Eleventh U.S. National Conference on Earthquake Engineering
Integrating Science, Engineering & Policy
June 25-29, 2018
Los Angeles, California

ACCOUTING FOR DEMAND VARIABILITY OF BRACED FRAMES WITH A COMBINED INTENSITY MEASURE

N. Marafi[1], T. Li[2], A. Sen[3], J. Berman[4], M. Eberhard[5], D. Lehman[5], and C. Roeder[5]

ABSTRACT

Even for motions with similar spectral accelerations at the elastic period of the structure, the deformation demands of structures subjected to ground motions can vary greatly. Much of this variability can be attributed to: (1) the ground-motion duration and (2) the shape of the response spectrum. This paper applies a scalar ground-motion intensity measure (IM) that accounts for these effects to explain the variability of the deformation demands and the variability of the IM at various damage states computed for three steel, braced-frame buildings, subjected to five sets of ground motions. The uncertainty of the IM at various damage states is much lower using the new intensity measure than in terms of the spectral acceleration.

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N. Marafi, T. Li, A. Sen, M. Eberhard, J. Berman, D. Lehman, and C. Roeder. Accounting for Demand Variability of Braced Frames with a Combined Intensity Measure. *Proceedings of the 11th National Conference in Earthquake Engineering*, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.

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ABSTRACT

Even for motions with similar spectral accelerations at the elastic period of the structure, the deformation demands of structures subjected to ground motions can vary greatly. Much of this variability can be attributed to: (1) the ground-motion duration and (2) the shape of the response spectrum. This paper applies a scalar ground-motion intensity measure (IM) that accounts for these effects to explain the variability of the deformation demands and the variability of the IM at various damage states computed for three steel, braced-frame buildings, subjected to five sets of ground motions. The uncertainty of the IM at various damage states is much lower using the new intensity measure than in terms of the spectral acceleration.

Introduction

The deformation demands and collapse capacities of structures subjected to ground motions can vary, even for motions with similar spectral accelerations at the elastic period of the structure. This variability is mainly attributed to ground-motion characteristics not captured by spectral acceleration alone, such as (1) the ground-motion duration and (2) the shape of the spectrum. To quantify the variability in demand associated with these characteristics, five sets of ground motions have been compiled with varying ground-motion durations and a wide range of spectral shapes [1]. Some of these motions were selected from crustal earthquake sources that are short in duration and motions from subduction earthquakes that are much longer. To vary the spectral shape, motions were selected from sites that are sitting on rock or outside deep sedimentary basins, and from stiff soil or deep basin sites, which typically amplify spectral shape at longer periods.

Modelling

The variability in deformation demands due to these ground-motion characteristics was studied using a set of 3-, 9-, and 20-story archetypical buildings [2]. Figure 1 shows the elevation and floor

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plans for the three archetypes. These archetypes were designed using modern codes to resist lateral forces using special steel concentrically braced frames (SCBF) for an example site in Seattle. The archetypes were modeled in OpenSees [3] using a methodology that has been vetted against quasi-static cyclic experimental tests. The OpenSees model simulates the non-linear response of the archetype using a 2-dimensional idealization of the building lateral-force resisting system. The OpenSees model is illustrated in Figure 2.

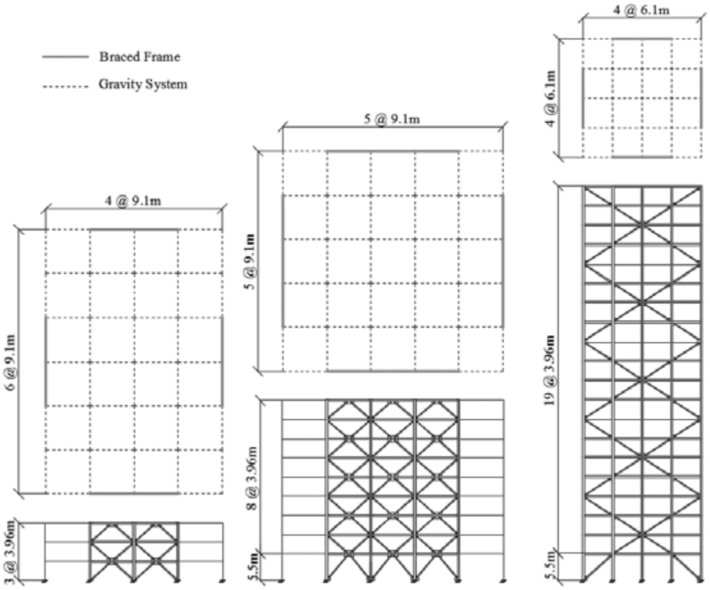

Figure 1. Elevations and floor plans of (a) 3-story, (b) 9-story and (c) 20-story buildings.

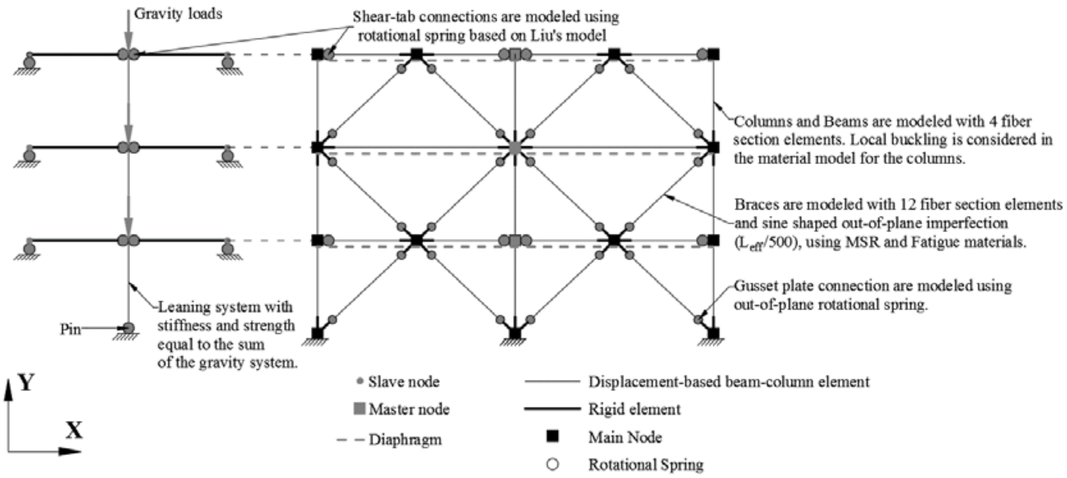

Figure 2. OpenSees Model

Archetype Response

Incremental dynamic analyses were performed for the three archetypes using five ground-motions sets: (1) a set of motions recorded during crustal earthquakes, which are part of the FEMA P-695 report [4], (2) motions recorded inside the Yufutsu basin in Japan during the 2001 Tokachi-Oki subduction earthquake, (3) motions recorded during that same earthquake but outside the Yufutsu basin, and motions selected from NGA-West-2 (from crustal earthquakes) that have similar spectral shapes (spectrally equivalent) as the (4) inside-basin and (5) outside-basin Yufutsu motions. Figure 3 shows collapse fragility curves as computed using the five ground-motion sets for the 3-story SCBF. The collapse capacities that correspond to the spectral acceleration corresponding to a 50% probability of collapse varied greatly among the ground-motion sets. The median collapse capacity varied from 1.21g for the inside-basin motions to 2.23g for the FEMA motions. This variation is attributed to ground-motion characteristics not captured by S_a but affect structural response.

To reduce this variation, a ground-motion intensity measure was formulated to account for the combined effects of spectral acceleration, ground-motion duration, and response spectrum shape. The intensity measure includes a new measure of spectral shape (SS_a) that integrates the spectrum over a period range that depends on the structure's ductility demand [5]. Figure 4 shows the same fragility function but defined with respect to a combined intensity measure (IM_{comb}) that is defined as $S_a D_s^{C_{dur}} SS_a^{C_{shape}}$ where D_s is defined as the 5-95% significant duration. The procedure to obtain exponents C_{dur} and C_{shape} is discussed in [5]. The collapse capacity of the structure is found to be more similar regardless of ground-motion set and the variability in collapse probability is shown to have reduced using IM_{comb} compared to S_a alone. This result indicates that variations in ground-motion duration and spectral shape explain much of the variation in collapse capacities for these frames.

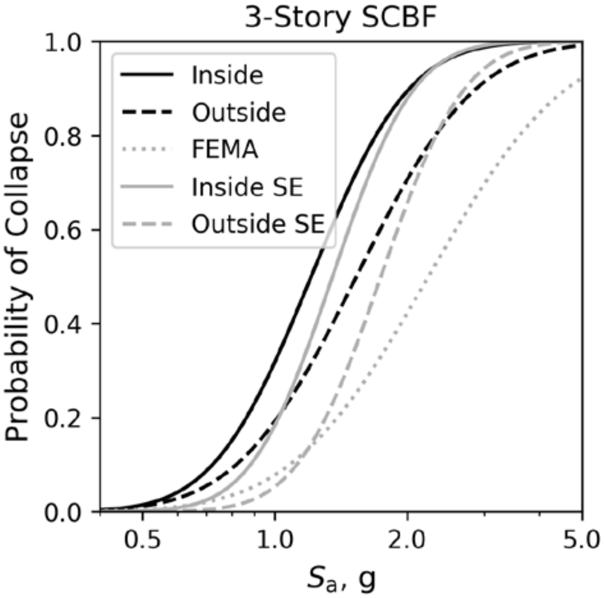

Figure 3. Collapse fragility function using spectral acceleration for the 3-Story SCBF using various ground-motion sets.

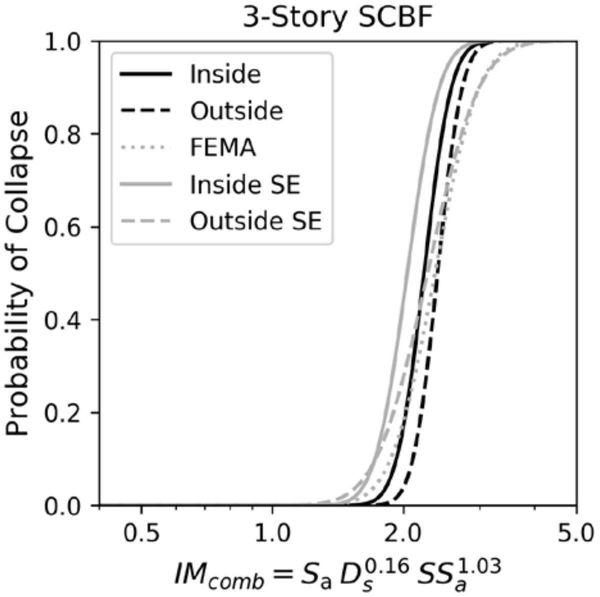

Figure 4. Collapse fragility function using a combined intensity measure for the 3-Story SCBF using various ground-motion sets.

The log-normal standard deviation of the maximum inter-story drift (an important deformation demand) was found to be ~0.9 for the 9-story archetype subjected to motions scaled to the maximum considered earthquake (MCE) spectral acceleration intensity at the structure's fundamental period. However, this variability was smaller (0.4-0.7) for ground-motion subsets from a particular source and site type, indicating that the entire set of recordings considered have characteristics which affect deformation demand that are unaccounted for in spectral acceleration. Using this combined intensity measure, the log-normal standard deviation of the deformation demand at an MCE hazard level reduced significantly (~0.3).

The combined intensity measure can also be used to reduce the uncertainty in the fragility function for other damage states. As an example, the fragility function for the 9-story SCBF is shown in Figure 5. The fragility functions shown predicts the probability of collapse (shown as a solid black line) and the probability of fracturing at least 10% of the braces in the building (shown as a dashed black line) for the recordings in all ground-motion sets combined. These collapse fragilities have been normalized by the median IM at each damage state in order to make the uncertainty comparable between damage states. Figure 5 shows that the uncertainty in reaching a damage state can be reduced using IM_{comb} (shown as gray lines) compared to S_a. This uncertainty can be quantified using the standard deviation of the IM (σ_{LN}) at a particular damage state. For the 9-story archetype, σ_{LN} was found to equal 0.46 and 0.36 for collapse and brace fracture, respectively. In contrast, σ_{LN} for IM_{comb} reduces to 0.23 and 0.26 for collapse and brace fracture, respectively.

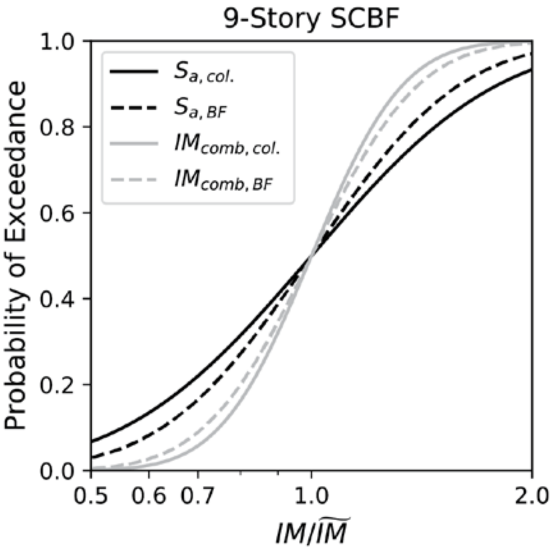

Figure 6. Fragility function for collapse and brace fracture using S_a and IM_{comb} for a 9-story SCBF

Conclusions

The combined intensity measure made it possible to explain the variability of the IM at various damage states (e.g., brace fracture and collapse) and the variability in the deformation demand with ground motions at MCE S_a intensity. This variability is attributed to key ground-motion characteristics not captured by commonly used IMs such as spectral acceleration. Future work will determine the sensitivity of various modeling parameters to different ground-motion characteristics at several damage states using the combined intensity measure.

Acknowledgments

This research was funded by the National Science Foundation under Grant No. EAR-1331412. The computations were facilitated through the use of advanced computational, storage, and networking infrastructure provided by the Hyak supercomputer system at the University of Washington.

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