BNCS: Full-Scale Structural and Nonstructural Building System Performance during Earthquakes

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1. Motivation

To date, only a handful of full-scale building experimental research has been conducted, among which only limited tests (in Japan) have emphasis on evaluating nonstructural components and systems (NCSs) responses during earthquake shaking. This belies the fact that NCSs encompass more than 80% of the total investment in building construction and over the past three decades, the majority of earthquake-induced direct losses in buildings are directly attributed to NCSs damage (Fig. 1).

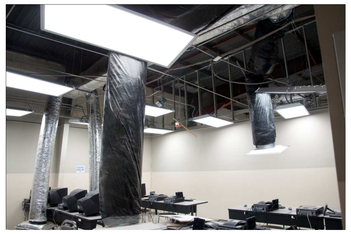

Figure 1. Damage of NCSs in the 2010 Baja California Earthquake (Photo courtesy of Richard Wood).

2. Research Significance

This landmark BNCS project involves the shake table test of a full-scale five-story building furnished with a variety of NCSs, including a passenger elevator, steel prefabricated stairs, and many other architectural (partition wall, ceilings, and glazing) and MEP (HVAC, piping) components. The project provides the unique opportunity to advance our understanding of the full-scale dynamic response and kinematic interaction of complex structural and nonstructural components and systems. In addition, this project will investigate the potential for protecting critical NCS systems by base isolating the building.

3. Structural System

The lateral force resisting system of the building specimen is a five story reinforced concrete moment resisting system (Fig. 2), representing a configuration commonly found in California. Different beam framing systems are adopted for every floor, which include the use of high strength steel, ductile rod connectors, and post-tensioned tendons.

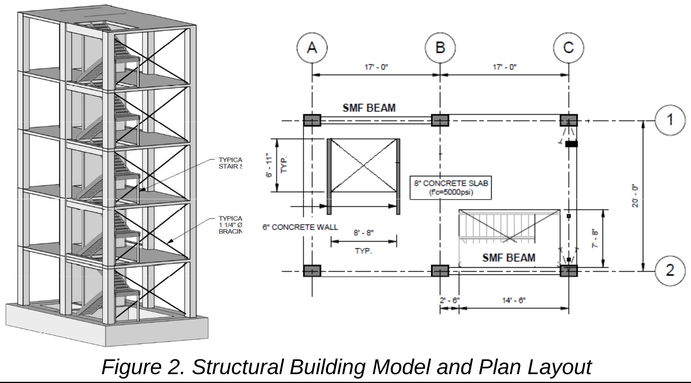

Figure 2. Structural Building Model and Plan Layout

NEES NSF Englekirk Center

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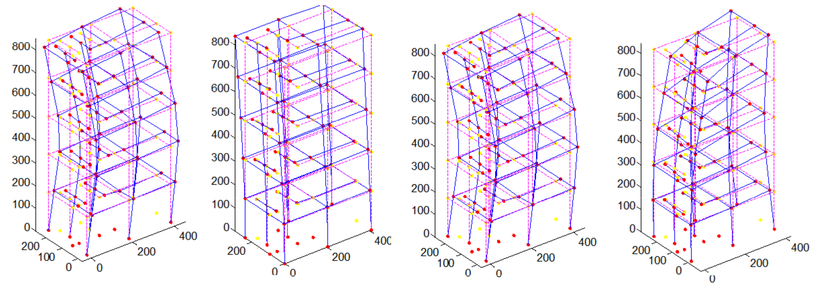
4. Numerical Simulation

A numerical model of the five-story building has been implemented in OpenSees. Force-based fiber beam-column elements are used for modeling columns, frame beams, and shear walls. Slab contribution is also taken into account with equivalent strut and tie truss elements. The total mass including all structural and nonstructural components added up to 140 kips per floor.

Modal Analysis



(a) 1st Mode (T = 0.84 s) *(b) 2nd Mode (T = 0.66 s)* *(c) 3rd Mode (T = 0.40 s)* *(d) 4th Mode (T = 0.37 s)*

Figure 3. Building Modal Shapes

Nonlinear Time History Analysis

Seven Maximum Considered Earthquake (MCE) ground motions, representing the probability of exceedance of 2% in 50 years, are used to validate the seismic performance of the five-story building. The acceleration spectra of these ground motions are given in Fig. 4. Figs. 5 and 6 provide the floor absolute accelerations and inter-story drift ratios.

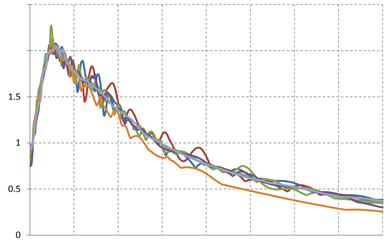


Figure 4. Pseudo-Acceleration Spectra of Input Ground Motion

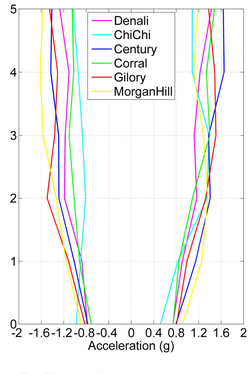


Figure 5. Floor Absolute Acceleration

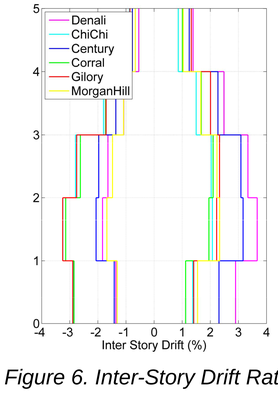


Figure 6. Inter-Story Drift Ratio

5. Base Isolation

Base isolation (Fig. 7) is a feasible solution for reducing the damage to both the building and NCSs due to an earthquake. With the period shift, the absolute acceleration and deformation within the building can be greatly reduced.

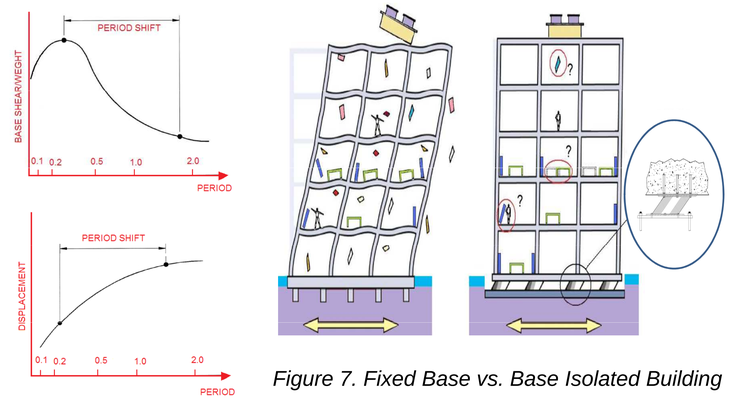


Figure 7. Fixed Base vs. Base Isolated Building

6. Organization and Scope

Core Team Members

- Tara Hutchinson (UCSD)
- Jose Restrepo (UCSD)
- Joel Conte (UCSD)
- Ken Walsh (SDSU)
- Claudia Marin (Howard)
- Robert Englekirk (Englekirk)
- Robert Bachman (Consultant)
- Matthew Hoehler (Hilti)
- Brian Meacham (WPI)
- Xiang Wang (UCSD)
- Mahmoud Faghihi (Englekirk)
- Michelle Chen (UCSD)
- Hamed Ebrahimian (UCSD)
- Elide Pantoli (UCSD)

Academic and Industrial Collaborators

- $5 Million, multi-organizational 3 year research project
- Full-scale shake table test of 5-story building on the NEES-UCSD Large High Performance Outdoor Shake Table (LHPOST)
- Fully outfitted with a range of NCSs
- Post-earthquake fire integrity tests following earthquake shaking
- 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 & government)
- Major funding agencies including National Science Foundation (NSF), Network for Earthquake Engineering Simulation (NEES), and California Seismic Safety Commission (CSSC)