



Total Project Planning – Case Study 3: **BNCS** Building

Building Nonstructural Components & Systems Project

Tara C. Hutchinson, Professor
UC San Diego
December 15, 2015



Outline

➤ **Motivation**

- Terminology, Justification

➤ **Project Overview**

- Vision, Scope, Resources (human & \$\$),
Timeline

➤ **Specifics**

- Design, Construction, Instrumentation, Test
Planning & Sequencing, Execution Guidance

➤ **A Few Important Findings**

- (there are many)

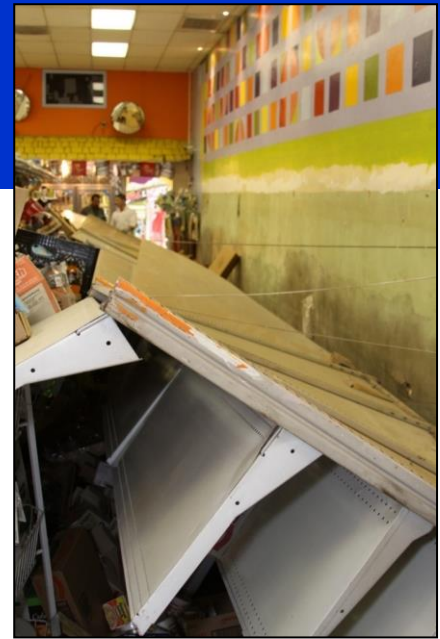
➤ **Project Accolades**

What is an NCS?

- **Nonstructural Components & Systems = **NCS** = common short name adopted in a number of building design codes. Visual elements around us in finished structures...**
- **Supported by primary structural system – not contributing to primary structural system load bearing needs**
- **Lightweight & low stiffness**, compared with supporting structure
 - Low damping (lack protection from sharp resonant motions)
- **Designed for functionality – often not considering earthquake loads**
- Often termed “secondary” systems
- **Broad classification: 1) MEP (mechanical/electrical/plumbing), 2) Architectural & 3) Contents**

Consequences of NCS damage

- Major problem during rescue operations
- Loss of functionality, facility downtime
- Excessive economic losses
- Threat to life



Calexico Schools
2010 Baja California EQ

- Hospitals & other critical facilities: post-earthquake operability of NCSs are *essential* (life saving equipment)
- Numerous NCSs play a critical role in minimizing *post-earthquake fire impacts – fire protection NCSs*



Project Motivation: 2011 Tohoku Earthquake, Japan

Sendai Mediatheque (library, constructed 2000)

Plaster board ceiling

Sprinkler head



Before the earthquake



After the earthquake

Courtesy of Shojiro Motoyui

Vision, Scope, Resources, Timeline

PROJECT OVERVIEW

Project Vision

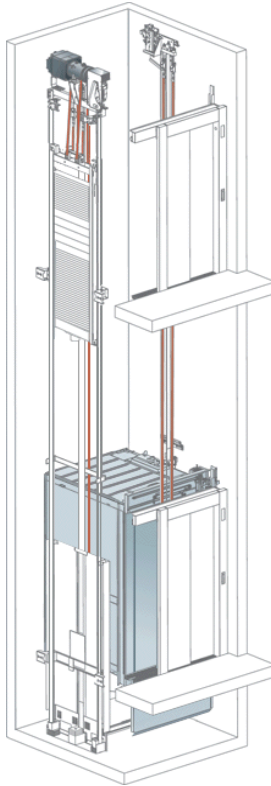
- ✓ To make breakthrough advances in the understanding of total building systems performance (structural *and* nonstructural systems) under moderate and extreme seismic conditions through full-scale testing.
- ✓ Obtain data, which are sorely needed to characterize the earthquake performance of structural 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
 - Advance current code guidelines

Project Overview

- Three-phased full-scale test program conducted on a 5-story building-NCS system (“total building system”)

Summary of Major NCSs:

- ▶ Egress systems:
 - ▶ Operable Elevator
 - ▶ Stairs
- ▶ Facades:
 - ▶ Concrete cladding
 - ▶ Balloon framing
- ▶ Hospital equipment
- ▶ Roof mounted equipment
- ▶ Sprinkler and riser systems
- ▶ Ceilings
- ▶ Interior partition walls



Testing Scope & Project Resources

➤ Three Test Phases

1. Base isolated building-nonstructural system
2. Fixed base building-nonstructural system
3. Controlled live fire tests

➤ ~5M US\$, multi-organizational 4 year project (2010-2014)

- NSF-NEES core research project - \$1.2M
- Englekirk Advisory Board - \$1.5M (est)
- Charles Pankow Foundation - \$250k
- California Seismic Safety Commission (hospitals) - \$360k
- Industry consortium - remainder \$ resources, materials, equipment, technical expertise, etc.



Large, Multi-disciplinary Team

- **Core Project Team (>20 faculty, students, engineers)**
 - UCSD, SDSU, Worcester Polytechnic & Howard University
- **Advisory Boards**
 - **Industry steering committee (ISC) (>40 companies)**
 - ✓ Manufacturers, Sponsors, Technical Advisors
 - **Engineering & regulatory advisory committee (ERAC) (10)**
 - ✓ Technical oversight (code-perspective)
 - **Academic/international liaison group (AILG) (10)**
 - ✓ Technical oversight (academic perspective)
 - **Englekirk Advisory Board (EAB)**
 - ✓ Building (skeleton) design & funding
- **Federal & state partners, foundations**
 - NSF-NEESR, California Seismic Safety Commission, California Hospital Authority, Charles Pankow Foundation, FEMA

More than 300 individuals interacting within this project!

Core Team

Name	Affiliation	Name	Affiliation
Tara Hutchinson (PI)	UC San Diego	Consuelo Aranda	San Diego State University
José Restrepo (Co-PI)	UC San Diego		San Diego State University
Joel Co			
Ken Wa			
Claudia			
Robert			
Brian M			
Matt Ho			
Robert Englekirk	UC San Diego / Englekirk & Sabol Consulting S.E., inc.		
Mahmoud Faghihi	Englekirk & Sabol Consulting Structural Engineers, inc.		



Partners



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

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

Government & Foundations



FEMA



CHARLES PANKOW
FOUNDATION

Building Innovation through Research

Design



ARUP



MACTEC



KLAUSBRÜCKNER
AND ASSOCIATES

Englekirk

Industry Partners



by Schneider Electric



Schindler

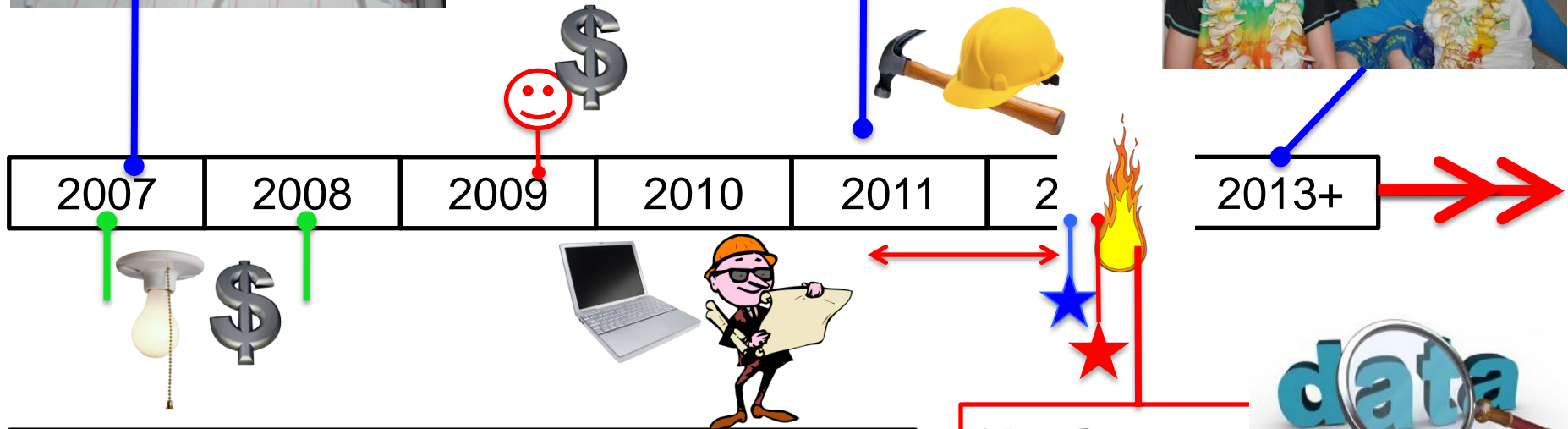


e.g. Hilti Team (32 individuals >10%!)



Temus: March 31, 2011

Project Timeline



- Pre-proposal workshop
- 😊 NEESR Funding & Kick-off meeting
- ↔ Construction (~9m)
- ★ ★ Seismic Testing Phases (~1m)
- 🔥 Live Fire Testing (~0.5m)



Design & Construction SPECIFICS

Shake Table Specimen Design Questions

➤ What type of structural skeleton is needed?

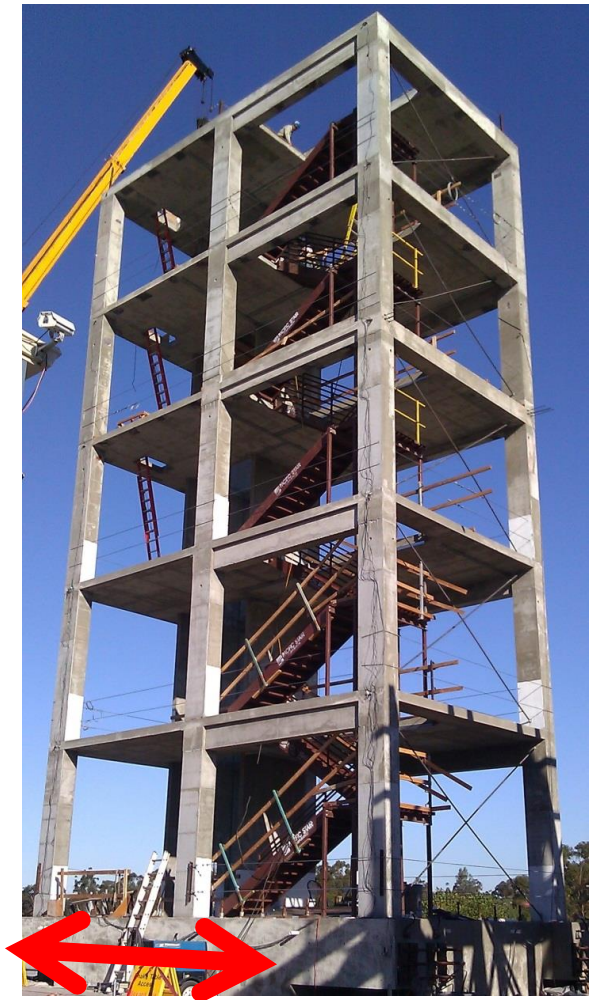
- Structural skeleton role: provide a vehicle for delivering demands to NCSs (accelerations & deformations)
- Many iterative discussions, options...
 - ✧ Flexible steel frame-braced structure
 - ✧ Stiff steel braced structure
 - ✧ Podium-style (lower concrete wall & upper flexible frame)
 - ✓ Reinforced concrete frame-braced
- Decisive aspects: cost (design team), balance between benefits of flexible frame (expect large lower floor drifts) & nominally large accelerations (upper floors); shake table platen size

➤ What types of nonstructural components are essential?

- Secure the key “bad actors” (or those lacking data!) early on prior to NEESR proposal submission e.g. (egress, façade, passive & active fire systems)
- “If we build it they will come”

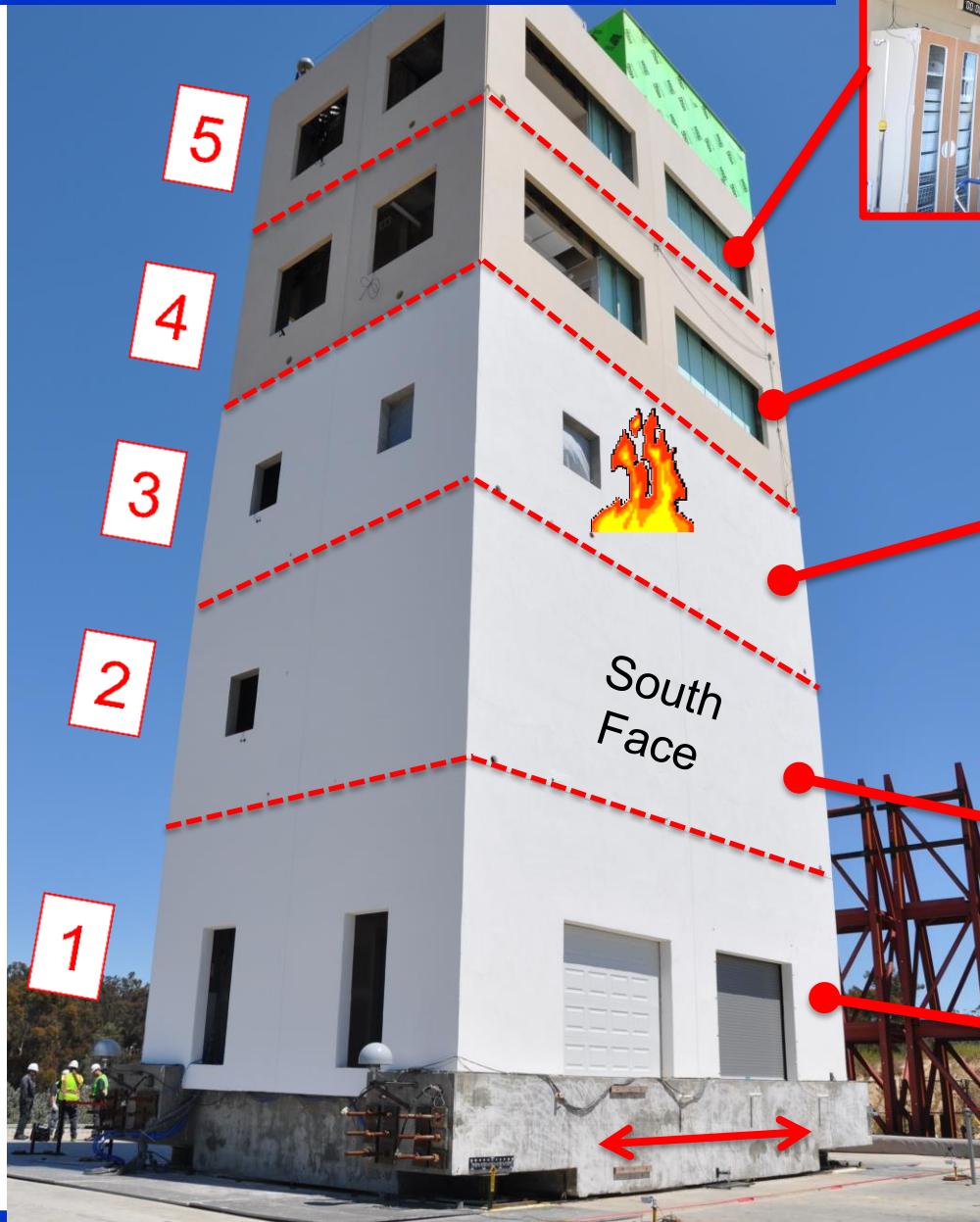
Structural System

- ▶ Design (criteria – community decision):
 - ▶ Downtown LA (site class D; 7 MCE motions, 3 service motions; 2-2.5% design interstory drift ratio, peak ~0.7-0.8g floor acceleration)
- ▶ Poured-in-place concrete
- ▶ **2 bay x 1 bay; pair of SMRF (shaking direction)**
- ▶ 4.2m story heights; 5 floors; 21.3m + 1.5m foundation + 4m tower = 26.8m (tallest on UCSD table)
- ▶ **Elevator shaft and stairway openings at floor diaphragms**
- ▶ 10.4m x 6.1m c/c footprint
- ▶ **~ 1 sec longitudinal (fixed base)**
- ▶ ~2.5 sec longitudinal (base isolated)



- **Bare structure: ~4900kN**
- **Building+NCSs: ~6300kN**
- **(Foundation = 1870kN)**

Architectural (NCS) Design



5: Surgery suite



4: ICU



3: Servers + Burn Floor



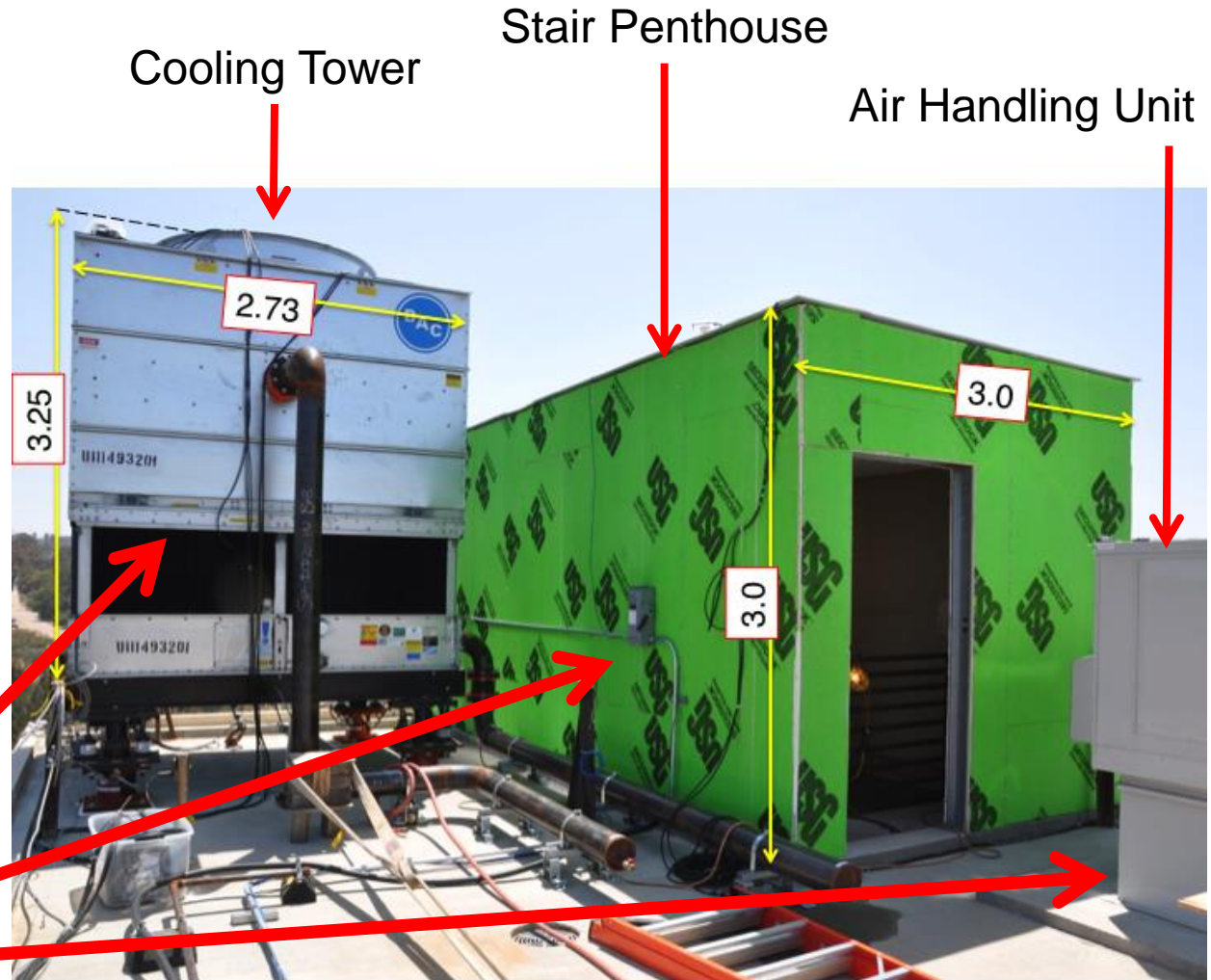
2: Lab + residential

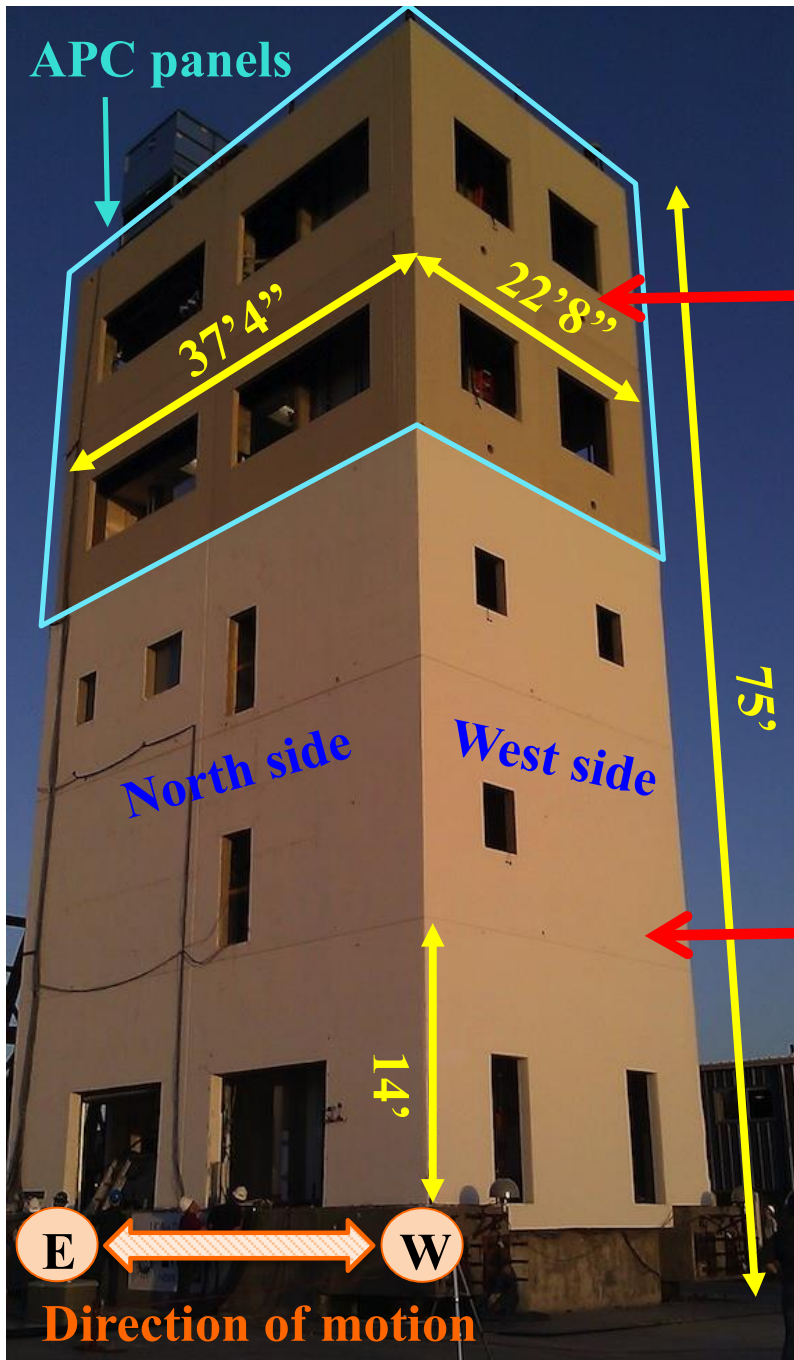


1: Utility



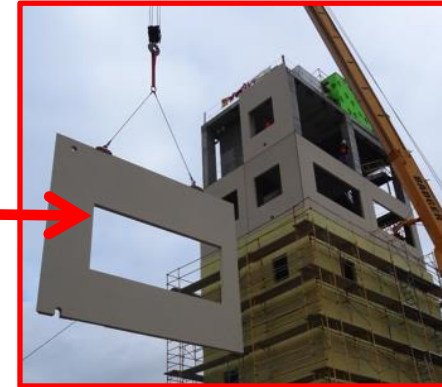
Roof Mounted Equipment



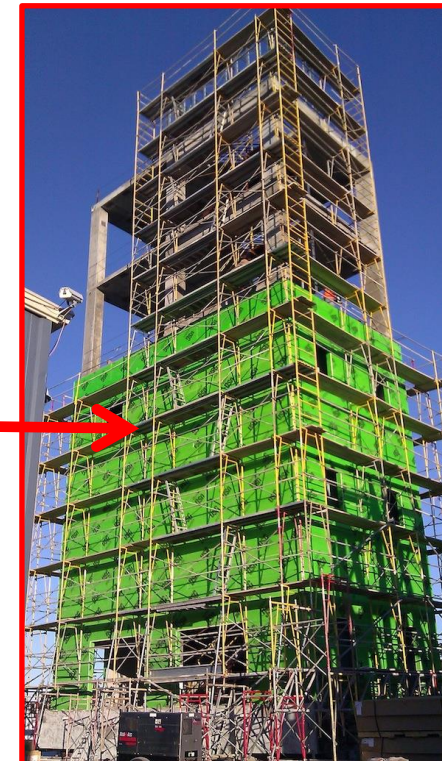


Exterior Facades

**Architectural Precast
Concrete Cladding**



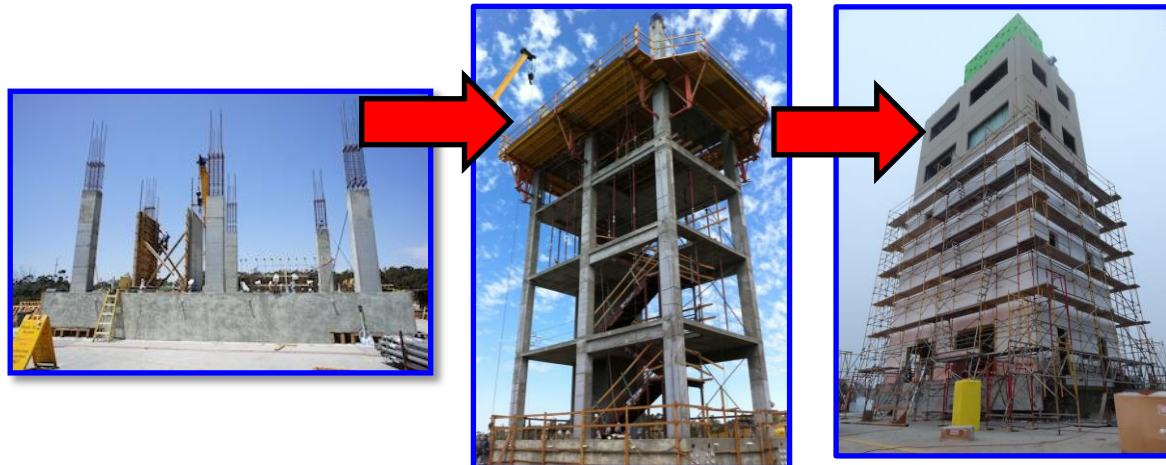
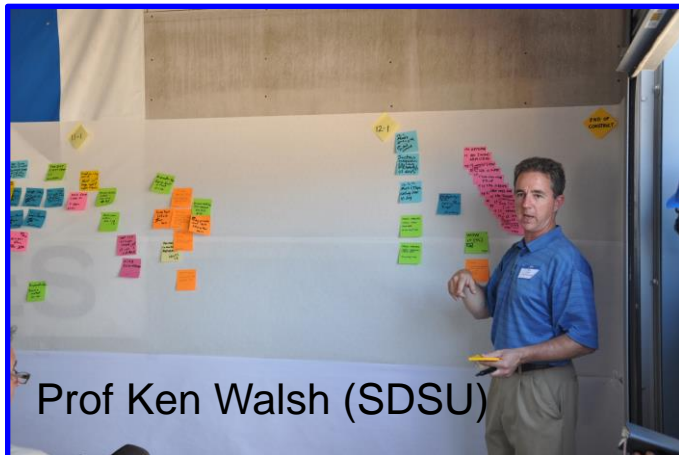
**Balloon-framed
metal stud+EIFS**



NW View

Construction Management

- **During construction, such a complex project needed careful planning. For this effort, SDSU led a comprehensive construction management effort**
 - Coordinating all superstructure construction phasing
 - Coordinating all nonstructural installation phasing
 - Documenting on-site deliveries
 - Dealing with construction delays (reorganizing subs)
 - We held multiple planning meetings (2009, 2010, 2011) with all industry partners & researchers



Construction (Superstructure)



ROOF SLAB:
September 21st, 2011

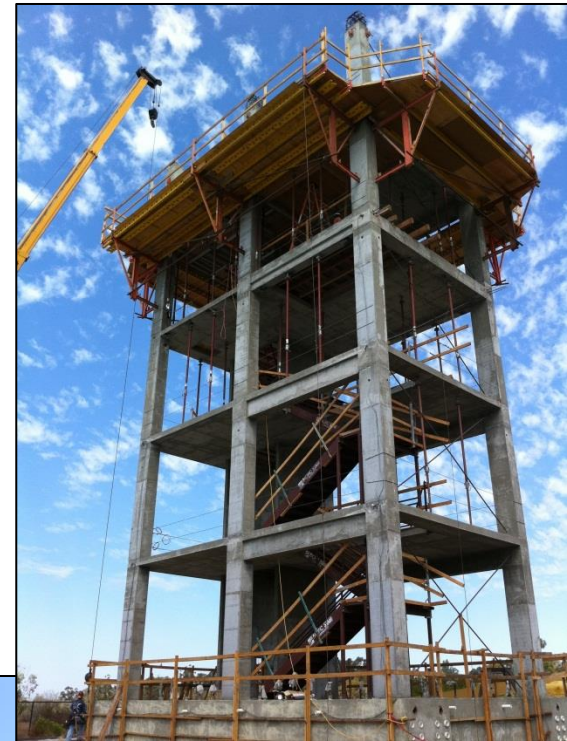
FIFTH FLOOR SLAB:
September 6th, 2011

FOURTH FLOOR SLAB:
August 19th, 2011

THIRD FLOOR SLAB:
August 3rd, 2011

SECOND FLOOR SLAB:
July 15th, 2011

FOUNDATION:
June 27th, 2011



Construction (Nonstructural)

2011

January	February	March	April
Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su
31 1 2	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3
3 4 5 6 7 8 9	7 8 9 10 11 12 13	7 8 9 10 11 12 13	4 5 6 7 8 9 10
10 11 12 13 14 15 16	14 15 16 17 18 19 20	14 15 16 17 18 19 20	11 12 13 14 15 16 17
17 18 19 20 21 22 23	21 22 23 24 25 26 27	21 22 23 24 25 26 27	18 19 20 21 22 23 24
24 25 26 27 28 29 30	28	28 29 30 31	25 26 27 28 29 30
May	June	July	August
Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su
30 31 1	1 2 3 4 5	1 2 3	1 2 3 4 5 6 7
2 3 4 5 6 7 8	6 7 8 9 10 11 12	4 5 6 7 8 9 10	8 9 10 11 12 13 14
9 10 11 12 13 14 15	13 14 15 16 17 18 19	11 12 13 14 15 16 17	15 16 17 18 19 20 21
16 17 18 19 20 21 22	20 21 22 23 24 25 26	18 19 20 21 22 23 24	22 23 24 25 26 27 28
23 24 25 26 27 28 29	27 28 29 30	25 26 27 28 29 30 31	29 30 31
September	October	November	December
Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su	Mo Tu We Th Fr Sa Su
1 2 3 4	31 1 2	1 2 3 4 5 6	1 2 3 4
5 6 7 8 9 10 11	3 4 5 6 7 8 9	7 8 9 10 11 12 13	5 6 7 8 9 10 11
12 13 14 15 16 17 18	10 11 12 13 14 15 16	14 15 16 17 18 19 20	12 13 14 15 16 17 18
19 20 21 22 23 24 25	17 18 19 20 21 22 23	21 22 23 24 25 26 27	19 20 21 22 23 24 25
26 27 28 29 30	24 25 26 27 28 29 30	28 29 30	26 27 28 29 30 31

Foundation

Stairs (I)

Superstructure

Stairs (II)

White Noise Test

Elevator/Stairwell Walls

Installation of
Balloon Framing

Construction (Nonstructural)

DECEMBER 2011						
SUN	MON	TUES	WED	THURS	FRI	SAT
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

Internal Partition walls
(ONGOING)

Electrical system
(ONGOING)

Fire sprinklers (ONGOING)

HVAC

Gas Pipes

Elevator

Waterproofing paint on
balloon framing

Precast concrete cladding

★ Cooling Tower

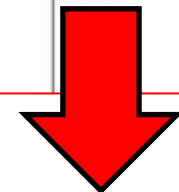
★ AHU

★ Isolators arrived on site

Construction (Nonstructural)

JANUARY 2012

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					



Feb & Mar 2012:
Final architectural installation
& instrumentation

Internal Partition walls
(ONGOING)

Electric system
(ON GOING)

Fire
sprinklers(ONGOING)
HVAC

Elevator(ON GOING)

Styrofoam exterior
balloon framing

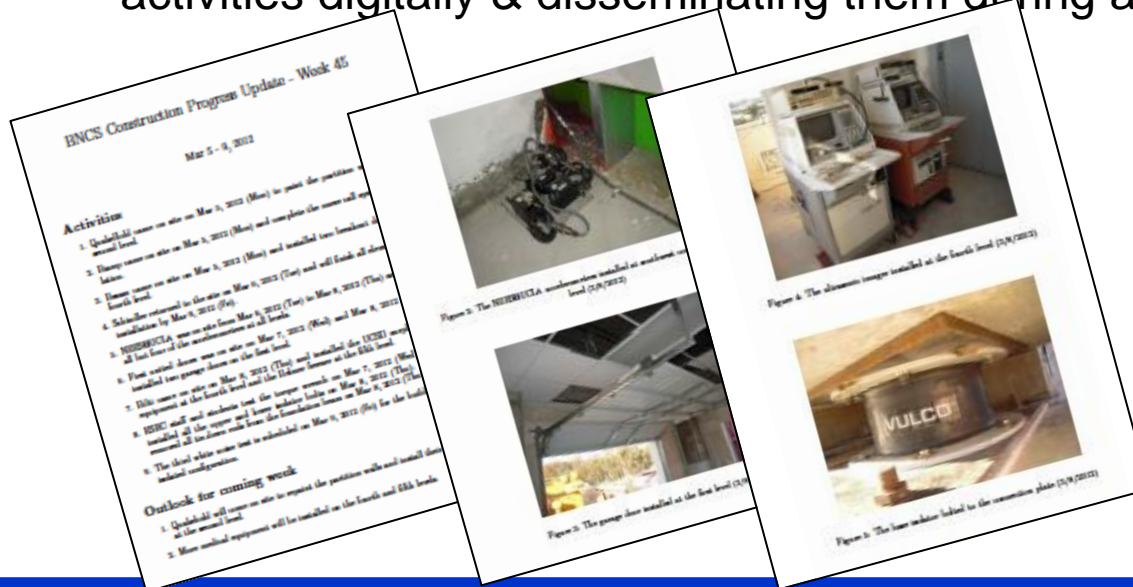
Roof pipes

MI grid

★ Medical Equipment
★ Ceiling

Research Activities (pre-test)

- **During construction, research team needed to multi-task**
 - Conduct pre-test simulations (guide motion selection, instrumentation layout)
 - Watch, document, & take part in (as feasible) construction
 - Create instrumentation drawings
 - Watch, document, & take part in (as feasible) construction
 - ✓ We created a weekly construction log documenting all key construction activities digitally & disseminating them during a weekly team meeting



Instrumentation, Test Planning & Sequencing

SPECIFICS

Instrumentation

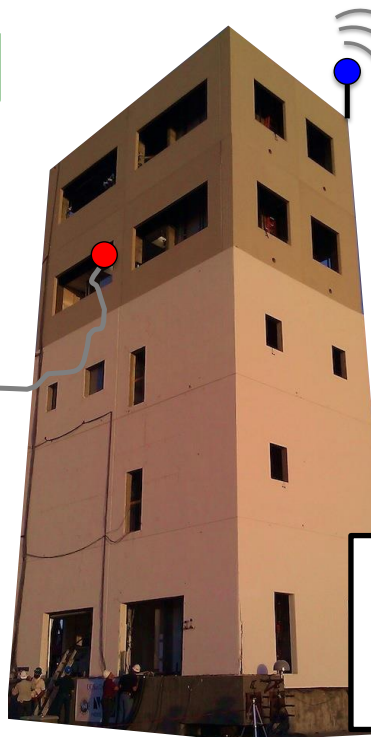
VIDEO CAMERAS

Provided by
industry partners
and by
NEES@UCSD



ANALOG SENSORS

Three DAQs provided by
NEES@UCSD and NEES@UCLA
(UCLA1 and UCLA2)



GPS

Provided by
the Scripps
Institute of
Oceanography



STILL CAMERAS

High resolution digital

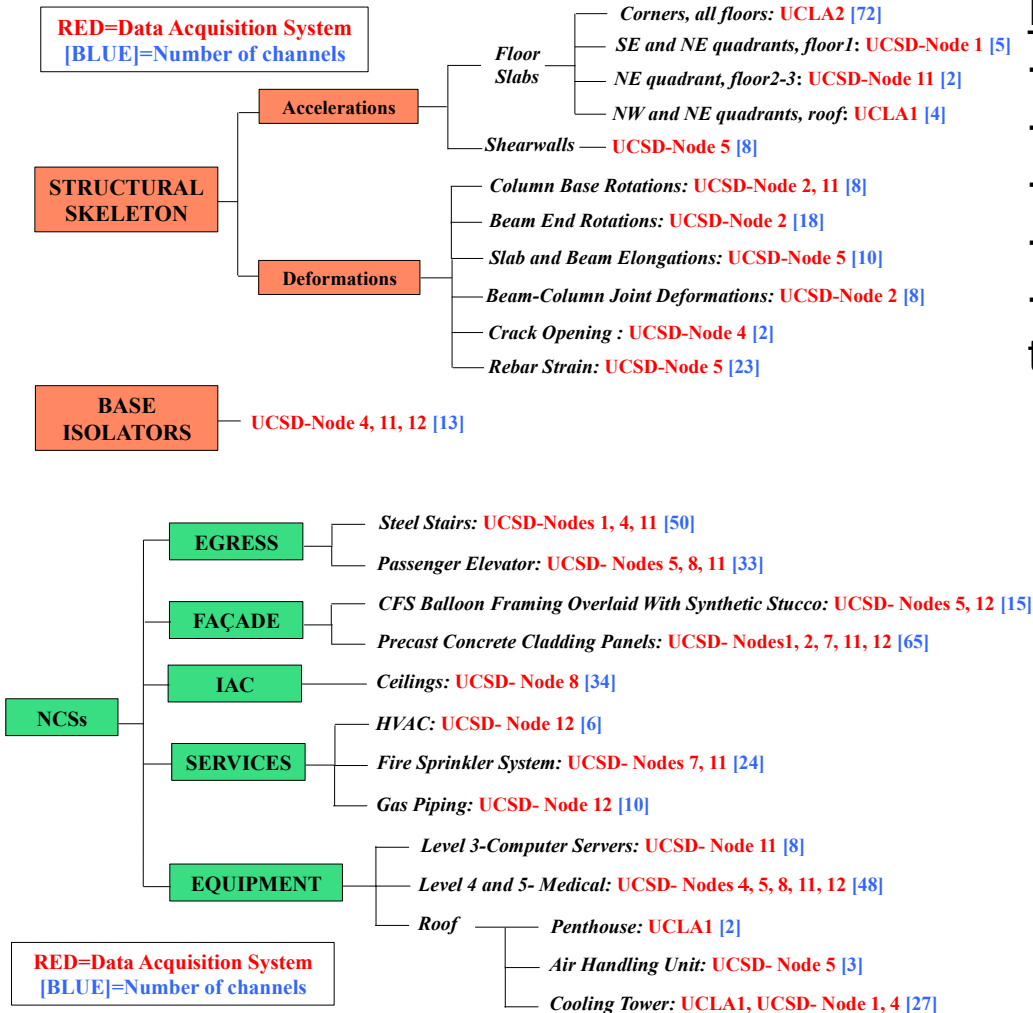
We produced an entire 200pg report
summarizing the instrumentation
(cameras & analog sensor details)

Analog:

420 channels: NEES@UCSD + 90 channels: NEES@UCLA
= 510 channels

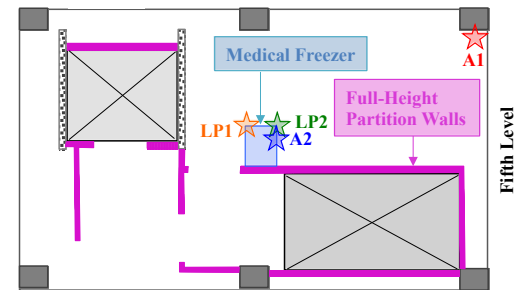
Structure (~1/3) + NCSs (~2/3)

Analog Sensors



Every sensor was:

- Physically attached to the structure
- Provided a unique name
- Cable-based connected to the DAQ
- Connected to a NODE
- Visually & digitally documented (during testing as well!)











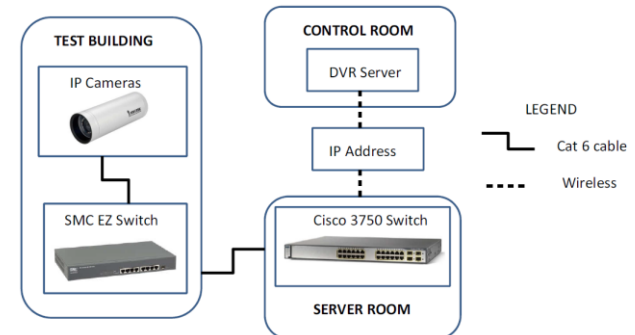
Medical freezer: Level 5

Video Imagery

➤ The importance of high quality video cannot be understated

Table 1. Cameras used during seismic test phase.

Camera Type	Typical Image of Camera	Number of Cameras	Uncut Data Collected (GB)	Sample Snapshot of Camera View
IP		56	~140	
Coax		16	~43	
HD Camcorder		8	~215	
GoPro HD HERO2		7	~200	



*Note: Not all cameras were used for each earthquake motion.

Panoramic Imagery

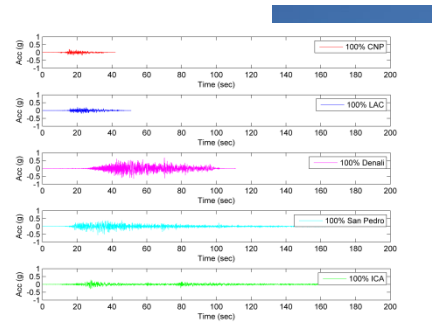


Third Floor (**before** fire testing)

Third Floor (**after** fire testing)



Phase 1: Base isolated building-nonstructural system

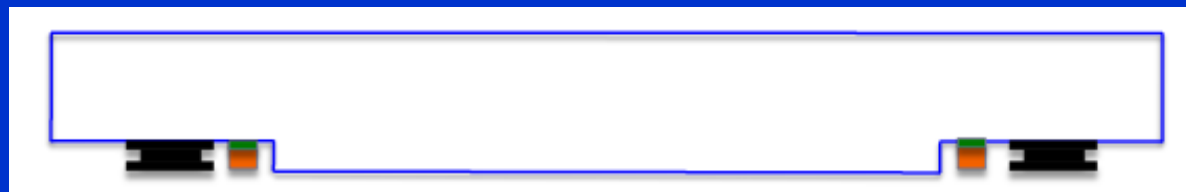


4 days of seismic motion testing (April 16-27, 2012)

1. High damping rubber, cylindrical bearings placed @ each corner of building (4 total)
2. Building elevated from shake table

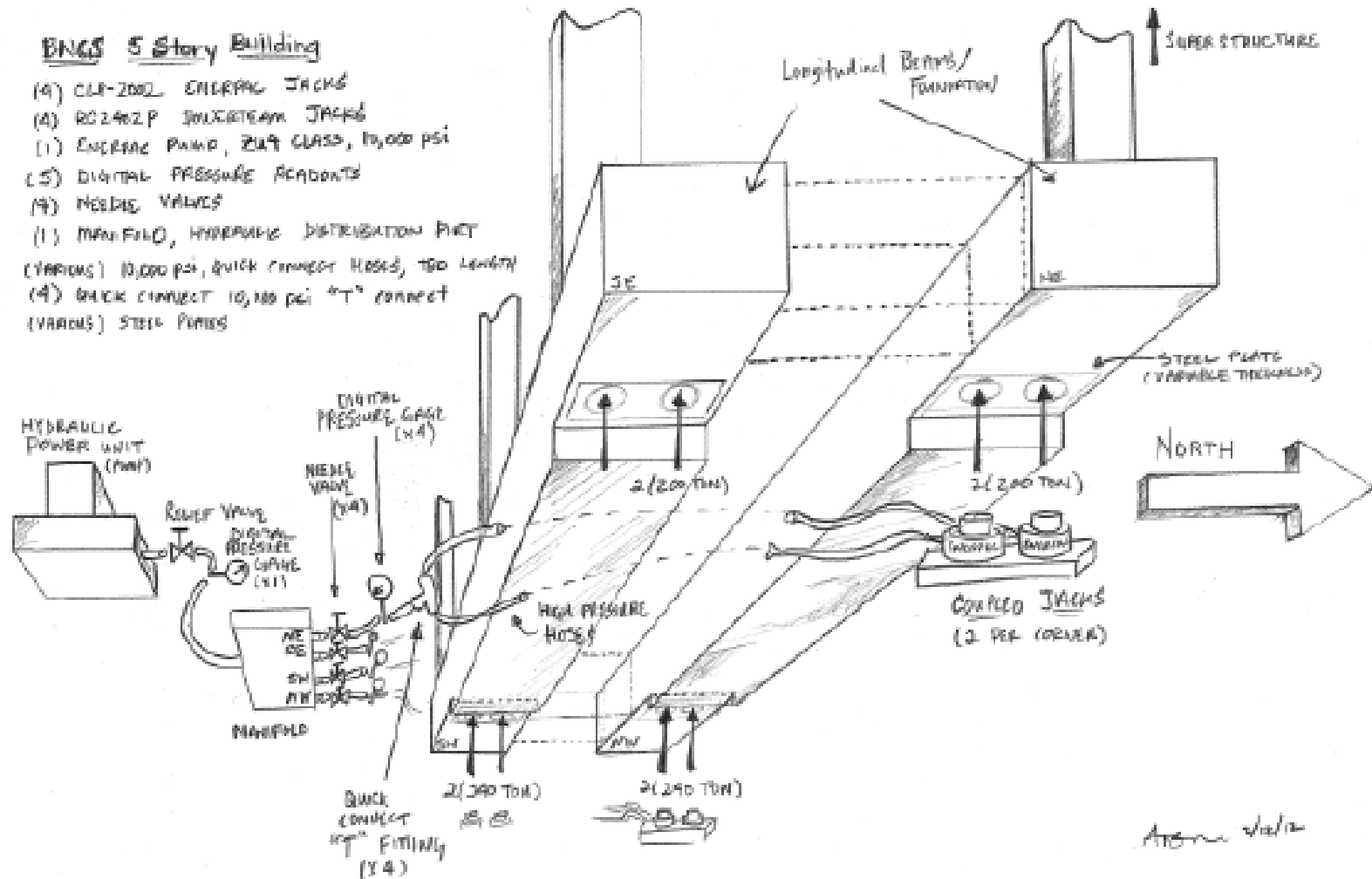


Building Lift



- **We lifted our ~700 ton building twice (to install & remove isolators)**
 - Building was cast with a 12" pedestal, isolator was 3-1/16" taller, therefore we lifted it 4"
- **Safety was of upmost importance; UCSD Site staff were outstanding in supporting and executing this effort**
- **Process:**
 - Propose a sequence of lift in close consultation site staff
 - Collect materials
 - ✓ Purchase/rent/pickup jacks (we used 8x energpac pancake jacks, 200 & 240ton@10ksi; we rented 4 of these, site had 4)
 - ✓ Test jacks
 - Un-PT and unbolt vertical rods, unbolt pedestals
 - Install jacks
 - Install linear potentiometers & redundant needle valves
 - Maneuver plates
 - Install isolators (or pedestal for the second lift)

Building Lift (artistic rendering, Gunthardt)



Phase 2: Fixed-base building-nonstructural system



4 days of seismic motion testing (May 7-15, 2012)

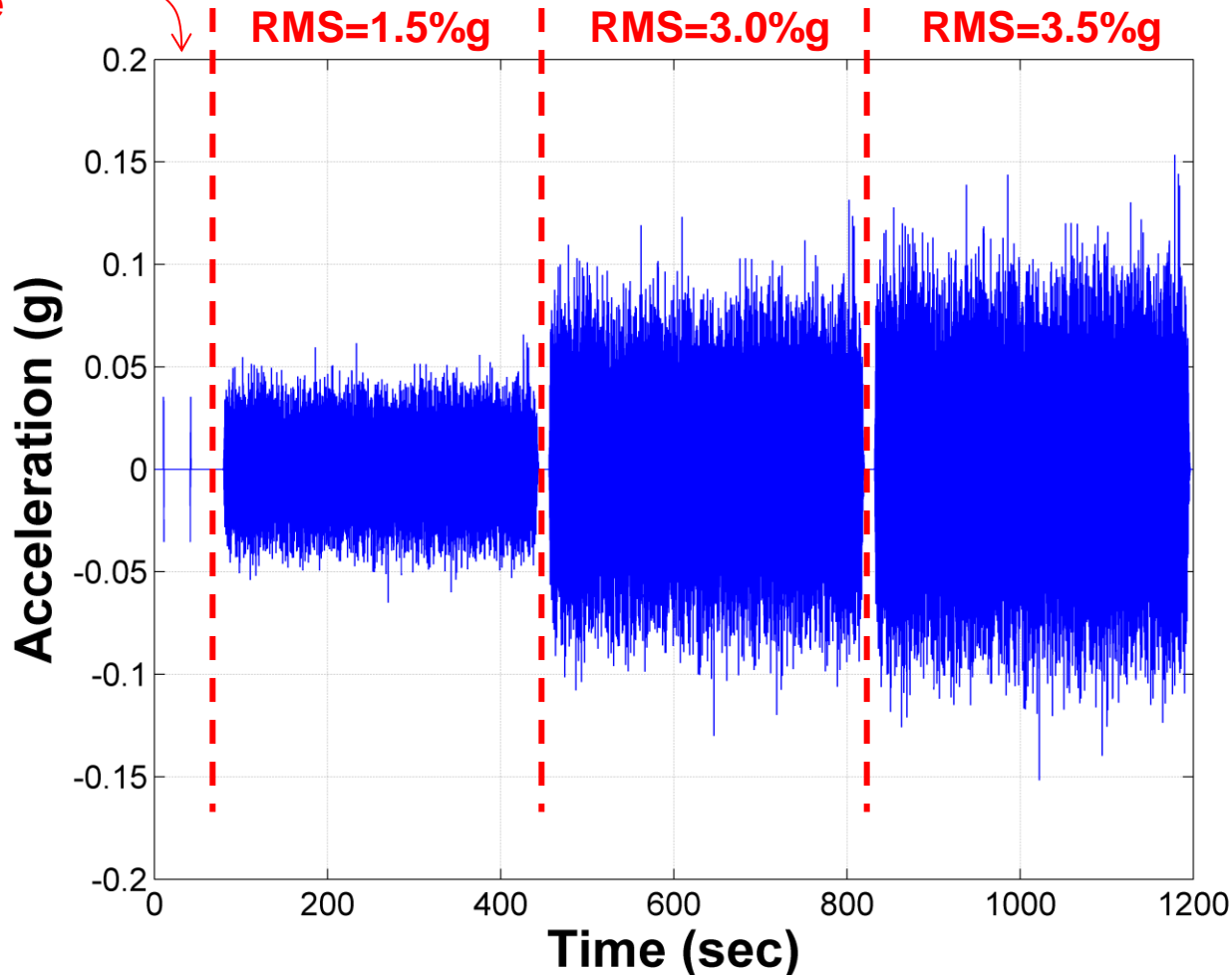


1. Building resting on shake table
2. Post-tensioned at its perimeter



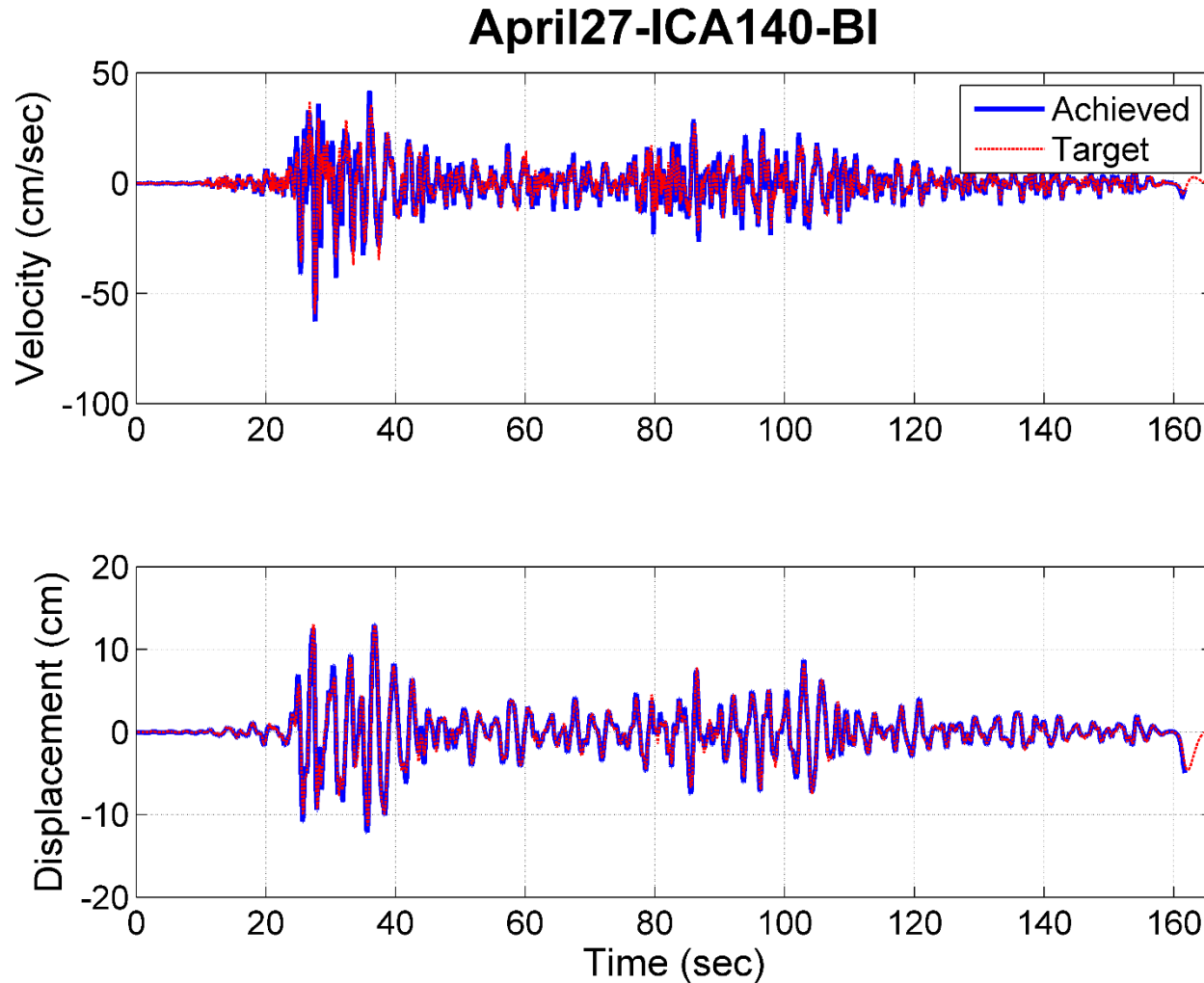
White Noise Motions

Double
pulse



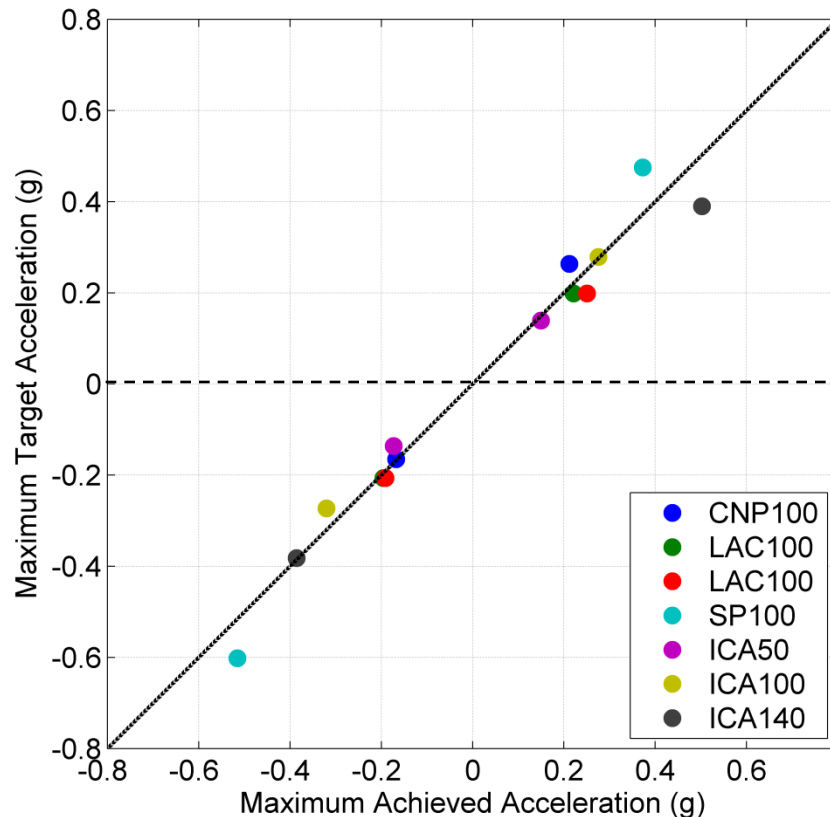
We performed WN
before and after
seismic tests to
asses the state of
the structure (SI)

Tracking the Table Performance



Maximum Acceleration

Base-Isolated



Fixed-Base

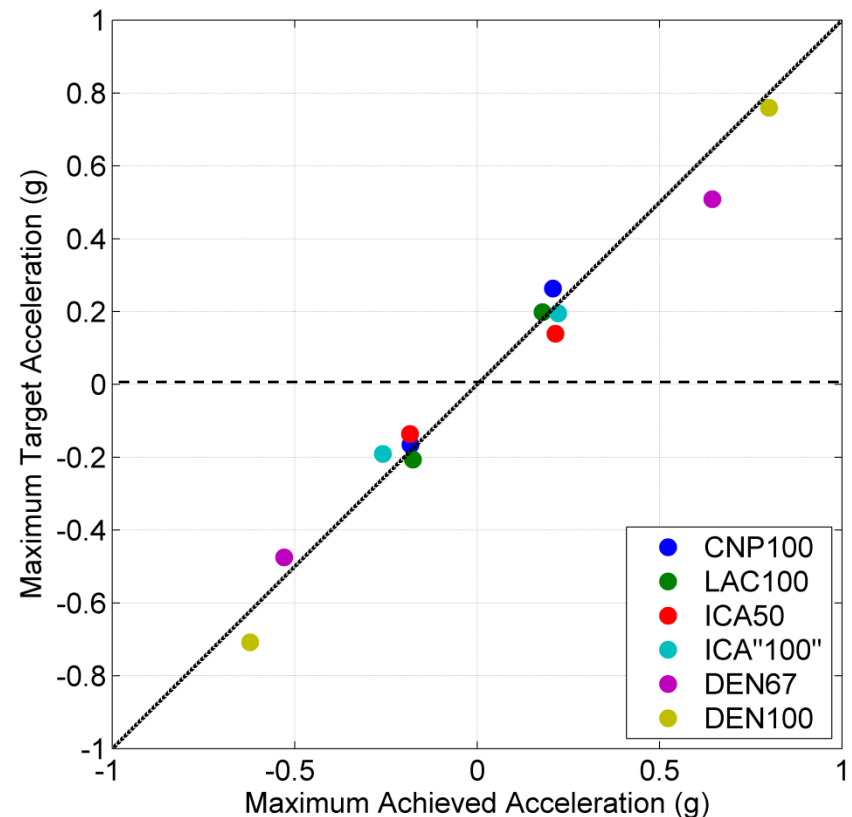
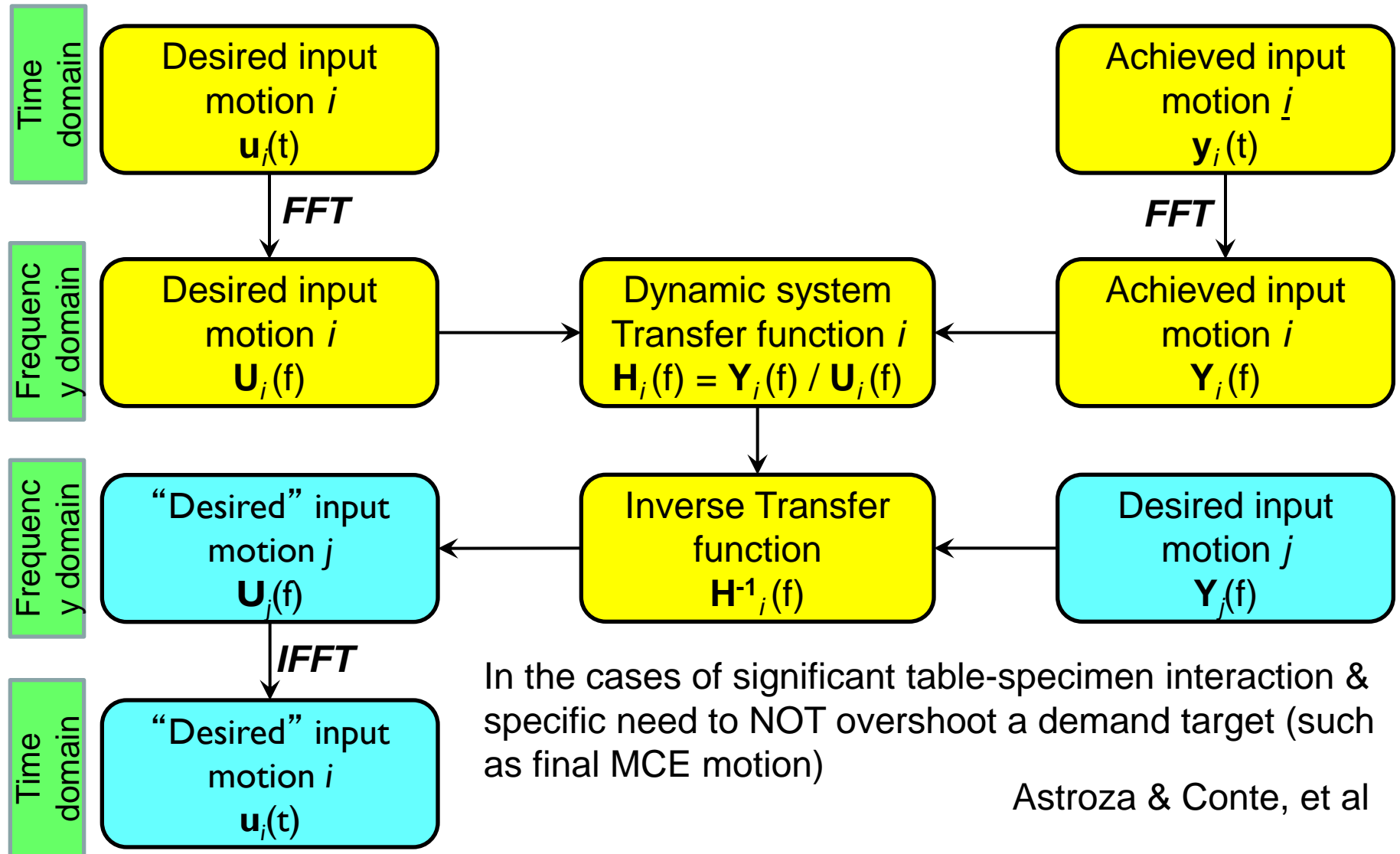


Table Performance: Guidance for Subsequent Motions

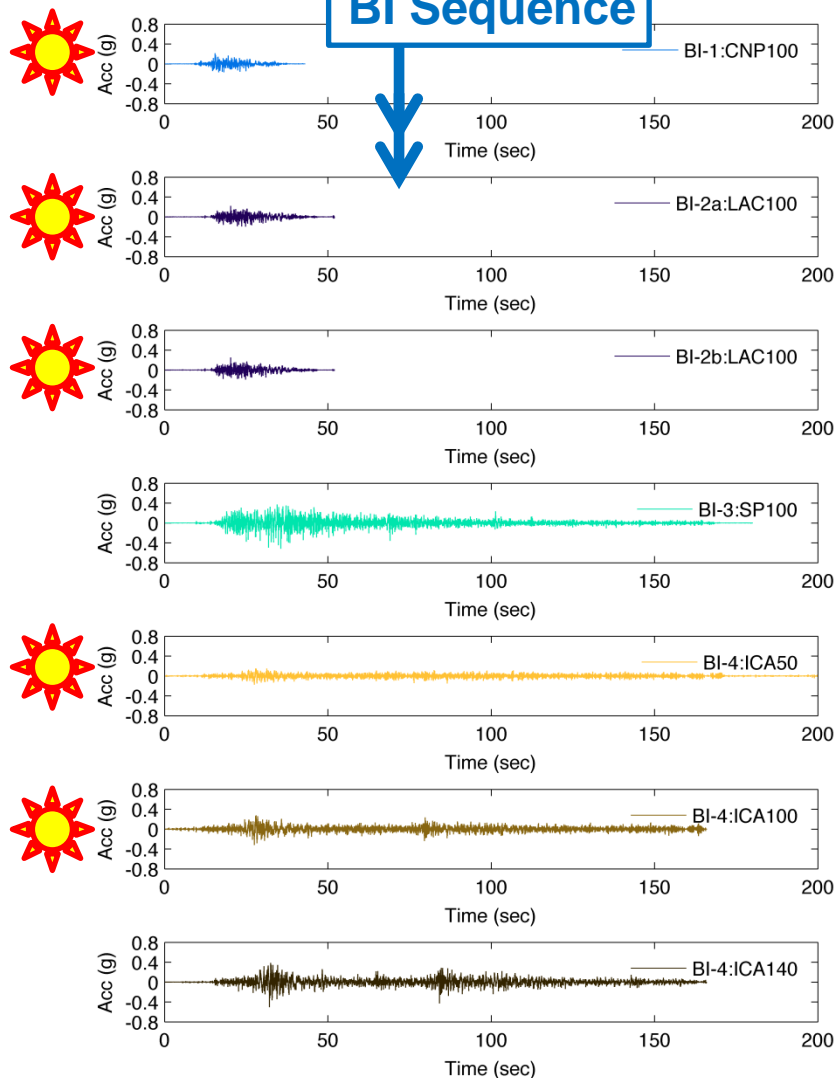


Motion selection, sequencing & scaling strategy

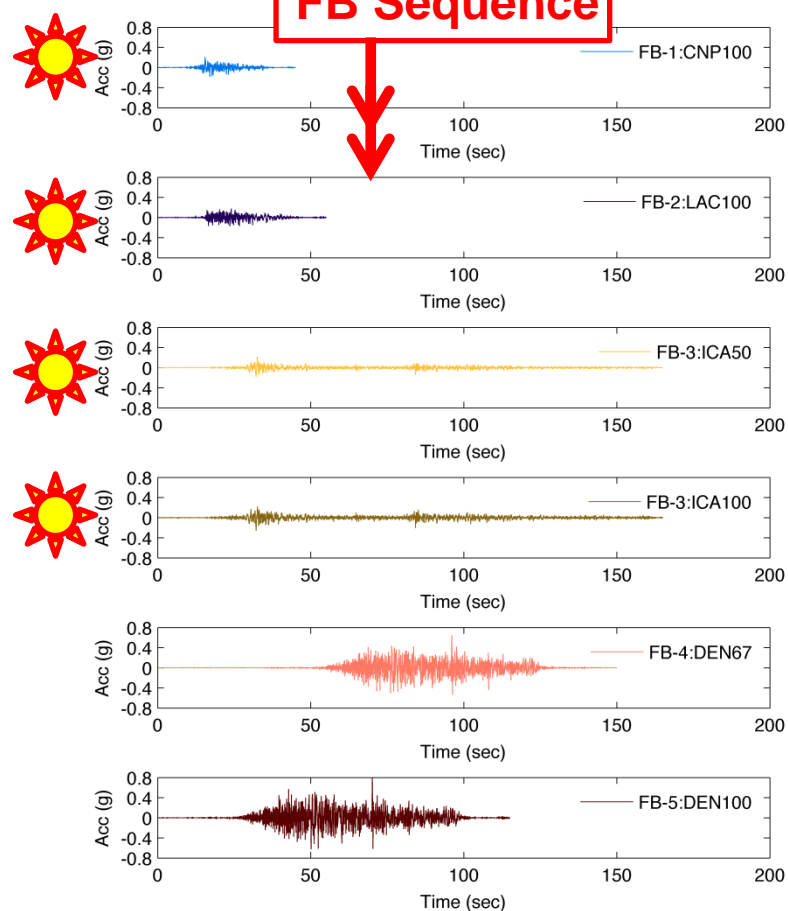
- **Overlap between portion of BI & FB motions**
- **< 0.5% Peak Interstory drift ratio (IDR) BI Phase**
 - Service level hazards (~43yr event)
 - Preserve structure for FB phase
- **Motions with varied characteristics**
 - Motion from CA/West coast US
 - Long duration of shaking
- **Achieve design performance objectives in building (FB)**
 - 2-2.5% Peak IDR
 - 0.8g or so PFA
 - ~Design earthquake event
- **Achieve well above design demands**

Seismic Motions: Achieved

BI Sequence



FB Sequence



Phase 3: Controlled live fire, pressurization & smoke tests



3 days of live fire testing
(May 23-25, 2012)

Test Execution, some informal guidance

SPECIFICS

Plan well in advance “between-motion activities”

- **Safety inspection – site staff – NO ENTRANCE into test specimen**
- **Tier 1 video & data analysis**
 - Rapid review of individual data channels
 - Safety & subsystem integrity checks
- **Tier 2 video & data analysis**
 - Specific components, subsystems
- **Tier 3 video & data analysis**
 - More detailed analysis (as time allowed)
- **Physical inspection – research team**
 - 2-3 research (core team) members were teamed with ALL invited industry partners (no industry partners were allowed to freely roam the building)

Continued....

- **Functionality checks**
- **Compartment pressurization tests (WPI)**
- **Replenish water cooling tower**
- **Replace push-pull rods at PCC connections**
- **Replace damaged ceiling tiles**
- **Replace sensors, reposition cameras**
- **Reposition equipment, replace component of a subsystem as needed**
- ***QuakeHold* – free BI; strapped FB**
- **...**

Media Exposure

- **Large-scale tests are a terrific opportunity to provide visibility to our efforts as a research community**
 - Video documenting the entire process (construction, testing, demolition)
- **Look for help/suggestions/media teams to provide support and help document all aspects**
- **We held three key “media days”**
 - UCSD-JSOE advertised (sent out media advisories & coordinated all incoming media groups)
 - All major national news channels were allowed on-site, several international media channels; interviewed project PIs & industry sponsors
 - Within one of these hosted an NSF-Live Science Webcast with Dr. Joy Pauschke (answering questions live between tests)

Media Exposure = Society Awareness

NBC NIGHTLY NEWS

San Diego



DODGERS SEEM TO HAVE PADRES' NUMBER

On a day honoring Jackie Robinson, the Padres lose a tough one to the Dodgers.

\$1.00
TAX INCL.

SECTIONS
INSIDE
Local
Business
Sports

MONDAY • APRIL 16, 2012

THE WORLD'S GREATEST COUNTRY & AMERICA'S FINEST CITY

UTSanDiego.com

TODAY'S DEAL

mission bay sports center

Today's deal is brought to you by Mission Bay Sport Center. A weeklong summer water sports camp for kids is only \$99 today at utsandiego.com. For video about today's deal, text "utdeals" to 56554.

THIS WEEK

TAX DAY: Tuesday is the deadline to file your federal and state income taxes for 2011, two days later than usual. Most post offices don't stay open late given that a majority of people file electronically.

DALAI LAMA IN TOWN: The Dalai Lama will give three public speeches during his first official visit to San Diego this week. Wednesday at UC San Diego, he'll discuss climate change. Later that day, at the University of San Diego, he'll focus on peace and justice. His final talk, Thursday at San Diego State, will be on ethics and compassion. All three appearances are sold out but will be webcast live at dalailama.com/tvweb.

MAYORAL DEBATE: The four major candidates for mayor of San Diego will face off Thursday, less than two months before the election on June 5.

BIG TENT GOING UP: Cirque du Soleil will put up its big tent and its Cirque du Soleil village Thursday at the Del Mar Fairgrounds. The show opens April 28.

JOBS REPORT: On Friday, the state will release the March unemployment figures for San Diego County. Nationwide the U.S. added 150,000 jobs in March, a slowdown after three straight months of adding more than 200,000 jobs. The country had

TALIBAN STRIKE AFGHAN CAPITAL

Afghan security forces respond with minimal help from NATO forces

NYT NEWS SERVICE

KABUL, AFGHANISTAN

Taliban suicide bombers and gunmen barraged the diplomatic

quarter and Parliament in the Afghan capital for hours on Sunday and struck at least three eastern provinces as well, in a complex attack clearly designed to undermine confidence in NATO and Afghan military gains. Though the overall death toll was low, with only six victims initially reported across four provinces, they were among the most

audacious coordinated terrorist attacks here in recent years. More than 14 hours after the initial explosions, there was still sporadic gunfire this morning in the capital, Kabul. The police kept parts of the city cordoned off, and the airport was closed to traffic, underscoring that although the attackers were relatively few in number, they could hold buildings for hours, disrupt

normal life and terrify residents. The attacks came near the peak of the U.S. military troop "surge" in Afghanistan, some of it designed around ensuring the security of the capital. And they were an early test for the Afghan National Security Forces, who responded with only minimal help from NATO, Western military officials said.

SEE AFGHANISTAN • A3

Shaking a finished, furnished building

UC San Diego and its collaborators will use the Large High Performance Outdoor Shake Table — the largest earthquake simulator in the U.S. — to study the effects of powerful quakes on the sort of five-story building commonly found in San Diego County. Engineers will shake the building multiple times to test different strengths.

Working elevator
and a stair system will show how evacuation routes are affected.

Roof
Water tower, heat and air conditioning unit.

The top two floors will be a **mock hospital** complete with a surgical suite and intensive care unit. There will also be medical storage and hookups for power and medical equipment.

In May, they will ignite a fire on the third floor to see the effects of smoke and flames on a building already damaged by severe shaking.

The building will have four rubber shock absorbers designed to prevent seismic energy from rising to the structure's upper floors. The design is called base isolation. Later, the shock absorbers will be removed and the building will sit squarely on top of the shake table.

The shake table can simulate most earthquakes on record, including the most powerful ones.



SCIENCE A3

Engineers' earthquake simulation ready to roll

Intricate structure at UC San Diego facility will undergo severe tests

GARY ROBBINS • U-T

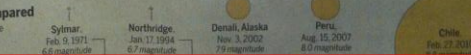
One of the biggest efforts ever made to understand how earthquakes affect buildings begins Tuesday at UC San Diego, where engineers will violently shake a five-story structure fitted with 500 sensors and 70 cameras.

The test is the first in a series meant to help scientists improve building codes and prevent fires, a common aftereffect of quakes. Scientists have shaken the skeleton of buildings before, but this is a complete mid-rise with electrical systems and a working elevator. The top two floors have been designed as a mock hospital, complete with a surgical suite and an intensive care unit. It is the most elaborately detailed quake test building ever created. The testing will be done at UC San Diego's Jacobs School of Engineering's facility in Scripps Ranch. The 1.4 million-pound building has been placed on top of the country's

SEE QUAKE • A3

Earthquakes compared

An increase in magnitude reflects an exponential increase in the power



What the bearings do is uncouple the building from the motion of the ground simulations ever attempted. Engineers

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Popular Mechanics

TRY: Best New

AUTOMOTIVE

TECHNOLOGY

SCIENCE

HOME HOW-TO

Homepage / Video: Shake Table Simulates 8.8-Magnitude Earthquake

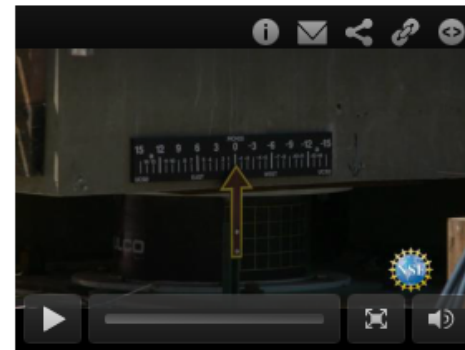
Video: Shake Table Simulates 8.8-Magnitude Earthquake

At the University of California, San Diego, a group of researchers is subjecting a five-story mock hospital to the force of an 8.8-magnitude earthquake to see how well our best building and preparedness practices stand up to the rage of a huge quake.

BY KALE THOMPSON

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

April 23, 2012 12:00 PM



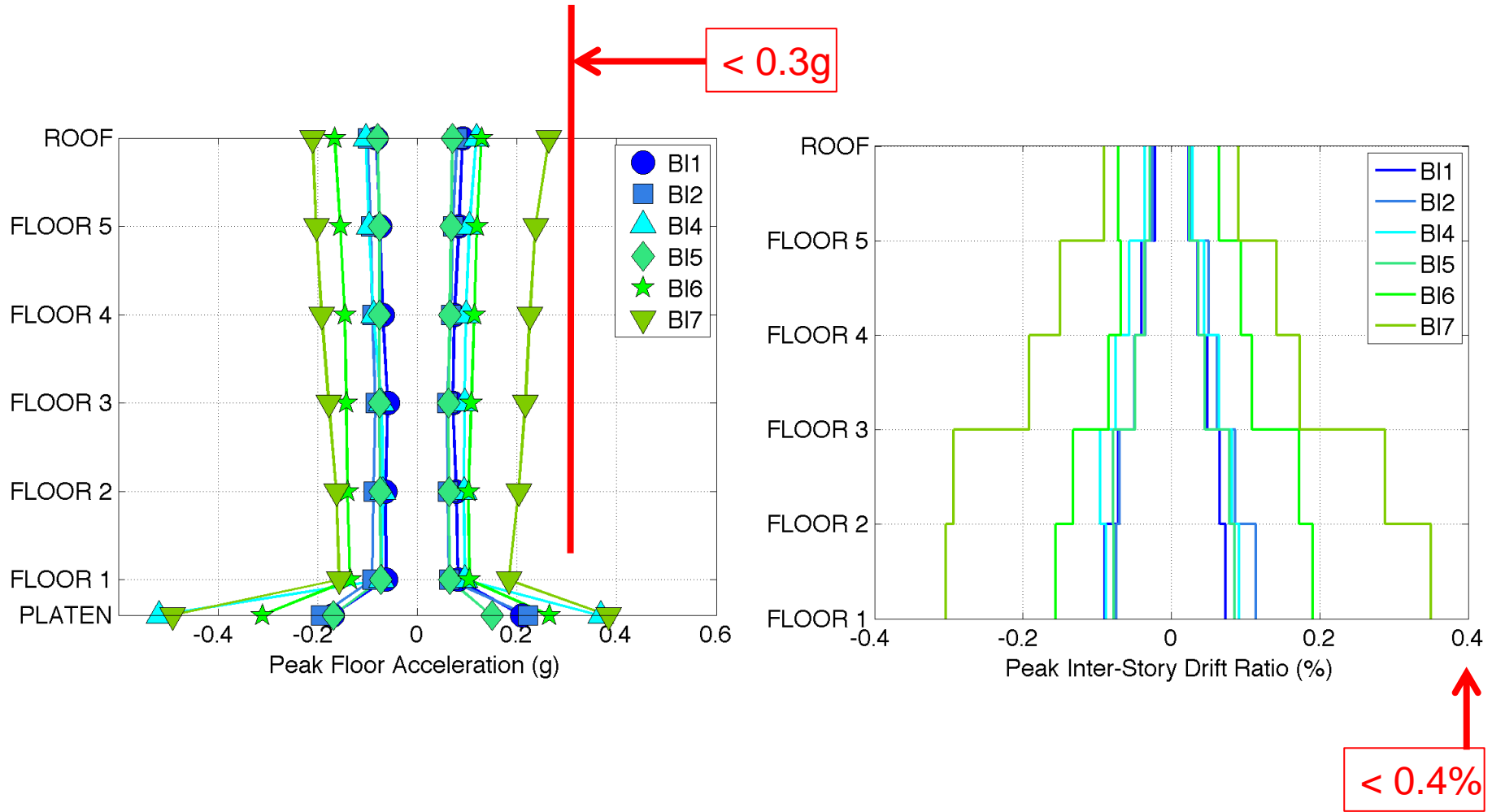
Devastating earthquakes often end up making buildings safer. After hospitals collapsed in southern California's 1971 Sylmar quake, for instance, the state adopted stringent new construction standards for hospitals and schools. In 1994's Northridge earthquake, buildings remained standing, but damage to equipment knocked some medical facilities out of service.

But engineers would prefer not to wait until the next disaster to put best practices to the test, which is why representatives from the National Science Foundation, the California Seismic Safety Commission, the University of California, San Diego, and a number of private companies were at a construction site on the campus of UC San Diego this week, staring up at a five-story hospital building and waiting for an earthquake to strike.

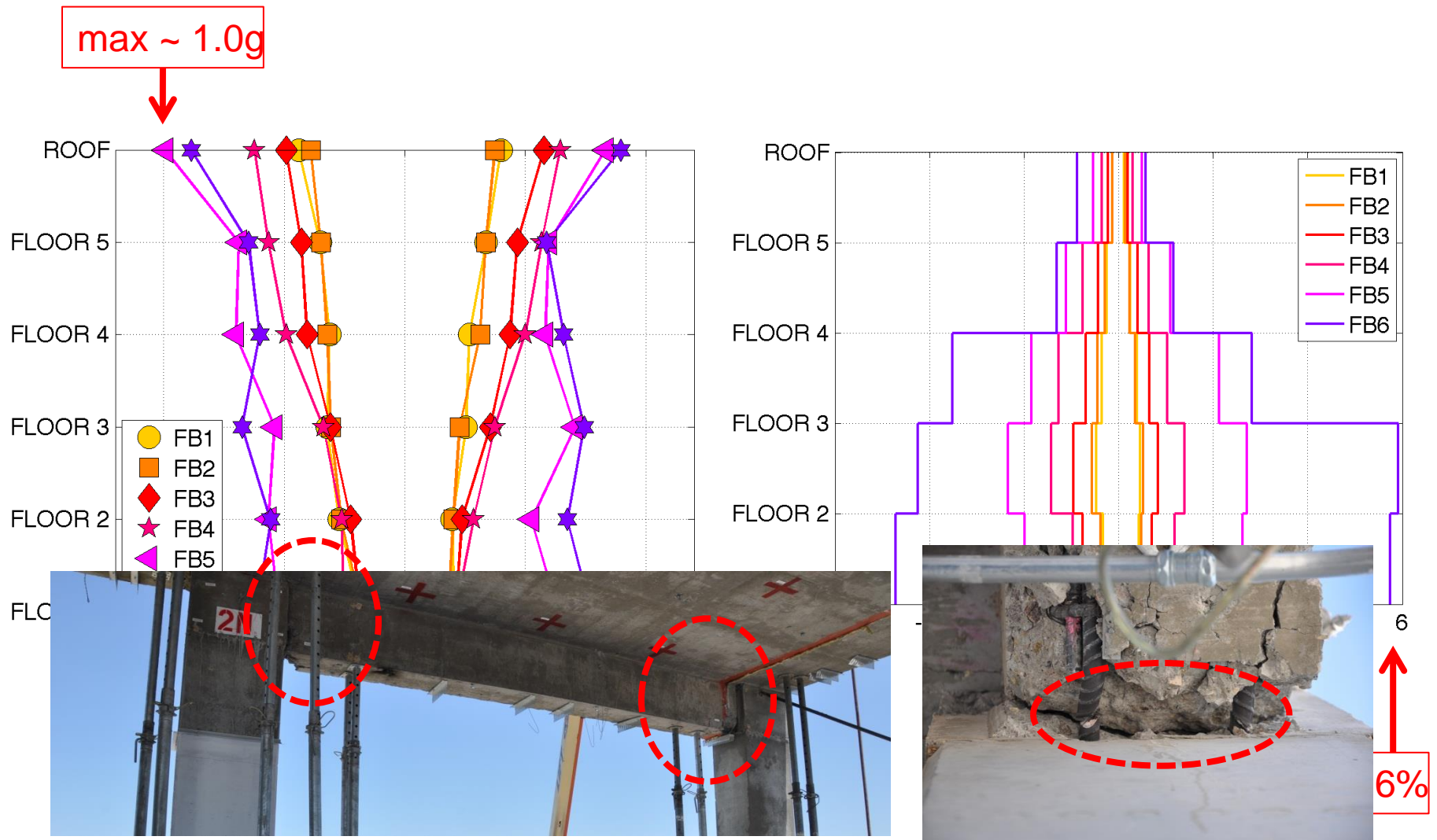
(there are many)

A FEW IMPORTANT FINDINGS

Phase 1: Base isolated building-NCS system

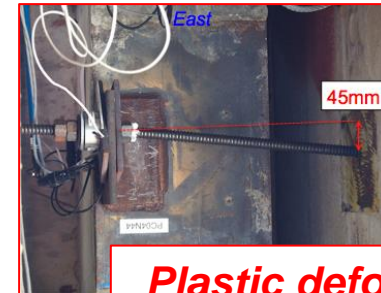
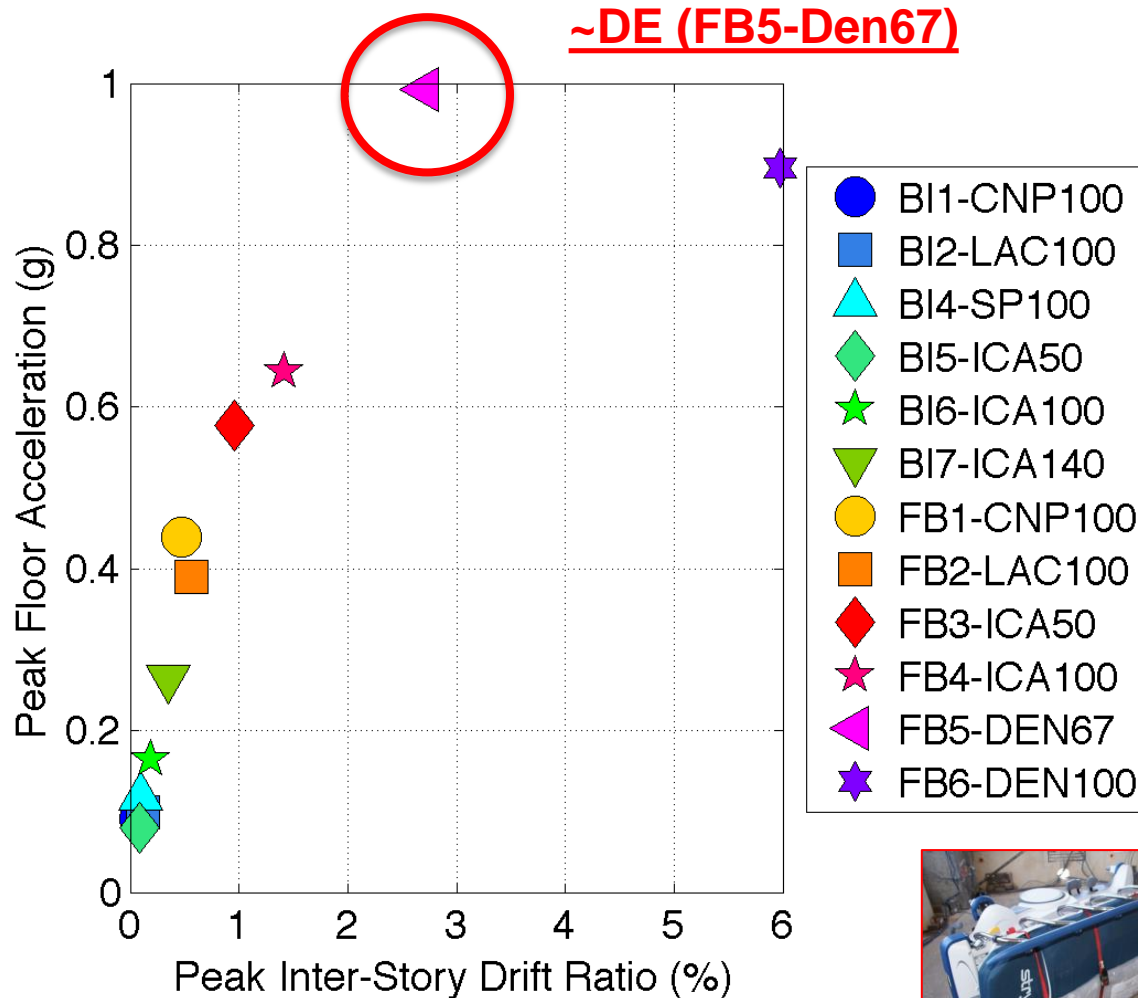


Phase 2: Fixed base building-NCS system



Peak Res

Failure of Stair Flight-Landing Connections



Plastic deformation in APC connections

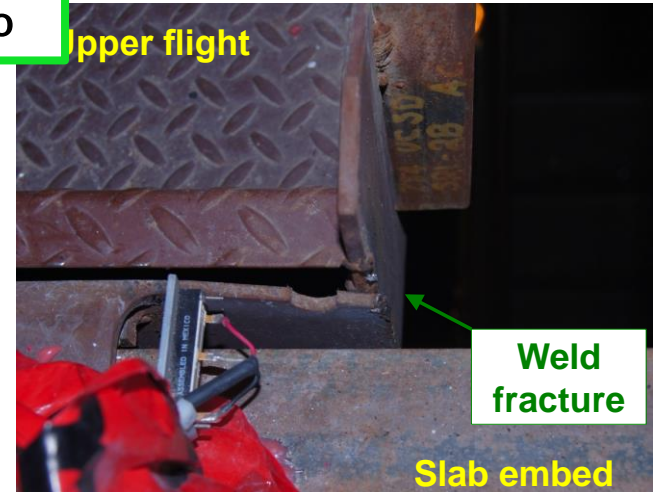
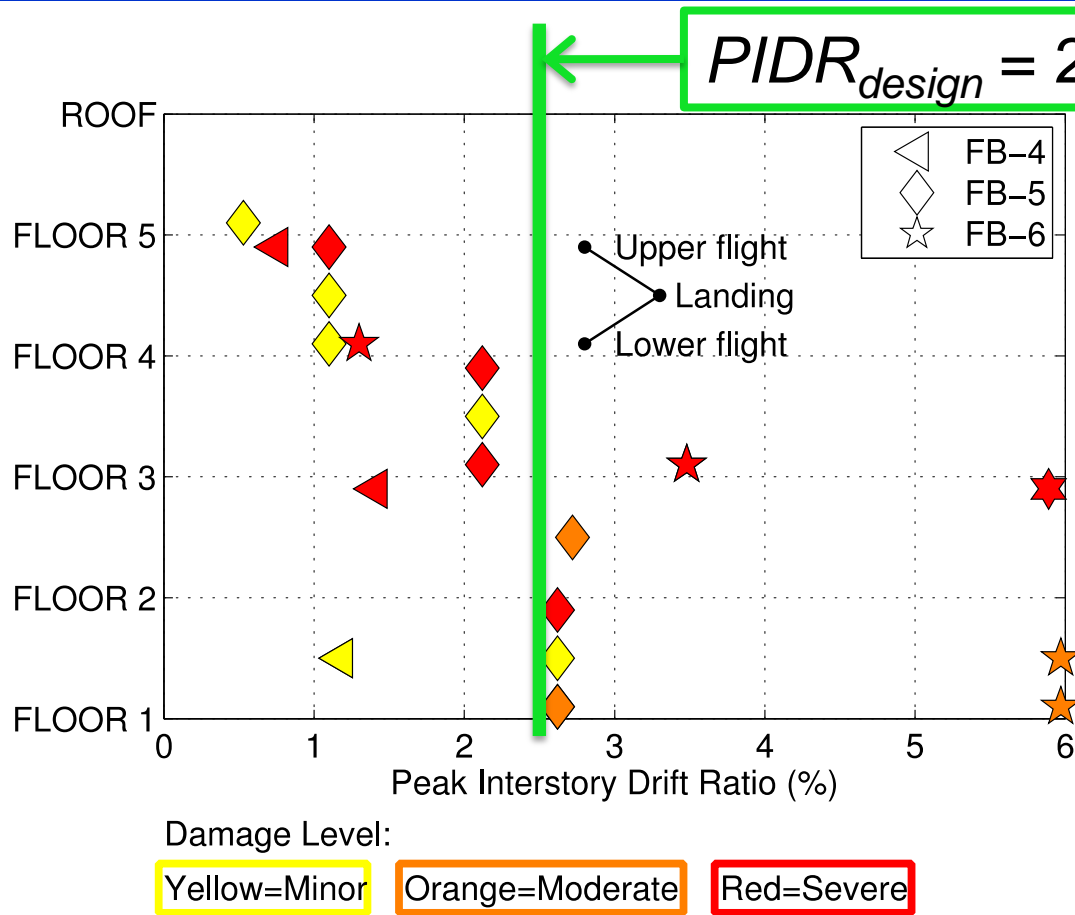


Balloon framing clip detachment

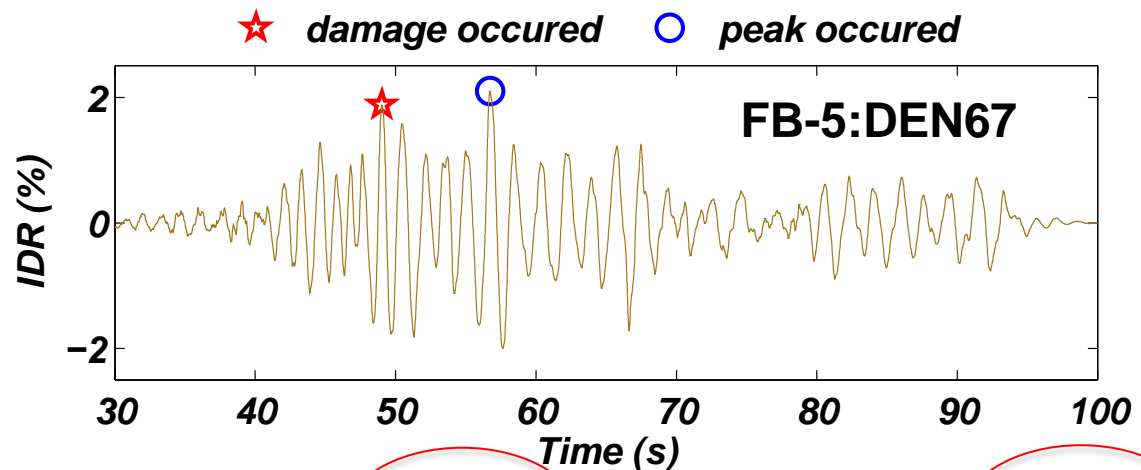
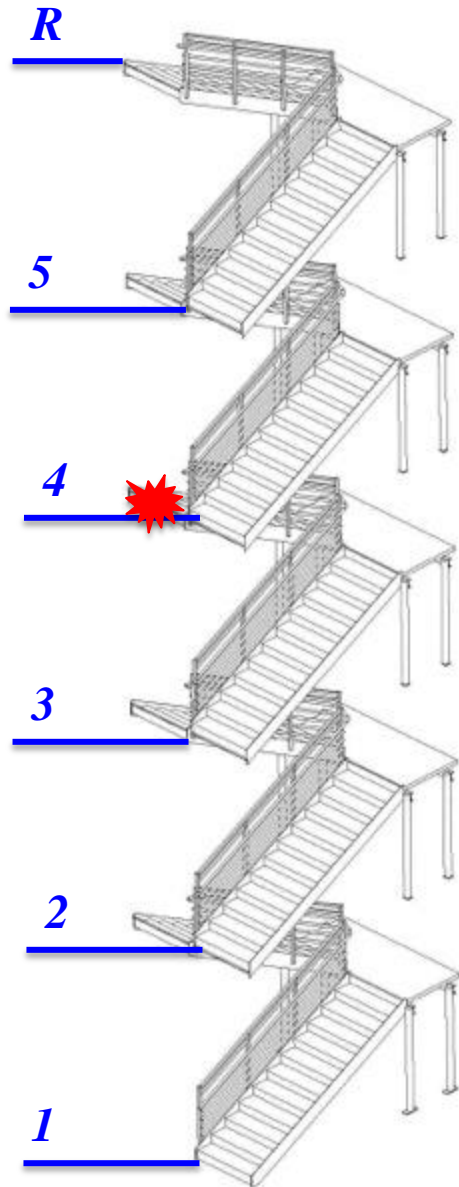


Toppled equipment

Egress: Stairs



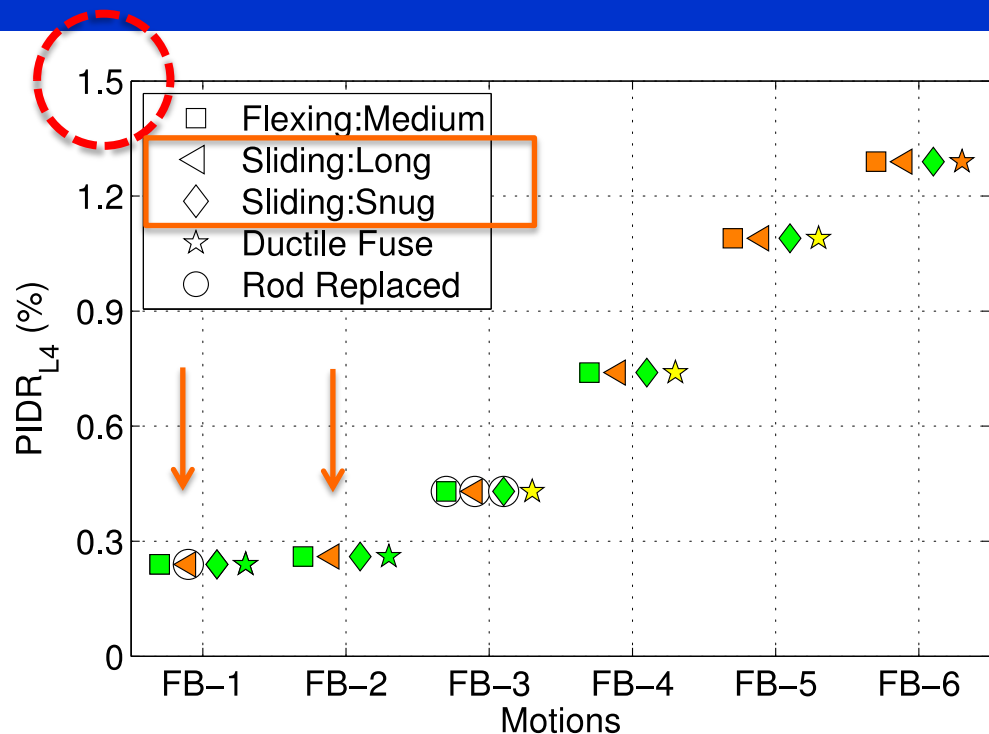
Upper Flight–Slab Connection Plate Fracture



IDRmax (%): 2.10

IDR@damage (%): 1.88

Drift-Compatible Façade Connections



Damage Level:

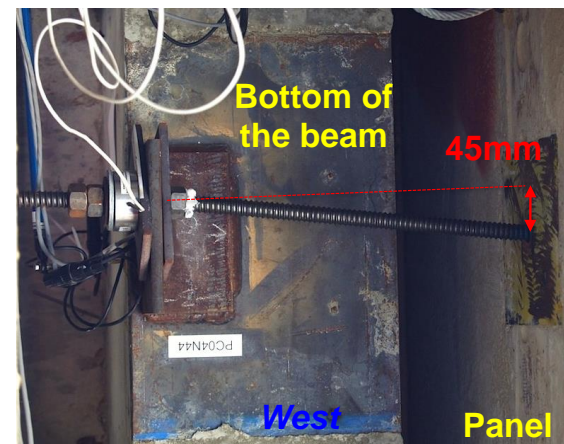
Green=None

Yellow=Minor

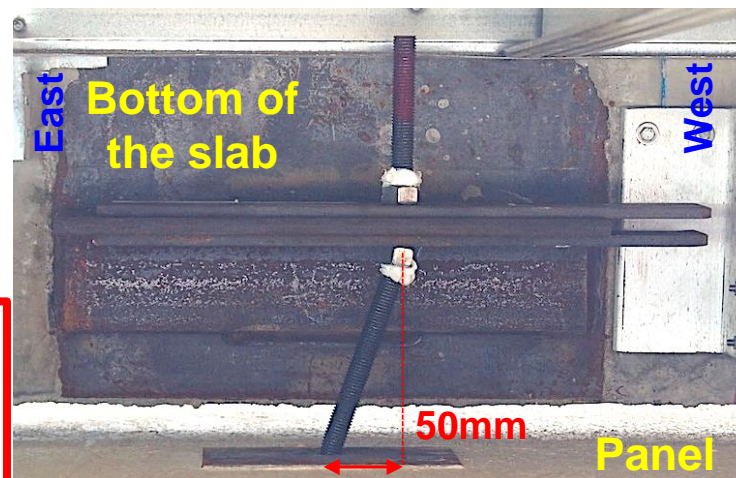
Orange=Moderate

Red=Severe

- 1) Intended performance of flexing connections
- 2) Unexpected yielding of sliding connections at low drift amplitudes

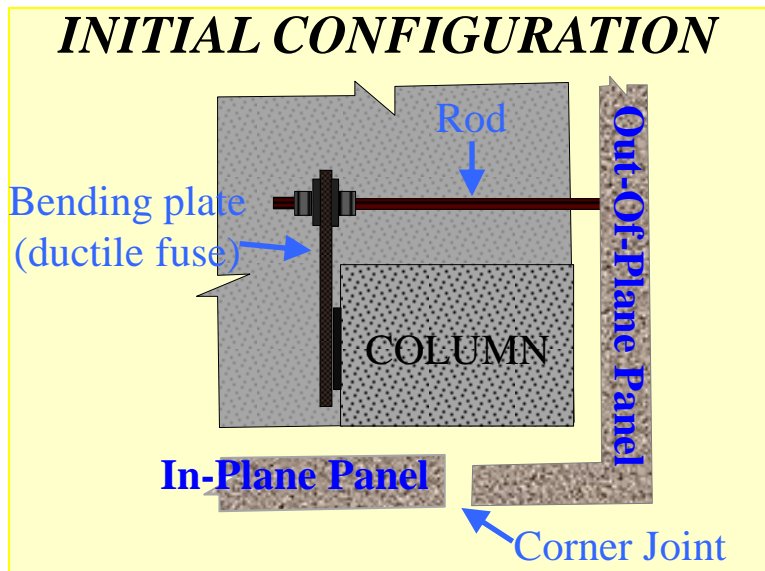
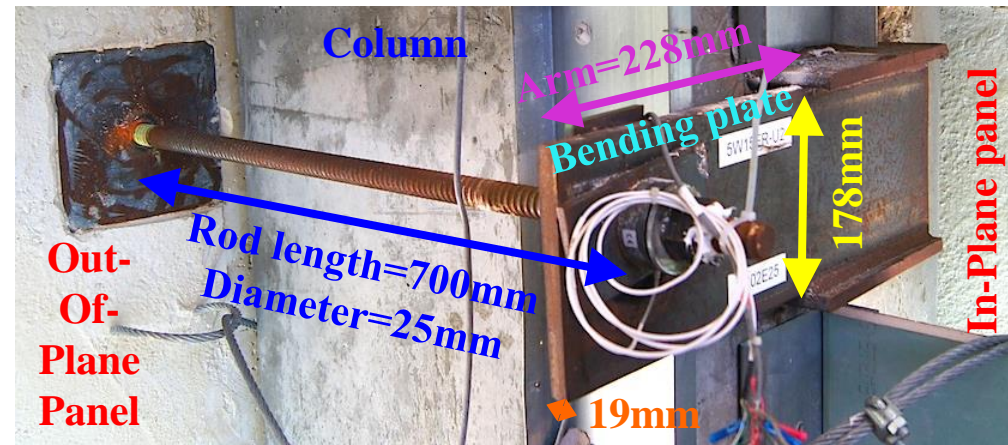


Flexing Connection



Sliding Connection

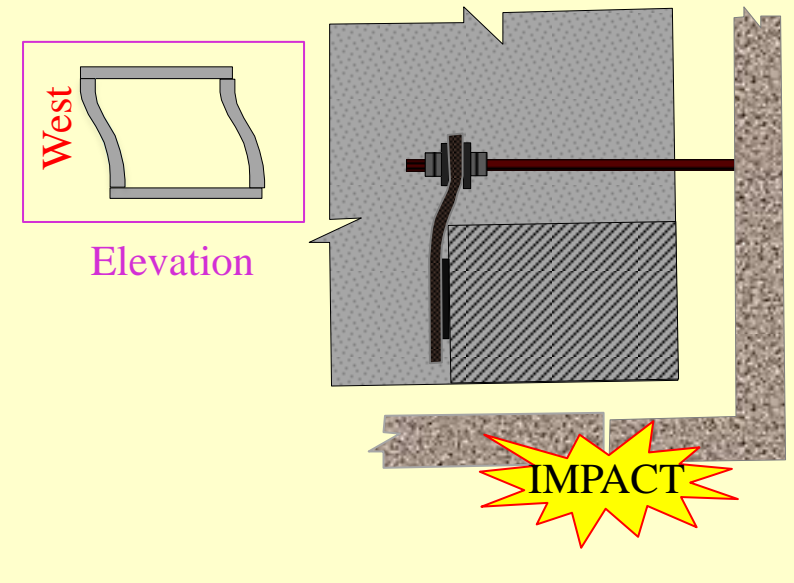
Colliding Corner – Ductile Fuse (new idea)



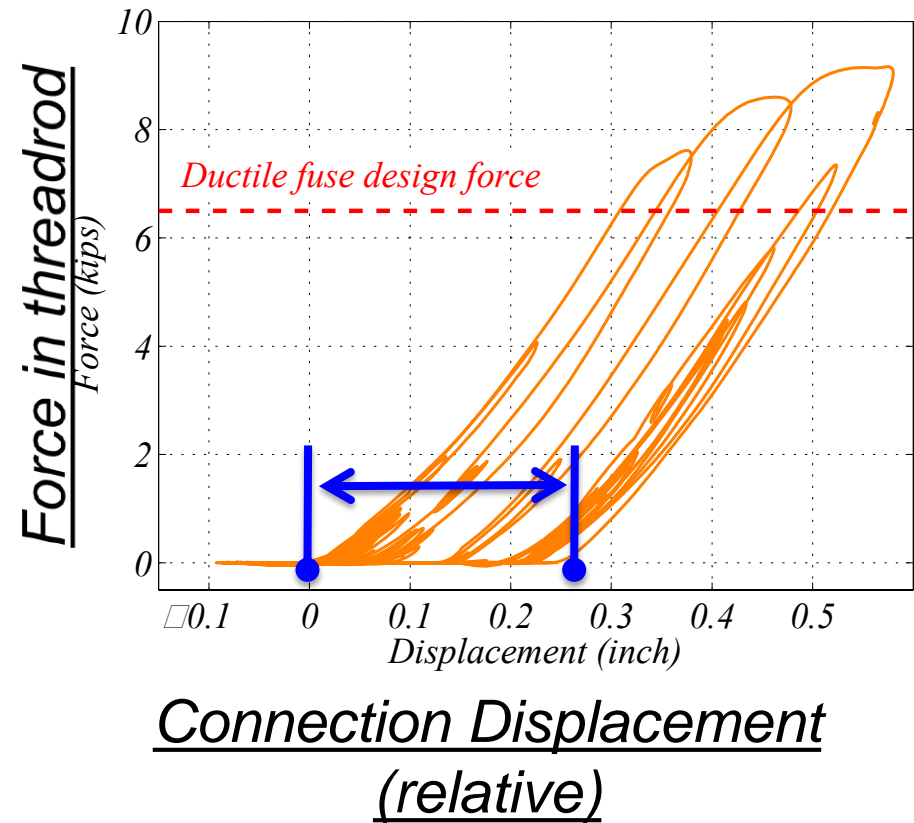
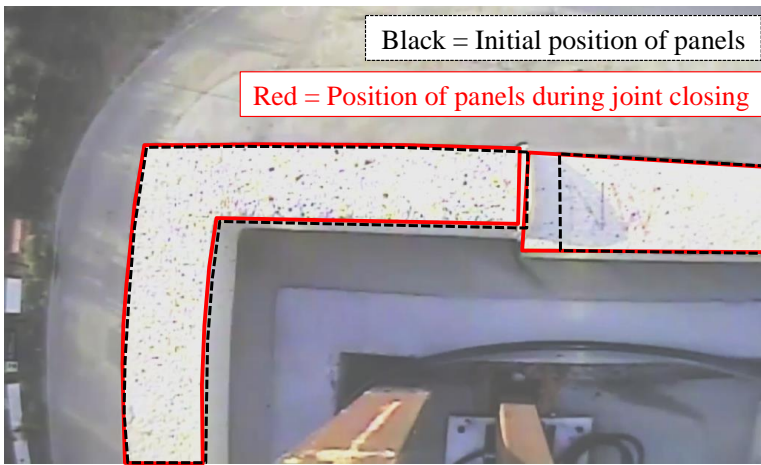
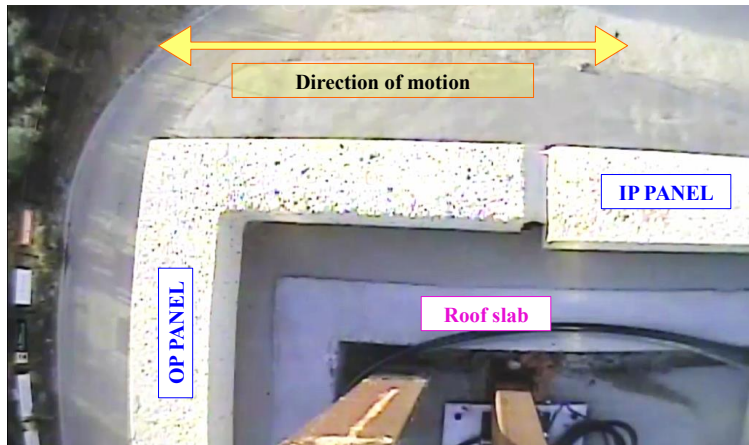
New corner system design to allow for smaller corner joints:

- Elastic Drifts → Gap closure
- Inelastic drifts → Impact but overload prevented by ductile fuse

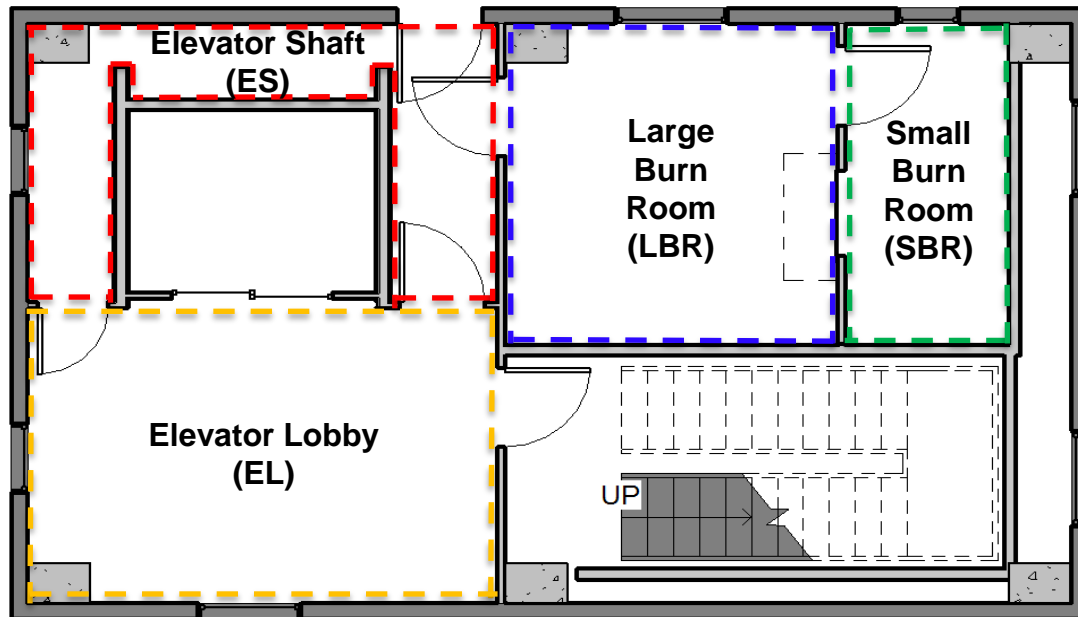
DEFORMED CONFIGURATION



Ductile, Colliding Corners



Live Fire Tests



Date	Sequence
May 23, 2012	1. LBR-1
	2. SBR
May 24, 2012	3. LBR-2
	4. ES
May 25, 2012	5. EL-1
	6. EL-2

- Series of 6 fires, heat release rate (HRR) varying from about 0.5 MW to about 1.5+ MW
- Goals: (a) obtain temperature data for simulations, (b) assess smoke spread, (c) assess potential for flame spread, and (d) assess potential for structural impact
- Burn time limited to about 15 minutes
- Heptane fuel - burned in pans (1 to 3, depending on desired fire size)

EL Fire Test 1/2: Representative Effects



Elevator controls melted



Spalling of concrete slab



Intumescing of fire stop

With the damage to the gypsum wall system due to seismic motions, the fire was able to bring the system to failure much more quickly than any fire rating would suggest



Failure of wall system (after EL 2 test)

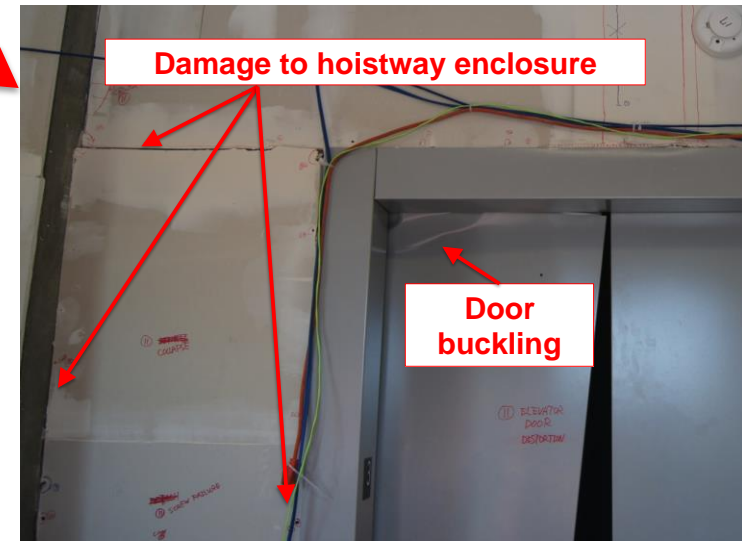
Egress: Elevator



**Door Jamb
After FB5-DEN67
(functional)**



**Door Jamb
After FB6-DEN100
(non-functional)**



Elevator Improvements



Schindler Corp

Phase 2: Fixed base building-NCS System

UC San Diego

Videos: bncs.ucsd.edu

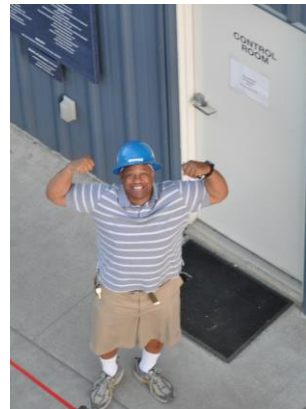
(there are many)

PROJECT ACCOLADES

Project Accolades: Human Resources



- UCSD: Astroza, Ebrahimian, Wang (PhD 2015) & Pantoli, Chen (PhD 2016)
- WPI: Park (2014 PhD); Kim (MS 2013)
- SDSU: Espino & Aranda (MS 2012, 2014)
- Univ of Bologna: Selva & Bezzi (MS 2012, 2014)
- NEES-REU (8 UGs from SJSU, VPI, UCSD)
- NEES-RET: 6 SD teachers outfitted with mini-shake tables
- 3 Payload projects: WPI (fire), SIO (GPS) & Cal Poly SLO (mini-shakers)

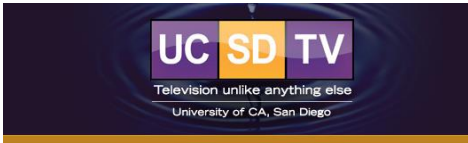


Project Accolades: Technical Contributions

- **Award in Excellence for Research Projects (Western States Seismic Policy Council, 2014)**
- **5-part Technical Report Series (UCSD), 2-part Technical Report Series (WPI)**
- **Numerous technical papers (conference, journal)**
 - 2-part Earthquake Spectra (overarching, 2015)
 - “Data Paper” Earthquake Spectra
 - System ID: Astroza et al., Modeling: Ebrahaminian, Wang, Facades Pantoli et al., Egress Systems: Wang
- **Large volume of data (image, analog) publically available -> NEESHub**
- **ASCE 7-16 Code Changes**
 - Precast cladding connections
 - Stair (drift limits, importance factor)
 - Elevator detailing

Project Accolades: Public Impact

- Professional video publication (UCSD-TV)



- Educational video module series (4-part structural; 2-part nonstructural; geared towards undergraduate learning)
- Documented extensive media exposure

Demolition – Don't forget it!

- **\$135k ++ lots of help from industry (\$98k in just structural concrete; removal of ceiling, stairs, elevator by others)**





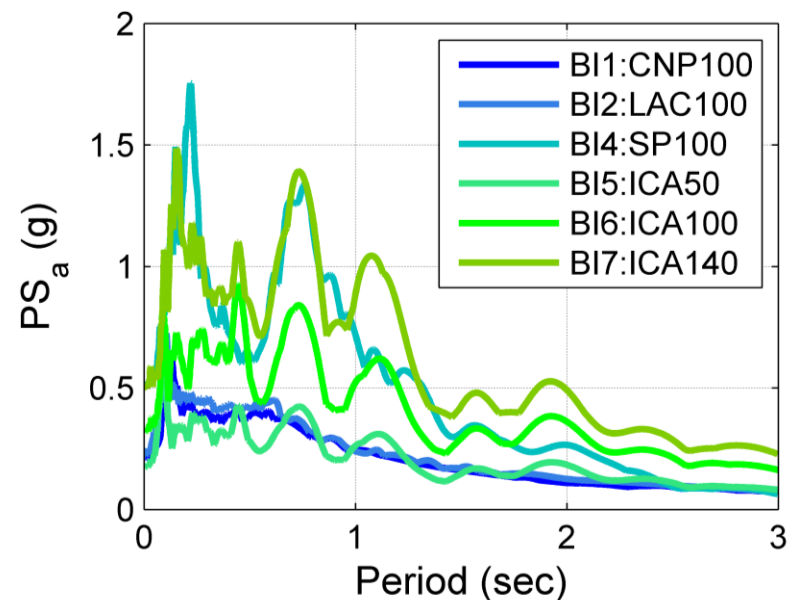
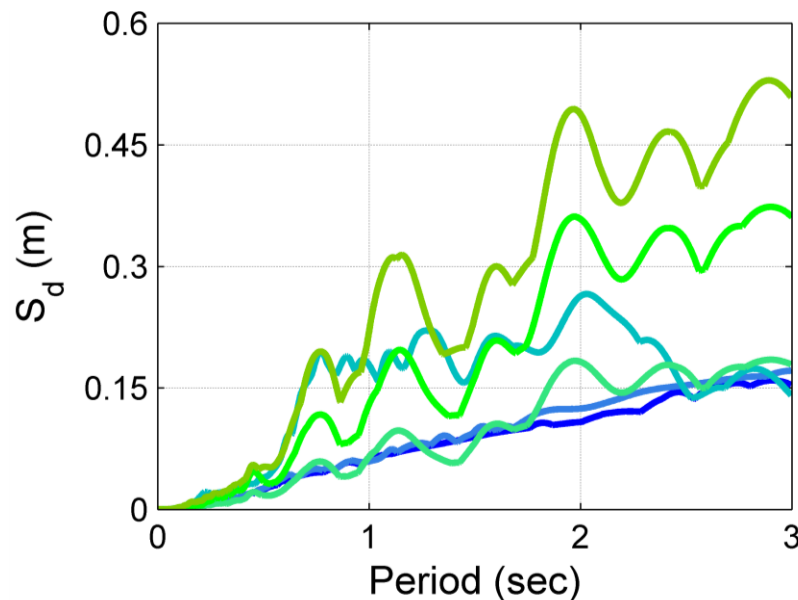
The real stars of the show....







Base	Station-scale (Earthquake)	Name	Type	Notes
Isolated (BI)	Canoga Park-100% (1994 Northridge earthquake)	BI-1: CNP100	SM	Serviceability level
	LA City Terrace-100% (1994 Northridge earthquake)	BI-2:LAC100	SM	Serviceability level
	LA City Terrace-100% (1994 Northridge earthquake)	BI-3:LAC100	SM	Serviceability level
	San Pedro-100% (2010 Maule-Chile earthquake)	BI-4:SP100	AM	Long duration
	ICA-50% (2007 Pisco-Peru earthquake)	BI-5:ICA50	AM	Long duration, multiple runs
	ICA-100% (2007 Pisco-Peru earthquake)	BI-6:ICA100	AM	Long duration, multiple runs
	ICA-140% (2007 Pisco-Peru earthquake)	BI-7:ICA140	AM	Long duration, multiple runs



Base	Station-scale (Earthquake)	Name	Type	Notes
Fixed (FB)	Canoga Park-100% (1994 Northridge earthquake)	FB-1:CNP100	SM	Low amplitude - expect service
	LA City Terrace-100% (1994 Northridge earthquake)	FB-2:LAC100	SM	Low amplitude - expect service
	ICA-50% (2007 Pisco-Peru earthquake)	FB-3:ICA50	AM	Long duration, multiple runs
	ICA-100% (2007 Pisco-Peru earthquake)	FB-4:ICA100	AM	Long duration, multiple runs
	Pump Station #9-67% (2002 Denali eq.)	FB-5:DEN67	SM	~Target design demand
	Pump Station #9-100% (2002 Denali eq.)	FB-6:DEN100	SM	~>50% larger than Design demands

