Full-Scale Structural and Nonstructural Building System Performance during Earthquakes

A Joint Venture between Academe, Industry and Government

Project Overview

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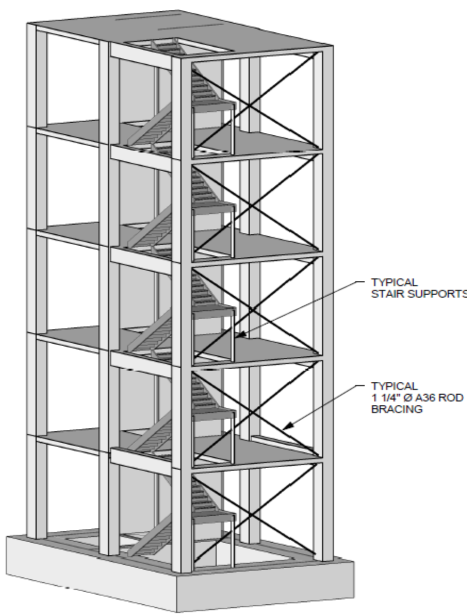
Scope of the Project

- $5 Million, multi-organizational 3 year research project
  - NSF / NEES core research project - $1.2 million
- Testing of a full-scale five-story building
- Fully outfitted with a range of nonstructural components and systems (NCSs)
- Testing first base isolation and then fixed base
- Unique opportunity to advance our understanding of the full-scale dynamic response and kinematic interaction of structural and nonstructural components and systems.



Partners

Funded by the National Science Foundation under Grant no.: CMMI-0936505

- Academic partners: University of California, San Diego (UCSD), Worchester Polytechnic Institute (WPI), San Diego State University (SDSU), and Howard University (HU)
- Broad stakeholder participation (industry and government)

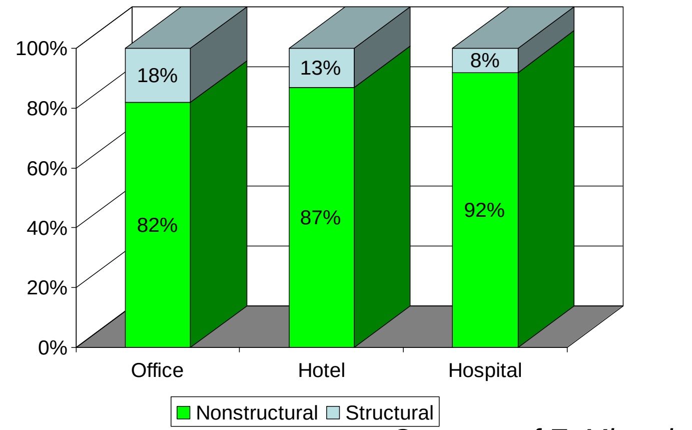
Testing Site: NEES @ UCSD

- Large High Performance Outdoor Shake Table (LHPOST)
  - The world's first outdoor shake table & the largest in the U.S

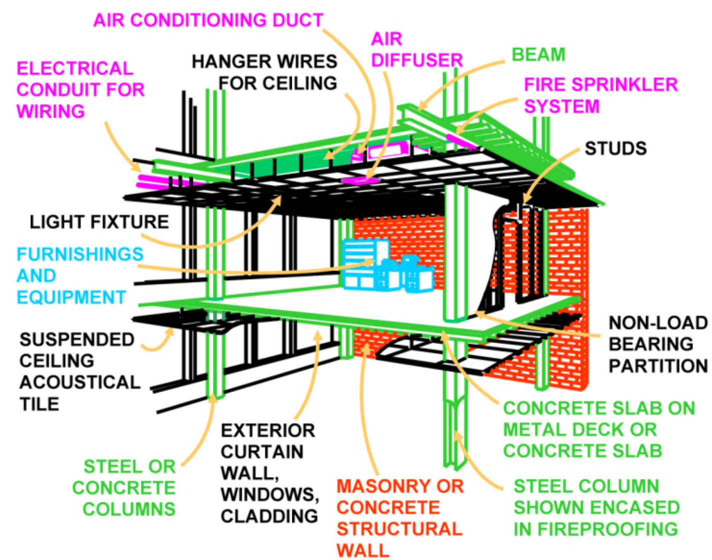
Size	7.6m x 12.2m
Peak Acceleration: bare table, 400 ton payload	4.2 g, 1.2 g
Peak velocity	1.8 m/s
Stroke	±0.75m
Maximum gravity (vertical) payload	20 MN
Force capacity of actuators	6.8 MN

Nonstructural Components & Systems

- NCSs make up ~80% of building's investment
- Broad classification:
  - Architectural, Mechanical, Contents
- NCSs are *supported* by the structure
  - Light-weight compared to the structure
- Designed for functionality – not to resist seismic forces
- Not usually considered by SE– under MEP designers' scope



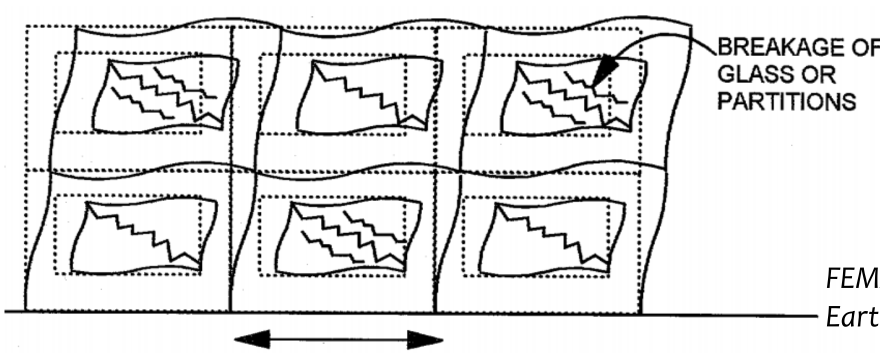
Courtesy of E. Miranda



FEMA 74-FM, "Earthquake Hazard Mitigation for Nonstructural Elements" Field Manual (2005)

Nonstructural Components & Systems

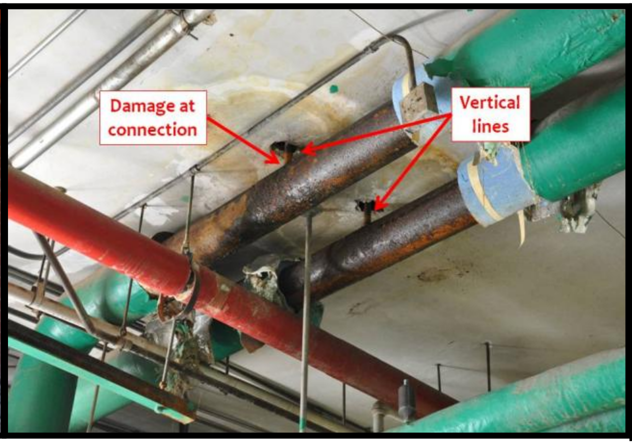
- Subjected to the dynamic environment within the building
  - Amplified motions generated by dynamic response of building
  - May contain parts sensitive to vibrations (even small amplitude).
- Damage to NCSs is initiated at much lower deformations than damage to the structural system
  - Brittle materials such as glass, plaster, drywall partitions, etc. fail at low drift levels compared to the structure
  - High floor accelerations that are associated with small drifts can potentially damage ceilings, piping, etc. without damaging the structure

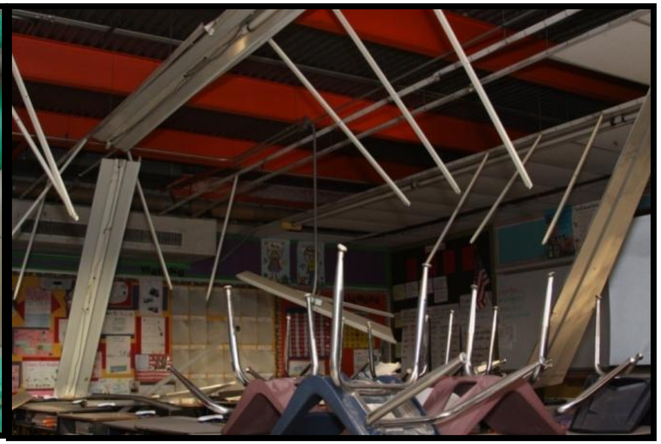


FEMA 74, "Reducing the Risks of Nonstructural Earthquake Damage" (1994)

Observations of NCS Damage

- Major problem during rescue operations
- Loss of functionality
  - …to NCSs as well as to usual building operations
- Excessive economic losses
- Threat to life





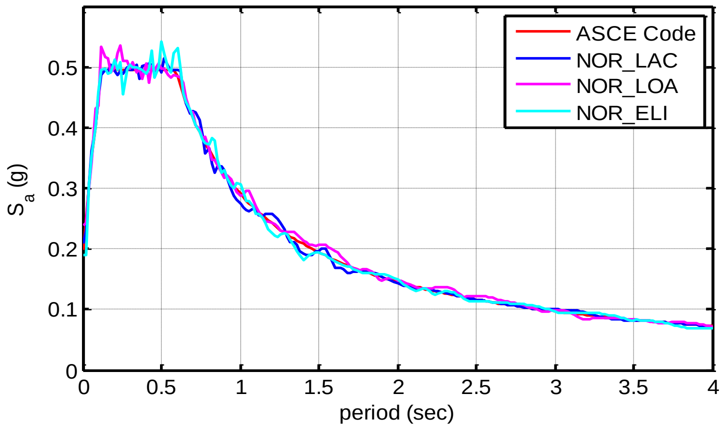
Courtesy of T. Hutchinson

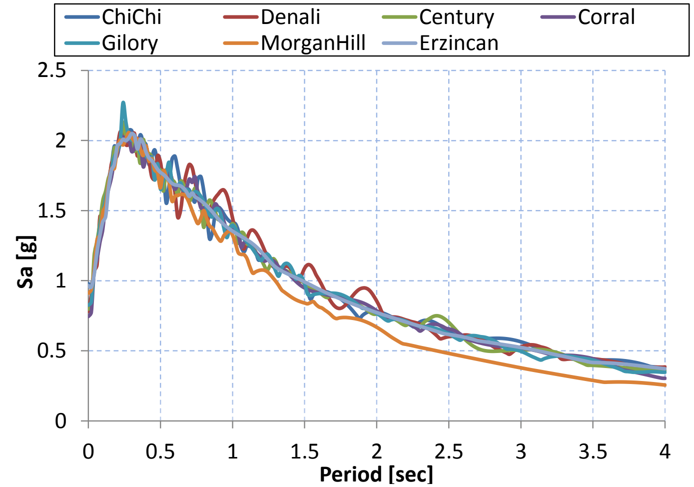
Vision

- To make breakthrough advances in the understanding of total building systems performance (structural *and* nonstructural systems) under moderate and extreme seismic conditions through full-scale testing.
- Obtain data, which are sorely needed to characterize the earthquake performance of structural and nonstructural building systems, including nonstructural systems with protective measures.
- Use this data to validate nonlinear simulation tools, which in turn can be used for higher-performance code design and performance-based seismic design of nonstructural and building systems.
- Infuse findings into seismic design guidelines and codes
  - Validate current code assumptions
  - Develop more precise and specific performance objectives to cater the clients' exact needs

Building Design

- Site Conditions
  - downtown LA - Site Class D
  - target MCE Sv=87in/sec
- Design Ground Motions
  - 7 MCE motions: site specific spectra for a site in downtown LA
  - 3 serviceability motions (return period of 43 years): 20% code specified MCE spectra for design purpose
- Balanced Strength/Capacity Design
- Performance Targets
  - 2%-2.5% lateral drift ratio
  - 0.7g-0.8g floor accelerations



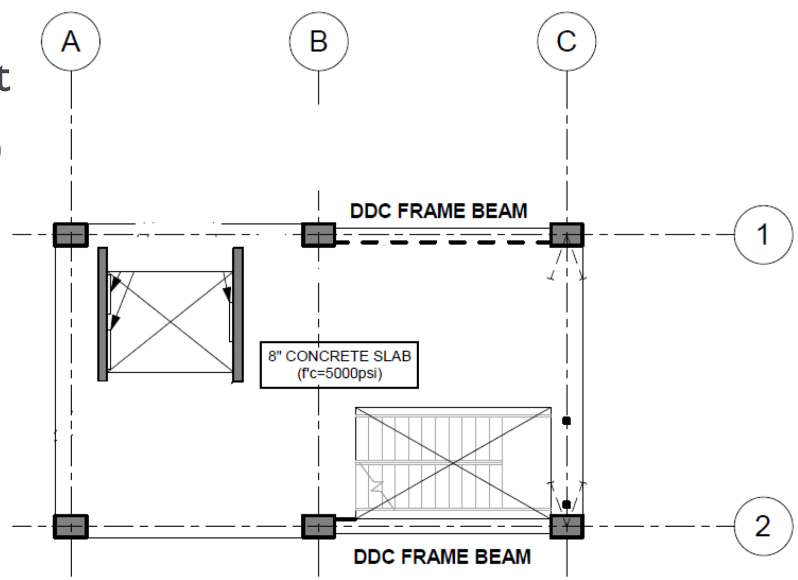


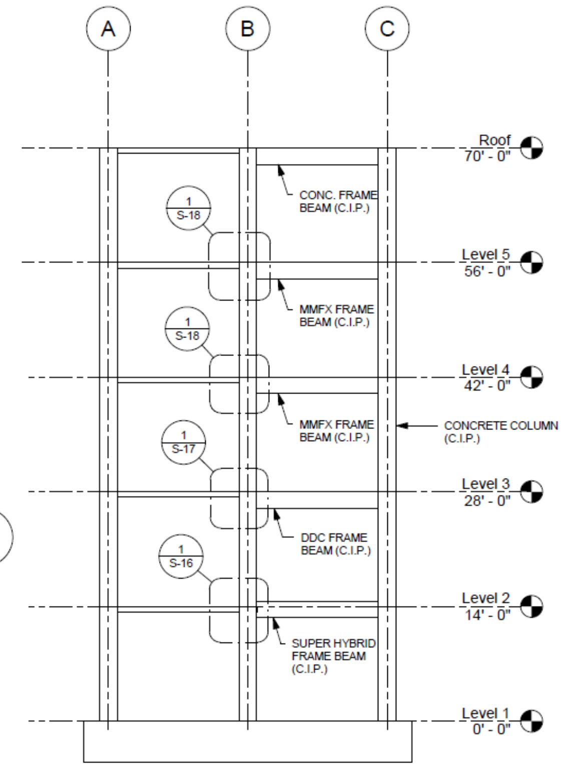
Current Design Philosophy

- 2 Levels of Earthquakes defined in ASCE: Maximum Considered Earthquake (MCE) and Design Earthquake
  - MCE: allows damage to structural components as long as collapse is prevented and life safety is preserved. No nonstructural requirements.
  - Design Earthquake: minimal structural damage.
    - Higher performance level: important components remain operational after design EQ
- Poor building performance in seismic events has prompted a need to develop performance based seismic design (PBSD)
  - Buildings can be designed to higher standards based on the desired performance
  - These limit states are often broad and need refinement
- Many criteria for higher performance level design were developed by seeking consensus of "experts" rather than on experimental data
  - There is a need to validate and refine current design limit states for different performance objectives

Structural System

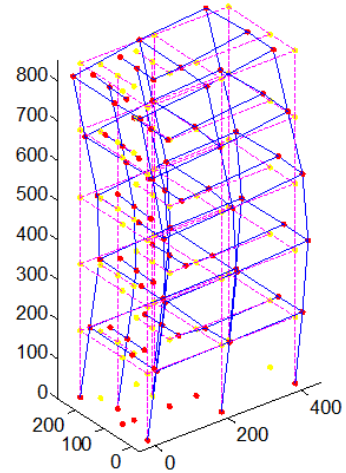
- Special reinforced concrete moment resisting frame as the lateral force resisting system
  - Different types of beams used at each floor, including the use of high-strength steel, ductile rod connectors, and post-tensioned tendons
  - Elevator shaft and stairway openings at floor diaphragms
  - 25’ by 40’ footprint (outer dimensions)
  - 14’ story height



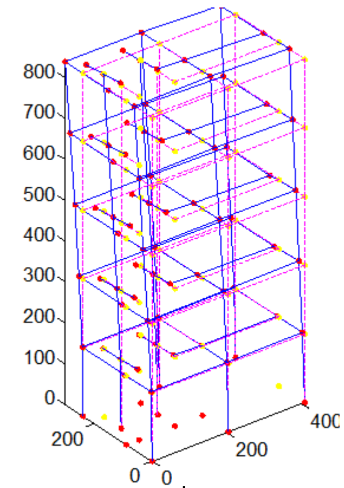


Building Dynamic Characteristics

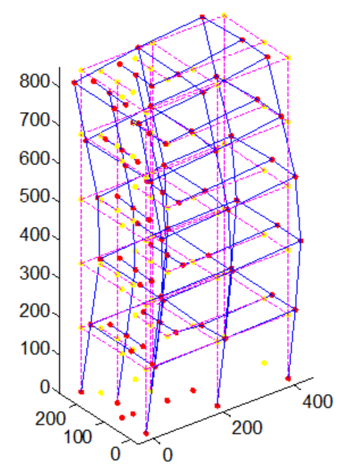
- OpenSees model of the five-story building
  - fiber beam-column elements for modeling columns, frame beams, and shear walls
  - slab contribution taken into account with equivalent strut and tie truss elements.
  - total mass including all structural and nonstructural components added up to 140 kips per floor.
- Perform 3D
- LS-DYNA
- DIANA



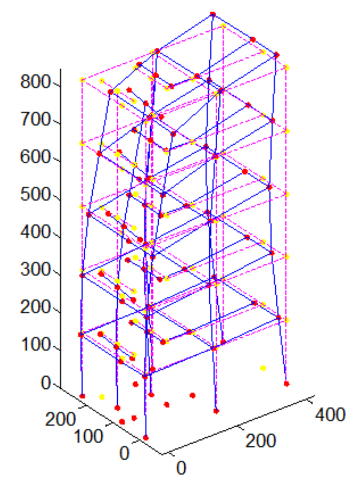
1^{st} Mode
(T=0.84 s)



2^{nd} Mode
(T=0.66 s)



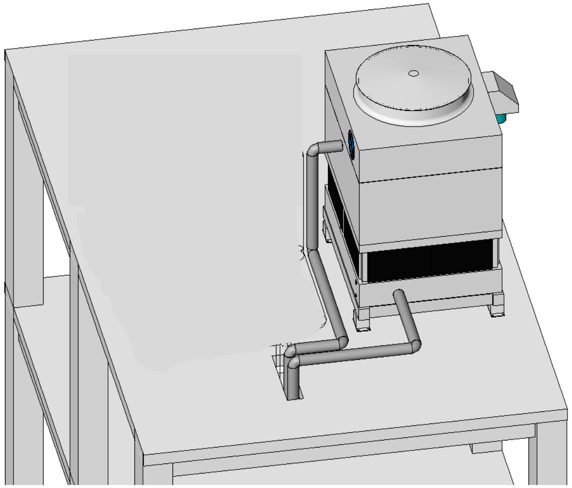
3^{rd} Mode
(T=0.40 s)



4^{th} Mode
(T=0.37 s)

NCSs in the Building: Overview

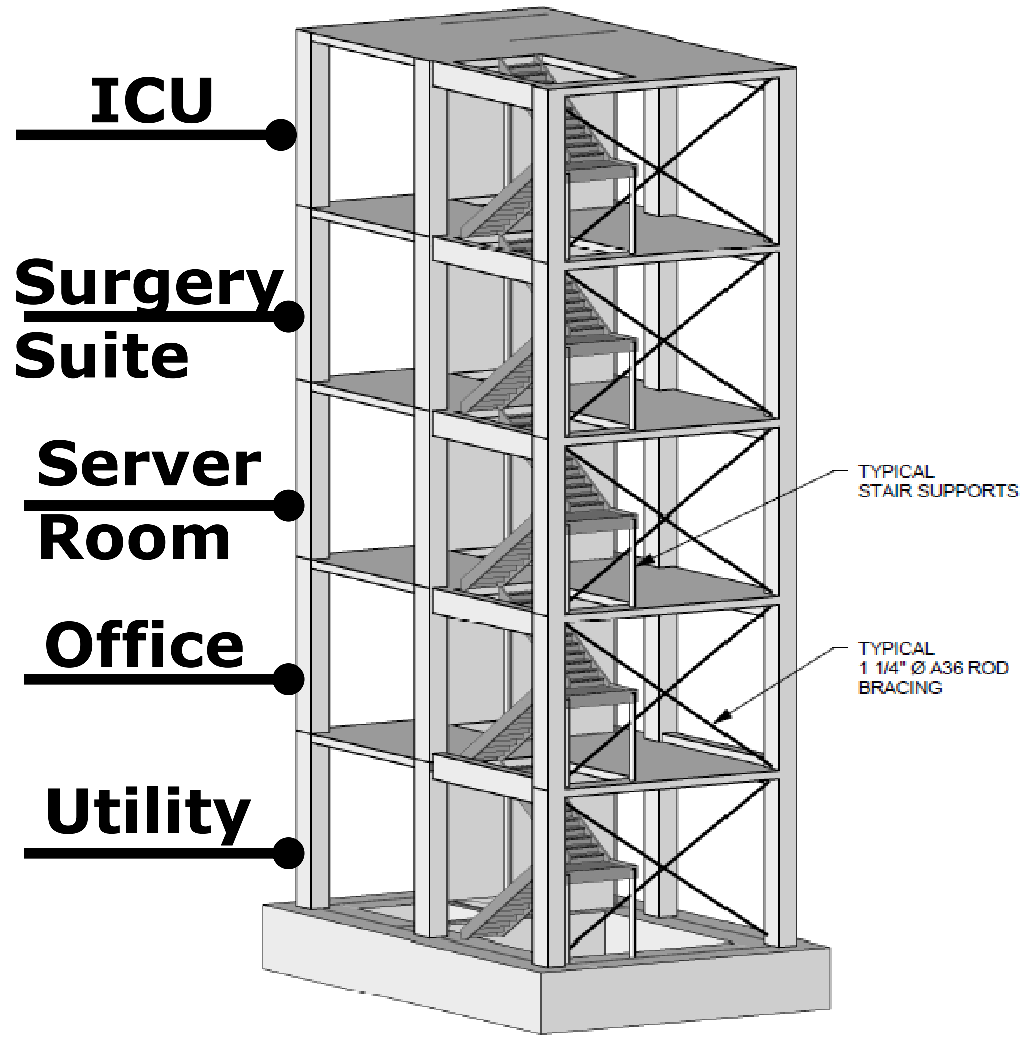
- The performance of the NCSs in the building will be monitored
  - Data will be used to validate previous assumptions and to develop protective systems to prevent damage to these specific nonstructural components and systems.
- NCSs including…
  - Operable Elevator
  - Stairs
  - HVAC components and subassemblies
  - Fire detection, alarm, sprinkler and riser systems
  - Ceiling subassemblies
  - Hospital equipment
  - Exoskeleton (TBD)
  - Access floors
  - Roof mounted chiller
  - Roof mounted air handling unit
  - Interior partition walls
  - Anchorage for various NCSs
  - Lighting
  - IBM servers



NCSs in the Building: Occupancy

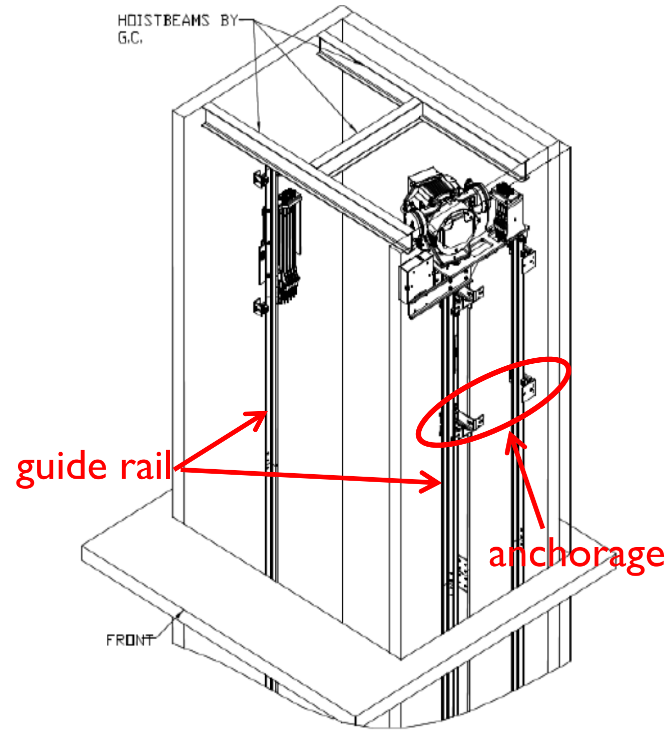
- Each floor will have a different type of occupancy
  - Two floors of hospital equipment
  - Two floors of office equipment

Courtesy of R. Wood



NCSs in the Building: Elevator

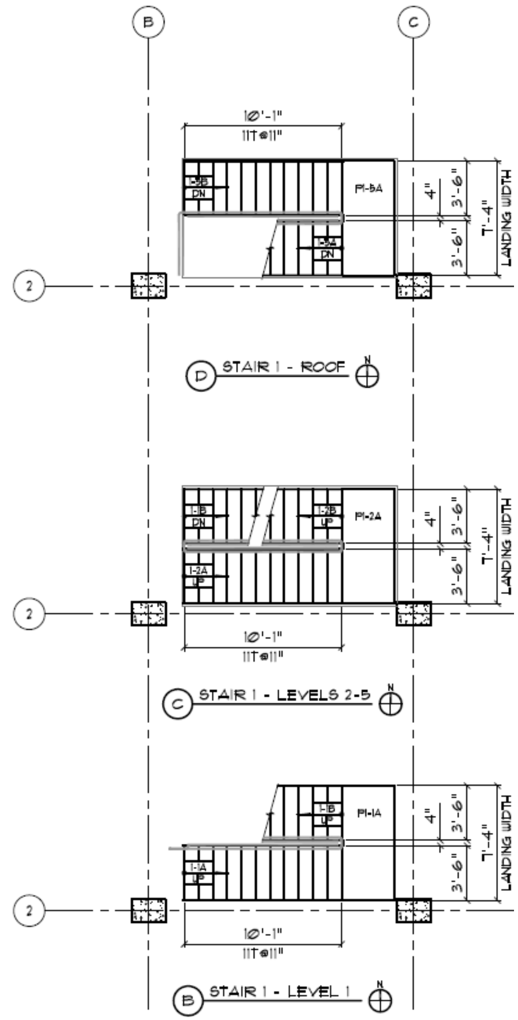
- Elevators serve a very important function in essential facilities (such as hospitals), and it is imperative that they remain operational after an earthquake, but they are highly susceptible to seismic damage.
- Typical Seismic Damage of Elevators
  - guide rail anchorage damage, bent guide rails, counterweight derailment, rope jumped or twisted, collision of counterweight and car, etc.
- Previous Observations
  - The 1964 Alaska Earthquake caused extensive damage to elevators, and thus lead to a study on seismic performances of elevators.
  - The ASME 17.1 Committee issued the first design procedures and guidelines to reduce the seismic damage of elevator systems after the 1971 San Fernando Earthquake.

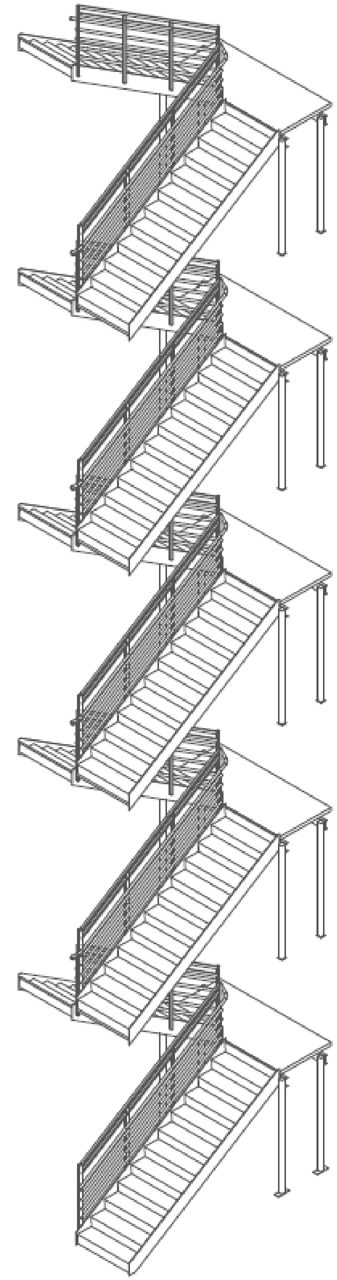


- 3.5k capacity
- Full building travel
- Complete with guide rail & counterweight system.
- Provided by Schindler corp.

NCSs in the Building: Stairs

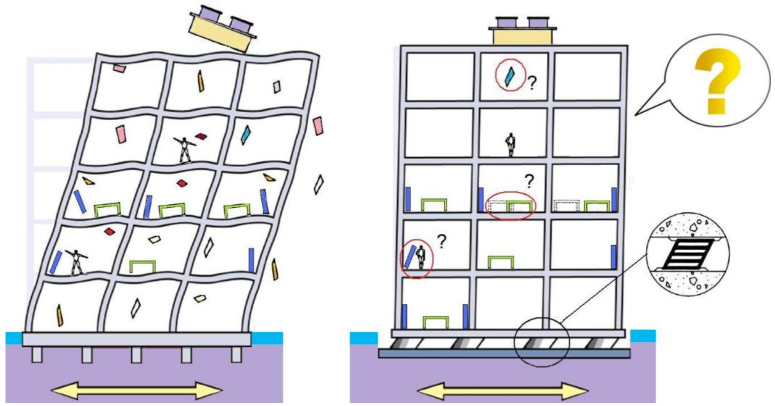
- Full height prefabricated metal stairs will installed in the building
- Prefabricated metal stairs by Pacific Stair in collaboration with Prof Chris Higgins (OSU)
- Higgins (2009) full scale tests at OSU on similar system with ends loaded by hydraulic actuators



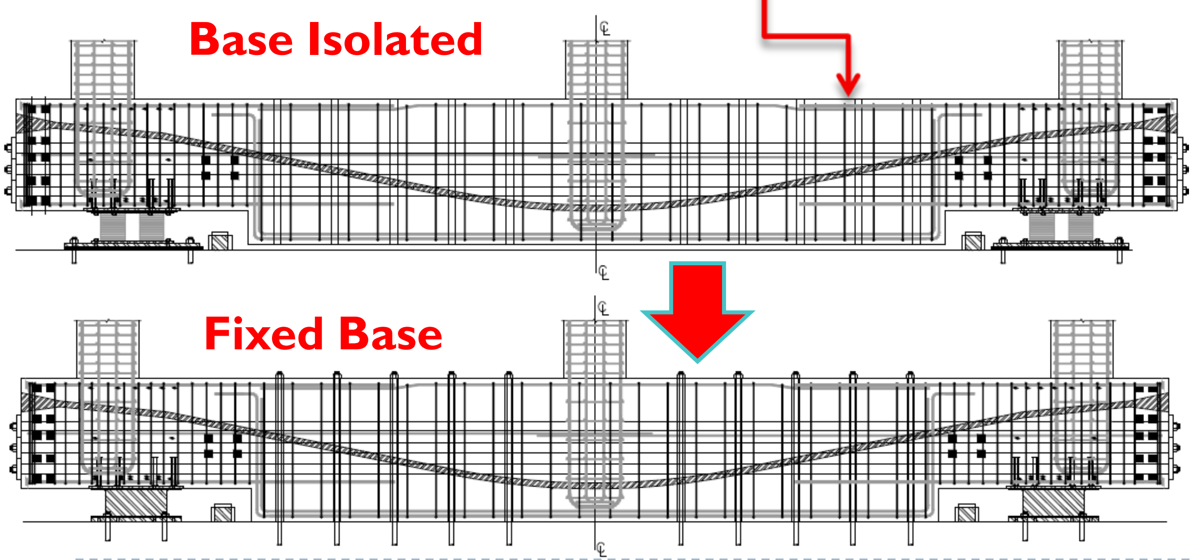


Protective Systems: Base Isolation

- Demonstrate the effectiveness of the base-isolation to enhance the performance of NCSs.
- Understand total system response of a base isolated building



Complex solution for foundation using a hybrid of post-tensioned rods and tendons

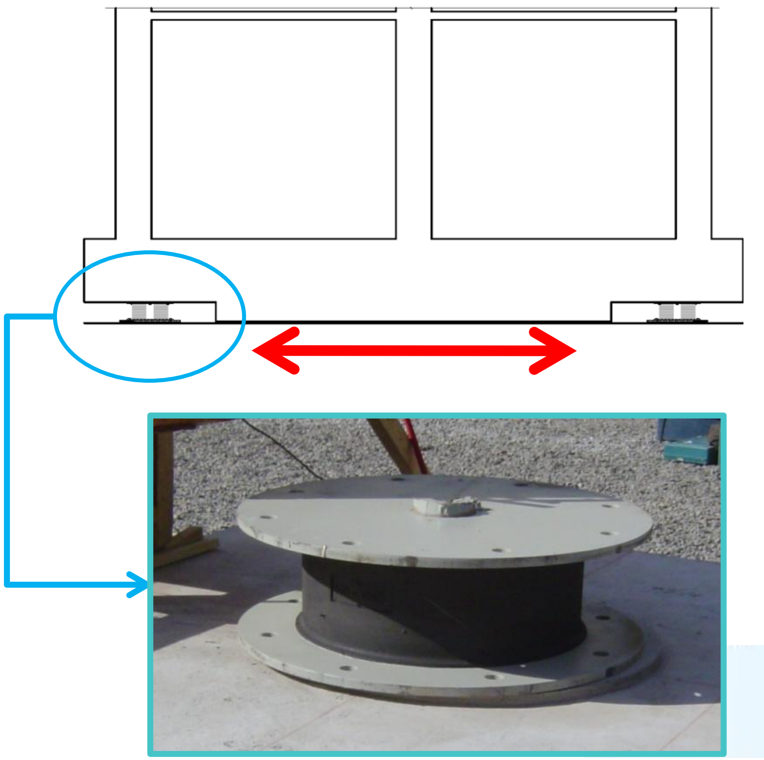


Testing Sequence

1) The building will first be tested on base isolators
2) Entire structure will be jacked up, isolators will be removed
3) Foundation will be post-tensioned to table for fixed-base testing

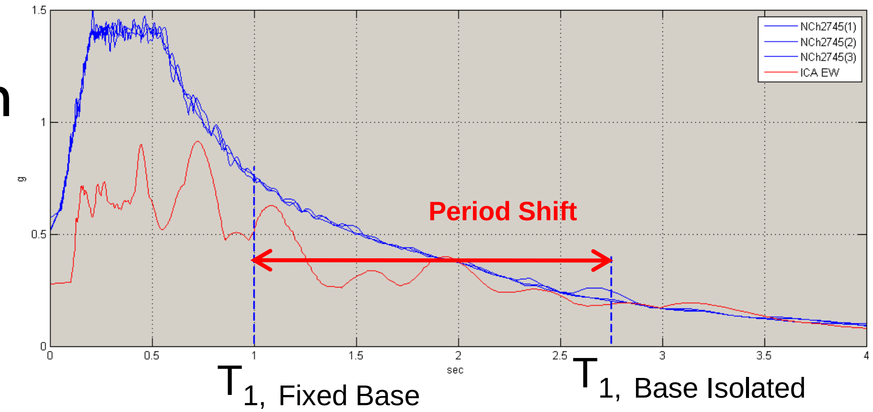
Protective Systems: Base Isolation

- 4 Lead-core Rubber Bearings
- Isolation period ~ 2.5s
- Max isolator displacement~25cm

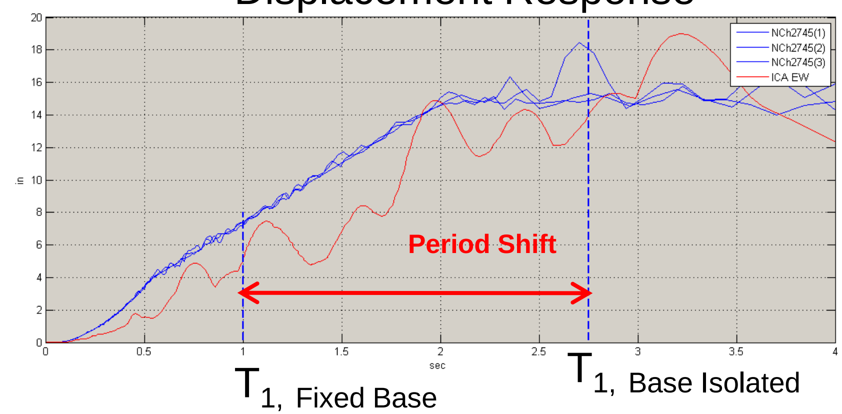


Courtesy of SIRVE

Acceleration Response



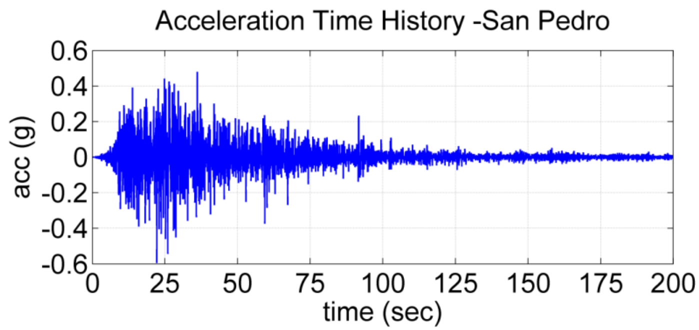
Displacement Response

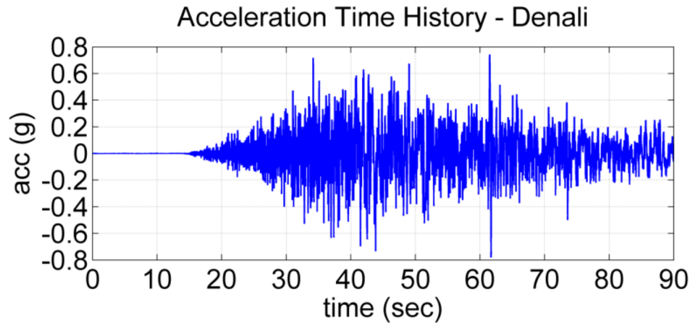


Tentative Test Ground Motions

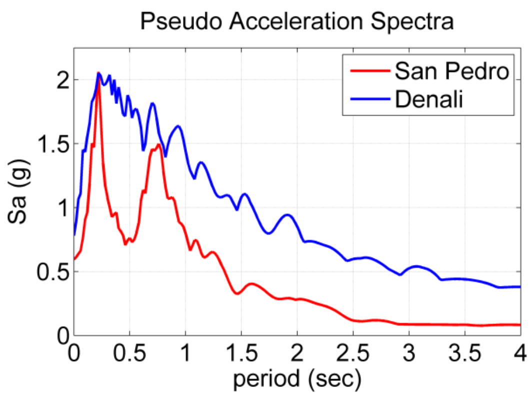
- Base Isolated Tests
  - 80% and 100% San Pedro motions (Chile earthquake, 2010) reflecting the Chilean design codes
- Fixed Base Tests
  - 4 Northridge motions spectrally-matched to 43 year return period design spectra (serviceability level)

    ($Sa_{0.2}$=0.496g and $Sa_{1.0}$=0.291g)
  - Denali (2002) motion as the MCE level earthquake



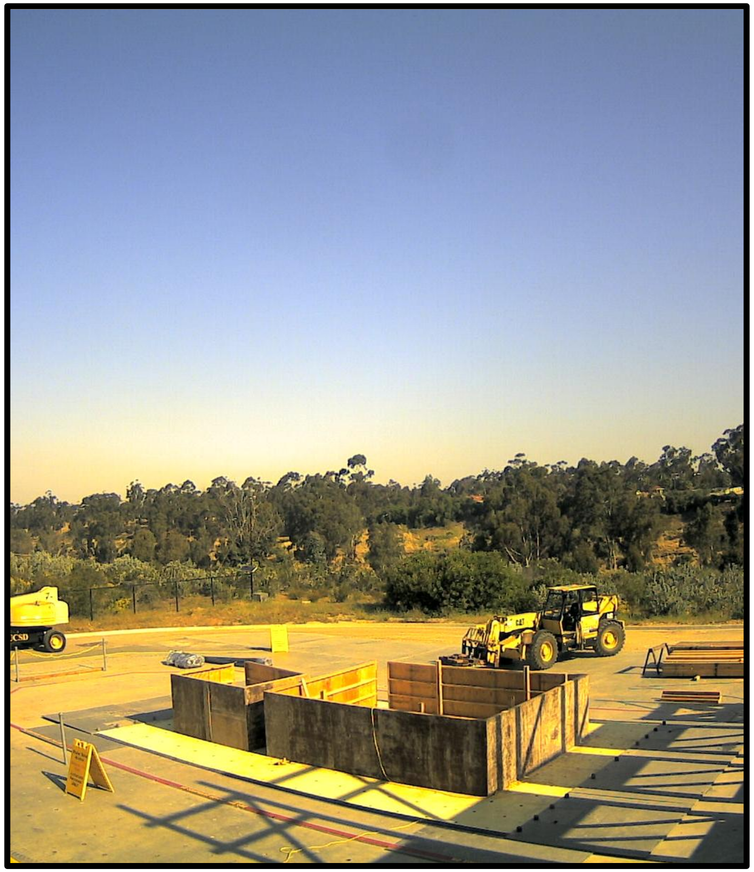


Ground Motion	PGA	PGV	PGD	Sa(0.2s)	Sa(1s)	Sd(1s)	Strong Duration	Total Duration
	(g)	(in/s)	(in)	(g)	(g)	(in)	(s)	(s)
San Pedro	0.60	18.62	5.02	1.78	0.80	7.78	73.99	200
Denali	0.78	54.15	31.83	1.94	1.44	14.07	47.25	92



Current Status & Schedule

- Construction of building commenced May 1, 2011
  - http://bncs.ucsd.edu/
  - http://nees.ucsd.edu/video/
- Foundation reinforcing currently being installed
- Building skeleton complete: End of Aug. 2011
- NCS installation: Aug. – Nov. 2011
- Instrumentation: Nov. – Dec. 2011
- Seismic testing: Dec. – Jan. 2012
- Demolition: Mar. 2012



Core Project Team

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