National Science Foundation

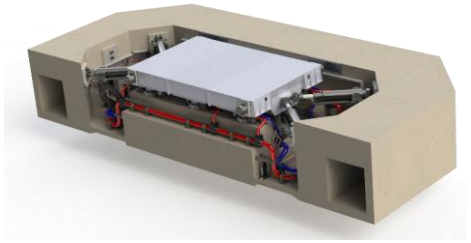
University of California at San Diego
NHERI
Natural Hazards Engineering Research Infrastructure

UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

Structural Systems:

List of Open Issues and Scope of Problems
Example Use of Facilities to Address Scientific Needs

Jose I. Restrepo, Professor in Structural Engineering
UC San Diego



NHERI@UC San Diego User Training Workshop

December 15-16, 2022
University of California, San Diego

Outline

1. Grand Challenges in Structural Earthquake Engineering

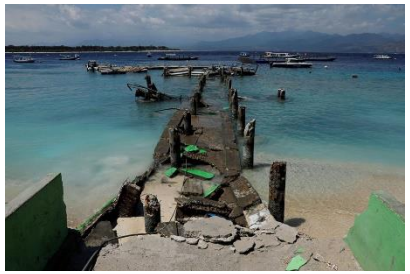
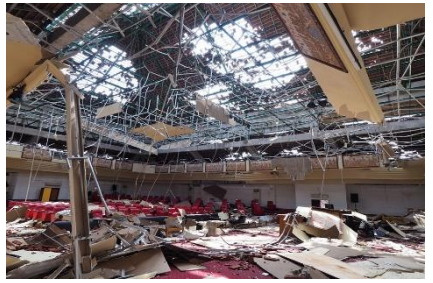
2. Example Projects:
   - Case Study 1: **NSF GOALI: Development of a Seismic Design Methodology for Precast Floor Diaphragms (DSDM)**
   - Case Study 2: **NSF NEES: Inertial Force-Limiting Anchorage Systems (IFAS)**

Part 1

Grand Challenges in Structural Earthquake Engineering

Grand Challenges in Structural Earthquake Engineering

7/29 M_w 6.4, 8/5 M_w 7.0, 8/9 M_w 6.2 & 8/19 M_w 6.5 + M_w 6.9 2018 Lombok Is. Earthquake Swarm, Indonesia


https://www.theatlantic.com/photo/2018/08/images-from-the-lombok-island-earthquake/567158/

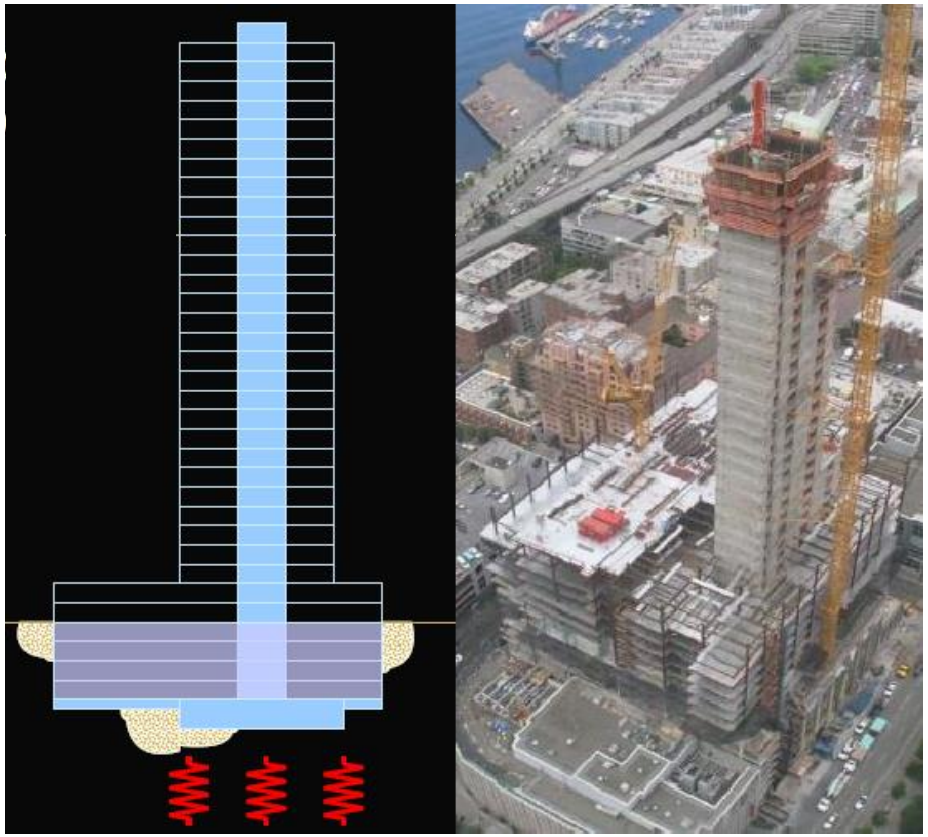
Tsunami Refuge Center, Pamenang, Lombok


Grand Challenges

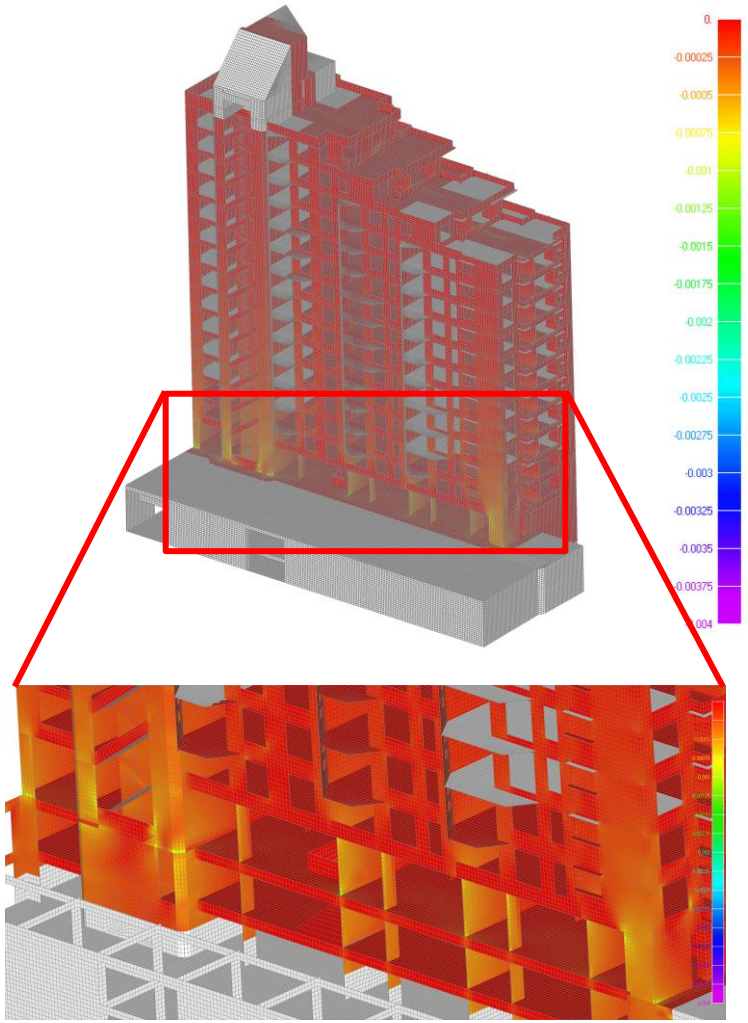
- Experimental research in structural earthquake engineering has shifted from isolated characterization testing of components:
  - System Behavior & System Interactions
  - Old and Vulnerable Systems
  - Low-Damage, Protective, and Smart Systems
  - Non-structural Components and Contents
  - Sensors and Monitoring
  - Risk Assessment and Hazard Mitigation
  - Multi-Hazard, Multi-scale Investigations
  - Model calibration

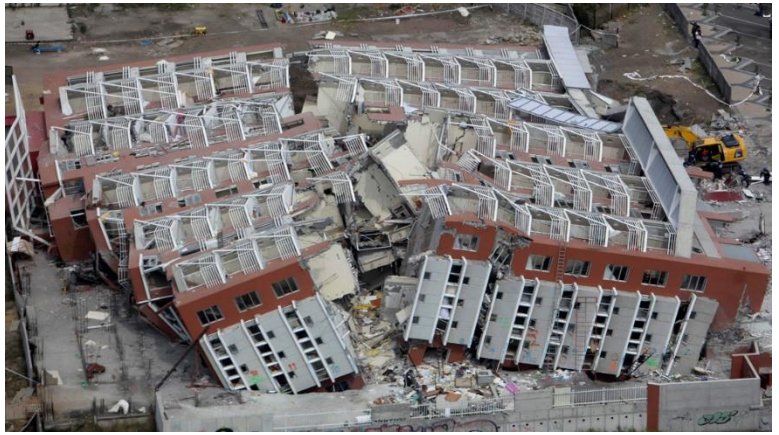
System Behavior & System Interactions

- **Complex System Behaviors:**
  - Tall Buildings
  - Discontinuities (e.g., Transfer Conditions)
  - Diaphragm action, Tie-back Effects
  - Construction staging effects – Top-down Construction
  - Structural Irregularity in Plan, Vertical Offsets
  - Better understanding of SSI



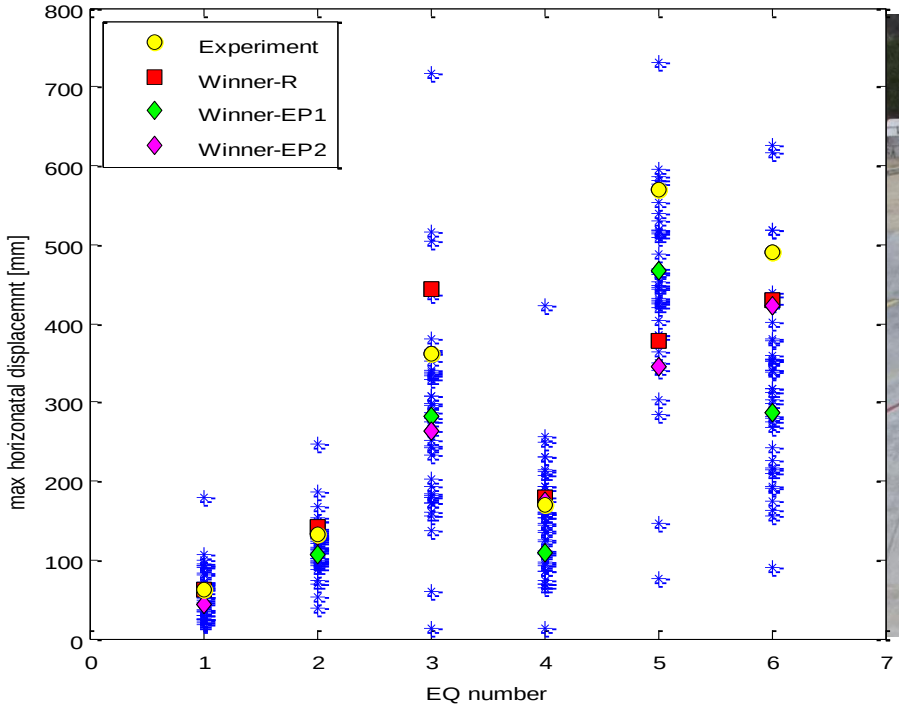
System Behavior & System Interactions

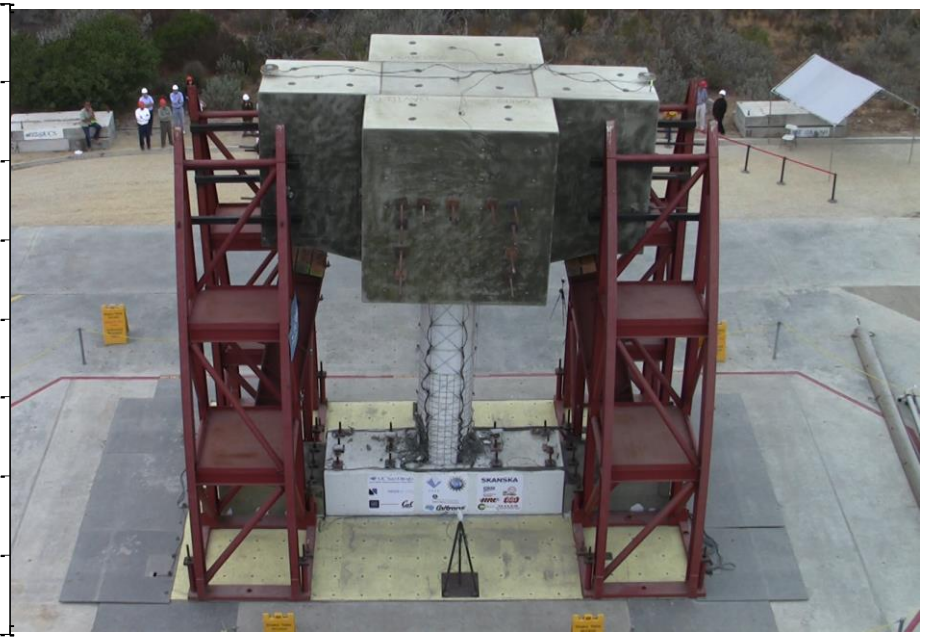




Model Calibration

- Involve practicing engineers and researchers to participate in blind prediction contests followed up by workshops





Low-damage Systems

PRESSS Capstone Test by Priestley et al. – UC San Diego 1999

Part 2
Example Projects

NSF GOALI: DSDM

NSF NEESR: IFAS

PCI DSDM & IFAS PROJECTS

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

Project 1: NSF GOALI - DSDM

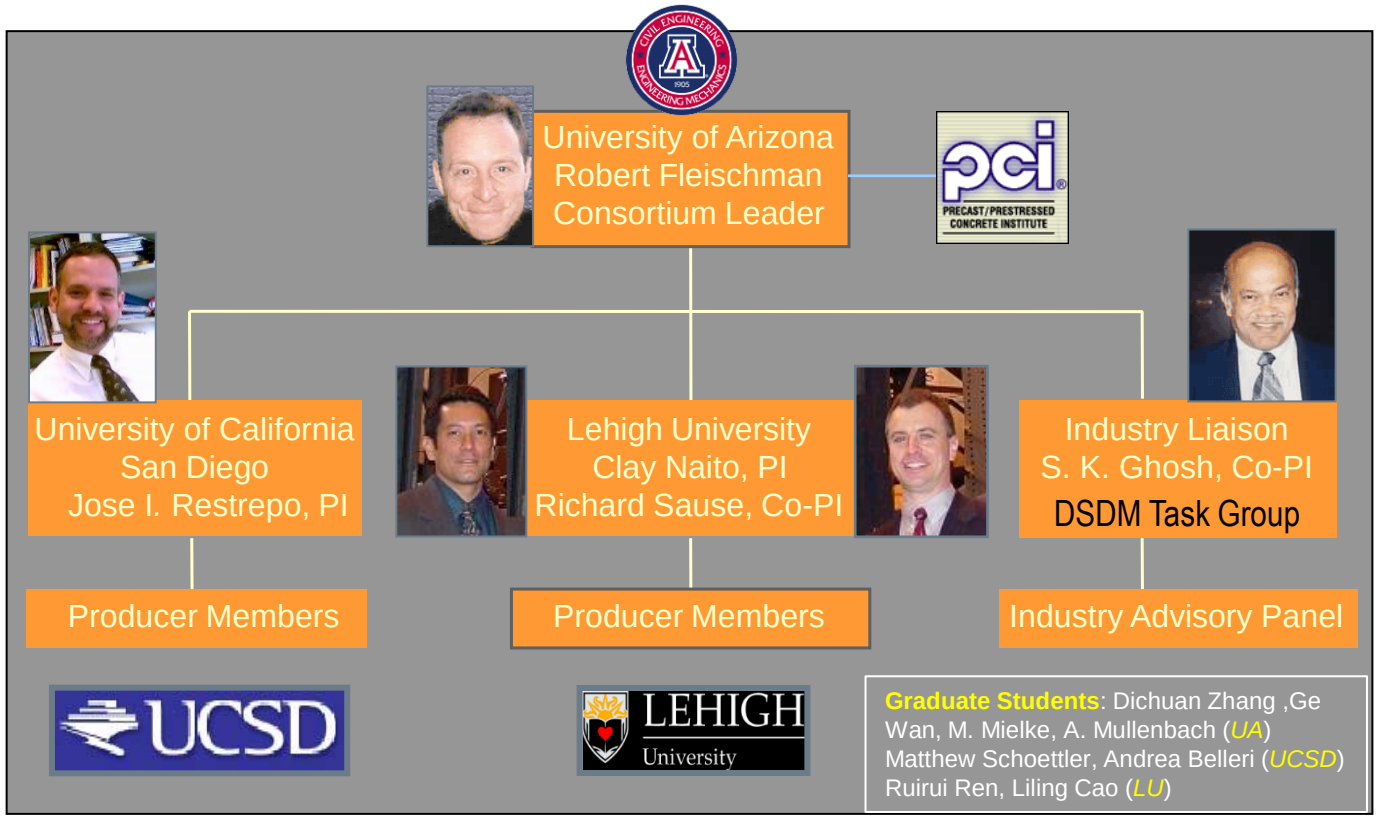
Development of a Seismic Design Methodology for Precast Floor Diaphragms (DSDM) 2005-2009

THE UNIVERSITY OF ARIZONA

UC San Diego

LEHIGH UNIVERSITY

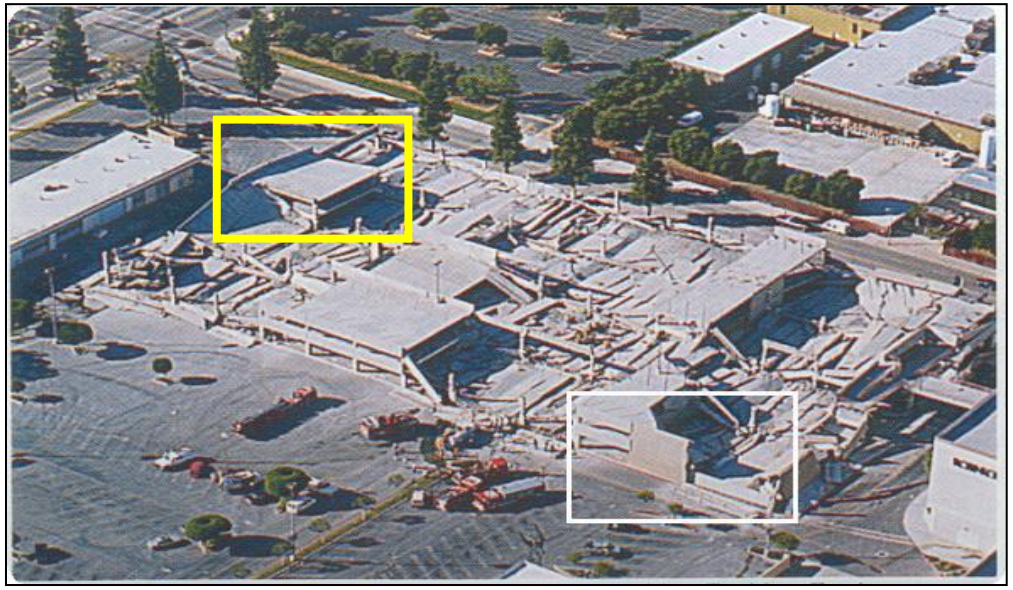
DSDM Research Team



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…



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 degrade.

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

System Level (UCSD)

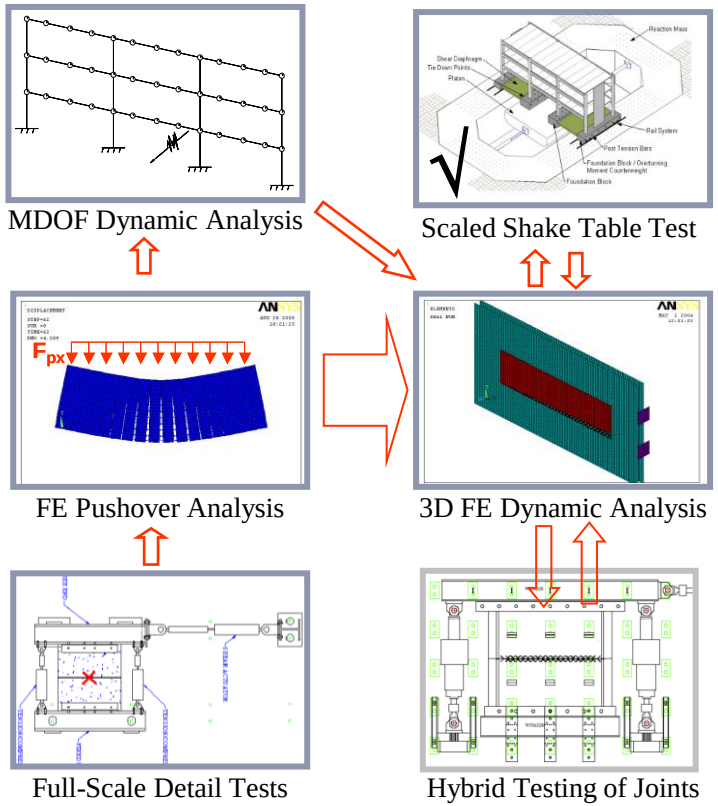
- Diaphragm Inertial Forces
- Flexible Diaphragm Structures

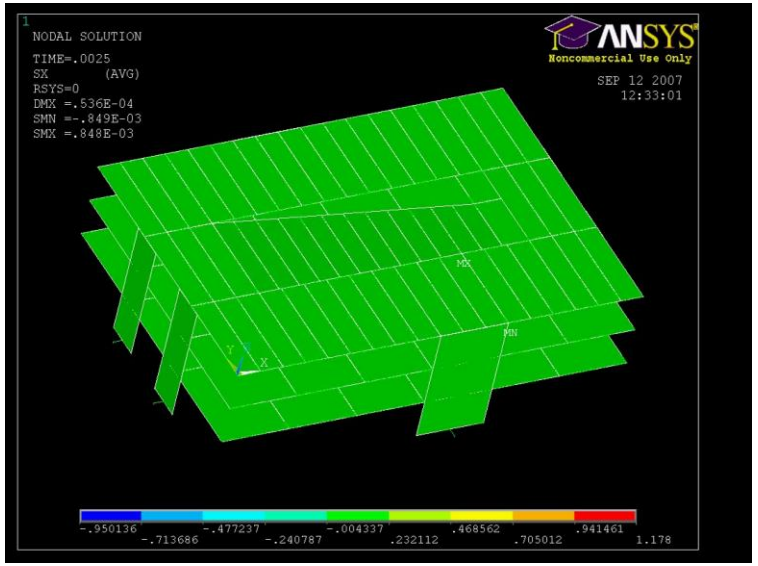
Diaphragm Level (UA)

- Diaphragm Capacity
- Diagram Load Paths & Limit States

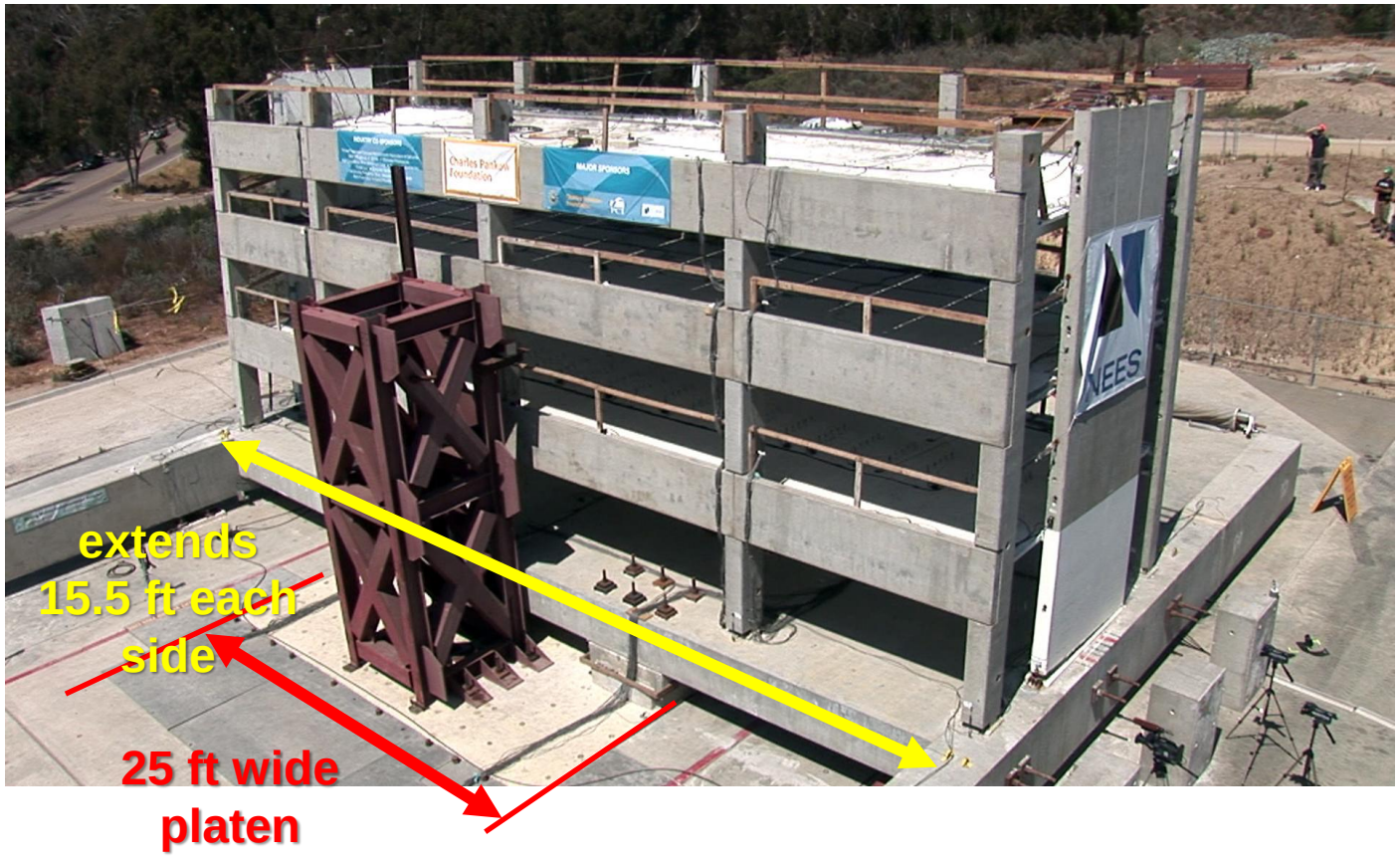
Detail Level (LU)

- Connector Properties
- Connector Classification

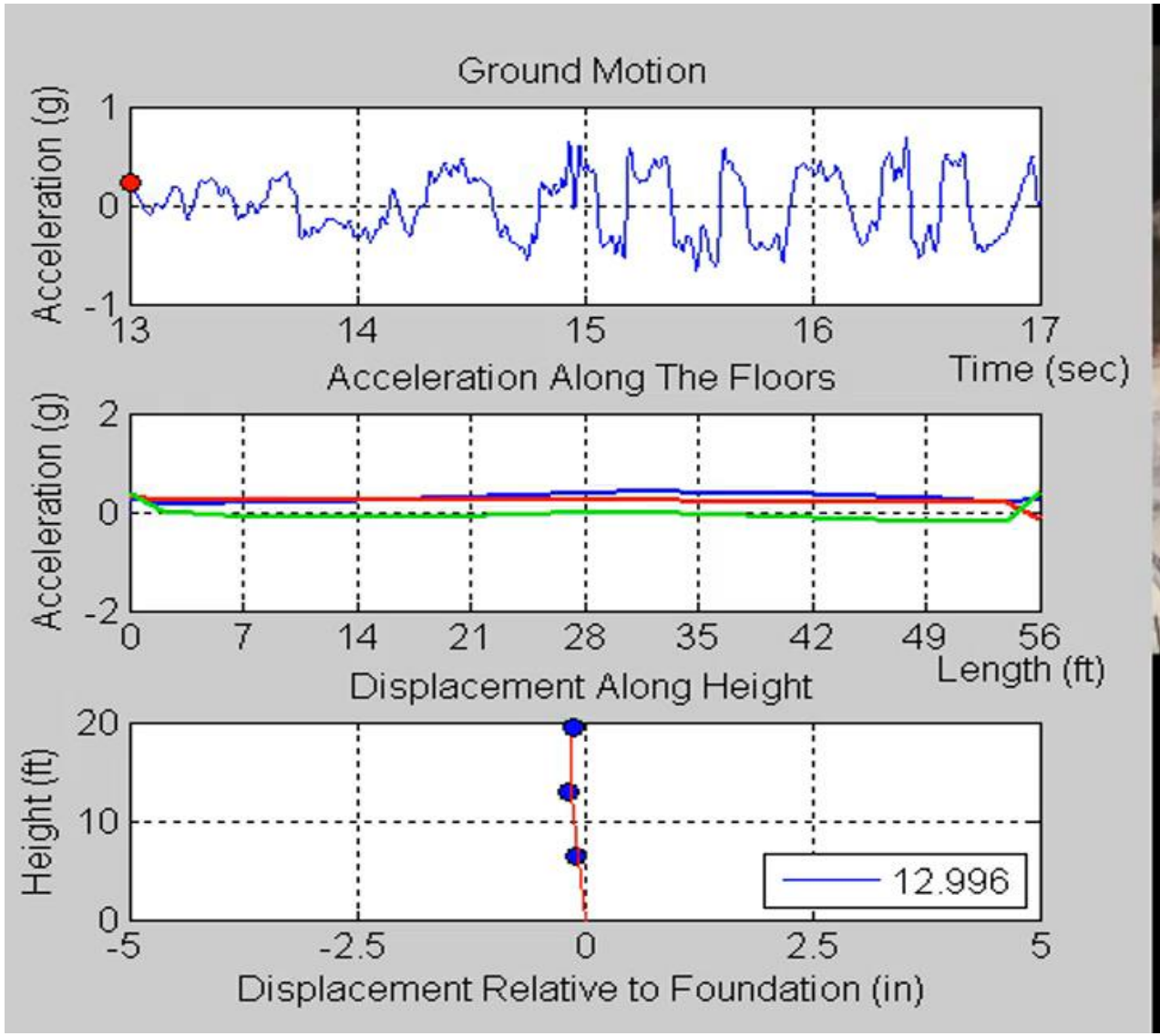




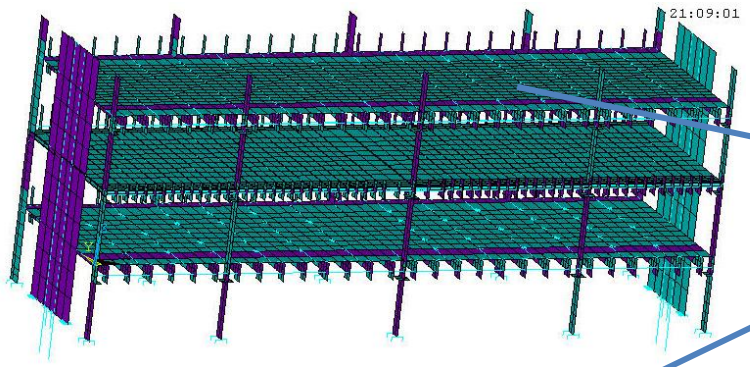
Practical Considerations

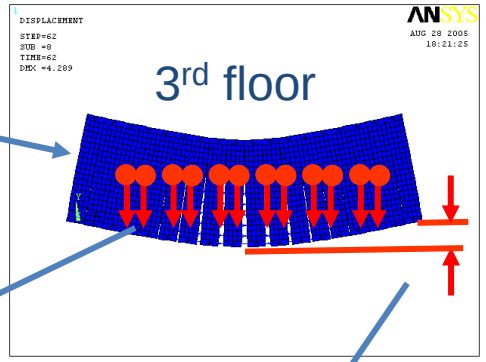


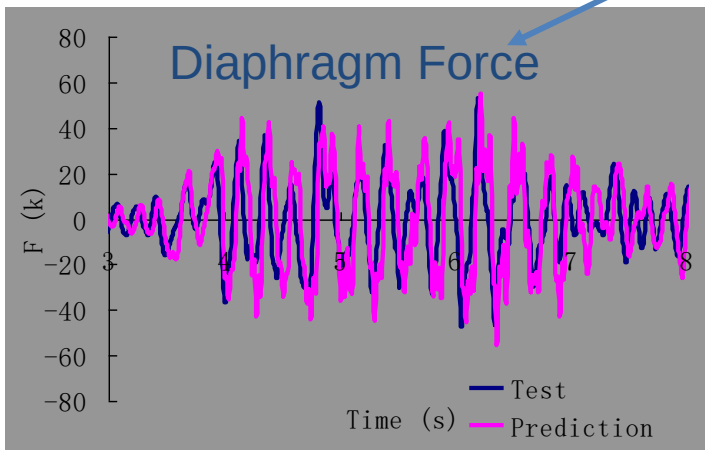
Shake Table Test

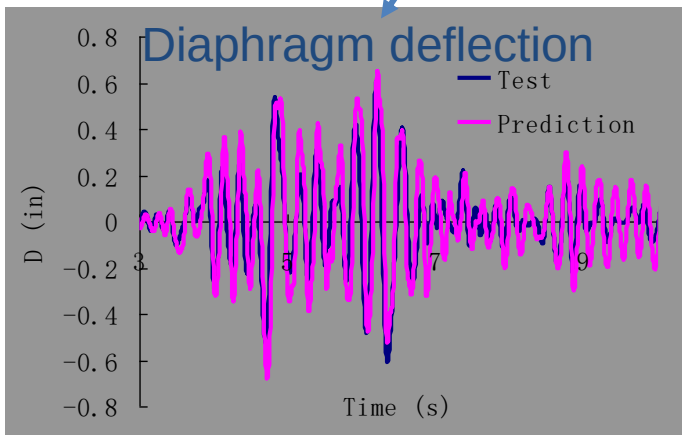


Analytical Simulation









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**.

2016 ASCE Pankow Award for Innovation

Project 2: NEESR IFAS

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

NEES @ UCSD

NEES @ Lehigh

THE UNIVERSITY OF ARIZONA

UC San Diego

LEHIGH UNIVERSITY

IFAS Project Team

Academic collaborators

The University of Arizona

Dr. Robert Fleischman, PI
Zhi Zhang, Ph.D. student
Ulina Shakya, Ph.D. student
Anshul Agarwal
Austin Houk, REU
Scott Kuhlman, REU
Mackenzie Lostra, REU
Daniel Lizarraga, REU
Fernando Gastelum, REU
Patrick Hughes, REU
Ziyi Li, REU

University of California, San Diego

Dr. Jose Restrepo, Co-PI
Arpit Nema, Ph.D. student
Gabriele Guerrini
David Duck, Nelson Angel
Armita Pebdani
Steve Mintz, Ph.D. student

Lehigh University

Dr. Richard Sause, Co-PI
Georgios Tsampras, Ph.D. student
Alronil Pacheco, REU (San Jose State University)

Nazarbayev University

Dr. Dichuan Zhang

Technical University of Bari

Dr. Beppe Marano
Dr. Giuseppe Quaranta

University of Rome

Dr. Giorgio Monti
Dr. Alessandro Scodeggio

K12 partner

Utterback Middle School

Griselda Meraz

Seismic Design Consultants

Rutherford + Chekene

Saeed Fathali

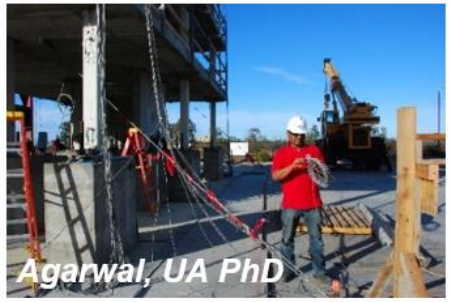
Maffei Engineers

Joseph Maffei

Tipping Mar

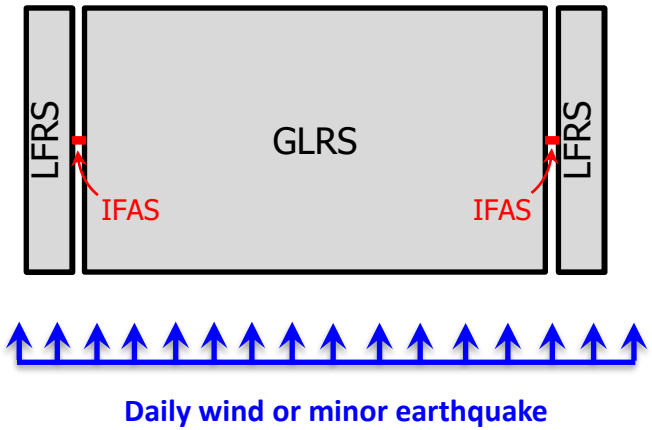
David Mar

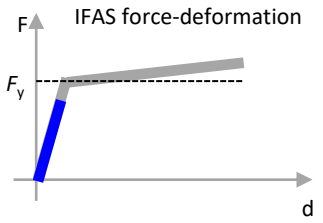
Student Participation



IFAS Concept

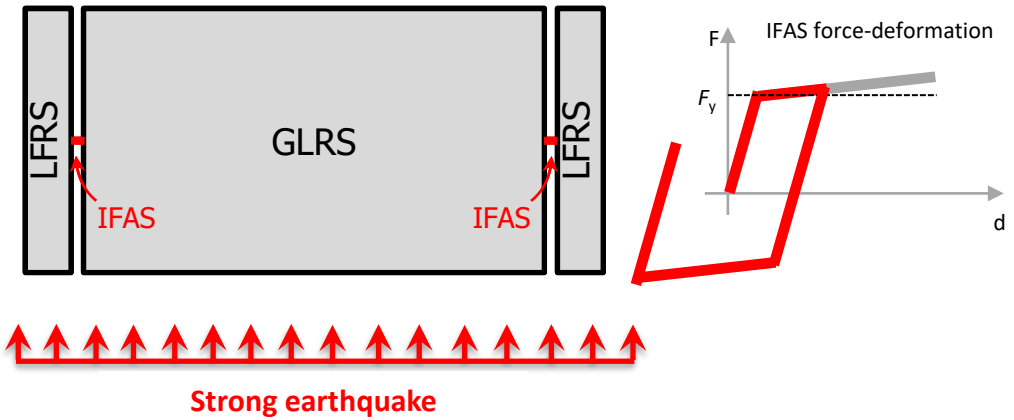
- Provides a deformable (ductile) connection between the floor system (GLRS) and the primary vertical plane LFRS elements (e.g., shear walls, braced frames)
- Designed with a predefined design strength *(F_y)* to partially uncouple the GLRS and the LFRS
- The structure acts as a traditional structure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



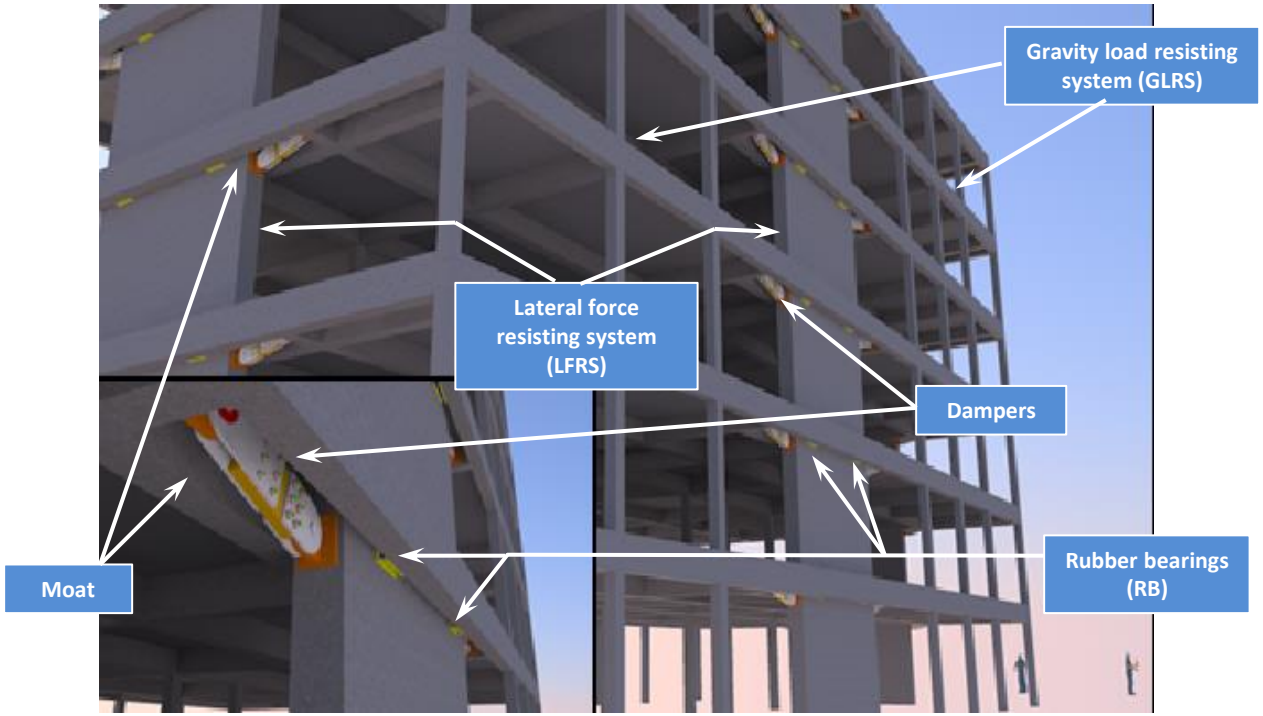


IFAS Concept

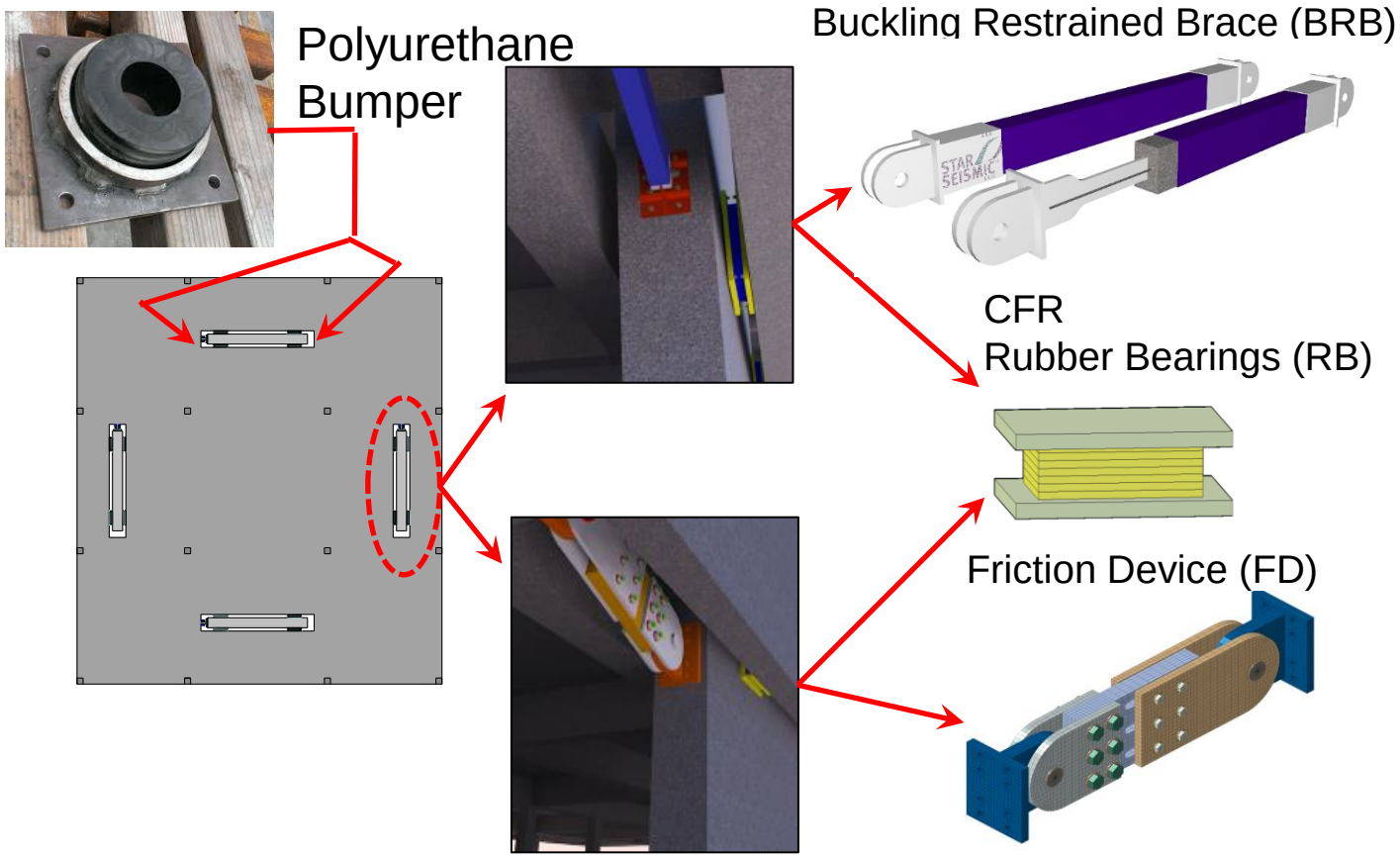
- The IFAS will reach its design strength in a strong earthquake…
- …and deform, thereby transforming the seismic demands into relative displacement between the GLRS and the LFRS…
- …dissipating energy and lowering seismic demands



IFAS Concept



IFAS Components



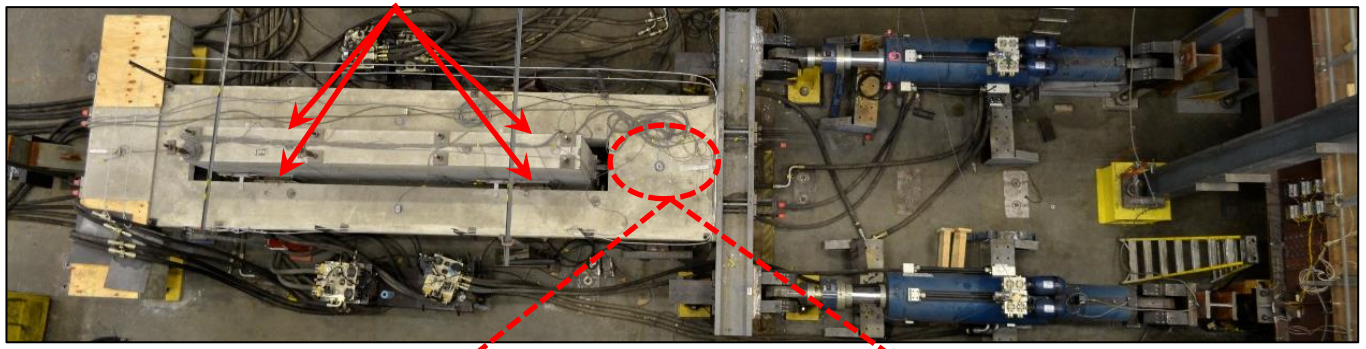
Subassemblage Testing: NEES@Lehigh

Lehigh Test Specimen

Full-Scale IFAS Testing: RB

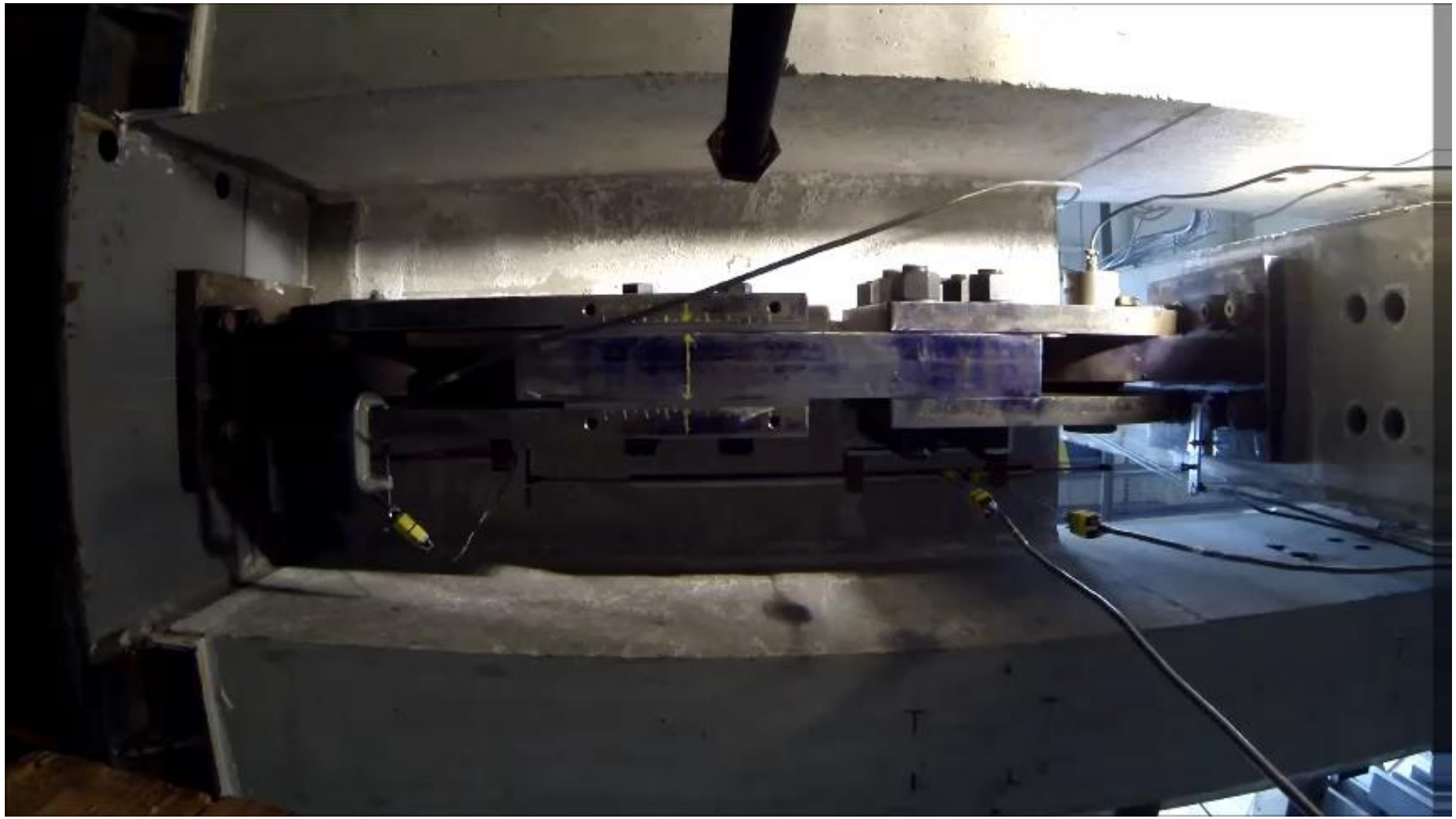
Full-Scale IFAS Testing: FD

Carbon Fiber Reinforced RB



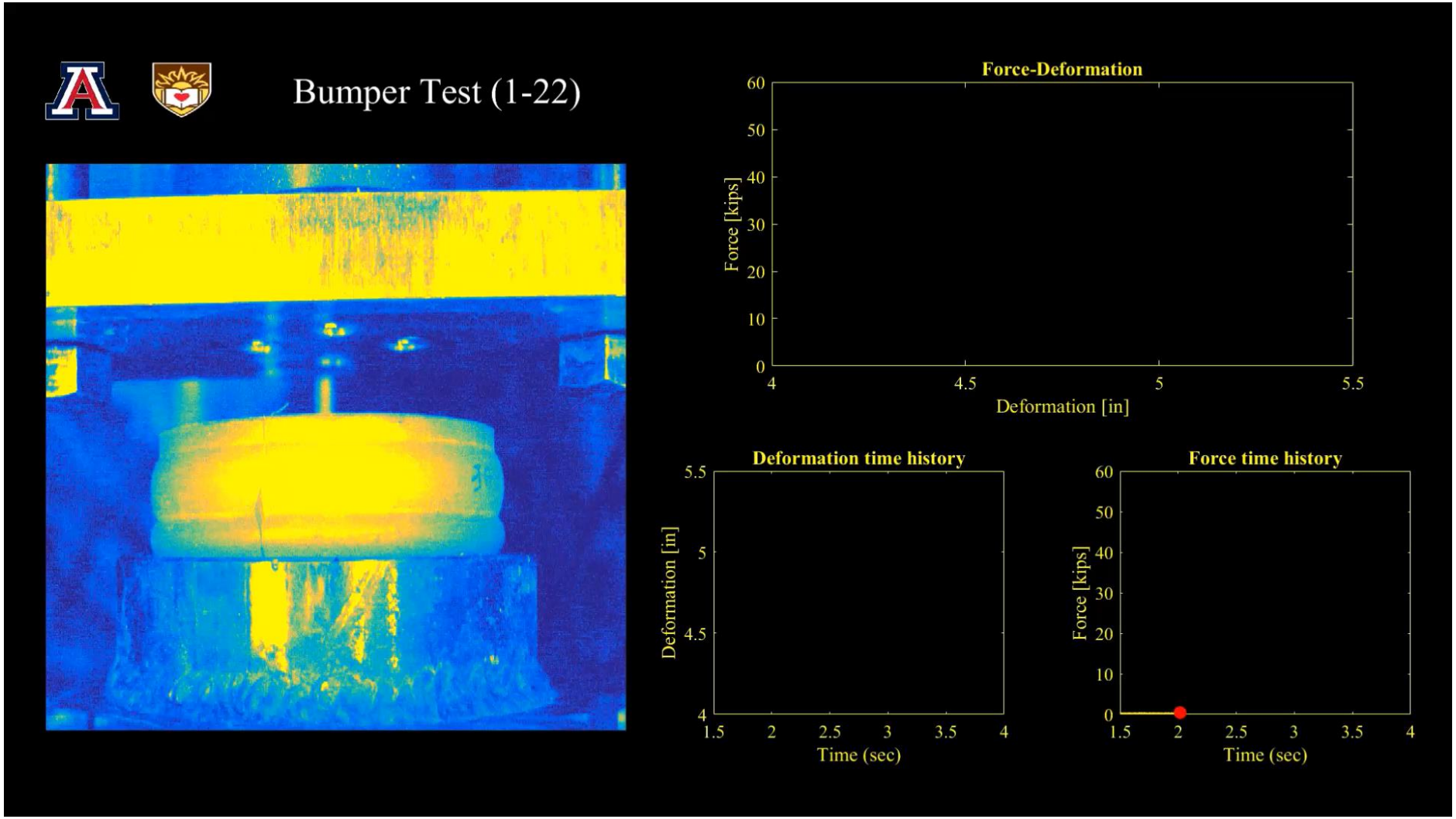
FD

Full-Scale IFAS Testing: FD



Bumper Impact Tests: NHERI@Lehigh

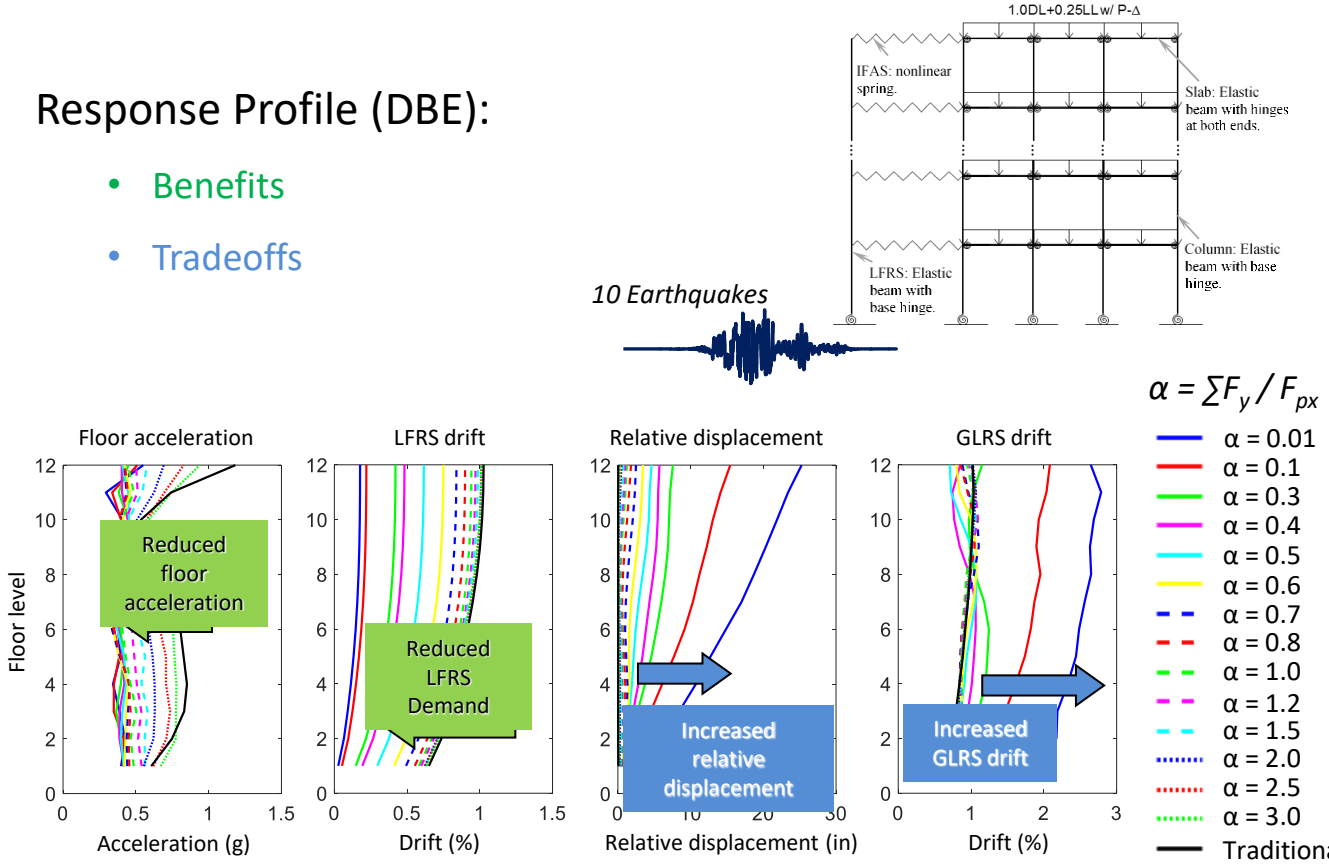
Bumper Impact Tests: NHERI@Lehigh



Analytical Research

Response Profile (DBE):

- Benefits
- Tradeoffs



Shake Table Test Structure

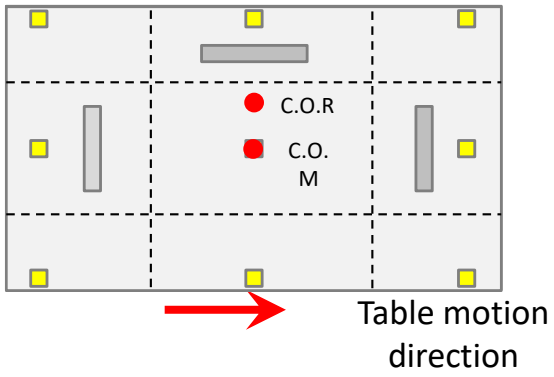
4-story reinforced concrete building

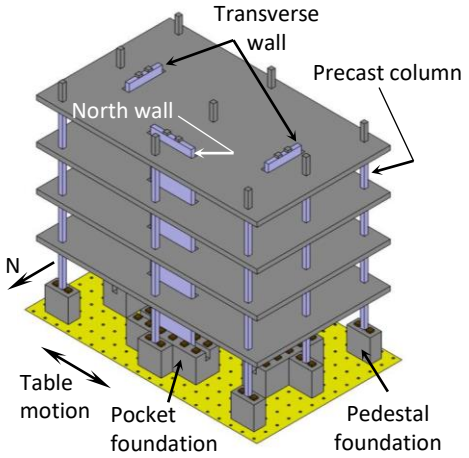
- Half-scale
- Provide direct comparison between IFAS and traditional
- Rocking Walls for repeatability

Shake Table Test Specimen

Test specimen description

- LFRS eccentricity was purposely introduced for torsional response

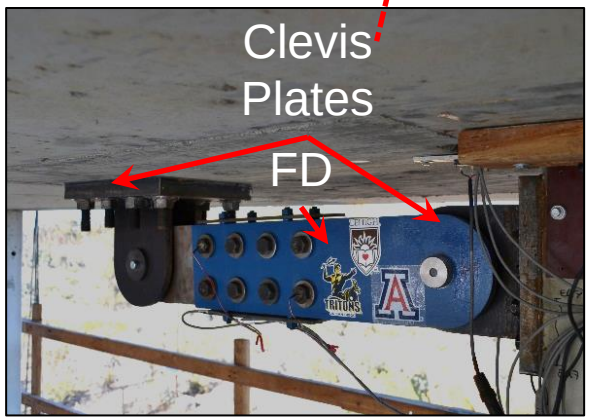


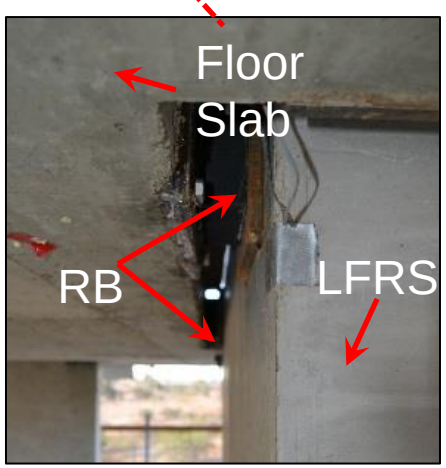


IFAS Shake Test Installation

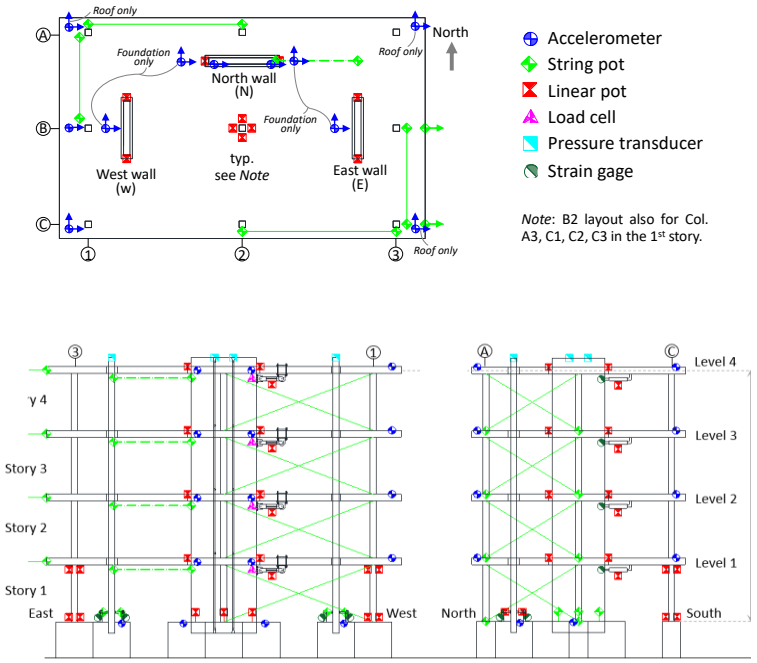
Half-Scale 4-story Precast Rocking Shear Wall Structure

NEES @ UCSD

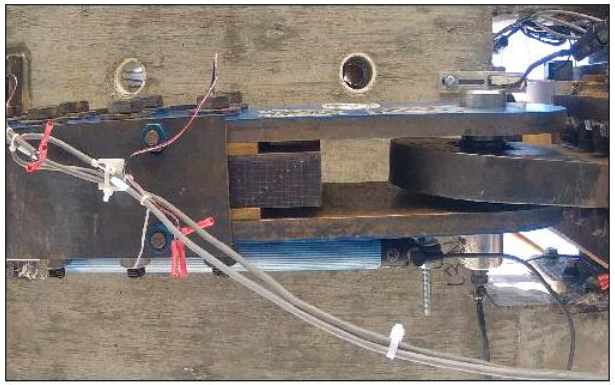


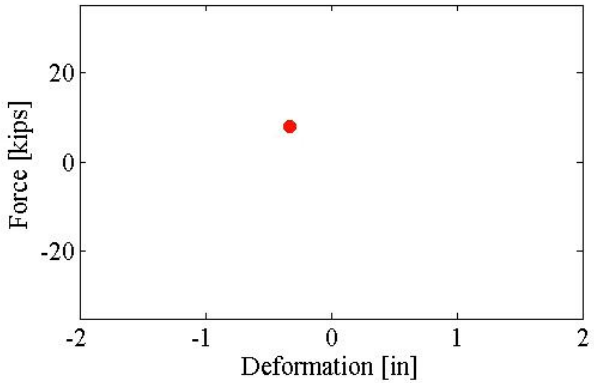


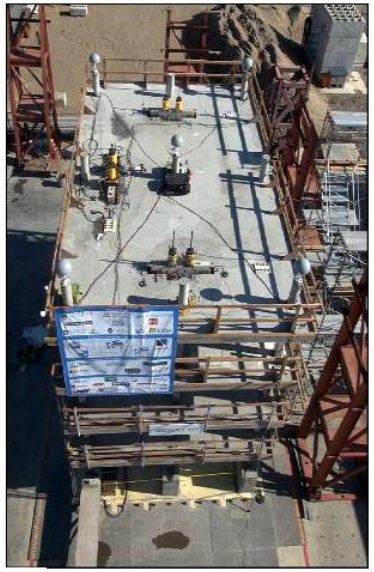
Instrumentation



IFAS Shake Table Response: NEES@UCSD

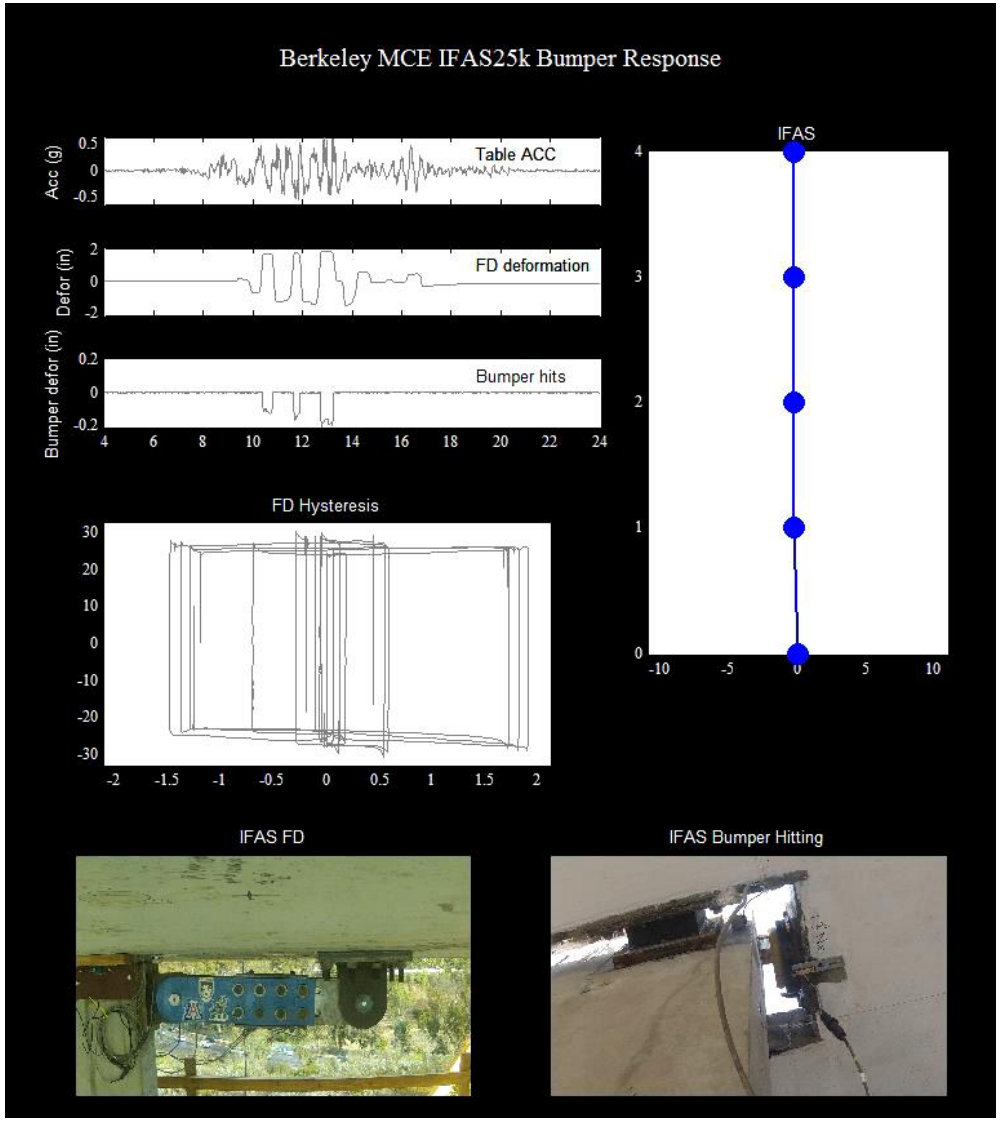






Shake Table Test Response

Bumper behavior



LEHIGH UNIVERSITY

THE UNIVERSITY OF ARIZONA

UC San Diego

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

Acknowledgements

A significant portion of this presentation was provided by Prof. Robert Fleischman of the University of Arizona, and PI in the NSF GOALI DSDM and NSF NEESR IFAS research projects.

Questions