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Seismic collapse prevention system for steel-frame buildings

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ABSTRACT

This paper presents an innovative "collapse prevention" system for seismic resistant design in new construction and existing buildings. The collapse prevention system consists of a collapse inhibiting mechanism, such as a pair of slack cables or loose linkages, working in tandem with the main lateral-force resisting system and engaging the gravity framing to avert collapse. In this holistic design approach, the main lateral-force resisting system and gravity framing are used to provide adequate performance under low to moderate level ground motions, and the collapse inhibiting mechanism is deployed as a back-up to provide life safety under extreme ground motions. The collapse inhibiting mechanism may be augmented with energy dissipation devices (small viscous fluid or visco-elastic solid dampers) to enhance performance under wind or small seismic events. Analytical performance of archetypical 1-story, 2-story, 4-story, and 8-story steel-frame buildings employing collapse prevention systems indicate that collapse prevention systems substantially reduce the probability of collapse during Maximum Considered Earthquake (MCE) ground motions, depending on the building and collapse inhibiting mechanism deployed. Seismic hazard data suggests that collapse prevention systems would provide a 1% or less risk of collapse in 50 years in many locations, mostly in the central and eastern United States.

1. Introduction

The current accepted practice in seismic resistant design of new buildings in the United States [1,2] is to proportion and detail structures such that there is no more than a 10% probability that the structure will collapse when subjected to the risk-based Maximum Considered Earthquake ground motions (MCE_R), which have a mean recurrence interval (MRI) of approximately 2475 years. While no explicit calculations are required to assess the true likelihood of collapse performance, safeguards are provided by well-established system configuration and detailing rules and by limits on computed drift.

The expectations for new building performance subjected to ground motions that occur more frequently than the MCE are loosely stated in the commentary for current design standards (e.g. [1]), but no calculations are required to assess the adequacy of the building's performance under such motions. However, there is significant historical evidence that earthquakes along the West Coast of the United States that occur more frequently than the MCE, and which produce less severe ground shaking than the MCE, can cause significant and unacceptable levels of damage. The 1994 Northridge California Earthquake, which caused an estimated $57 billion in losses [3], is a case in point. This earthquake had a magnitude of 6.7, and earthquakes of equivalent size are expected to reoccur once every 35 to 40 years in that area. Although it is technically incorrect to associate a single event with a return period, Northridge was one of many moderate-magnitude earthquakes that caused extensive economic loss in California during the span of only a few decades [4]. Thus, a significant shortcoming of the current practice for designing new buildings is that it does not explicitly address the lower hazard-level ground motions.

1.1. Performance-based design in the central and eastern United States

A broadened seismic design philosophy called performance-based earthquake engineering has emerged as a potential remedy, where the goal is to meet or exceed predefined performance objectives under different levels of ground motion. Although there is general agreement for the recurrence intervals assigned to the Design Basis Earthquake (DBE), and the MCE level ground motion, various performance-based design provisions assign different recurrence intervals for lower (serviceability and immediate occupancy) level ground motion (see commentary on the *International Performance Code* [2]). These intervals can vary anywhere from a 25-year MRI to a 72-year MRI.

Performance-based design was developed based on the characteristics of tectonic plate boundaries, like the western United States, where it has been the experience that frequent and occasional earthquakes can be very significant, as was the case with Northridge. While this expectation is appropriate for the western United States, it is not necessarily correct in the central and eastern United States.

Differences between seismic ground shaking that occurs more frequently than the MCE are plainly evident in many regions and across a wide range of low-hazard levels [5]. For example, Fig. 1 shows spectral

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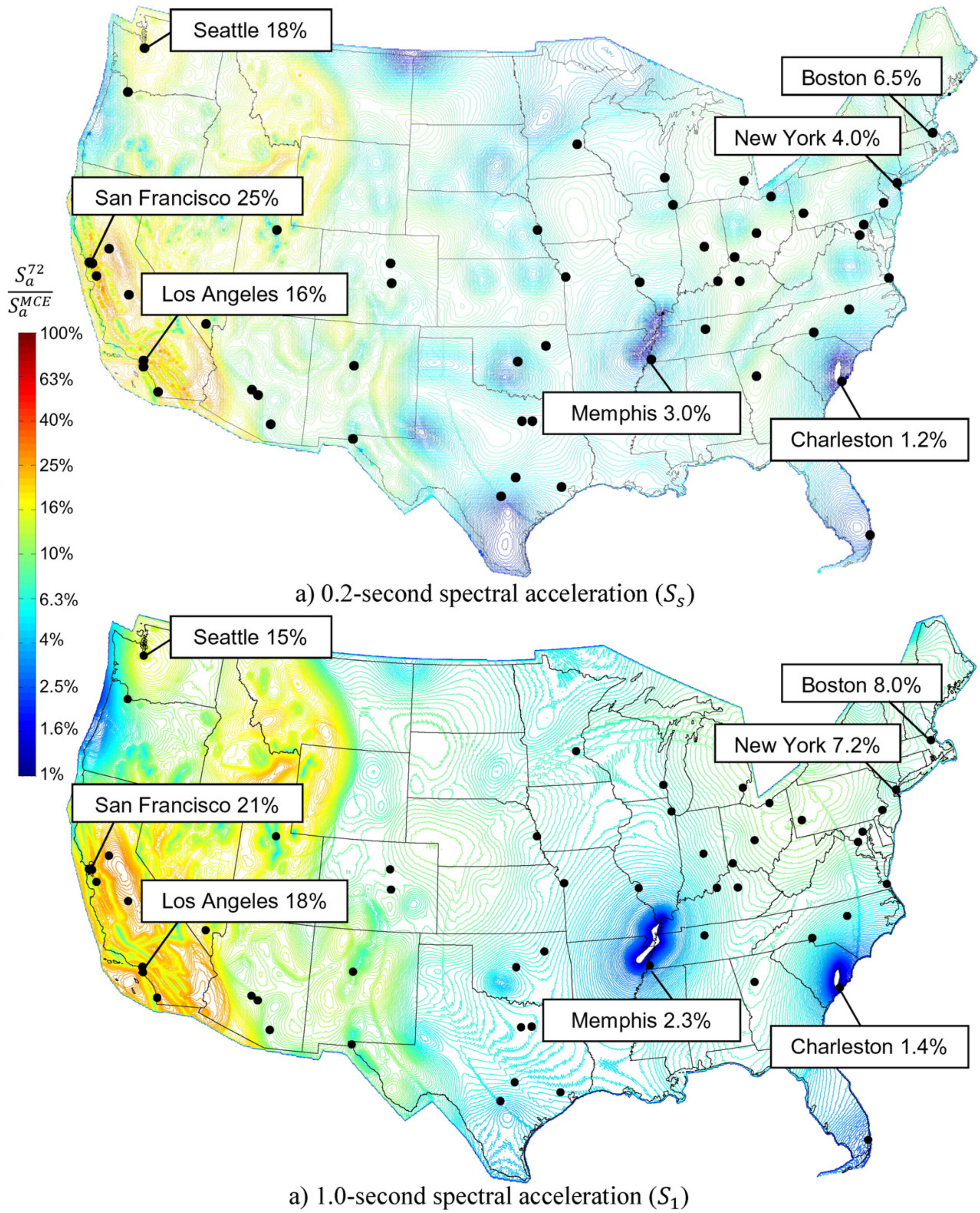

Fig. 1. Ratio of 72-year MRI spectral acceleration compared to MCE (2475-year MRI).

acceleration for the 72-year MRI compared to the MCE (2475-year MRI). The deterministic cap on ground motion used in ASCE 7–10 is not included. Fig. 1a compares the 0.2-s spectral accelerations (S_s), and Fig. 1b compares the 1.0-s spectral accelerations (S_1) using contour lines of constant values. Generally speaking, spectral demand with a 72-year MRI, is approximately 10% or less of the MCE for the central and eastern United States, and 20% of the MCE for the western United States. The ratio for high-seismic regions in the central and eastern United States is much lower (1% to 3%).

Thus, the nature of the overall seismic hazard is quite different in the central and eastern United States. Large magnitude earthquakes are possible outside the west, but they are rare. The impact of this difference is illustrated in Fig. 2, which shows the probability over the next 100 years of a 6.7-magnitude earthquake occurring in Los Angeles, California compared to Charleston, South Carolina. The probability was calculated using the USGS 2009 earthquake probability mapping application [6]. The probability is extremely high in Los Angeles (as high as 100% in many regions), but is less than 15% in Charleston, and the