# Evaluation of Ground Motion Scaling Methods for Nonlinear Analysis of Structural Systems

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## Motivation

The selection and scaling of ground motion records is a major challenge for structural engineers to conduct nonlinear response history analysis (RHA) for seismic design. This is because:

- There is a lack of consensus on which scaling method(s) should be used
- Large variability in engineering demand parameters (EDPs) estimated by certain scaling methods (e.g., ASCE 7) leads to uncertainties in design

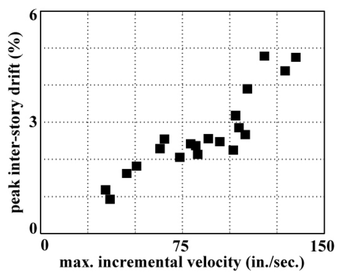


*Figure shows significant variation in inter-story drift ratios from a six-story building subjected to 10 pairs of Maximum Considered Earthquake (MCE) ground motion records satisfying the ASCE 7 scaling method*

- No experimental study is available yet for validation and verification of ground motion selection and scaling methods

## Objectives and Tasks

**The project aims to answer the following questions:**

- Given design specifics on structural properties and seismic hazard, how should an appropriate suite of ground motions be selected?
- How should these records be scaled to obtain accurate and efficient estimates of median EDPs?
- What is the minimum number of records needed to retain accuracy in the median demand estimates with minimum dispersion?

**To achieve these objectives, the project has the following major tasks:**

- Conduct small-scale shake-table tests of MDOF structures under unscaled ground motion records as well as records scaled using
  - ASCE 7 scaling method
  - Spectral acceleration [$S_a(T_1)$] based scaling (Shome et al. 1998)
  - Maximum incremental velocity [MIV] based scaling (Kurama and Farrow, 2003)
  - Modal-pushover based scaling (Kalkan and Chopra, 2010)
- Investigate how site parameters and structure characteristics affect the accuracy and efficiency of these scaling methods
- Develop design guidelines for selecting and scaling ground motion records for nonlinear RHA of structures

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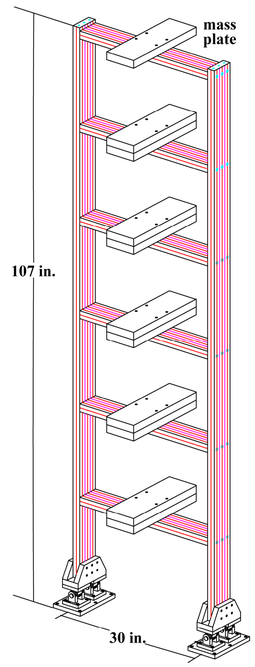
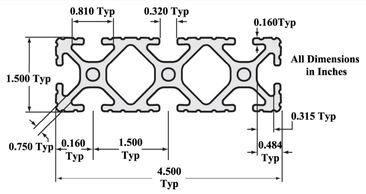
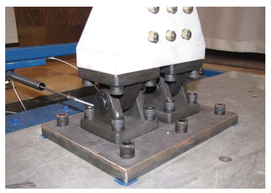
## Test Specimen

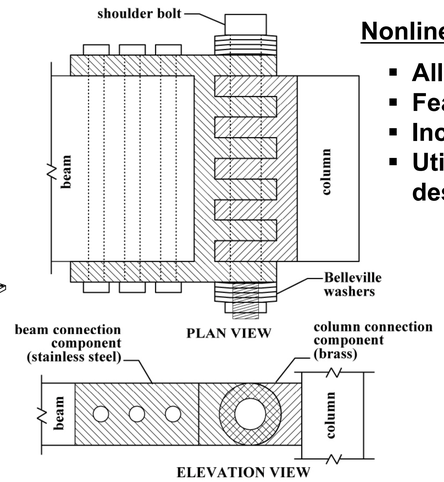



**One-Bay Six-Story Frame Structure:**

- Length-scale of 1/10
- Extruded aluminum alloy members with yield strength of 35 ksi
- Pinned column bases
- "Rigid" beam-column connections using three high-strength bolts that pass through the column and screw into holes tapped into the beam at each end

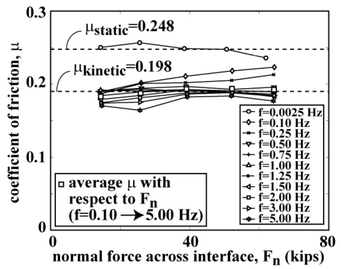


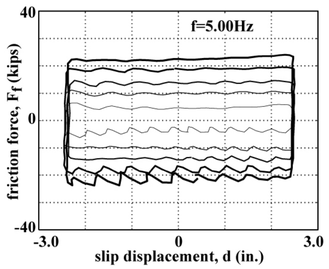






**Nonlinear Beam-Column Joints:**

- Allow for testing of nonlinear structures with different lateral strengths
- Feature a reconfigurable and reusable design for repeated testing
- Incorporate a friction fuse with stainless steel against brass friction surfaces
- Utilize a combination of shims and Belleville washers to consistently achieve the desired beam end moment capacity in each test

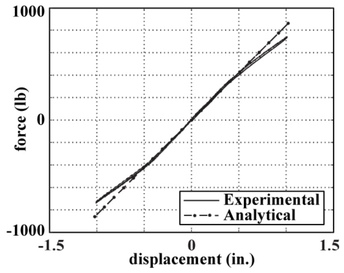



## Preliminary Test Results from Linear-Elastic Model

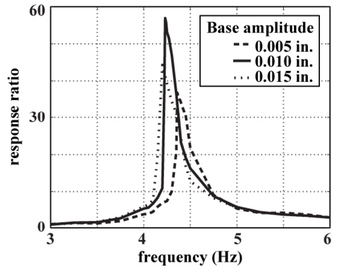
**Monotonic and Cyclic Pushover Tests:**

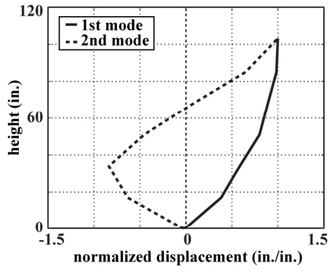
- 4th floor of structure held while base is displaced laterally using the shake table
- Force at 4th floor measured using a load cell while relative displacement with respect to the base measured using two string pot transducers
- Onset of nonlinear behavior occurred as the beam ends lost full contact with the columns due to the stretching of the beam-column connection bolts
- DRAIN-2DX and OpenSees analytical models show good comparison

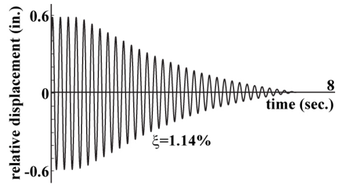


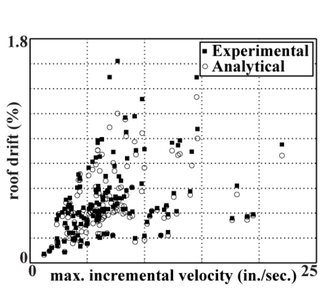
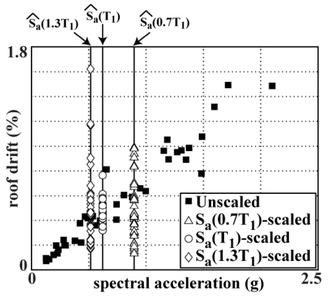
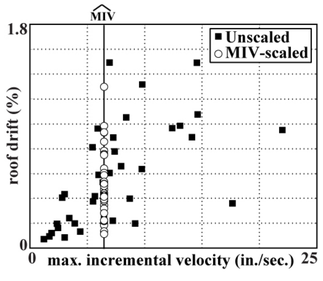

**Dynamic Sine-Sweep Tests:**

- Time-scale of 1/3
- Measured period of $T_1$=0.23 sec. (full-scale period of 0.69 sec.)
- Measured damping ratio of ξ=1.14%




**Earthquake Ground Motion Response:**

- 37 ground motion records scaled to
  (1) median $S_a(T_1)$; and
  (2) median MIV
- Records also scaled to
  (3) median $S_a(0.7T_1)$; and
  (4) median $S_a(1.3T_1)$
  to investigate uncertainties in period estimation
- Experimental and analytical results match well
- For the linear-elastic structure, $S_a(T_1)$ scaling method produced smallest dispersion in peak roof drift
- Dispersion more than doubled with 30% error in period estimation
- Remainder of project to focus on nonlinear structures