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Seismic Design Loads for Controlling Site-Specific and Aggregate Risks

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Abstract

The purpose of seismic design is to reduce the risk to life and property from future earthquakes, where risk is defined as the probability of a loss. An increase in the seismic design load should reduce the seismic risk if everything else remains the same. The current approach toward seismic design is to reduce the risk at individual locations (site-specific risk) to an acceptable level. This approach is reasonable from the perspective of a building owner but not from the perspective of an entire community, because this approach does not ensure that the risk to multiple locations affected by the same earthquake (aggregate risk) is also reduced to an 'acceptable' level. This paper discusses a method of calculating the seismic design loads for controlling both the site-specific and the aggregate risks.

1. INTRODUCTION

Buildings and other structures are designed for seismic loads in order to keep the risk to life and property at an 'acceptable' level. There are two types of risk: (1) site-specific and (2) aggregate. The site-specific risk is from the perspective of a building owner. The aggregate risk is from the perspective of an entire community. The site-specific risk can be quantified as the annual probability of a loss exceeding a certain amount from a given building. The aggregate risk can be quantified as the annual probability of a loss exceeding a much greater amount from multiple buildings in the region.

The seismic design should be aimed at reducing both the site-specific and the aggregate risks (Malhotra 2007). Due to the highly random nature of earthquake ground motions, and uncertain construction quality, it is not possible to eliminate the seismic risk entirely, but it is possible to reduce it to an 'acceptable' level, assuming that the 'acceptable' level can be established. Ignoring the uncertainty in construction quality, we can say that the site-specific risk is proportional to the chance of exceeding the seismic design load at a given location and the aggregate risk is proportional to the chance of exceeding the seismic design load at many locations simultaneously. Therefore, the seismic design load for controlling both the site-specific and the aggregate risks should satisfy the following two criteria:

1. **Site-specific criterion.** The seismic design load at each site in the region should not be exceeded more than 0.002 times per year (or it should have an exceedance return period of 500 years for each site).
2. **Aggregate criterion.** The seismic design load over an area ≥ 100 km^2 (contiguous or separated) should not be exceeded more than 0.002 times per year (or it should

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have an exceedance return period of 500 years for an area ≥ 100 km^2 anywhere in the region).

The first criterion can be satisfied by performing a site-specific probabilistic seismic hazard analysis (e.g., Cornell 1971, Reiter 1991, McGuire 2004) of each site in the region and selecting design ground motions with a return period of 500 years. This is the current approach for obtaining the design ground motions (hence loads). The second criterion can be satisfied by performing an aggregate hazard analysis, discussed in this paper. The seismic design load should be the higher of the loads obtained from the two criteria. The idea of aggregate hazard has been discussed in the past. Rhoades and McVerry (2001) estimated the joint hazard at two sites. Wesson and Perkins (2001), Smith (2003), and Bazzurro and Luco (2005) estimated the aggregate (or portfolio) loss. This paper discusses the design ground motions for controlling the aggregate loss.

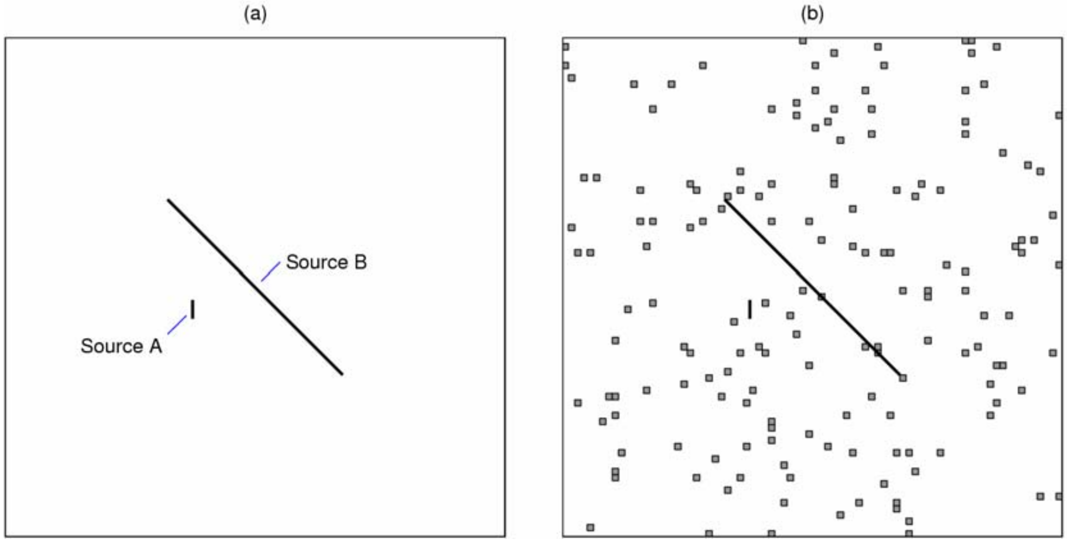

Figure 1. A region affected by two seismic sources: (a) Source A produces magnitude 6 M_w earthquakes and Source B produces magnitude 7.5 M_w earthquakes; (b) The shaded squares represent the area of interest, i.e., the area of current or future planned development in the region.

2. PROBLEM STATEMENT

Figure 1a shows a 400 km × 400 km region with only two seismic sources (faults). Source A produces only magnitude 6 M_w earthquakes with a recurrence interval of RI_A = 50 years or an occurrence rate of 1/50 = 0.02/year. Source B produces only magnitude 7.5 M_w earthquakes with a recurrence interval of RI_B = 450 years or an occurrence rate of 1/450 = 0.0022/year. The lengths of these sources are approximately given by the Wells and Coppersmith (1994) relationship. For the sake of simplicity, we assume 'firm rock' (BSSC 1998) site conditions throughout the region (average shear wave velocity of 760 m/s in the top 30 m). The earthquakes on Source B are only $1/9^{th}$ as frequent as the earthquakes on Source A, but they are much bigger in size, or they affect a much larger area compared to earthquakes on Source A. The shaded squares in Figure 1b represent the area of interest, i.e., the area with current or future planned development in the region. We will calculate the seismic design loads satisfying the site-specific and the aggregate criteria for the entire region.

3. METHOD

We use a statistical approach to calculate both the site-specific and the aggregate hazards for the region. First, we simulate numerous ground motion scenarios for earthquakes on Source A and Source B, considering the inter- and intra-event variabilities of ground motions (Brillinger and Preisler 1984, Abrahamson and Youngs, 1992, Wesson and Perkins 2001, Boore and Atkinson 2007). Figures 2a and 2b show two possible scenarios of peak ground accelerations (PGAs) due to earthquakes on Source A and Source B, respectively. Of course, infinite such scenarios are possible. No matter how high the design accelerations are for the region, there is some chance that the design accelerations will be exceeded (at a location or over a certain area) during a future earthquake. In the site-specific hazard analysis, we obtain the design accelerations at each location which will be exceeded at a rate of 0.002 times per year. In the aggregate hazard analysis, we systematically raise the design accelerations for the region, such that the design accelerations are exceeded over an area ≥ 100 km^2 at a rate of 0.002 times per year. While, the site-specific hazard analysis is performed separately for each site, the aggregate hazard analysis is performed simultaneously for the entire region.

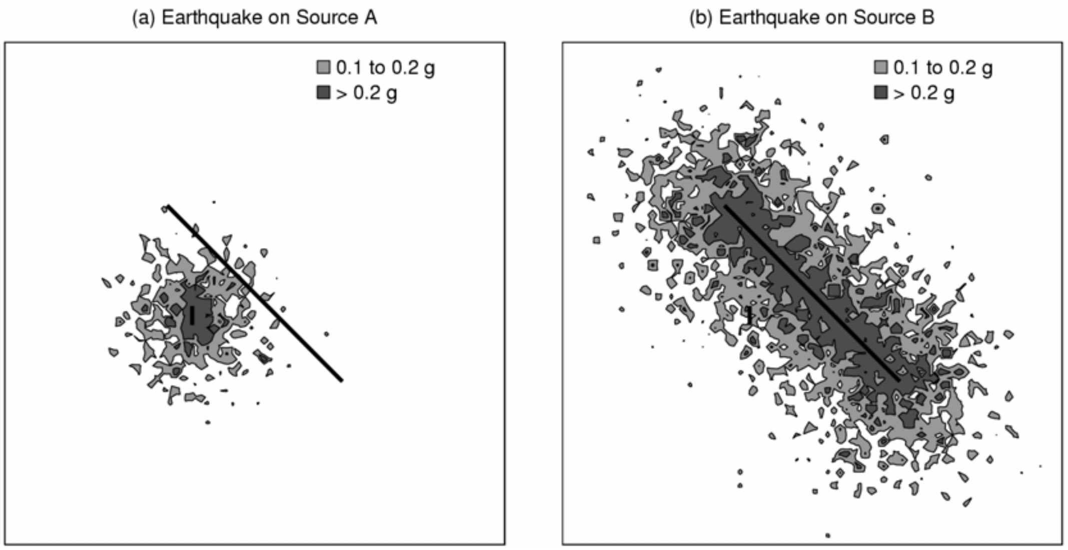

Figure 2. Peak ground acceleration (PGA) contours for two possible earthquake scenarios for: (a) Source A, and (b) Source B.

4. RESULTS

Figure 3a shows the 500-year return period PGAs from the site-specific hazard analysis. The seismic design of buildings, based on the 500-year return period site-specific PGAs, will keep the site-specific risk at an acceptable level because the design acceleration at any given location will only be exceeded 0.002 times per year. However, there is no guarantee that the seismic design based on the 500-year return period site-specific PGAs (Figure 3a) will keep the aggregate risk at an acceptable level, because when the design acceleration is exceeded at one location, it may also be exceeded at numerous other locations, thus posing an unacceptable aggregate risk. In order to control the aggregate risk, the seismic design accelerations should satisfy the aggregate criterion.

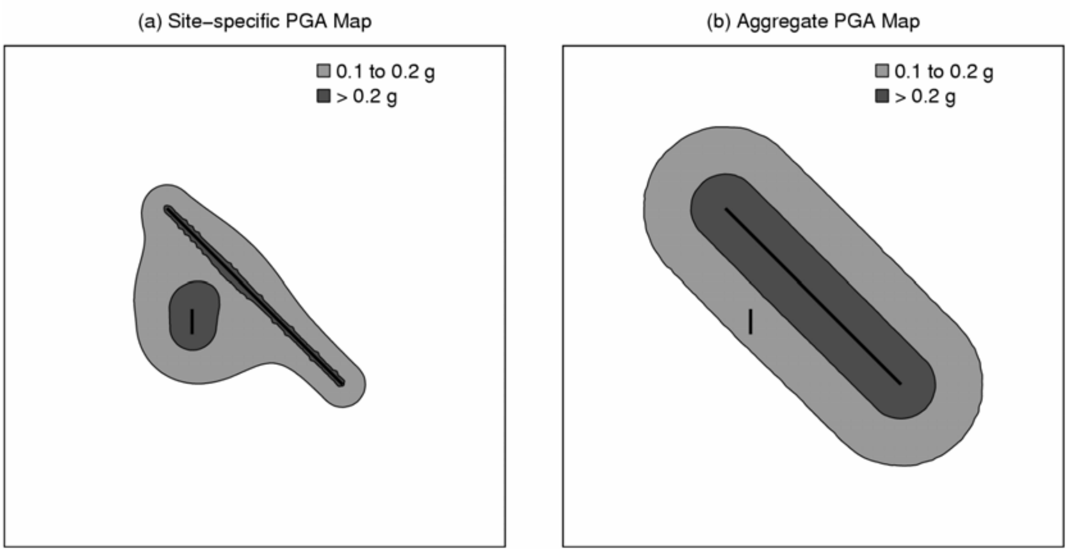

Figure 3. Design accelerations satisfying the: (a) site-specific criterion, and (b) aggregate criteria.

Figure 3b shows the design accelerations from the aggregate hazard analysis. The accelerations shown in Figure 3b will be exceeded over an area ≥ 100 km^2 with a return period of 500 years. Figure 4a shows the higher of the PGAs from Figures 3a and 3b. Therefore, the PGAs displayed in Figure 4a satisfy both the site-specific and the aggregate criteria. Figure 4b shows the controlling criterion at each location. The site-specific criterion controls the design accelerations near the more active seismic source (Source A), while the aggregate criterion controls the design accelerations near the larger source (Source B).

5. CONCLUSIONS

1. There are two types of seismic risk: (1) site-specific risk is from the perspective of a building owner; (2) aggregate risk is from the perspective of a community.
2. The seismic design loads for controlling both the site-specific and the aggregate risks should satisfy the following criteria:
    a. **Site-specific criterion.** The seismic design load at each site in the region should not be exceeded more than 0.002 times per year.
    b. **Aggregate criterion.** The seismic design load over an area ≥ 100 km^2 (contiguous or separated) should not be exceeded more than 0.002 times per year.

   The site-specific criterion is satisfied by performing a site-specific seismic hazard analysis. The aggregate criterion is satisfied by performing an aggregate hazard analysis discussed in this paper.

3. The site-specific hazard analysis is carried out for each site independently of other sites in the region. The aggregate hazard analysis is carried out simultaneously for all sites in the region.
4. The site-specific hazard is controlled by frequent earthquakes even if they are small in magnitude. The aggregate hazard is controlled by large earthquakes even if they are rare.

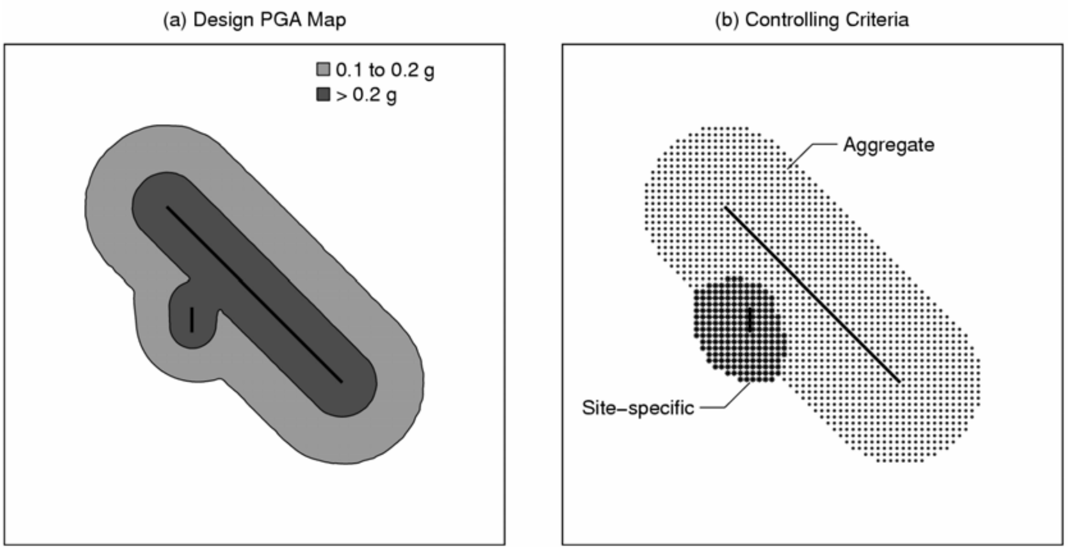

Figure 4. Combining site-specific and aggregate maps: (a) Design accelerations satisfying both site-specific and aggregate criteria, and (b) Controlling criterion for design accelerations at different sites.

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