:
    - ✓ e.g. Infills



Department of Building and Housing, Canterbury Earthquake Royal Commission



New Materials and Processes

- **New Materials and Processes**
  - Polymer concrete, Ductile concrete
  - Self-healing materials and systems
  - High Performance Materials
  - 3D Printed Components
  - 3D Printed Concrete
  - New materials being used for sustainability:
    - ✓ Recycled / upcycled materials
    - ✓ energy efficient materials, high albedo, thermal mass, etc.

Protective Systems, Low Damage Systems

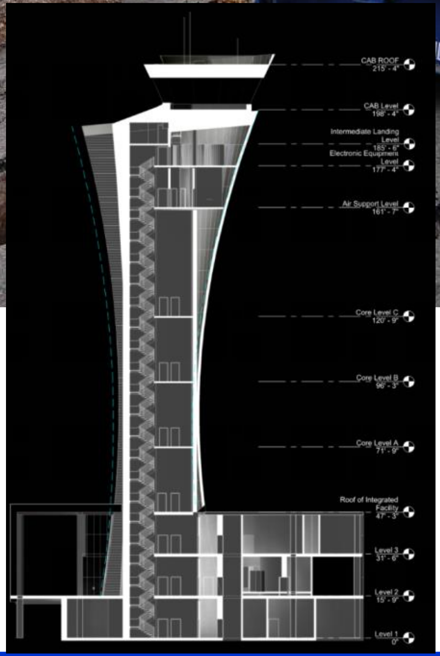
- **Innovative Devices and Structures**
  - Active, Semi-Active, Passive
  - Negative Stiffness Devices, Energy Sinks
  - Self Centering
  - Low Damage Systems
  - Protective Systems
  - Semi-Active Cladding Systems
  - New Devices, New Systems

Non Structural Components and Contents

- Stairs, Elevators
- Cladding, Glazing
- Mechanical Systems

Special Structures

- Lifelines: Water, sewer, gas, electric
- Wind Turbines
- Rooftop Solar
- Power Substations
- Marine structures, Ports, Piers
- Control Towers

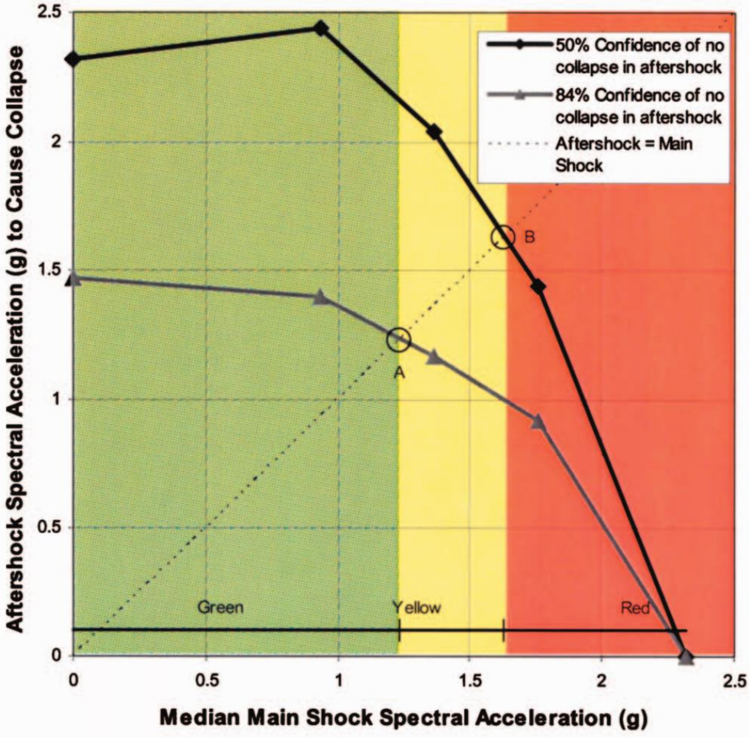


L. Burkett,
Rutherford & Chekene

Risk Assessment and Hazard Mitigation

➢ Risk Assessment & Hazard Mitigation

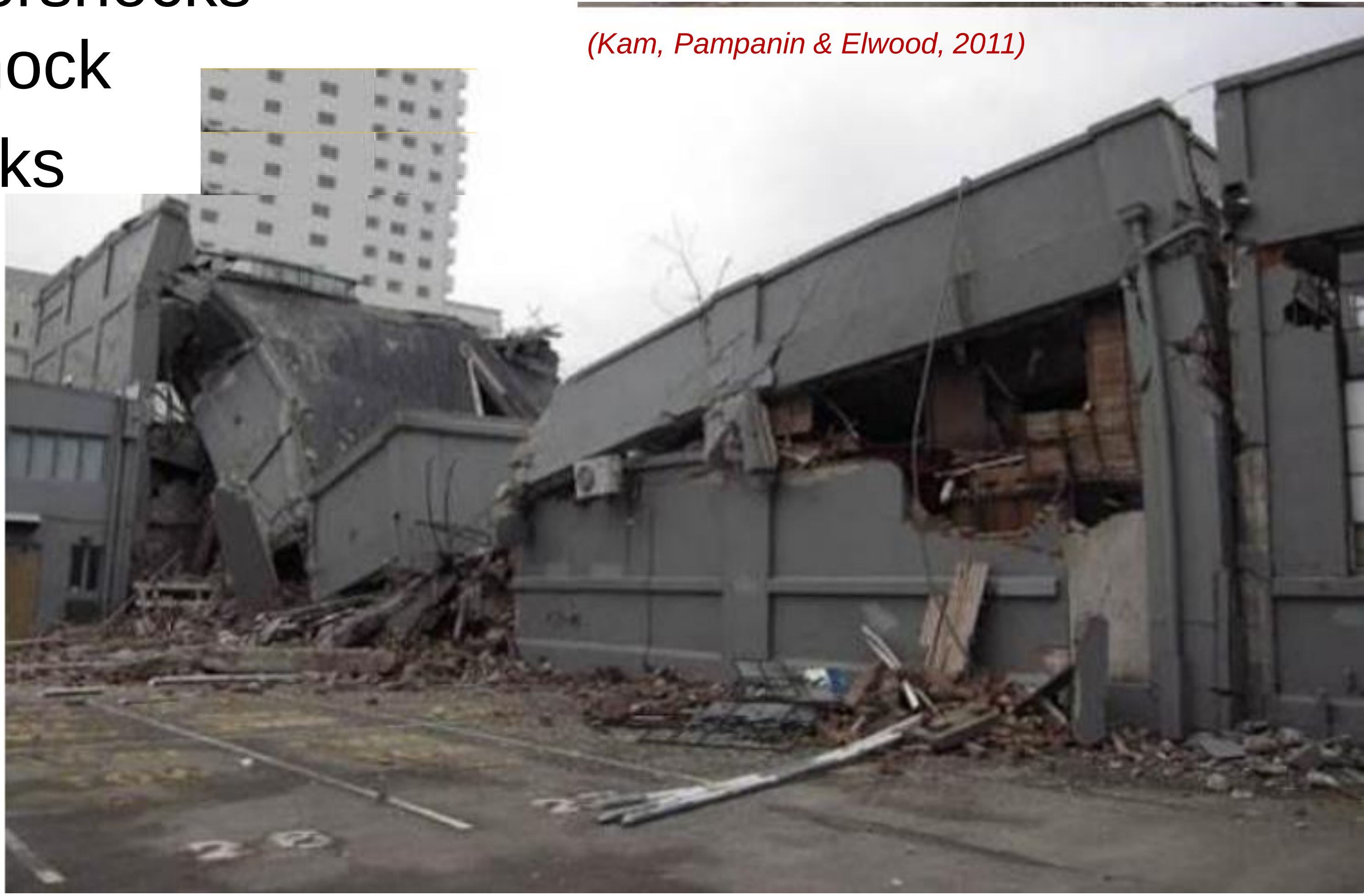
- Fragility of structures in aftershocks after damage in the mainshock
- Monitoring, sensors networks



(Maffei. et al., 2008 EQ Spectra)

Collapse after June 2011 aftershock

(Kam, Pampanin & Elwood, 2011)



Grand Challenges

Grand Challenges are Evolving

- Construction methods are perpetually changing based on new knowledge, new materials, new manufacturing processes
- Some new methods are introduced directly for resilience; while others may be necessitated by sustainability needs, shifting demographics, limited resources or economic constraints
- These new materials and techniques require evaluation on a system basis

Grand Challenge Research Tools

Research Tools are Evolving

New Testing Capabilities:

- e.g. NHERI UCSD 6-DOF Shake Table

New Simulation Tools:

- e.g.SimCenter quoFEM – PBE work flows

Emerging Testing techniques using existing NHERI or other facilities:

- e.g. Hybrid shake table testing method,
- Nonstructural demand simulators, fault displacement effects
- real time hybrid testing of axially stiff systems,
- soil-foundation testing at larger scales (e.g. soil box)

New Measurement Techniques

- e.g. DIC, etc.

Approaches for Integrating Experiments & Simulation

SWOT of Physical Experiments & Simulation

Laboratory Testing

Ability to straightforwardly characterize components and subassemblages from the elastic range to ultimate limit states under well-defined loading and measurement

Shake Table Testing

Ability to examine system behavior, including the ability to generate realistic inertial force paths and realistically enforce distributed boundary conditions

Comp. Simulation

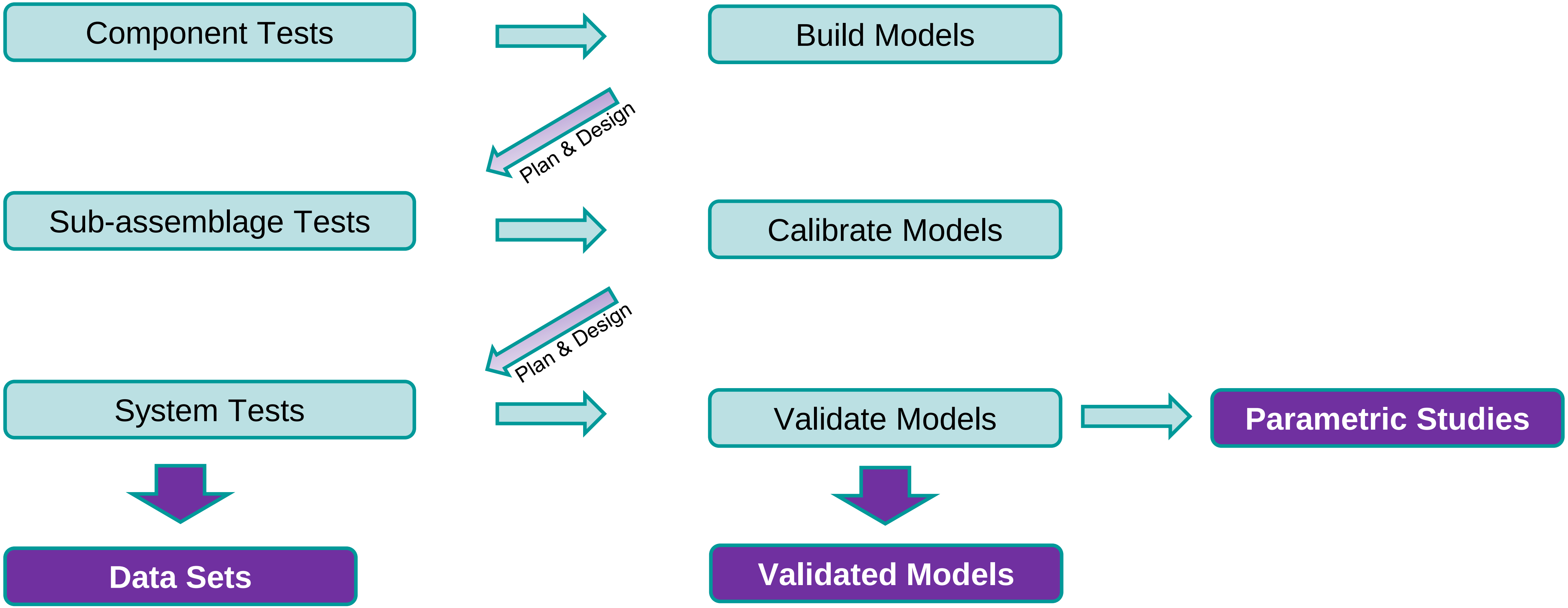
Ability to cost-effectively evaluate and comprehensively measure many scenarios, design parameters, and loading conditions, without *physical* limitations on model size.

Grand Challenges

CODES
REGION
COMMUNITY
PORTFOLIO
SYSTEM
SUB-ASSEMBLAGE
COMPONENT
DETAIL
HAZARD

- PBEE
- Community & Regional Resilience
- Societal and Economic Impacts
- Simulation, Monitoring
- NHERI EFs
- Geoscience (e.g. SCEC), Simulation, Ground Motion Scaling, etc.

An Approach for Integrating NHERI EFs & SIM



Case Studies

Illustrative Topic: Horizontal Elements

Horizontal Elements

- How behave? How interact? Failure critical?
- Force Demands (Restrepo, Rodriguez)
- Vertical Compatibility (Sritharan, Henry)
- Big Box Rigid-Wall Flex Diaphragm (Koliou, Filliatrault)
- Flexible unfilled metal deck (Tremblay)
- Steel diaphragms (Schafer, Eatherton, Hajjar, Easterling)
- Composite Systems (Gravity Load, Moment Frame)
- Disproportionate Collapse (Main, Sadek, Fahnestock, etc.)
- Fire (NIST, Choe etc.)

Example Projects

- Example Projects: Seismic Design of Horizontal Elements
  - Case Study 1: **NSF GOALI: Development of a Seismic Design Methodology for Precast Floor Diaphragms (DSDM)**
  - Case Study 2: **NSF NEES: Inertial Force-Limiting Anchorage Systems (IFAS)**
  - Case Study 3: **NSF ENH: Development of New Knowledge for Steel Seismic Floor and Roof Collectors**

Project Case Studies: Characteristics

- Multi-University Research Projects
- Lehigh & UCSD co-PIs and Grad Students
- Full- or Large-Scale Testing
- Strong Simulation Component
- Design Consultant Oversight
- Industry Partners
- General Topic: Floor Systems

NHERI LEHIGH & UCSD EF CAPABILITIES

Laboratory simulations and tests enabled by the **NHERI Lehigh EF** include:

1. **Hybrid simulation (HS)**
2. **Geographically distributed hybrid simulation (DHS)**
3. **Real-time hybrid earthquake simulation (RTHS)**
4. **Geographically distributed real-time hybrid earthquake simulation**
5. **Dynamic testing (DT)**
6. **Quasi-static testing (QS)**

Laboratory simulations and tests enabled by the **NHERI@UCSD EF** include:

1. **Shake Table Testing**
2. **Blast Simulator**

Project Case Studies: NHERI EF Usage

- **Lehigh Testing Program used for:**
  - Component Characterization
  - Analytical Model Construction
  - Prototype Development
  - Guidance for Large Scale System Tests

- **UCSD Testing Program used for:**
  - System Level Experiments
  - Model Validation
  - Demonstration of Concept

Project 1: NSF GOALI - DSDM

Development of a Seismic Design Methodology for Precast Floor Diaphragms (DSDM) 2005-2009

DSDM Research Team

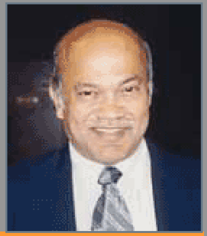
University of Arizona
Robert Fleischman
Consortium Leader

University of California
San Diego
Jose' Restrepo, PI

Producer Members

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

Producer Members



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

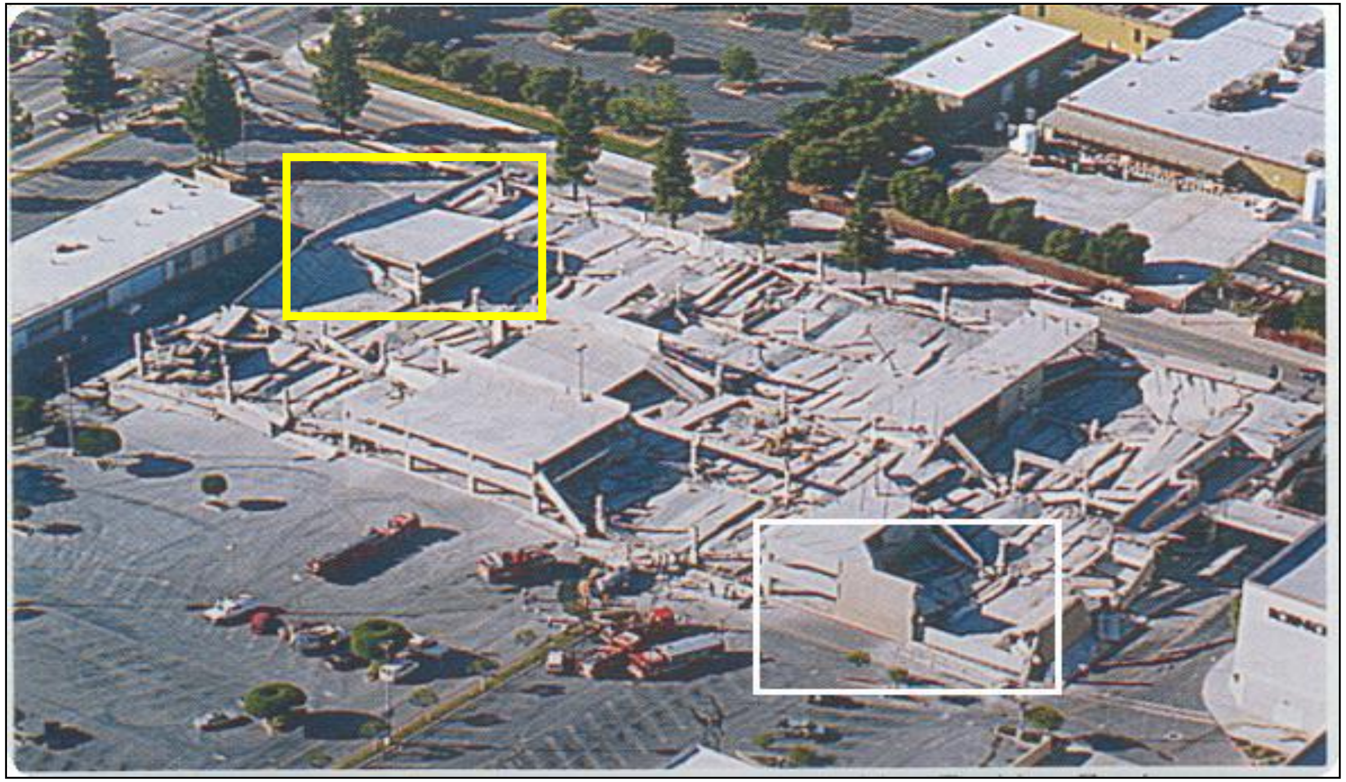
Industry Advisory Panel

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

Precast Concrete Diaphragms

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

Precast floor diaphragms have shown a vulnerability in past earthquakes…



Research Challenges: Precast Diaphragms

Research Challenges: Precast Concrete Floor Diaphragms

- Vulnerable System
- Poorly known Capacities
- Poorly known Demands
- Absence of Applicable Design Rules
- Complex Dynamic Response
- Complex Load Paths
- Complex Boundary Conditions

Research Objective: Precast Diaphragms

Research Objective: Precast Concrete Floor Diaphragms

- Characterize the precast diaphragm reinforcement/connectors
- Develop and validate reliable nonlinear dynamic models for structures with precast diaphragms: including diaphragm flexibility and diaphragm limit states
- Enable direct measurements of force and deformation demands on precast diaphragm connectors
- Perform extensive parameter studies examining capacity and demand
- Develop and codify new design provisions

Rationale for Large Scale Laboratory Testing

- **Rationale for laboratory testing**:
  - Limited information existed on the characteristics of precast diaphragm connectors
  - No information on the response of precast diaphragm connectors under non-proportional shear and tension
  - No models existed for the nonlinear or non-ductile response of precast floor diaphragm systems

- **Rationale for ATLSS Laboratory**:
  - Ability to create multi-axis control for cyclic shear, tension/compression, and positive/negative moment
  - Ability to perform hybrid testing to develop realistic combinations of force, and adapt as the joint and connectors degrad.

Rationale for Large Scale Shake Table Testing

- **Rationale for shake testing**:
  - Boundary Conditions of a distributed system such as a diaphragm do not lend themselves to concentrated actions (e.g. from actuators)
  - Finite Element Analysis can produce realistic boundary conditions, but *calibrated* models are required for code change.

- **Rationale for NEES@UCSD Shake Table**:
  - Scaling of precast elements, reinforcement and connectors has lower limit of 1/3rd to ½ scale before testing details become "toys"
  - Observed diaphragm failures in precast diaphragms have historically occurred in longer span floor decks

Research Flow

Structure Level (UCSD)

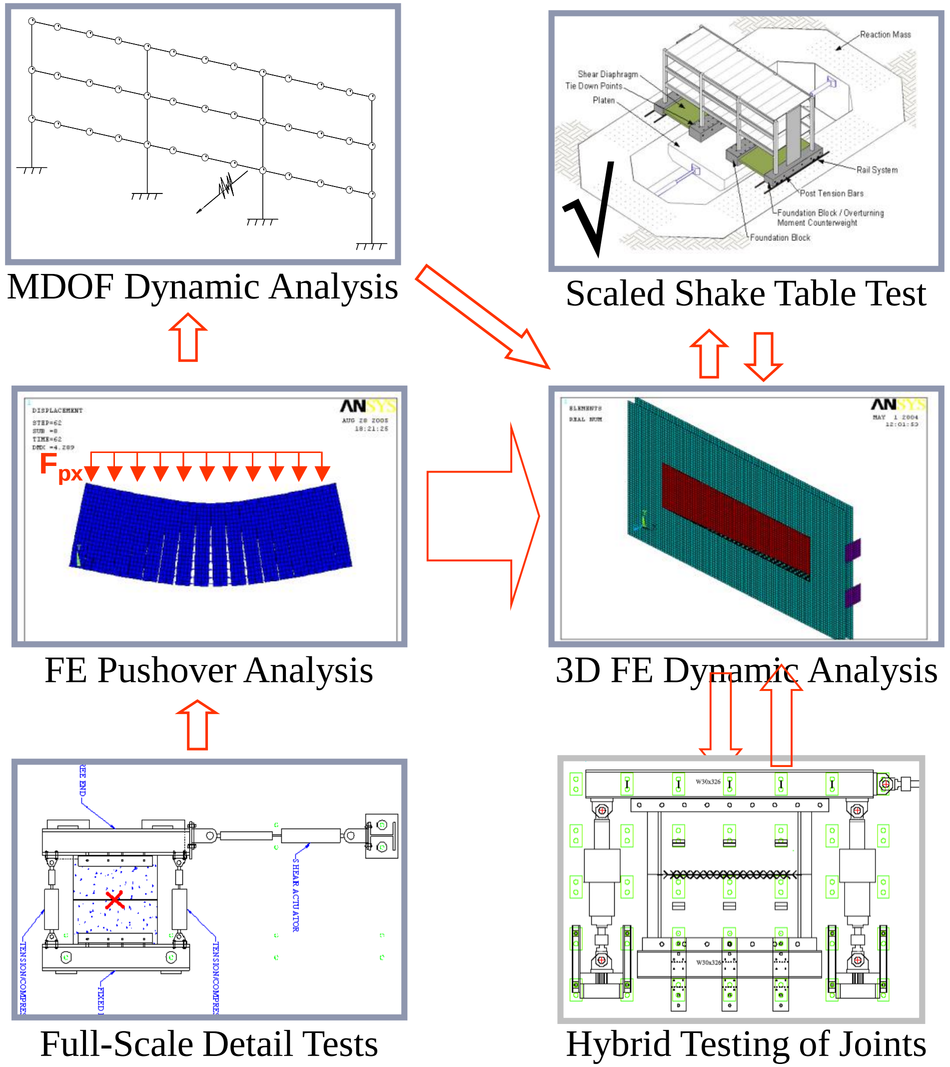
- Diaphragm Inertial Forces
- Flexible Diaphragm Structures

Diaphragm Level (UA)

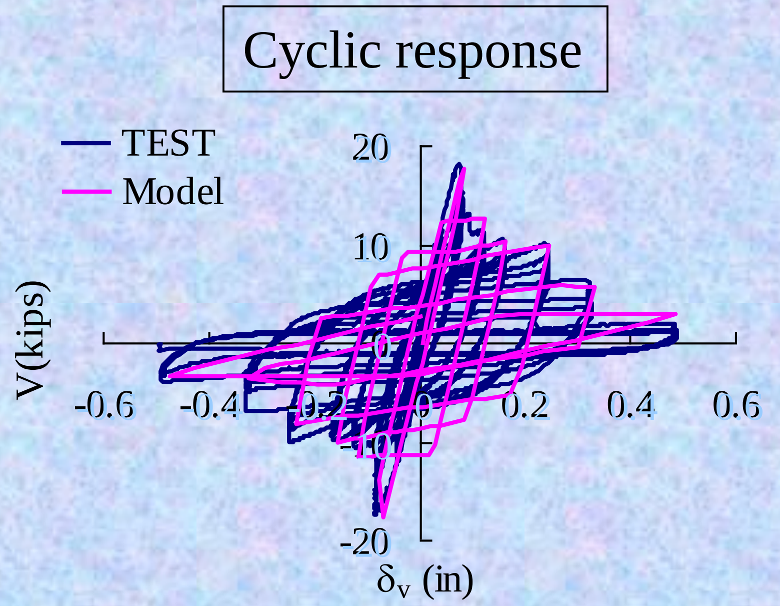
- Diaphragm Capacity
- Diagram Load Paths & Limit States

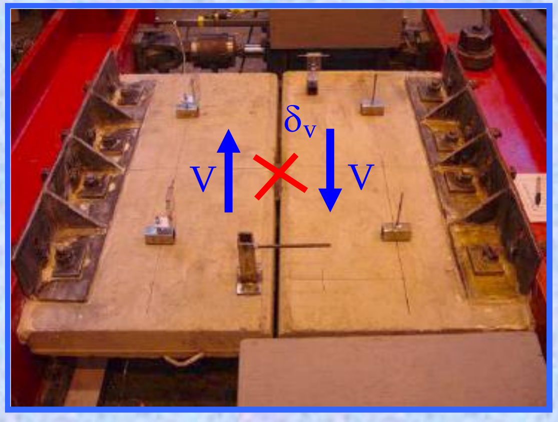
Detail Level (LU)

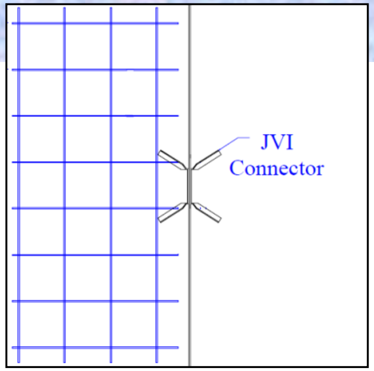
- Connector Properties
- Connector Classification



Shear Connector Model Calibration

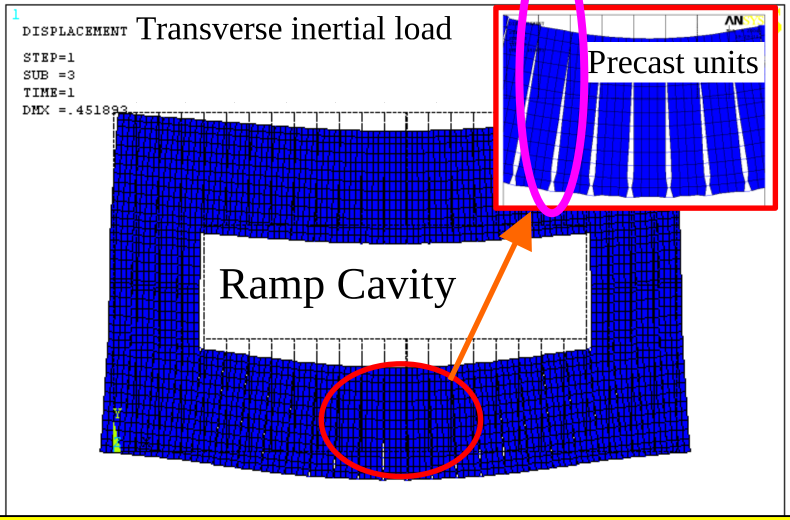


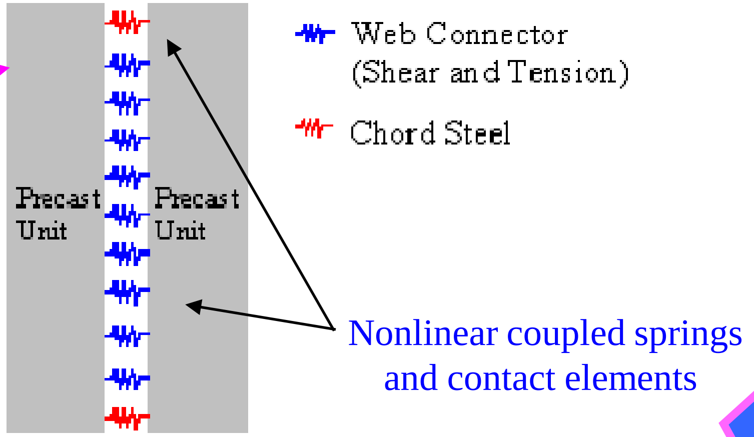


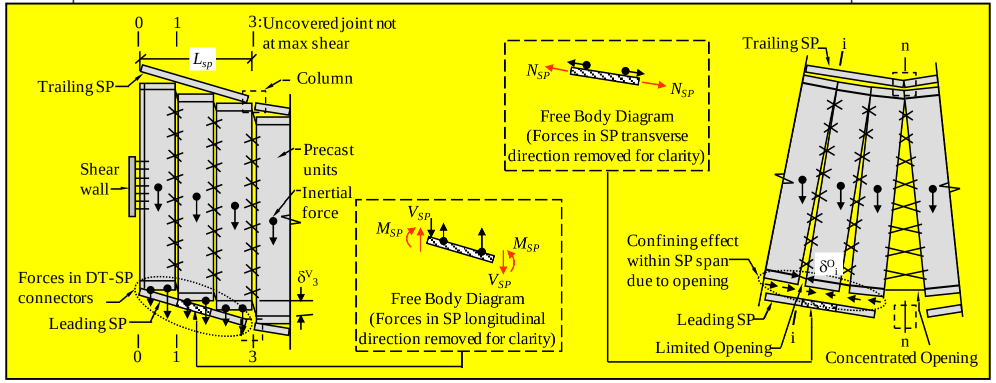


Diaphragm Analytical Models

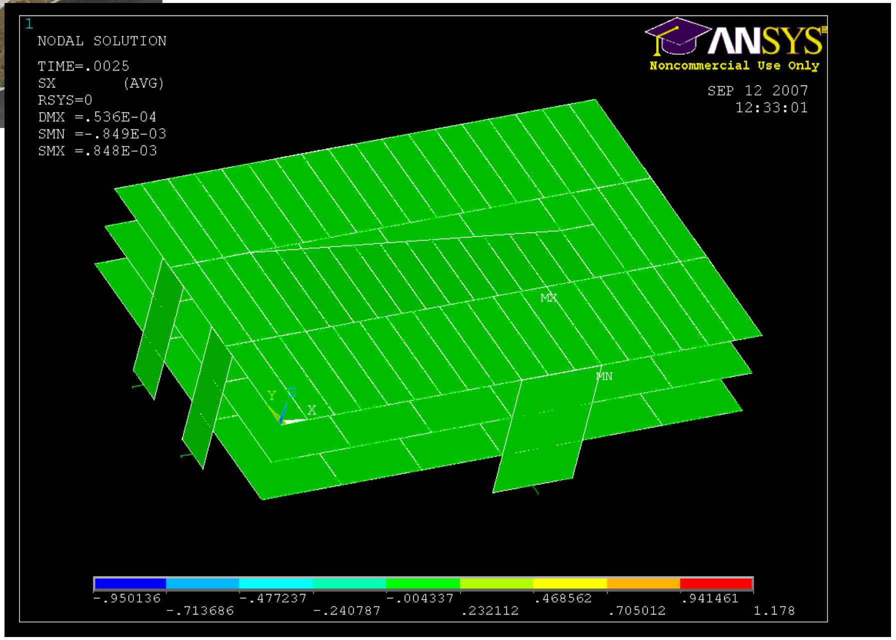
"Discrete Connector" FE models



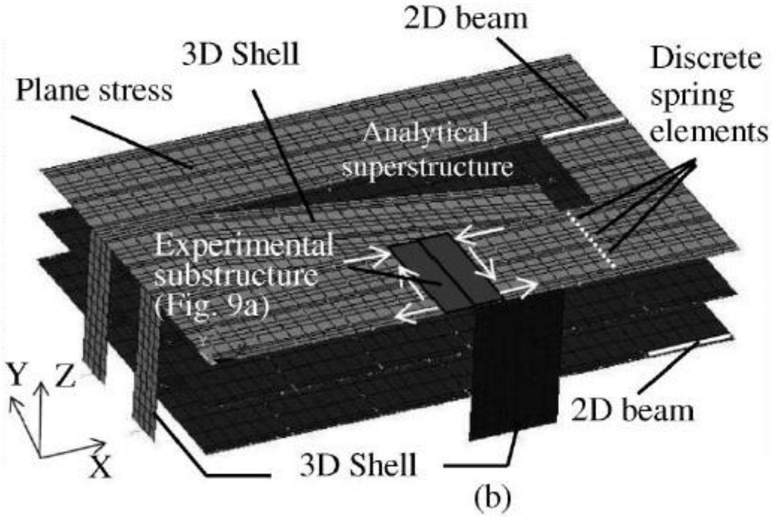


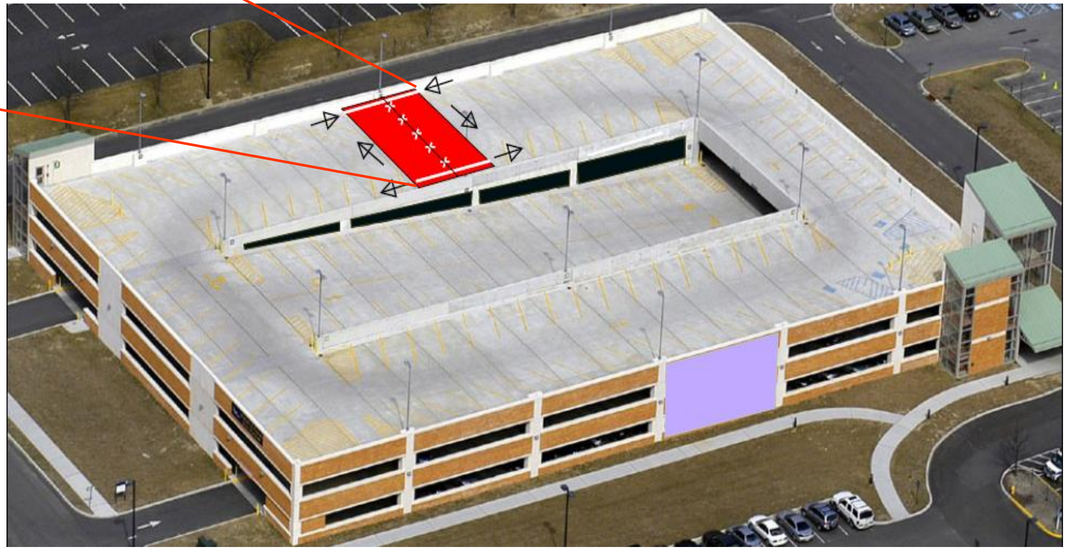


Nonlinear Dynamic Analysis

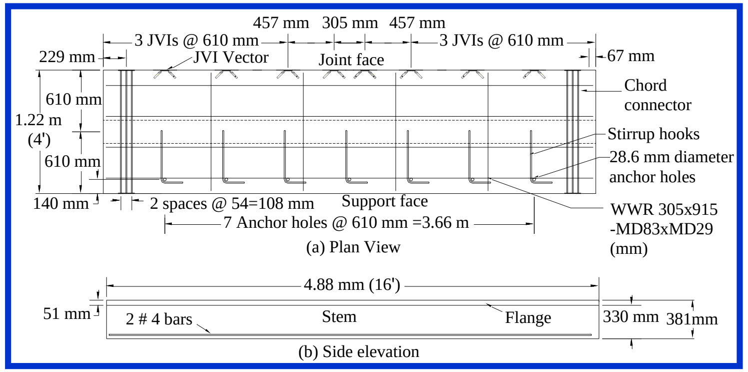


Test Substructure: Panels at Critical Joint



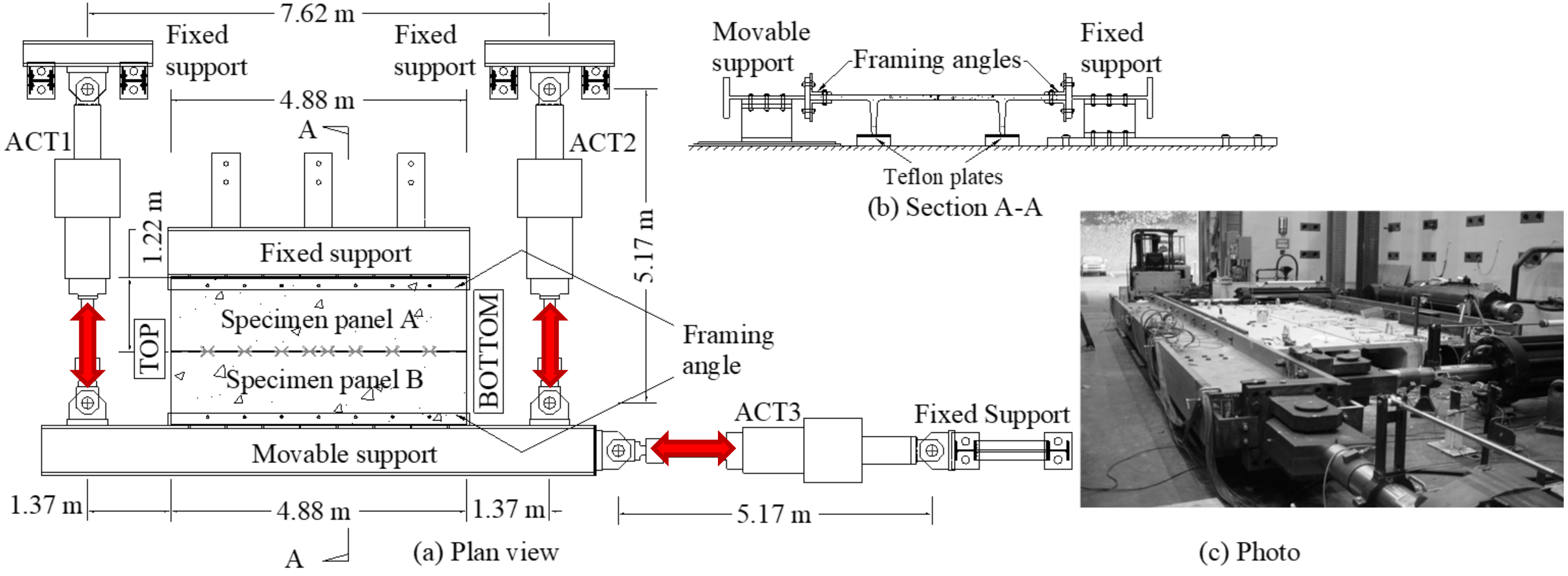


Lehigh MDOF Test Fixture



(a) Plan View

(b) Side elevation



(a) Plan view

(b) Section A-A

(c) Photo

Predetermined Displacement History Tests

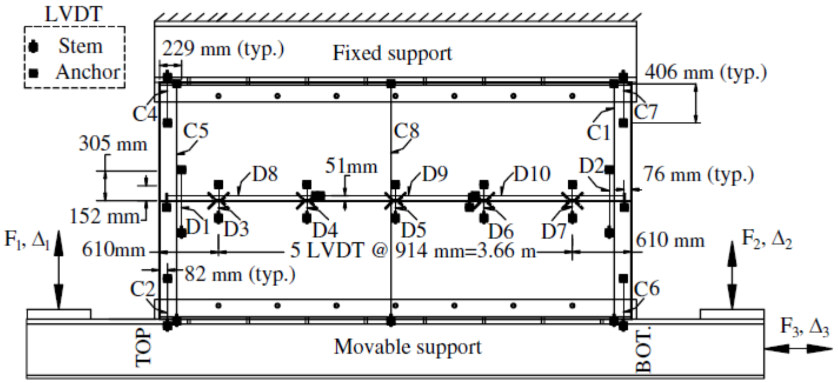


Fig. 11. Instrumentation layout

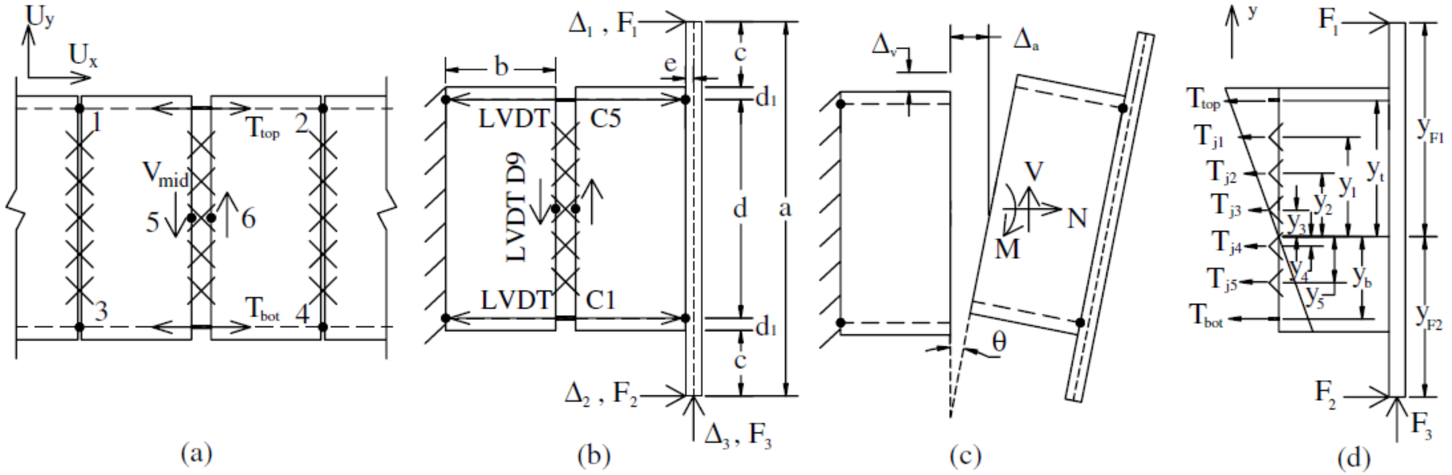
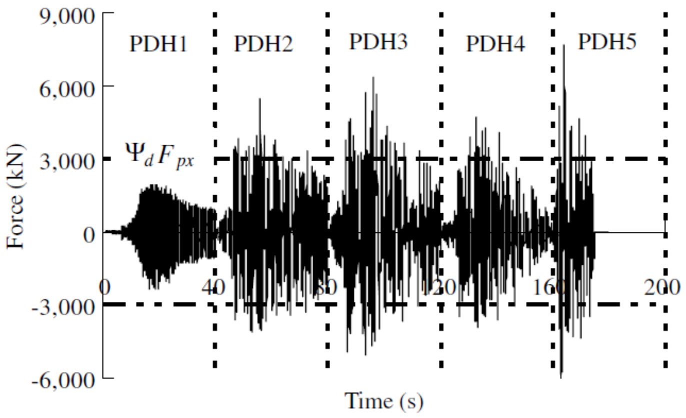


Fig. 12. DOF and force transformations: (a) FE model; (b) test specimen; (c) deformed shape; (d) free body diagram

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



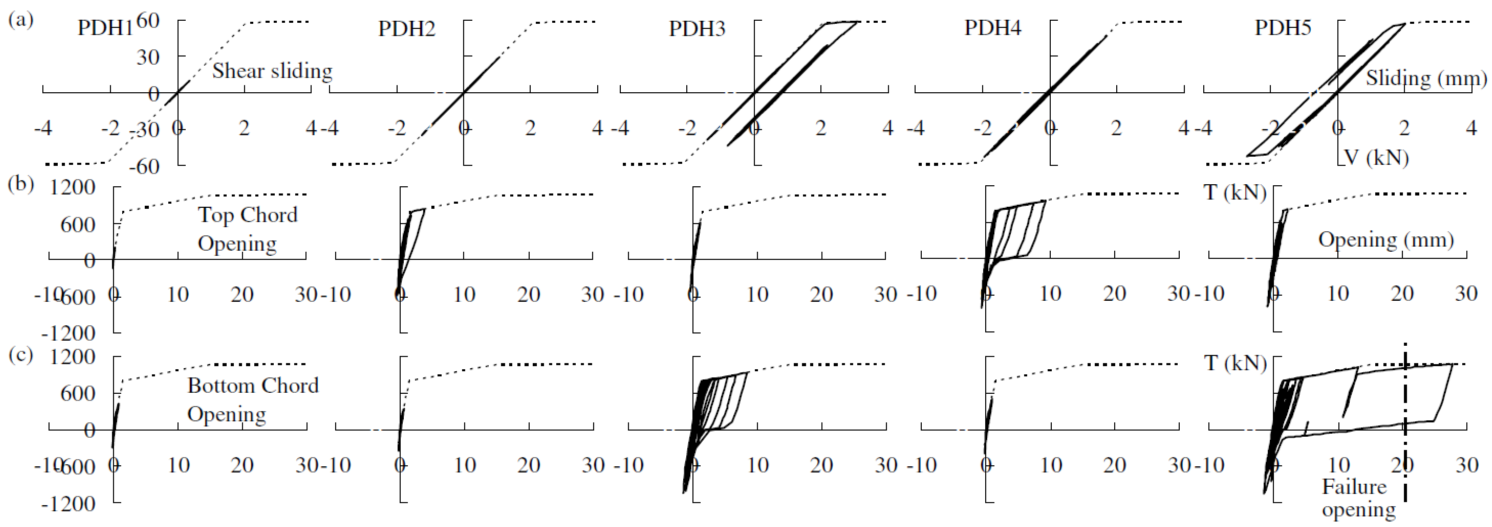
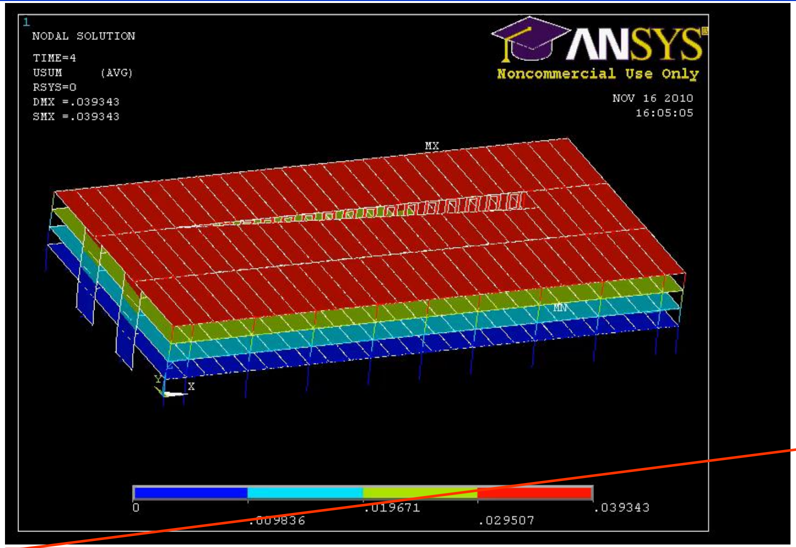
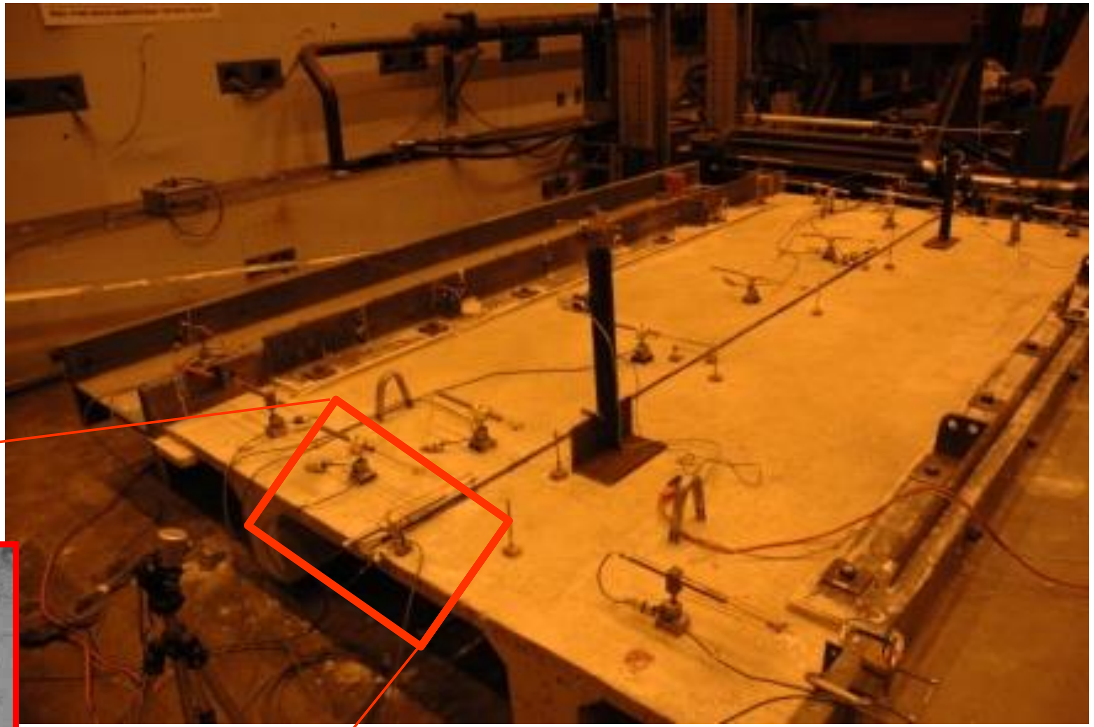


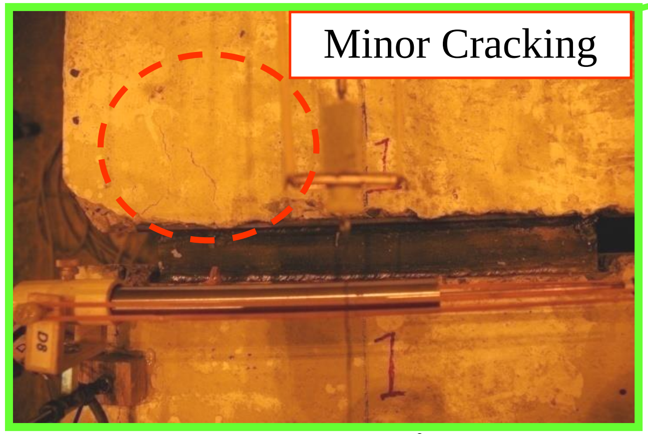
Fig. 5. Reinforcement: (a) connector shear; (b) top chord tension; (c) bottom chord

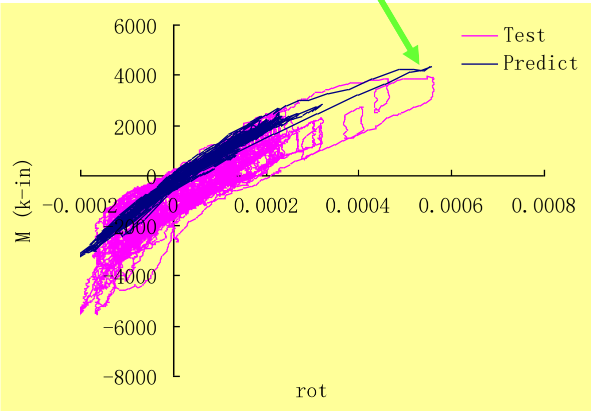
PDH Test Response



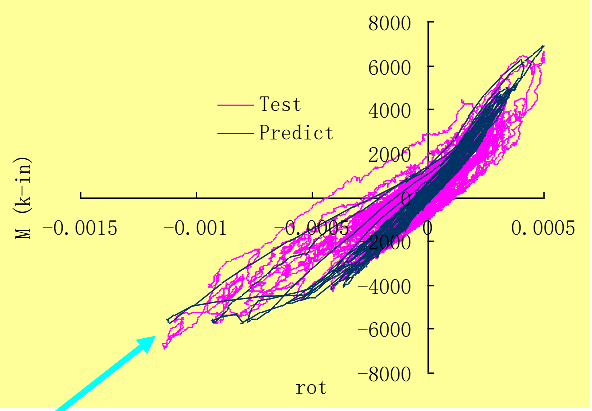


PDH Test Results: Flexure

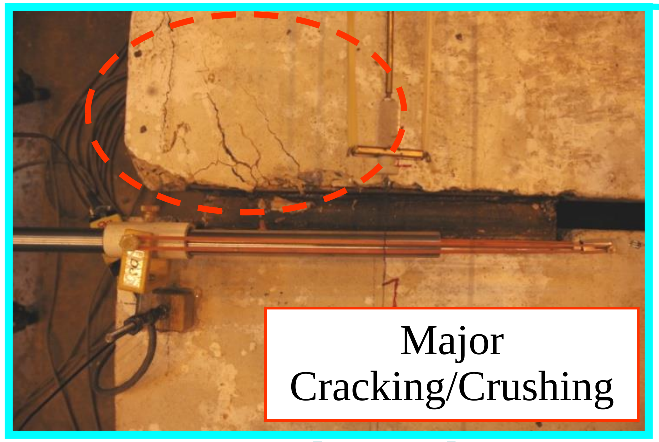


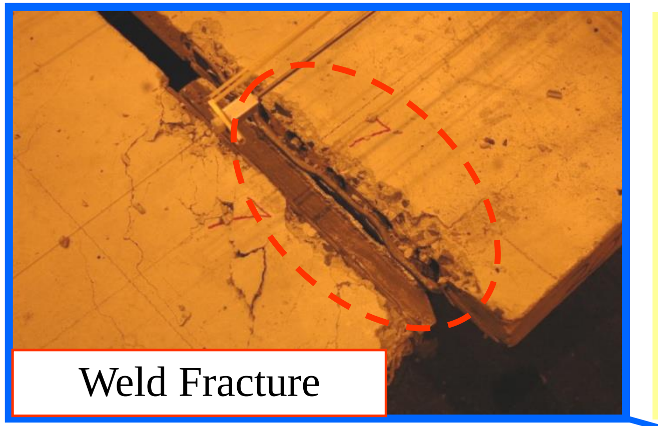


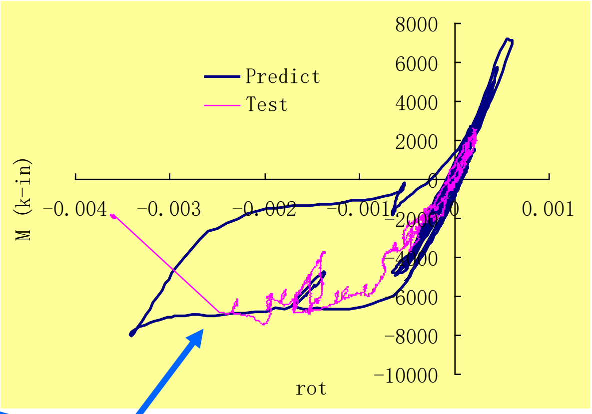
CH DBE



CH MCE

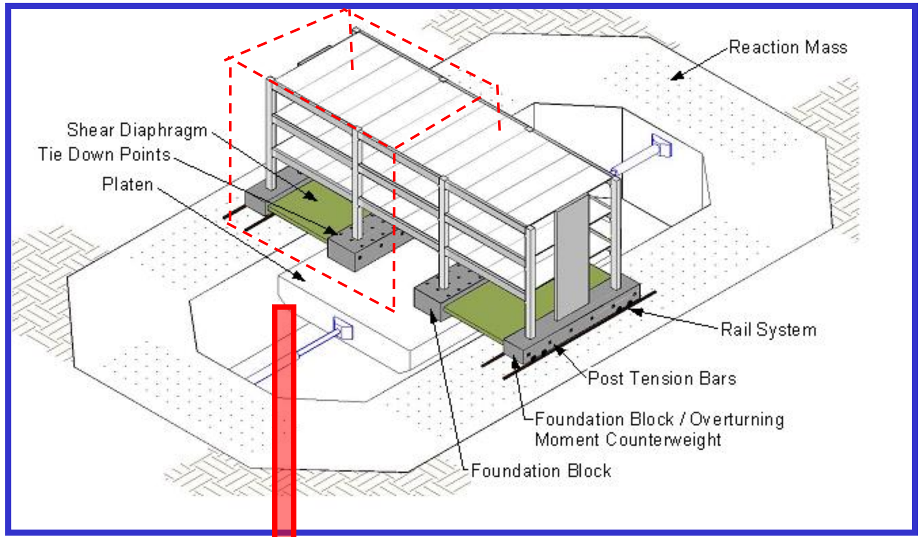


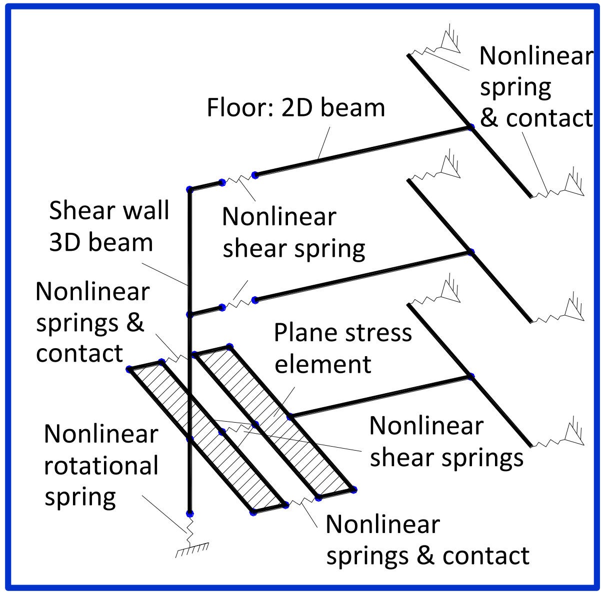


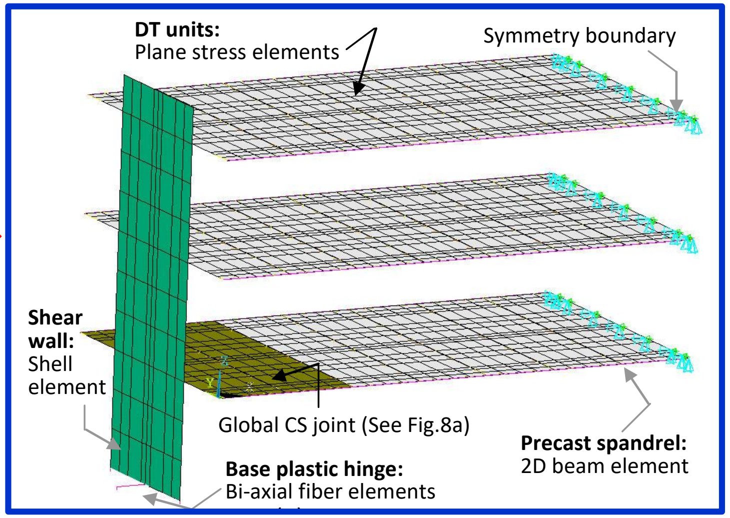


BK MCE

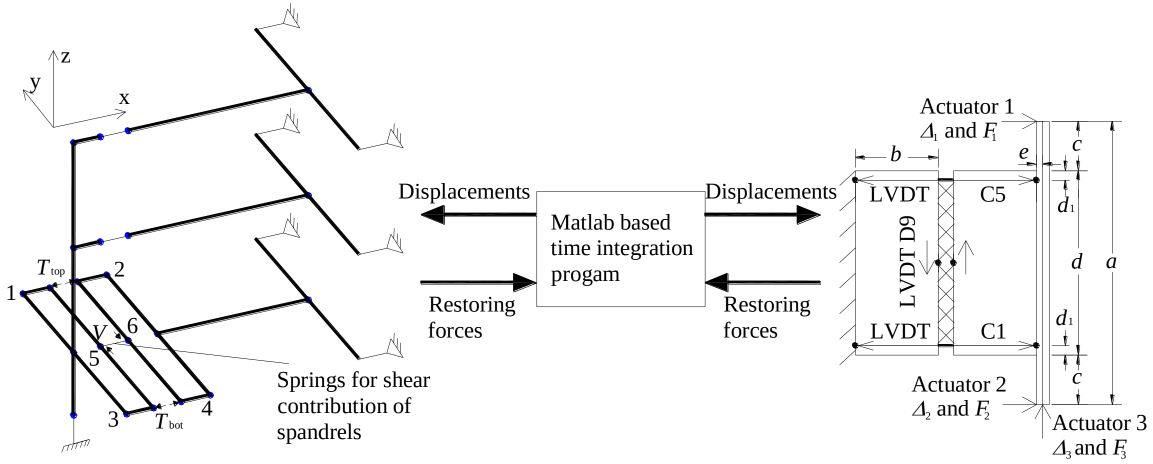
Critical Shear Joint: Hybrid Test

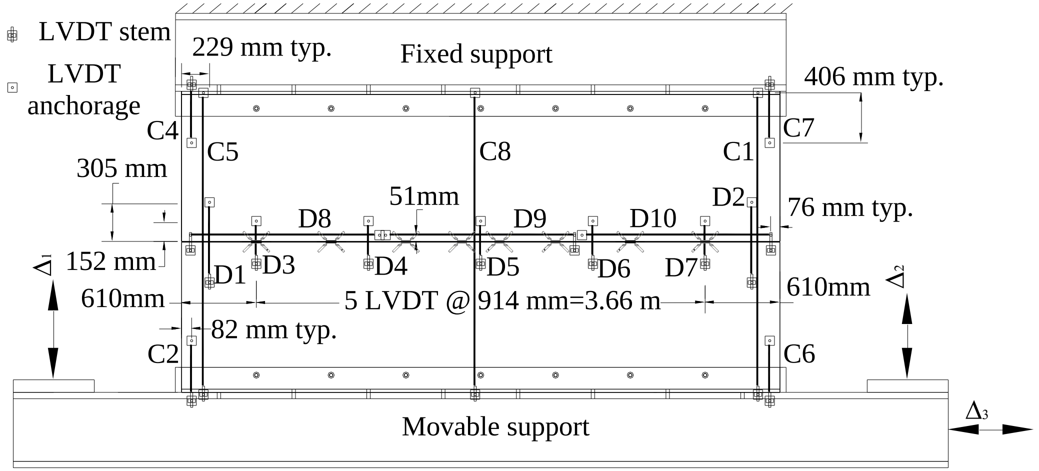






Lehigh Test Algorithms: Hybrid Testing

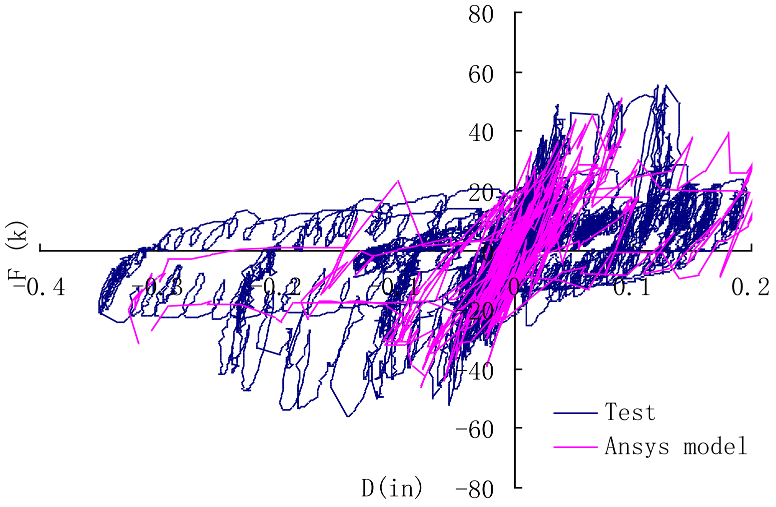


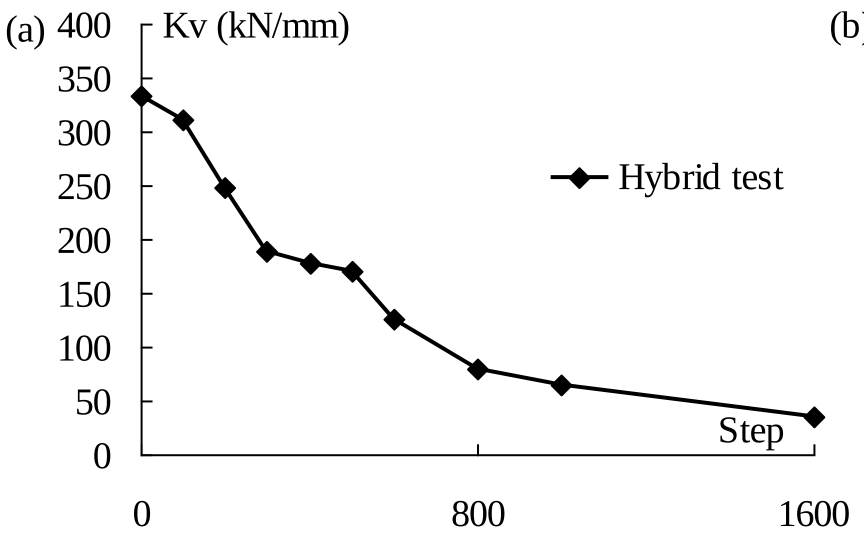


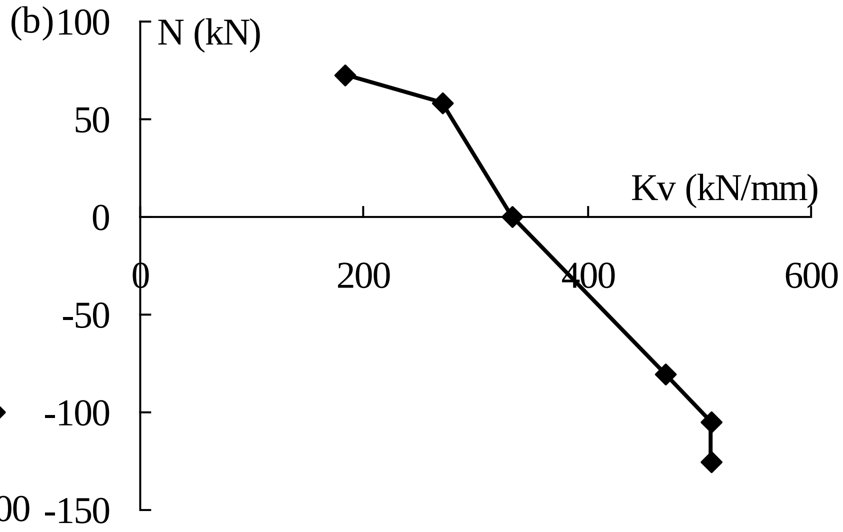
Hybrid Testing :

- 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

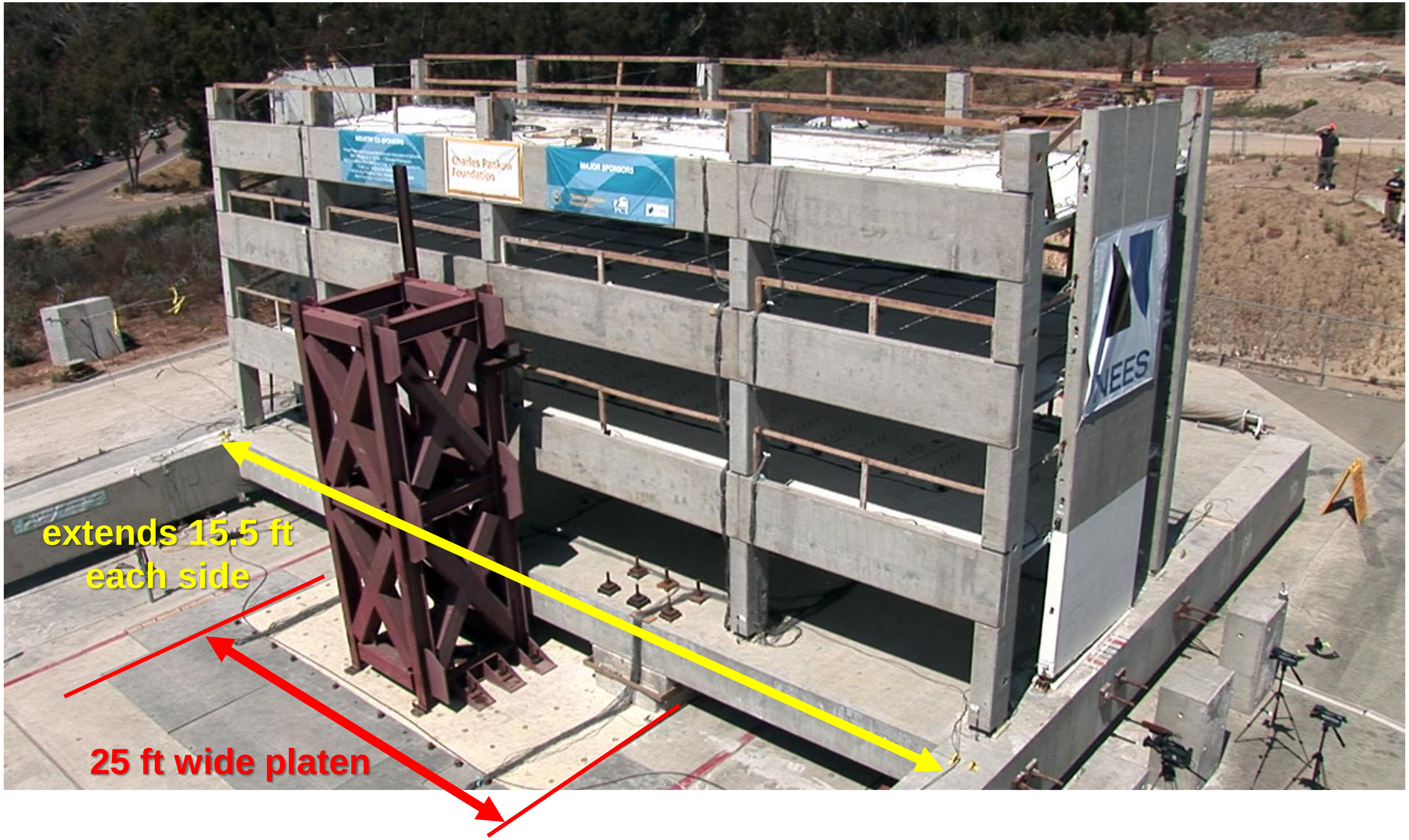






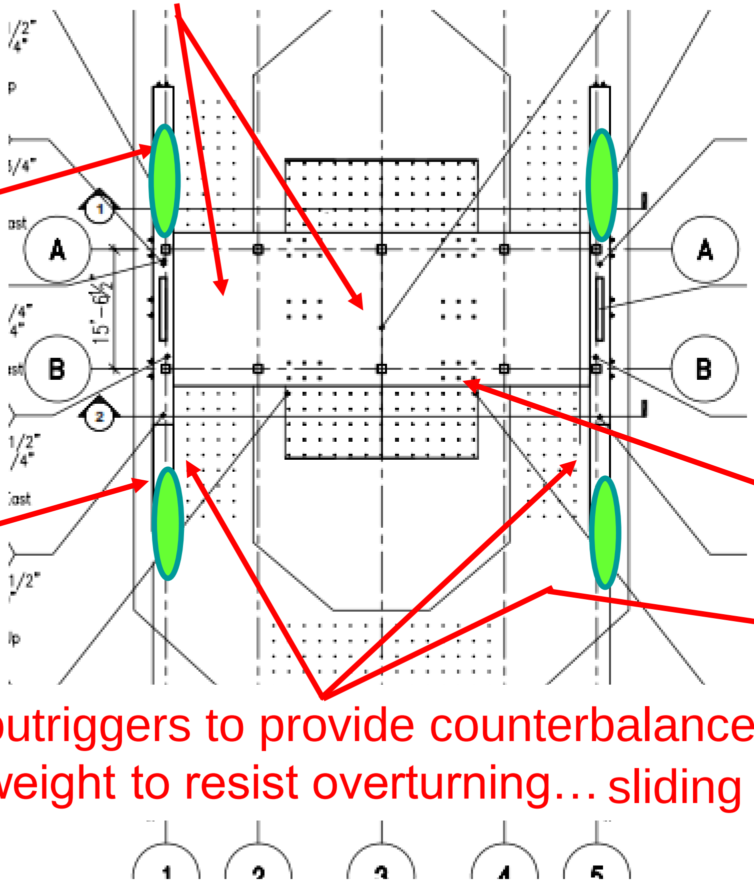
Practical Considerations

Proposal Planning



Practical Considerations

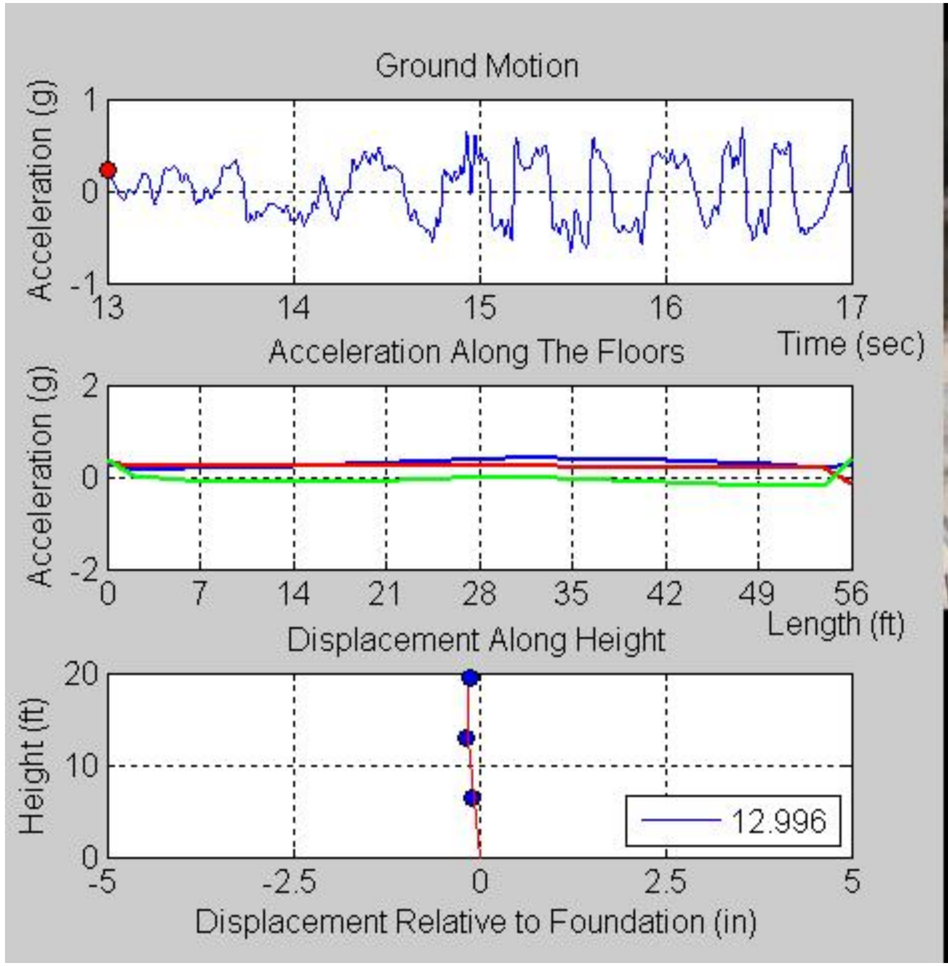
7” thick, in situ concrete topping
for stiff and strong diaphragm

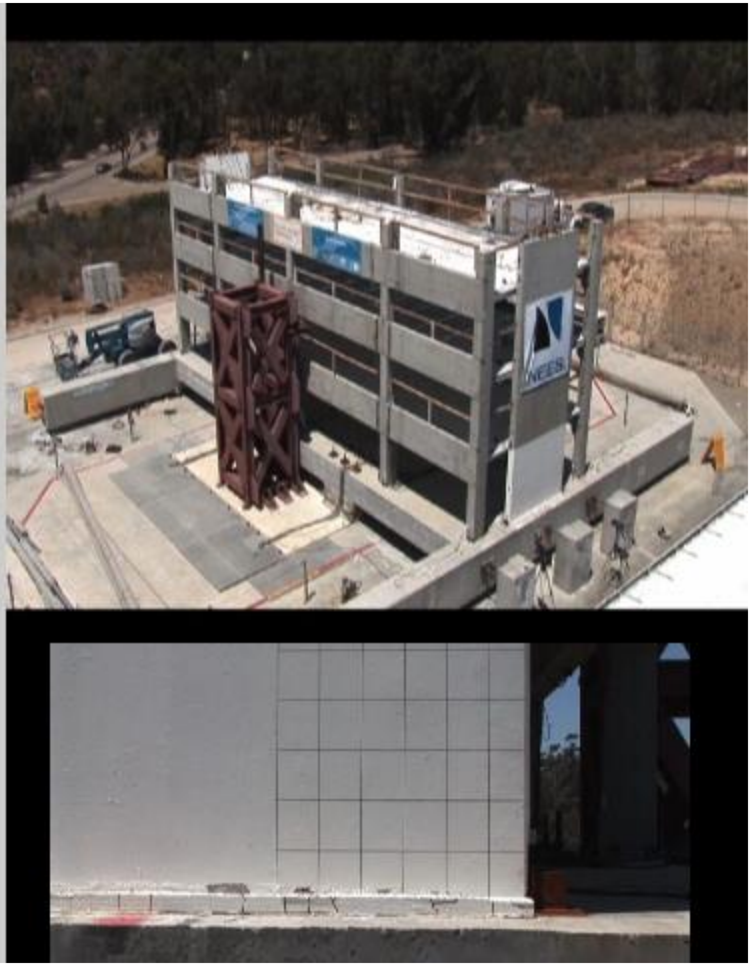


outriggers to provide counterbalance
weight to resist overturning… sliding on

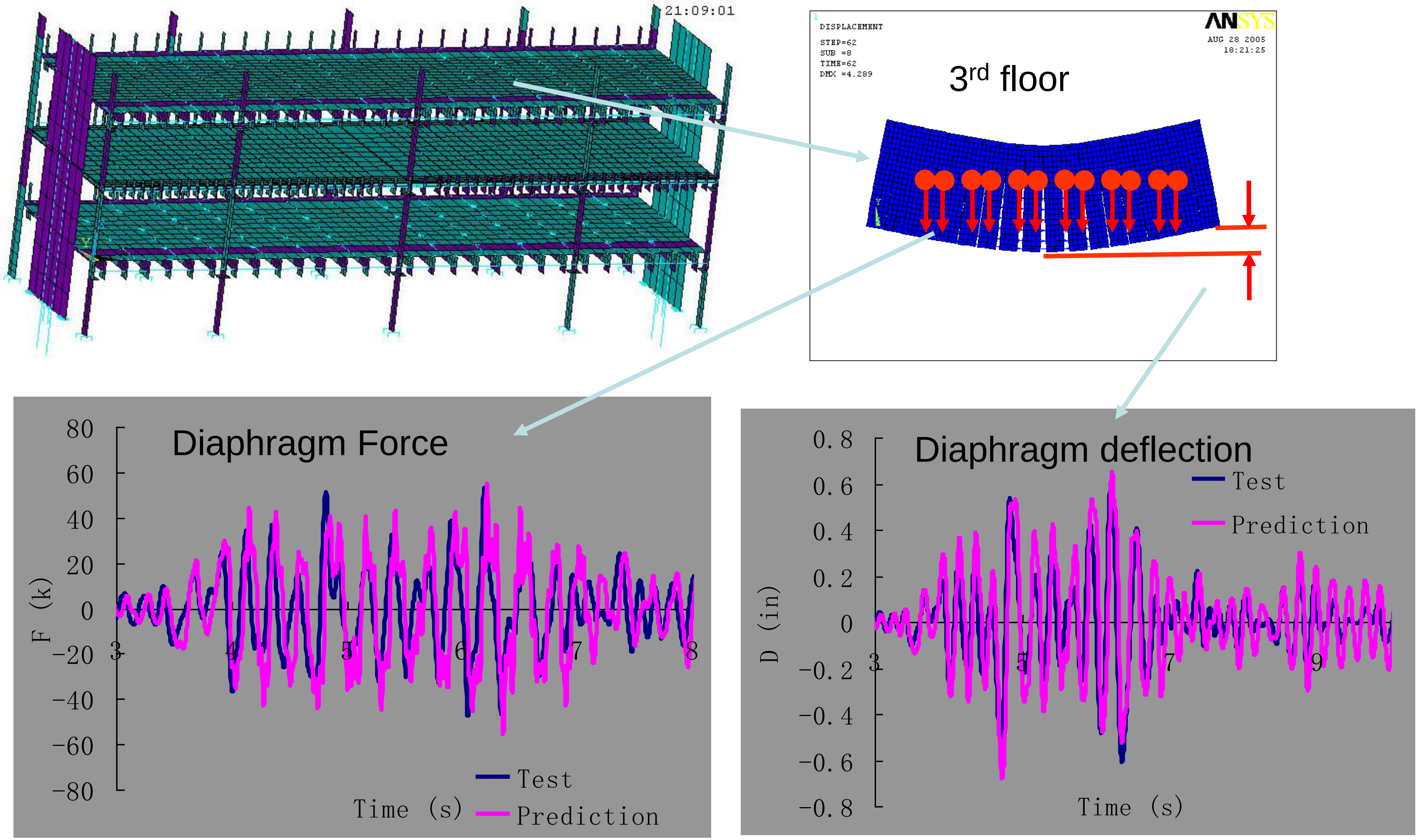
pre-compressed hydrostatic slider bearings
on mirrored-finish stainless-steel plates

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

IFAS Project Team

Academic collaborators

The University of Arizona

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Lehigh University

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Nazarbayev University

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Dr. Giuseppe Quaranta

K12 partner

Utterback Middle School

Gricelda Meraz

Seismic Design Consultants

Rutherford + Chekene

Saeed Fathali

Maffei Engineers

Joseph Maffei

Tipping Mar

David Mar

Industry Partners: NEESR Shake Table Test

PCI

CHARLES PANKOW FOUNDATION

MIDSTATE PRECAST

T.B.PENICK &SONS,INC.

MAFFEI STRUCTURAL ENGINEERING

DW

PCI WEST
A Chapter of Precast/Prestressed Concrete Institute

STAR SEISMIC LLC

R+C RUTHERFORD + CHEKENE

Mar STRUCTURAL DESIGN

MMFX TECHNOLOGIES CORP

Reiger

BASF The Chemical Company

HRC

JVI

FYFE Tyfo FIBRWRAP Systems

ATLAS CONSTRUCTION SUPPLY, INC.

Triton structural concrete

CLARK PACIFIC Precast. Building for Life.

WESTERN CONCRETE PUMPING

DYMAT DYNAMIC MATERIALS

BREWER CRANE AND RIGGING
CALIFORNIA'S PREMIER CRANE COMPANY

STEEL CITY SCAFFOLD INCORPORATED

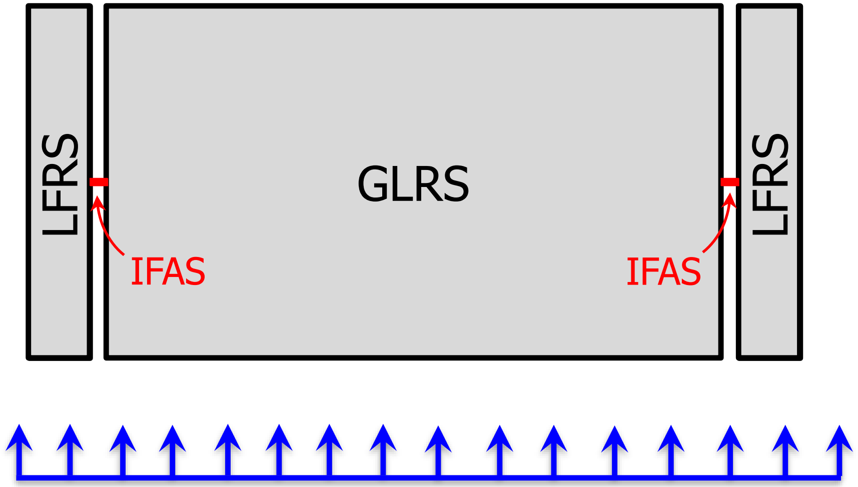
TM

Research Team

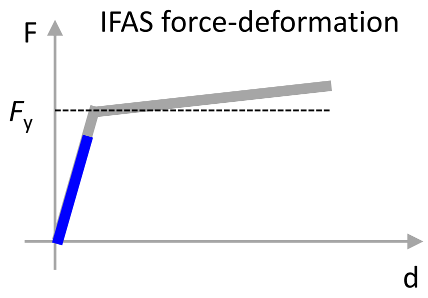
Research Meeting #3 at R&C Offices

IFAS Concept

- Provides a deformable (ductile) connection between the floor system (GLRS) and the primary vertical plane LFRS elements (e.g., shear walls, braced frames)
- Designed with a predefined design strength *(F_y)* to partially uncouple the GLRS and the LFRS
- The structure acts as a traditional structure for daily loads

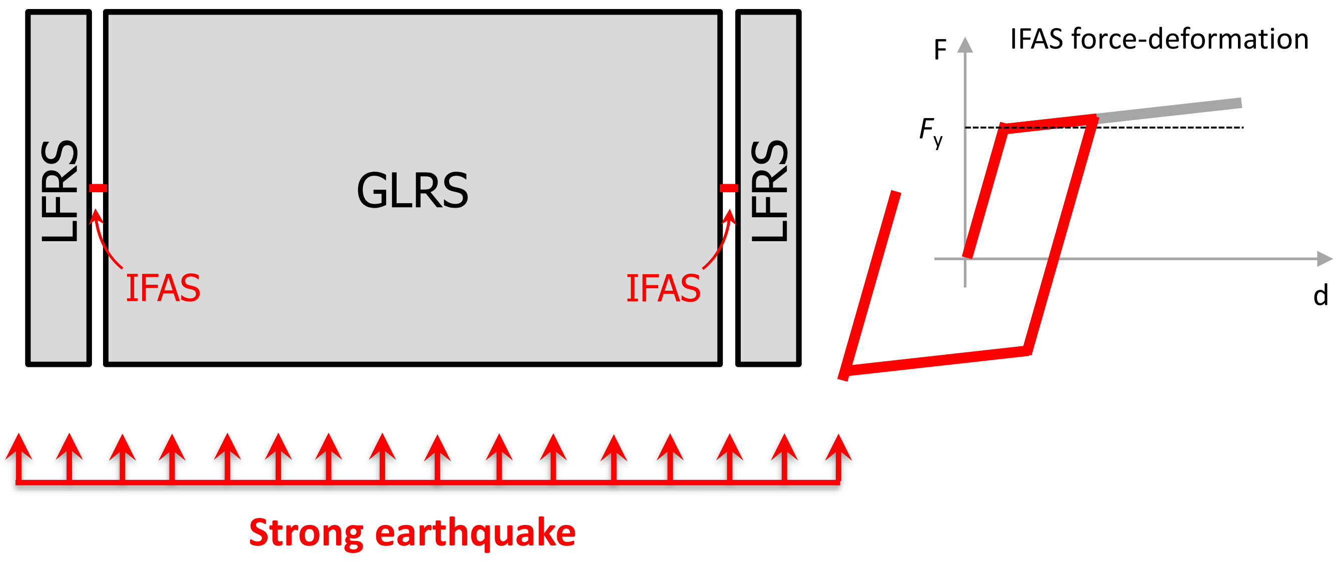


Daily wind or minor earthquake

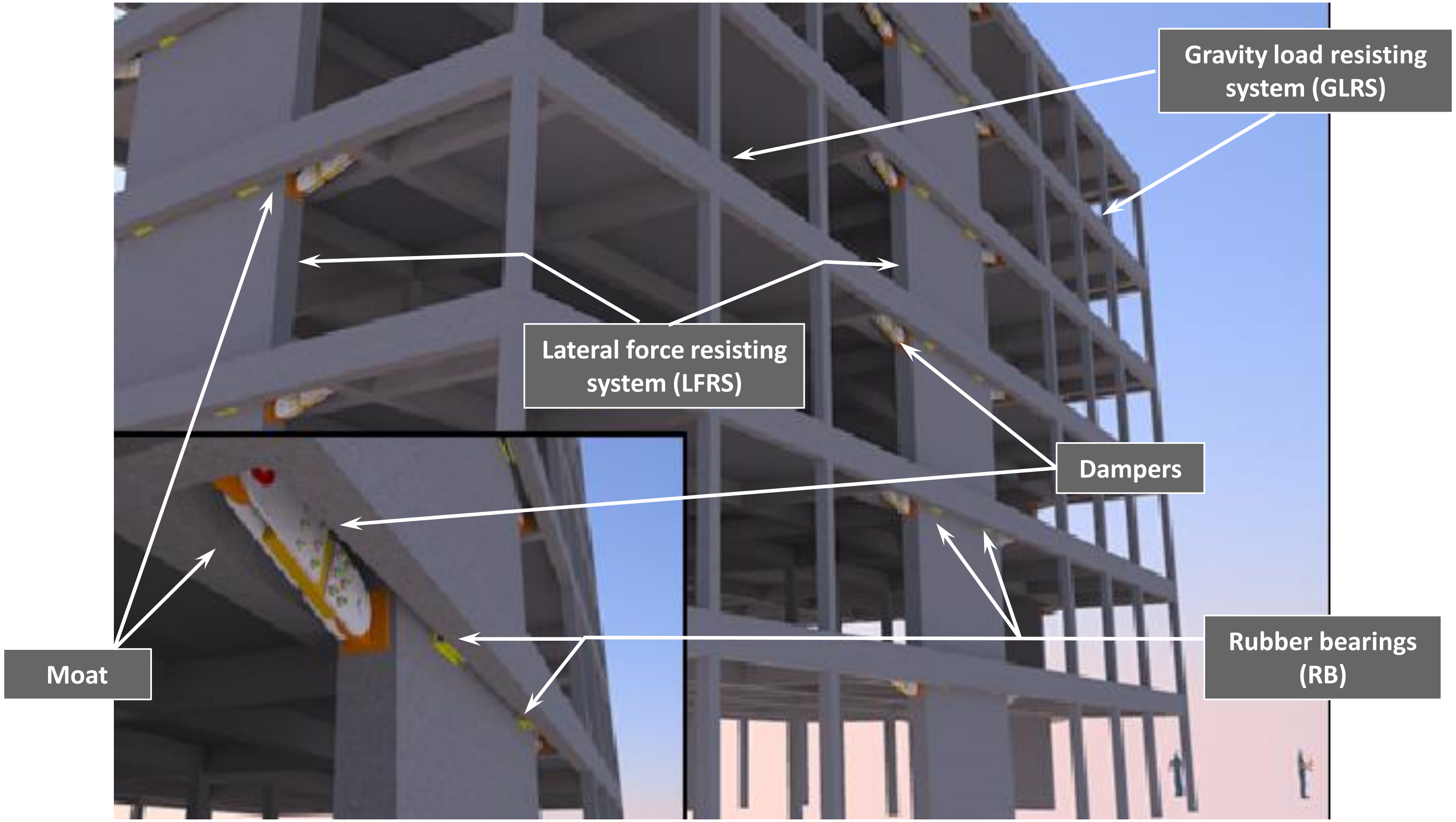


IFAS Concept

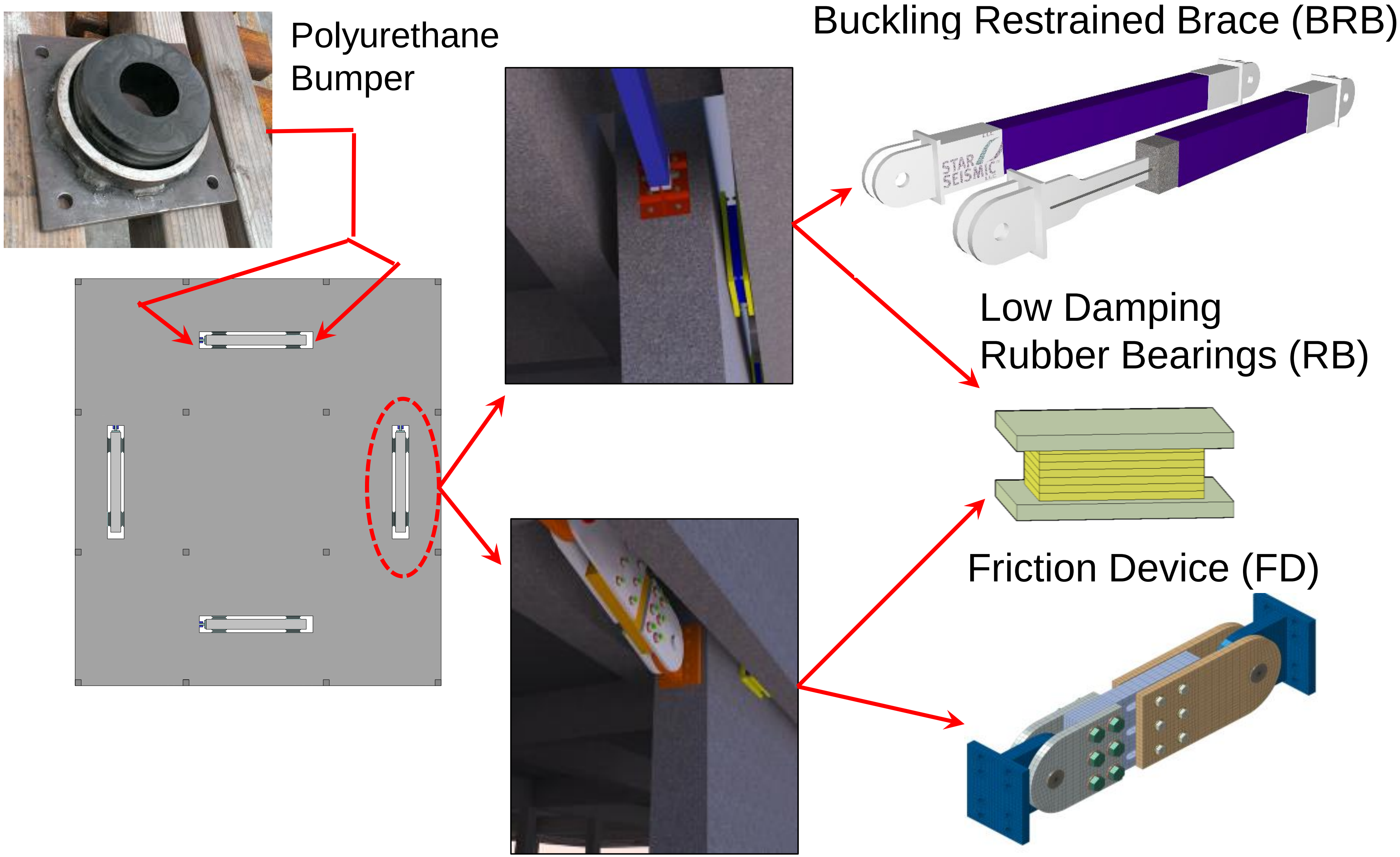
- The IFAS will reach its design strength in a strong earthquake…
- …and deform, thereby transforming the seismic demands into relative displacement between the GLRS and the LFRS…
- …dissipating energy and lowering seismic demands



Prototype IFAS System



IFAS Components



Subassemblage Testing: NEES@Lehigh

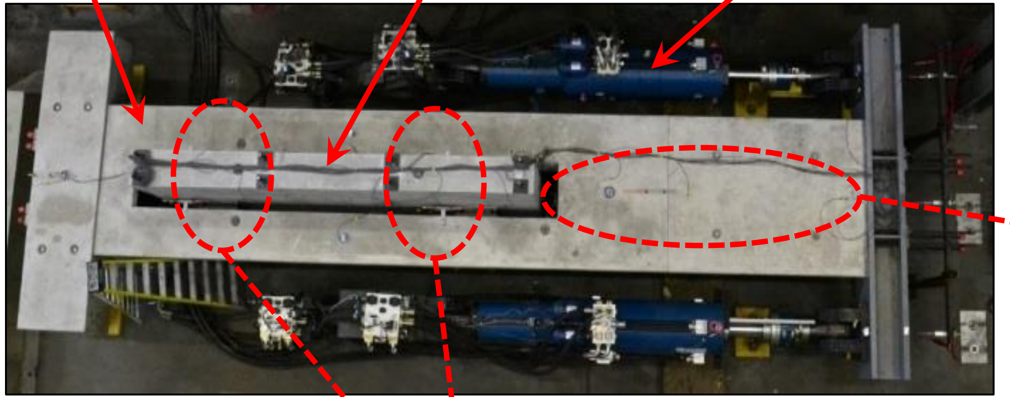
Lehigh Test Specimen

Full-Scale IFAS Testing: BRB

Floor Slab

Wall Stub

NEES Hydraulic Actuators



BRB

Steel Reinforced RB

NEES @ Lehigh

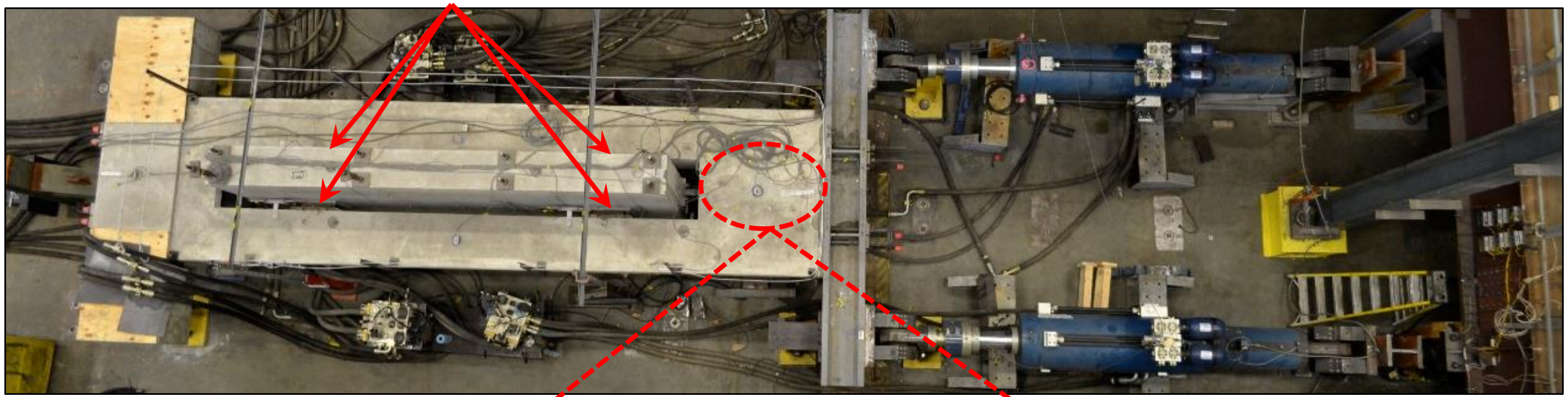
Full-Scale IFAS Testing: BRB

Full-Scale IFAS Testing: BRB

Full-Scale IFAS Testing: RB

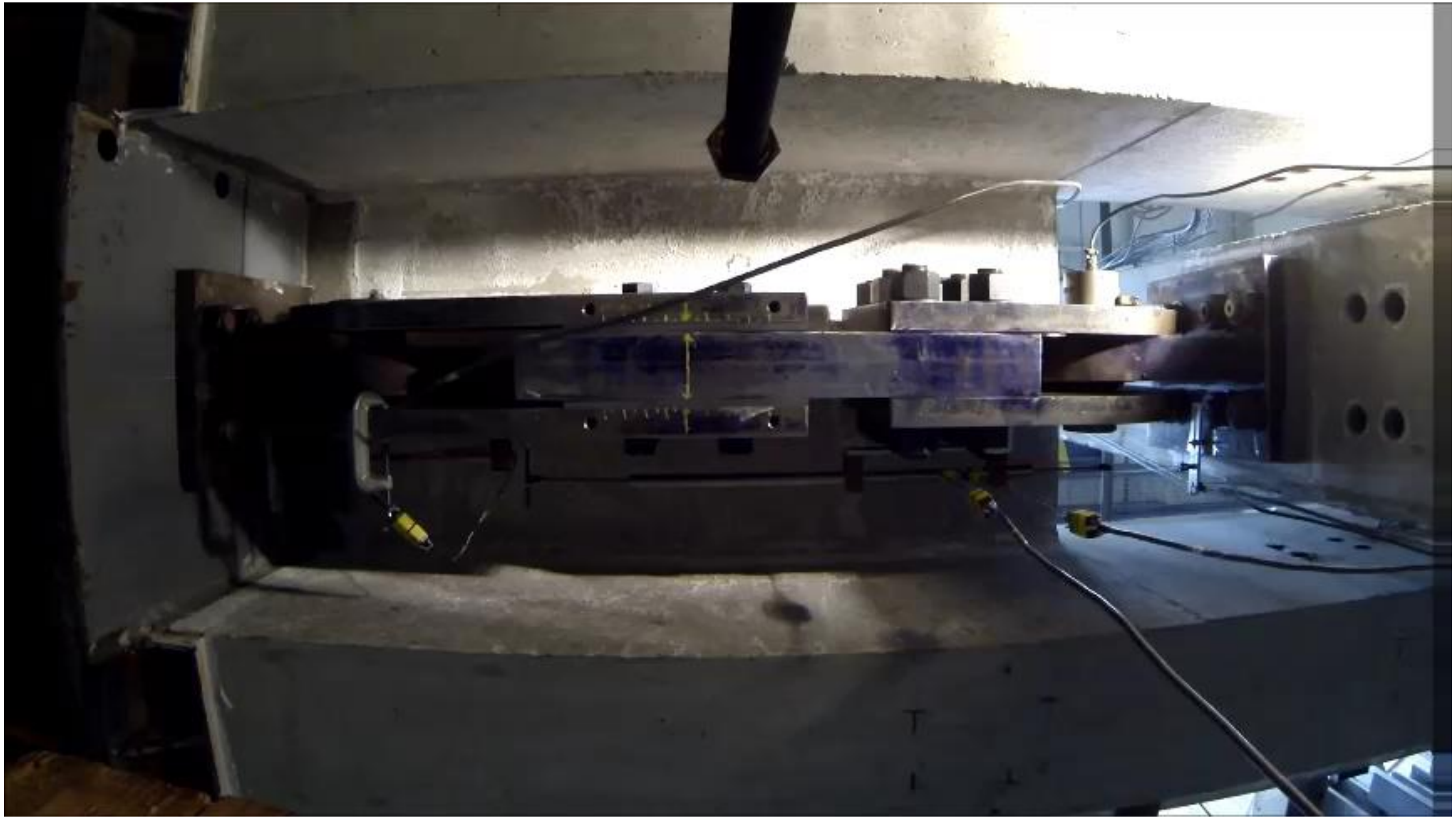
Full-Scale IFAS Testing: FD

Carbon Fiber Reinforced RB

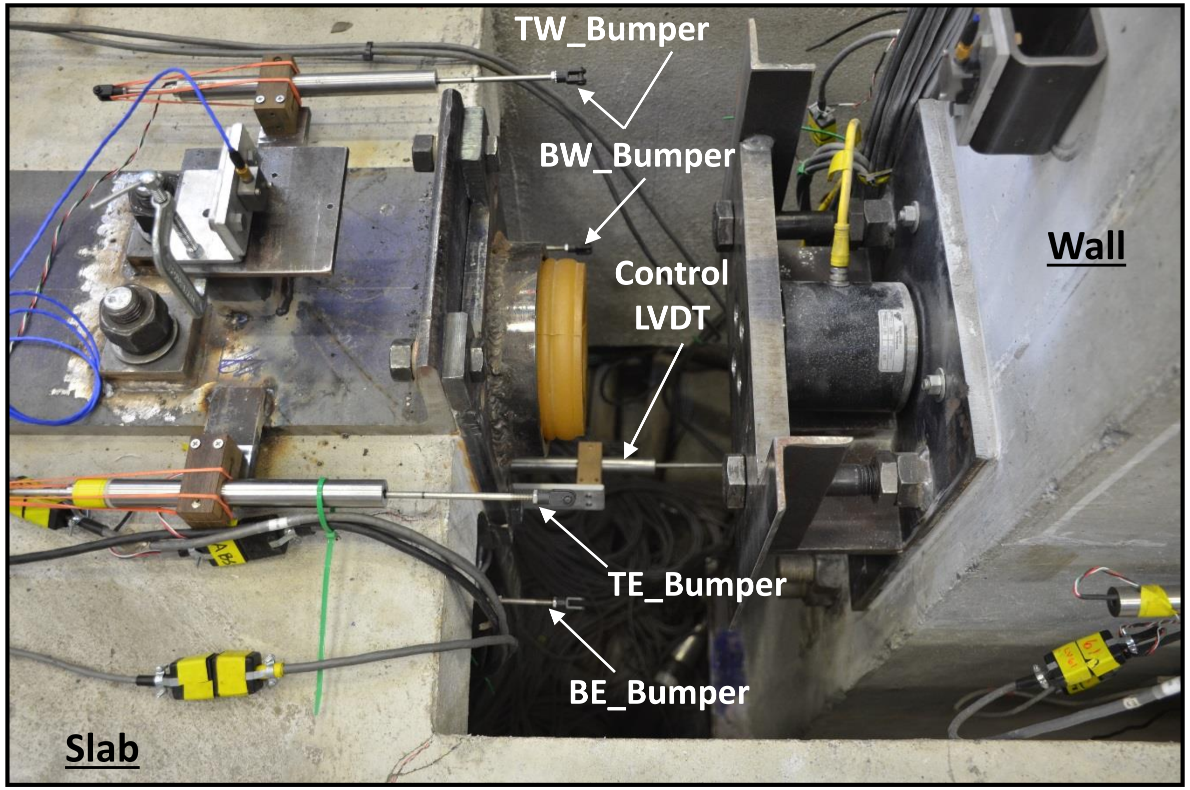


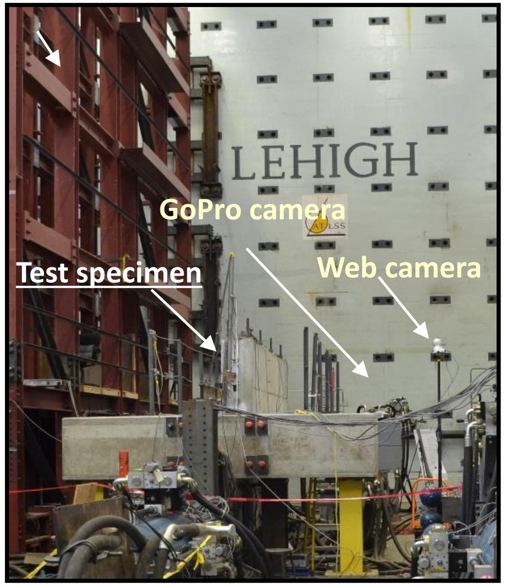
FD

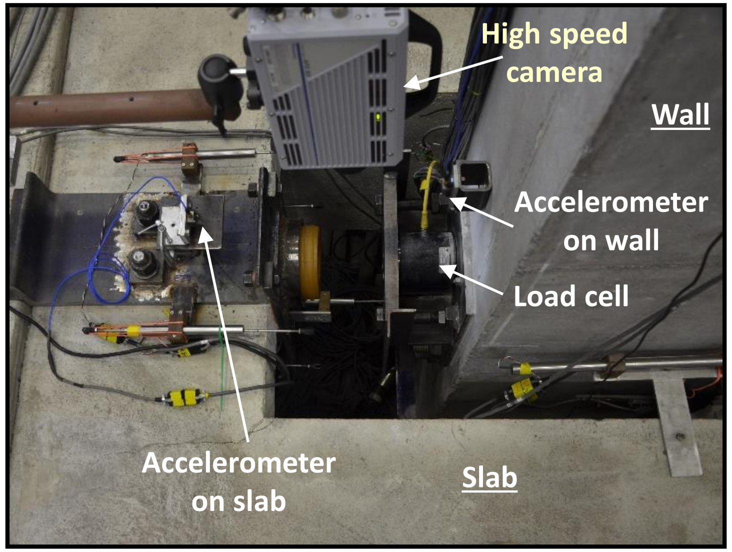
Full-Scale IFAS Testing: FD



Bumper Impact Tests: NHERI@Lehigh

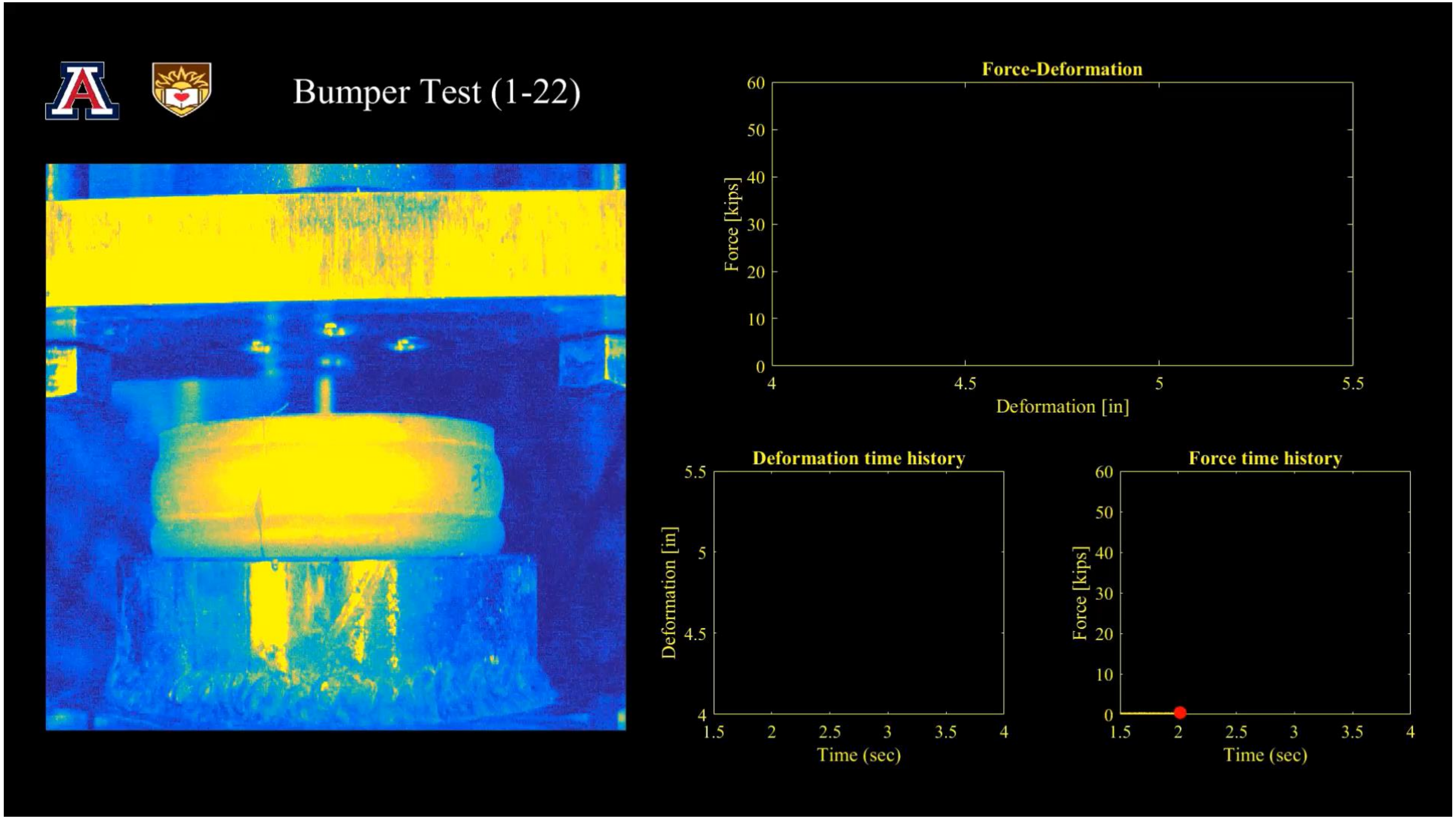






Bumper Impact Tests: NHERI@Lehigh

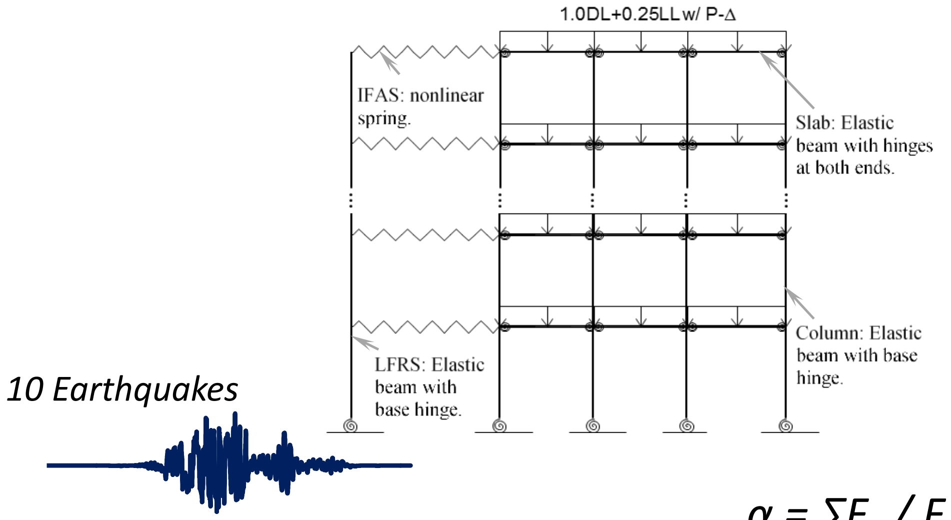
Bumper Impact Tests: NHERI@Lehigh



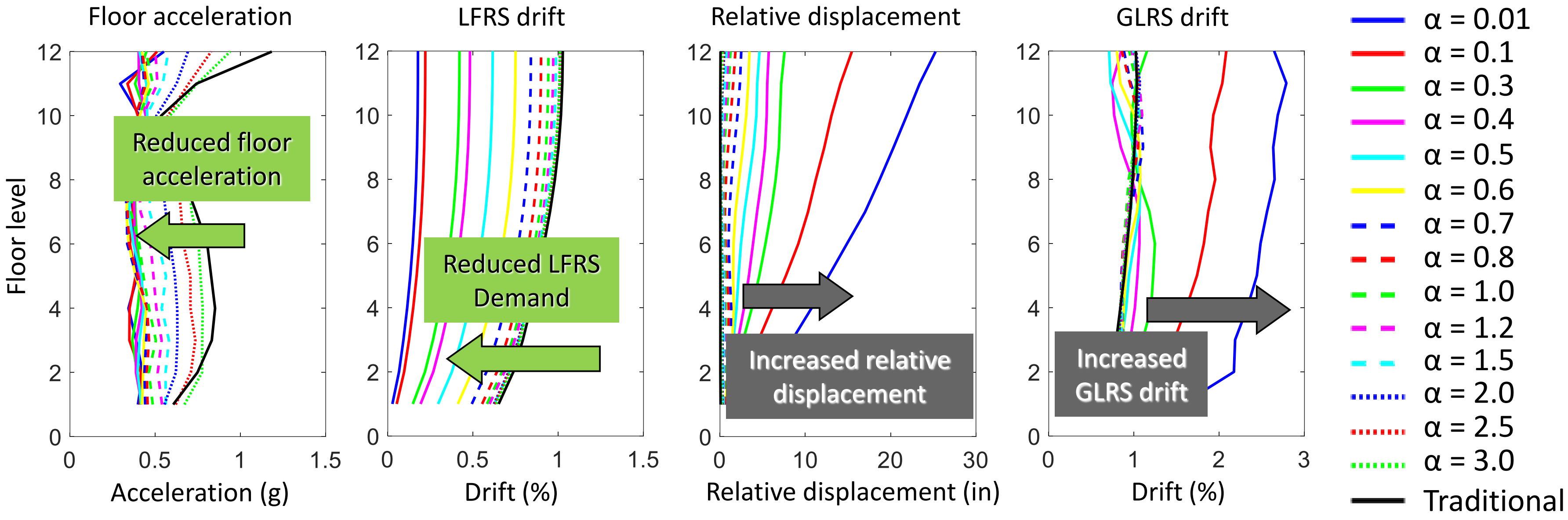
Analytical Research

Response Profile (DBE):

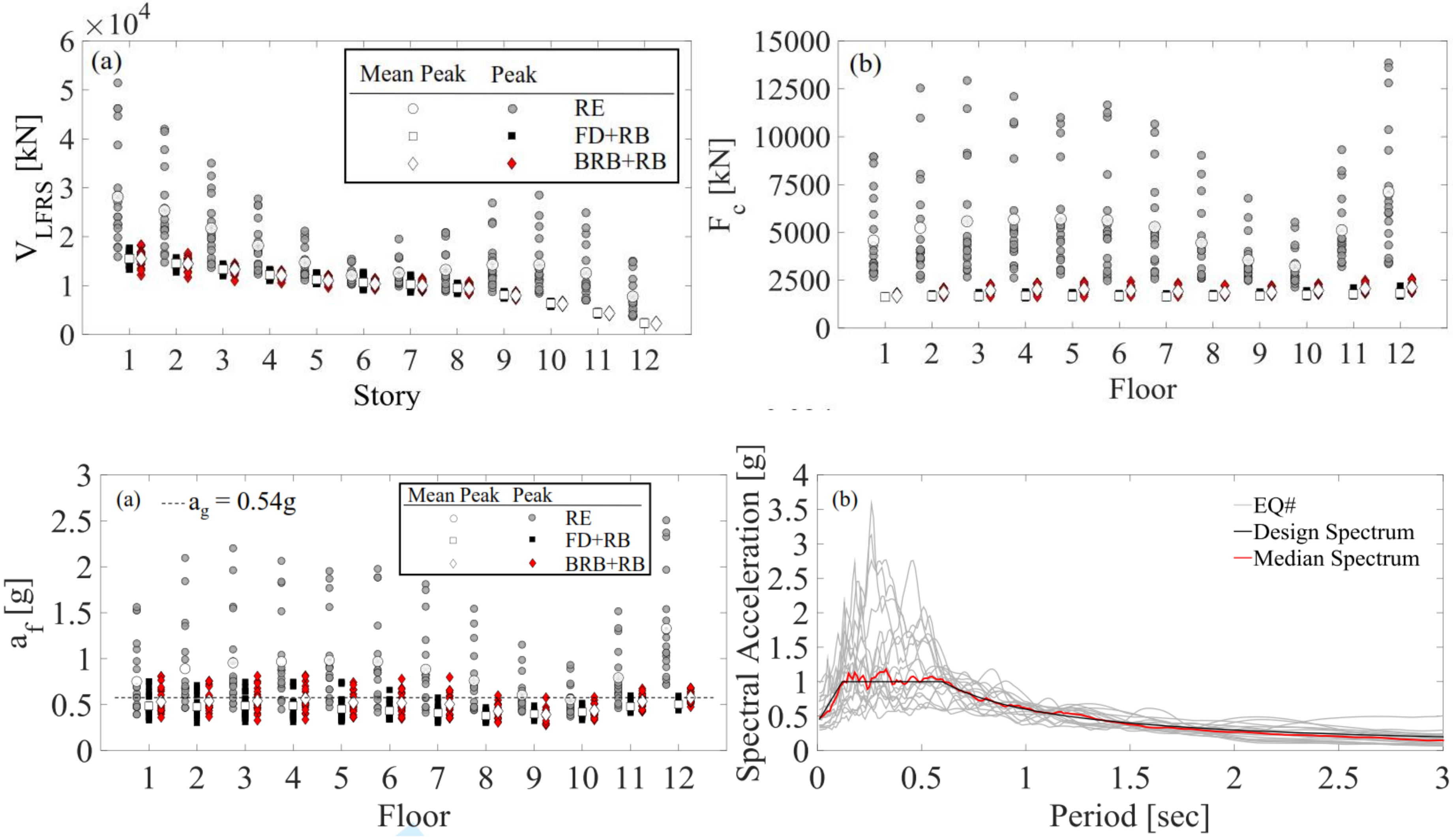
- Benefits
- Tradeoffs



$\alpha = \sum F_y / F_{px}$



Analytical Results



Shake Table Test Structure

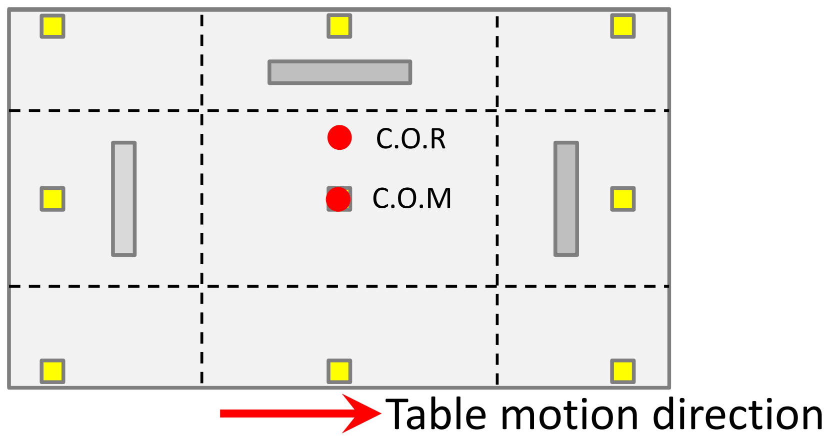
4-story reinforced concrete building

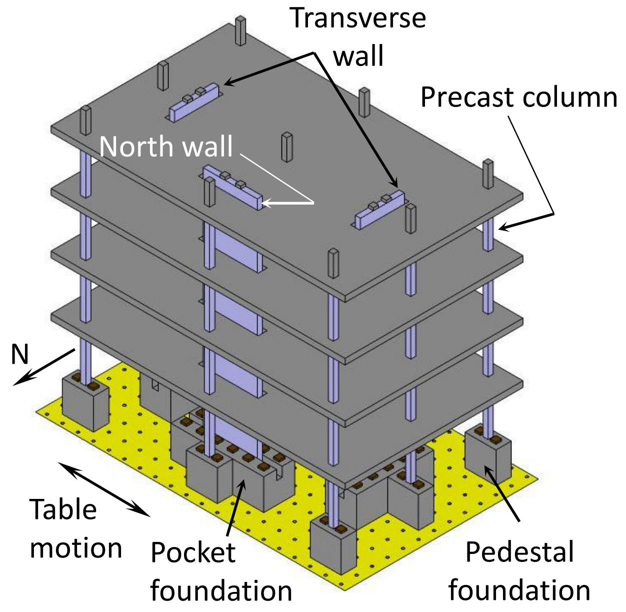
- Half-scale
- Provide direct comparison between IFAS and traditional
- Rocking Walls for repeatability

Shake Table Test Specimen

Test specimen description

- LFRS eccentricity was purposely introduced for torsional response

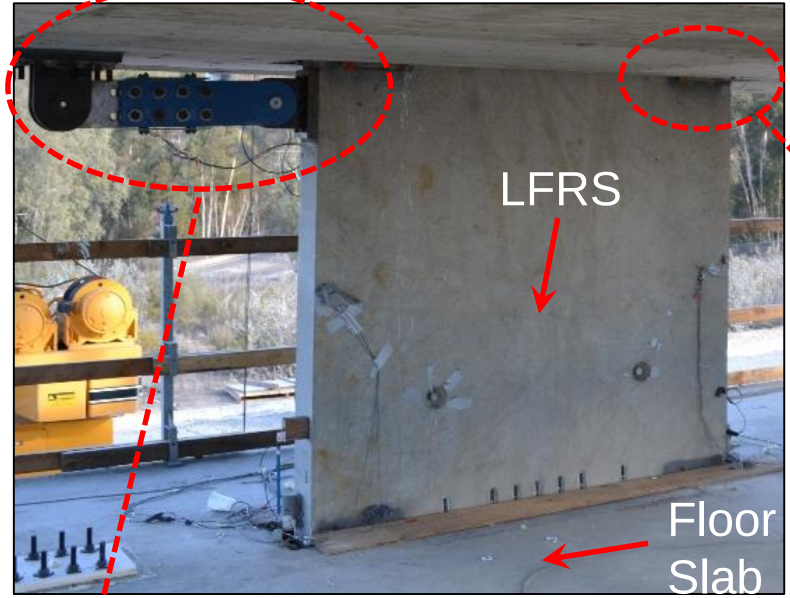


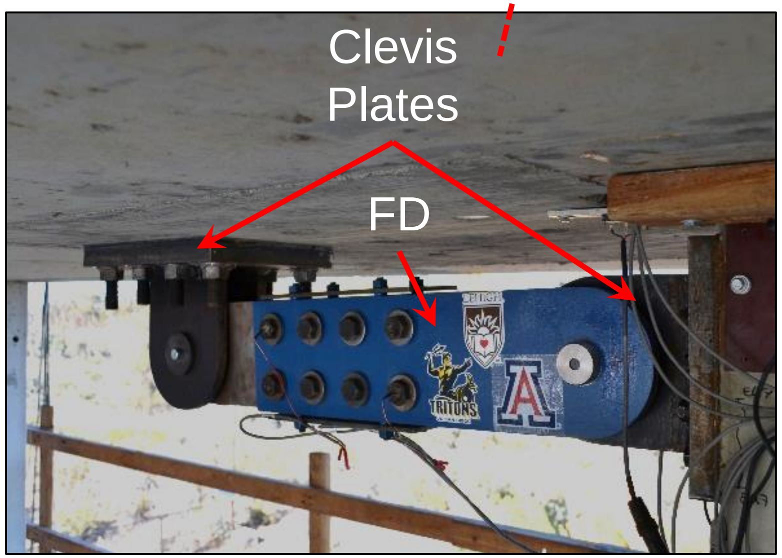


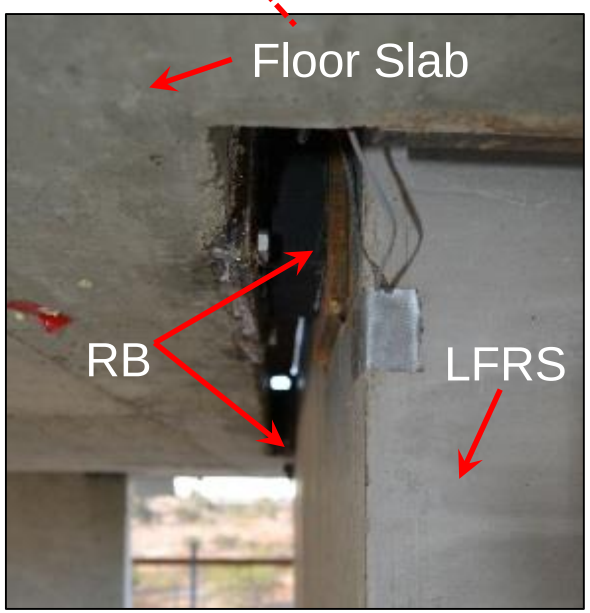
IFAS Shake Test Installation

Half-Scale 4-story Precast Rocking Shear Wall Structure

NEES @ UCSD

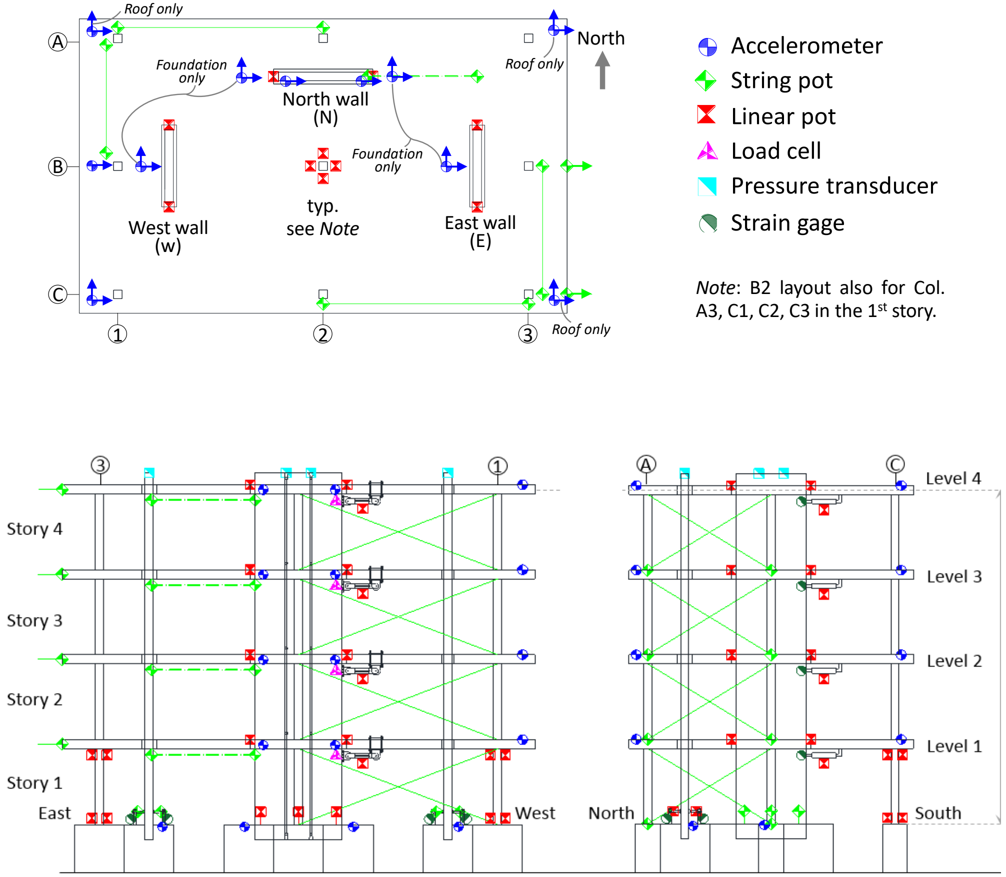


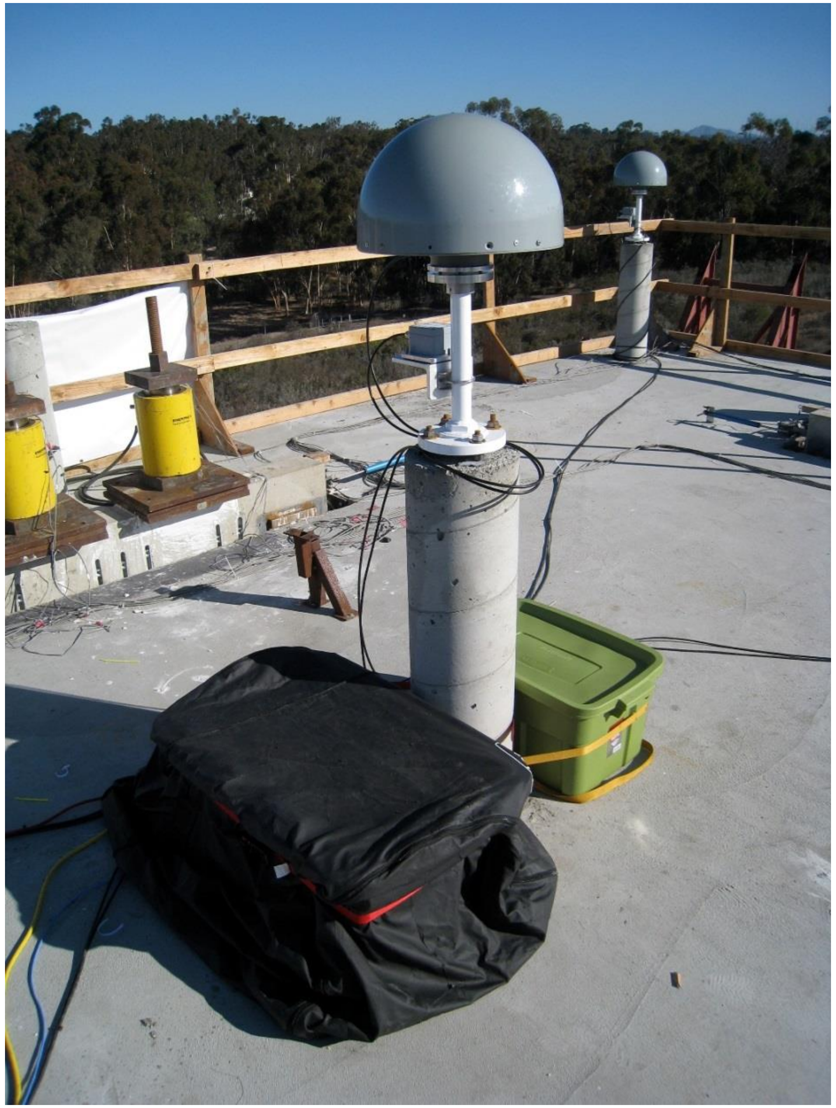




Instrumentation

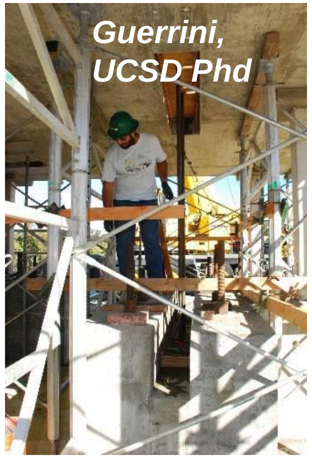
Project Testing Phase

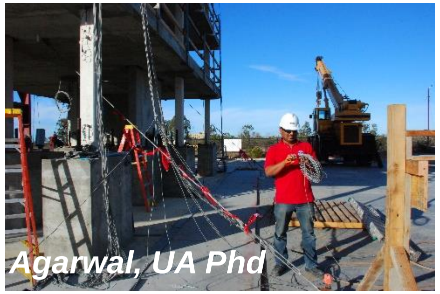


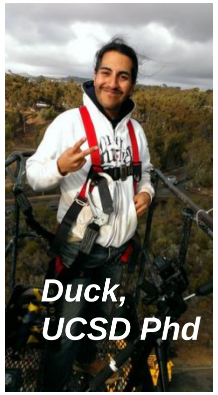


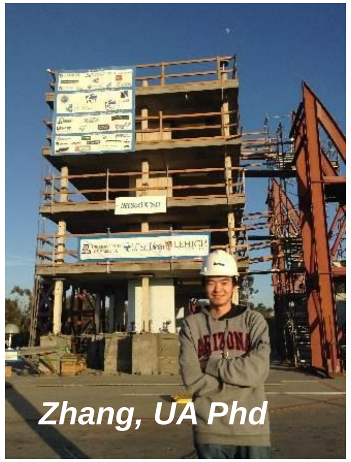
Student Participation

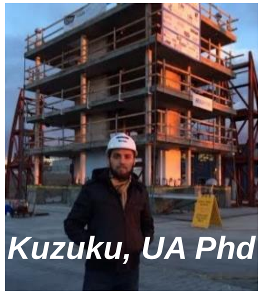
Specimen Construction/ Instrumentation



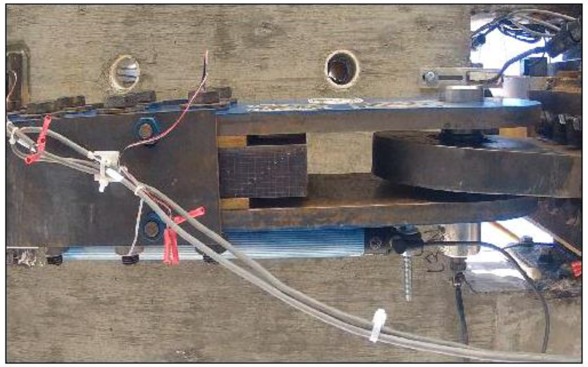


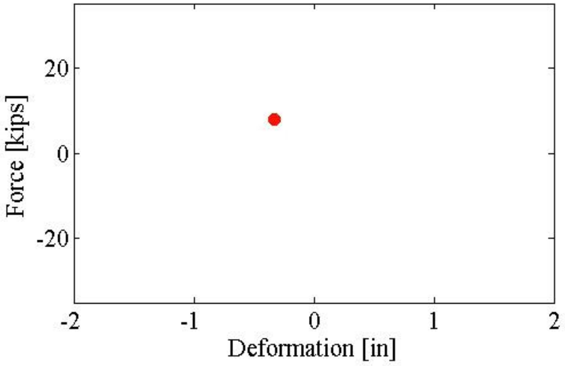


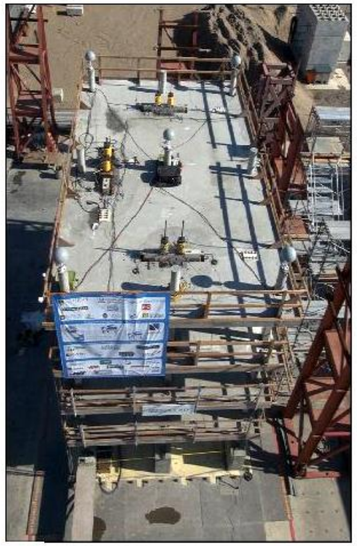




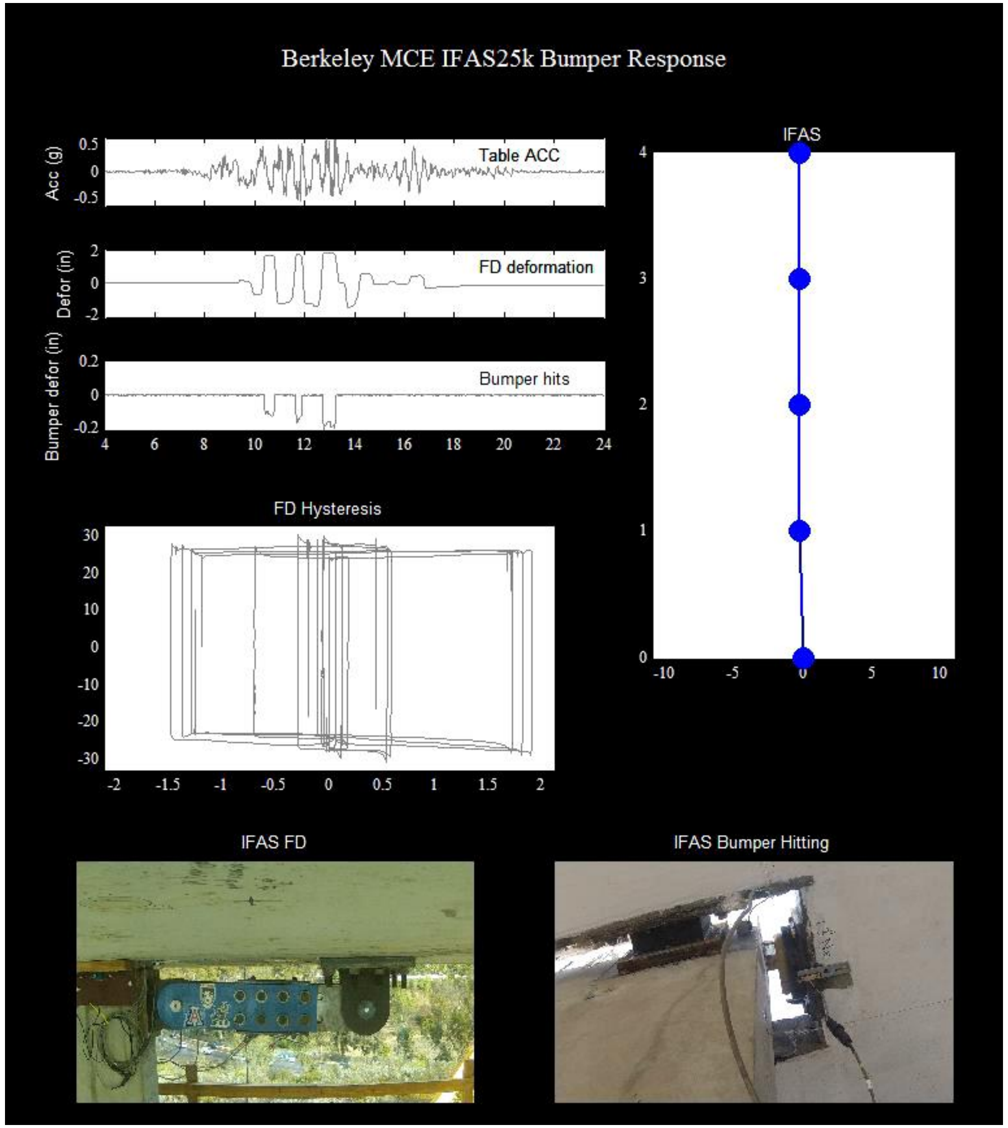
IFAS Shake Table Response: NEES@UCSD







Shake Table Test Response



Bumper behavior

Shake Table Testing: NEES@UCSD

Shake Table test

Rocking of Main(North) wall

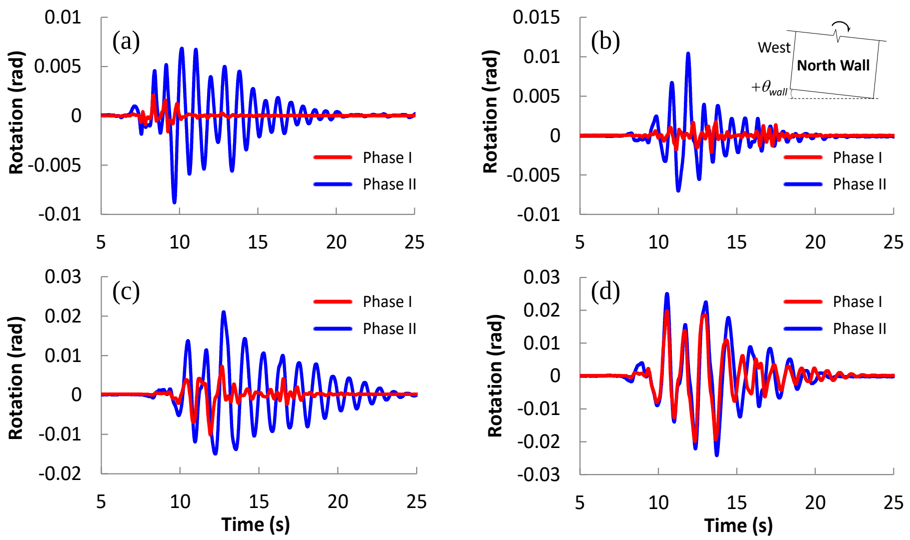
PHASE I VS PHASE II

LEHIGH UNIVERSITY | THE UNIVERSITY OF ARIZONA | UC San Diego

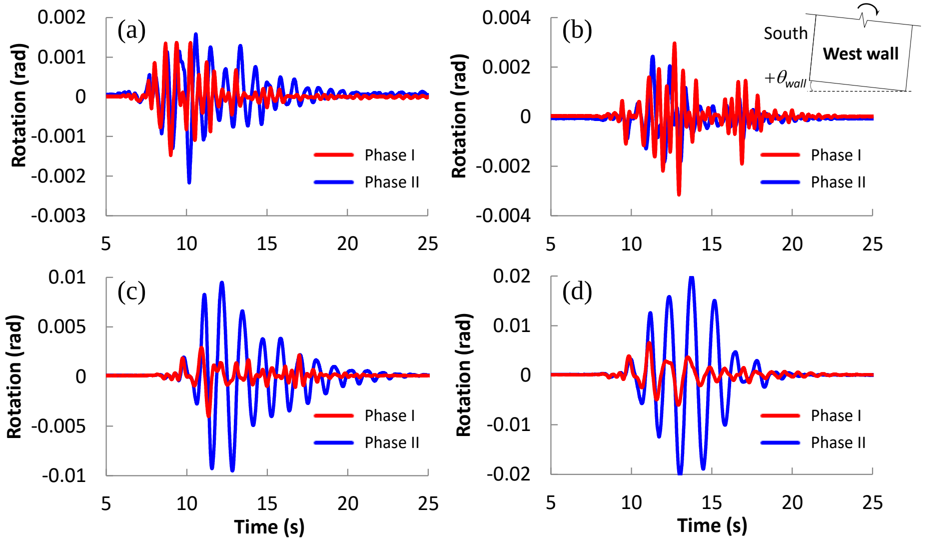
Berkeley BE05 MCE
Traditional system vs IFAS

PLAN VIEW COMPARISON

Shake Table Test Results: NEES@UCSD



Comparison to Traditional Structure



Project 3: Steel Seismic Collectors

NSF ECI / ENH: Advancing Knowledge on the Performance of Seismic Collectors in Steel Building Structures

NHERI @ UCSD

NHERI Lehigh

Background
SFRS for Steel Structures

Vertical-plane SFRS elements provide a laterally stiff load path to the foundation

Seismic Collectors serve as the critical link between the diaphragm and the vertical elements

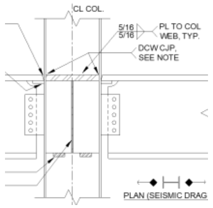
Floor diaphragms transfer inertial forces laterally from the floor slab and attached elements

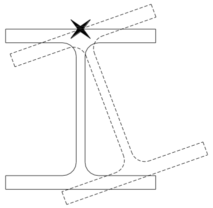
Load Path from the seismic mass to the foundation

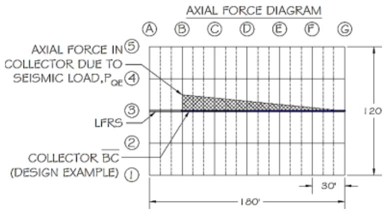
Project 3: Research Approach

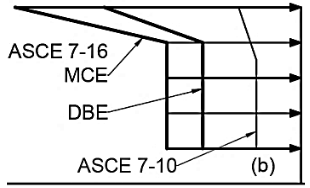
Research Thrusts	Collector Connection	Collector Element	Collector System	Seismic System

DESIGN

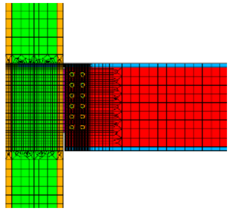


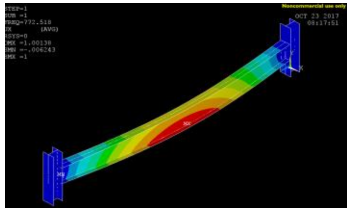


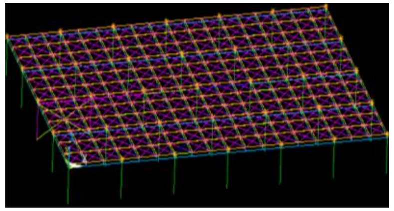


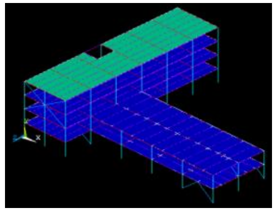


ARIZONA

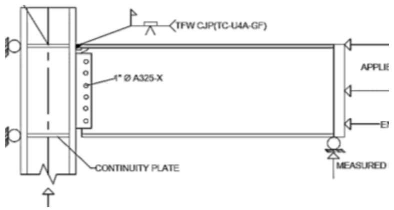


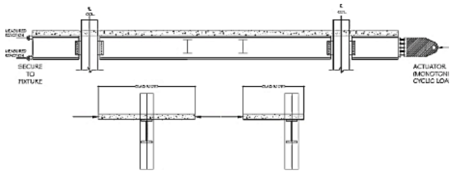




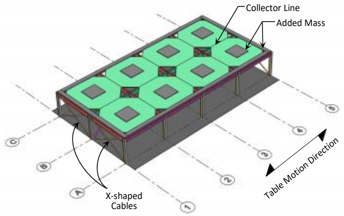


LEHIGH





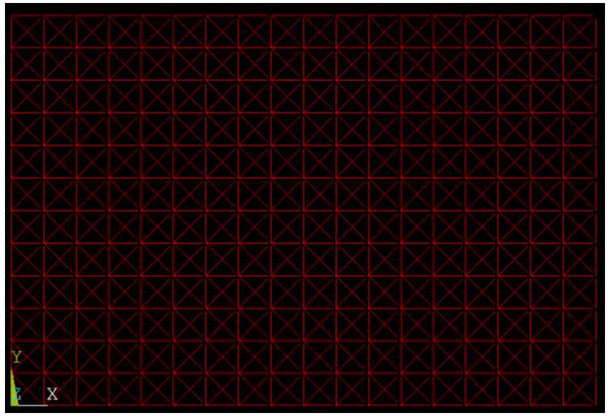
UCSD



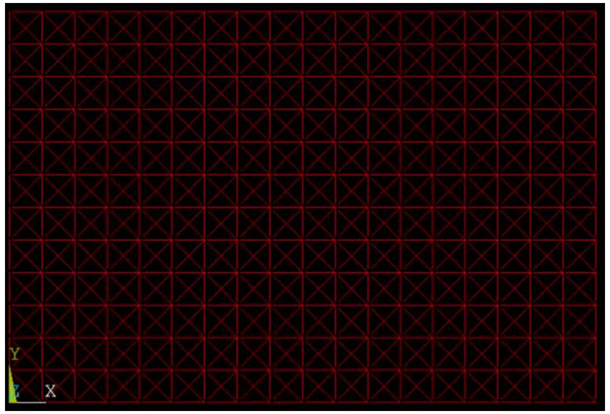
Analytical Work

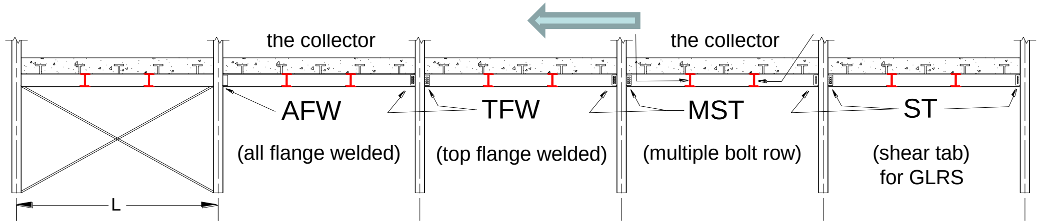
Compression Load Path

Compression Strut

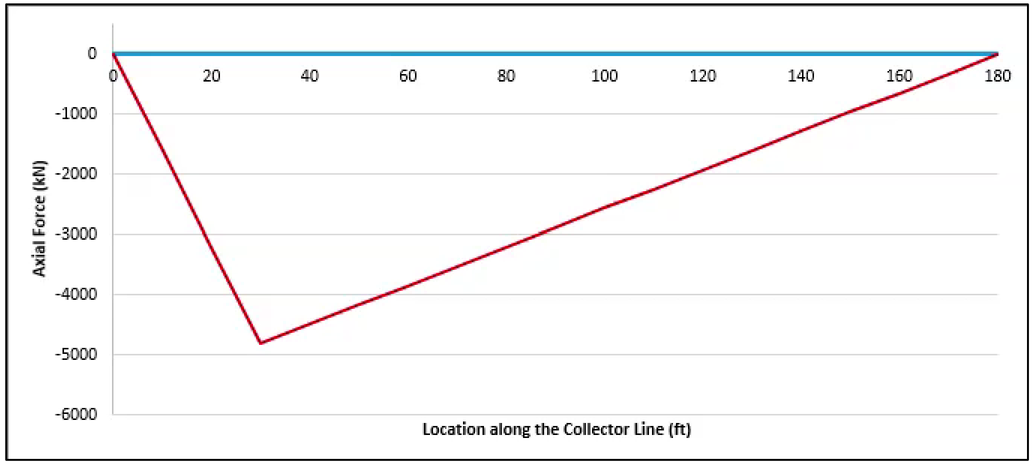


Tension Strut





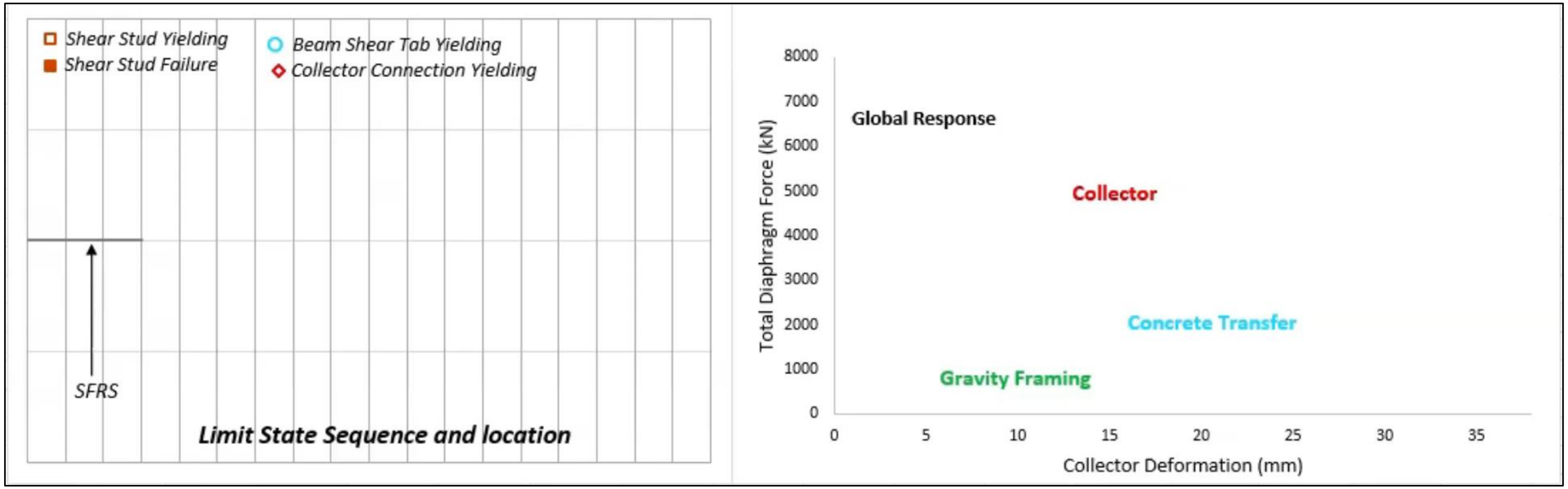
Collector Axial Force Profile with Concrete Strut Action



Body Force Producing Compression in the Collector

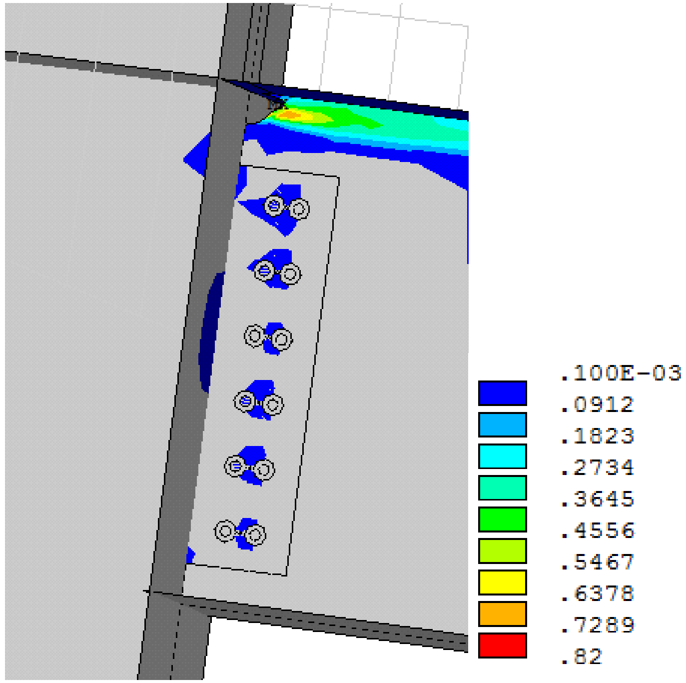
Analytical Work

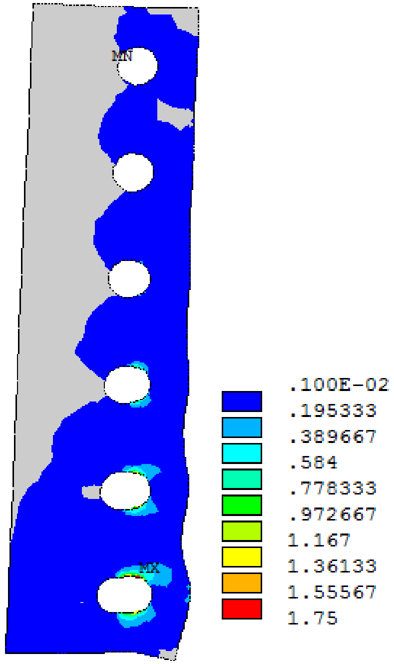
Limit State Sequence: Compression

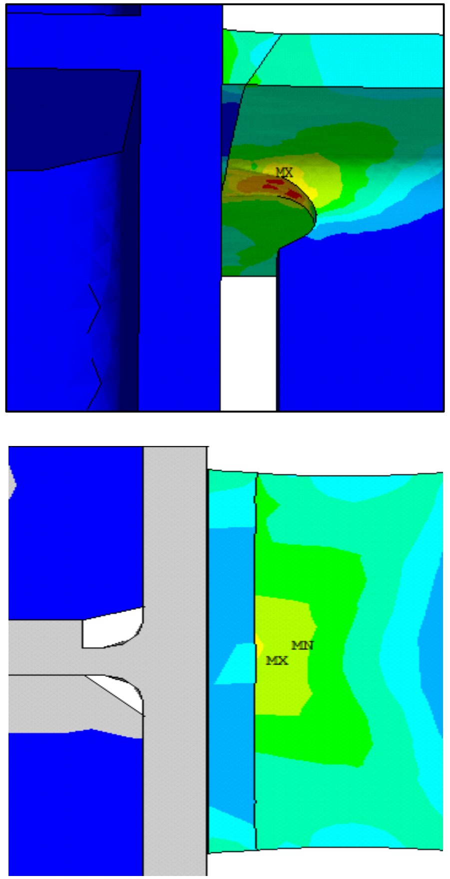


Body Force Producing Compression in the Collector

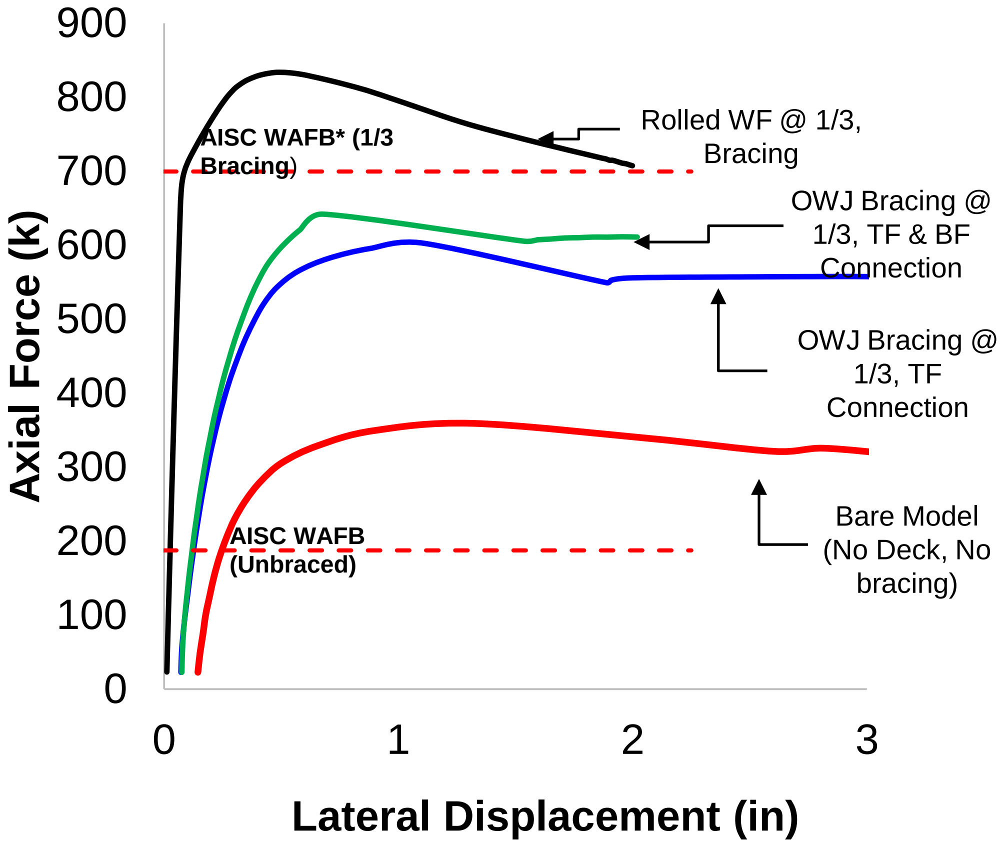
Collector Connection Limit States



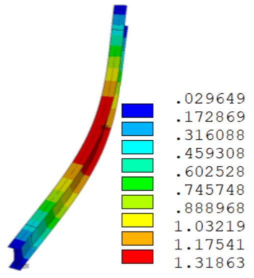




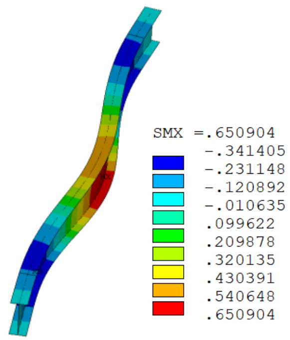
Roof Collector Members Stability Modes



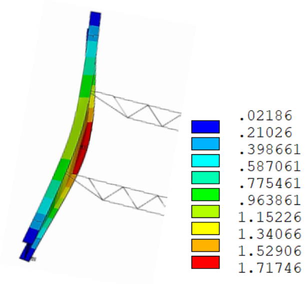
Contour Plots of Lateral Displacement



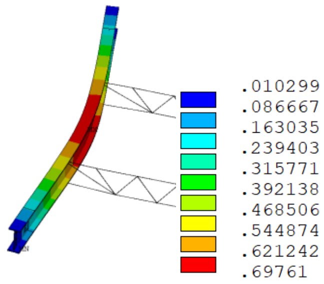
Bare Collector



Rolled WF @ 1/3, Bracing



OWJ Bracing @ 1/3, TF Connection

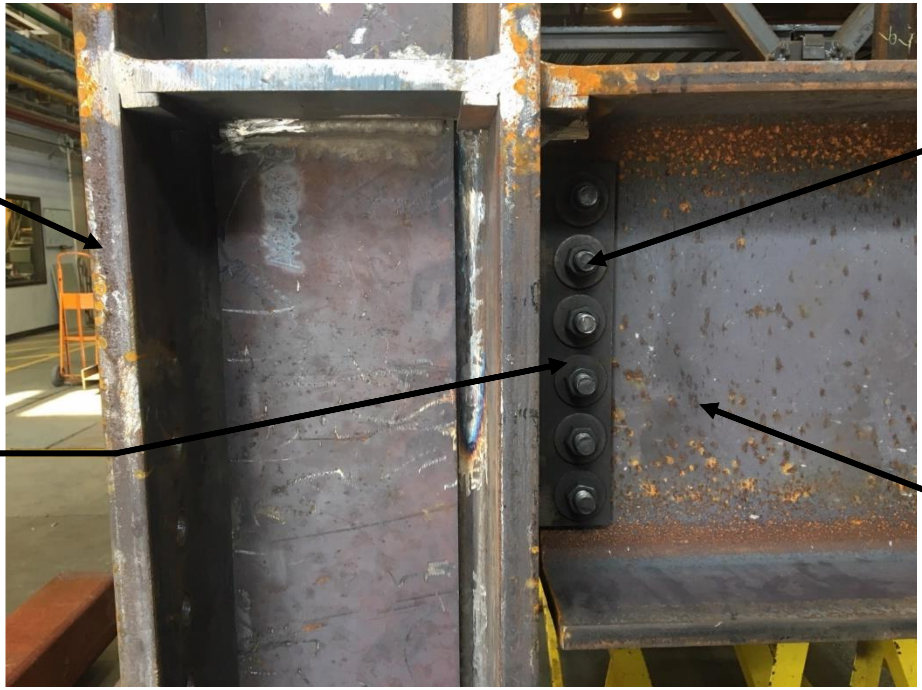


OWJ Bracing @ 1/3, TF & BF Connection

Fabricated Specimen: Top Flange Weld (TFW)

W12x136
Column

13.75”x3.25”x3/8”
Shear Tab



6 – 3/4” dia.
A325 Snug
tight bolts

W18x97
Collector

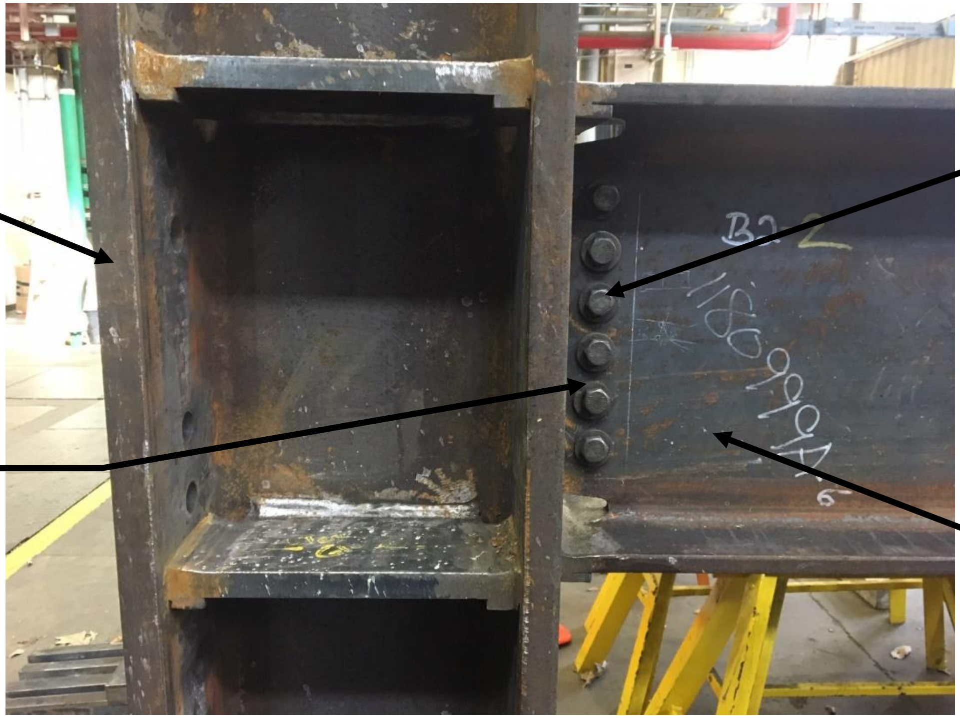
The TFW is a 3/4-scale test specimen based on a Full-Scale Prototype

Scale	Section	Length	Shear Tab (H x W x t)	Bolt Dia	# of bolts	Factored Strength	Maximum Exp. Axial Capacity
		ft	*in x in x in*	*in*		*k*	*k*
1.0	W24X162	30	18 x 4.5 x 1/2	1.00	6	714	1499
0.75	W18x97	20	13.75 x 3.25 x 3/8	0.750	6	435	940

Fabricated Specimen: All Flange Weld (AFW)

W12x136 Column

11.8"x3.25"x3/8" Shear Tab



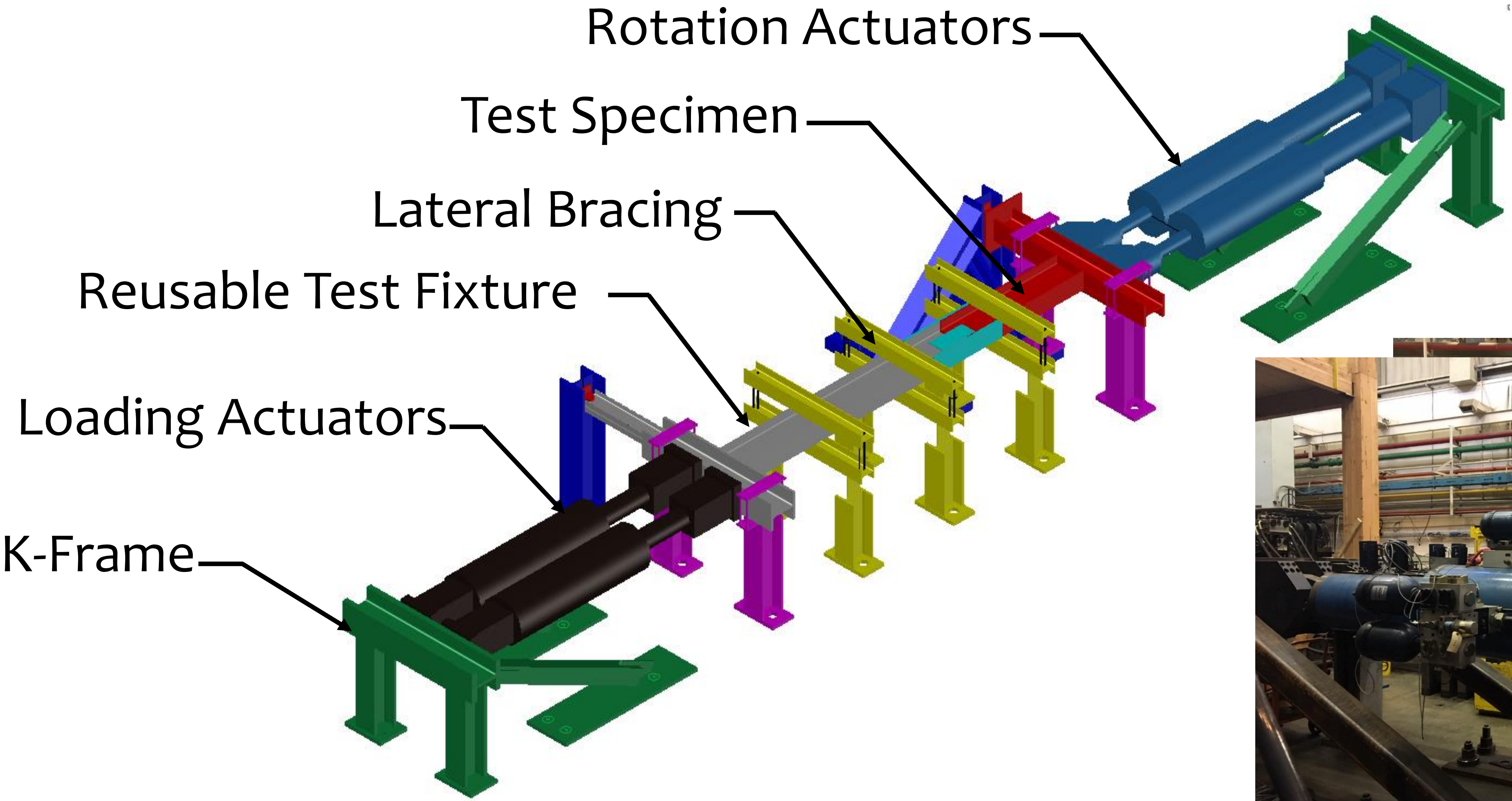
6 – 5/8" dia. A325 Snug tight bolts

W16x57 Collector

The AFW is a **2/3-scale test specimen** based on a **Full-Scale Prototype**

Scale	Section	Length	Shear Tab (H x W x t)	Bolt Dia	# of bolts	Factored Strength	Maximum Exp. Axial Capacity
		ft	*in*	*in*		*k*	*k*
1.0	W24X162	30	18 x 4.5 x 1/2	1.00	6	1427	2633
0.67	W16x57	20	11.8 x 3.25 x 3/8	0.625	6	458	978

Test Set Up (3D Model)



UCSD Shake Table Specimen

Thank You!