Ninth Canadian Conference on
Earthquake Engineering
Ottawa, Ontario, Canada
26-29 June 2007

USE OF MINIMUM CAV IN SEISMIC HAZARD ANALYSES

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ABSTRACT

Current seismic hazard methods generally utilize a lower bound body wave magnitude cut-off value of 5.0 (approximate moment magnitude of 4.6) to integrate the probabilistic seismic hazard. This lower bound magnitude cut-off level is unrealistically sharp, and can lead to overrepresentation of small magnitude earthquakes in areas where hazard is controlled by source zones. Reed and Kennedy (1988) recommended cumulative absolute velocity (CAV) as a characterization of the potential for small earthquakes to damage industrial facilities. A CAV value of 0.16 g-sec was defined in past studies to characterize a conservative estimate of the threshold between damaging earthquakes and non-damaging earthquakes for engineered structures. Watson-Lamprey and Abrahamson (2007) modeled CAV as a function of the uniform duration, magnitude, peak ground acceleration, and site shear wave velocity. An example application of the CAV filtering to seismic hazard in the ENA is presented. For return periods of 10,000 years the application of a minimum CAV value significantly reduces the contribution of small magnitude earthquakes to the total hazard. The magnitude of the dominant earthquake increases by applying the minimum CAV. This example shows that the standard PSHA studies which use a minimum magnitude of 4.6 can overestimate the hazard by including earthquakes that are not damaging but may have large high frequency response spectral accelerations.

Introduction

Probabilistic seismic hazard analysis (PSHA) for a site integrates the hazard from all possible earthquakes in the site region that are potentially damaging. In current practice, non-damaging earthquakes are those with magnitudes below a conservatively determined lower bound earthquake magnitude. For these applications, earthquakes above the minimum magnitude are considered to be potentially damaging, and earthquakes below the minimum magnitude are not potentially damaging. This lower bound is included in the PSHA by setting the minimum magnitude in the hazard integral as shown in Equation 1.

$$\nu(Sa>z)=\sum_{i=1}^{N_{source}} N_i(M>M_{\min}) \int_{M_{\min}}^{M_{\max_i}} \int_{r=0}^{\infty} f_{mi}(M)\, f_{ri}(r,M)\, P(Sa>z \mid M,r)\, dr\, dM \qquad (1)$$

where $\nu(Sa>z)$ is the hazard rate, f_m and f_r are probability density functions describing the distributions of

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earthquake magnitudes and distances, respectively, and $N_i(M>M_{min})$ is the rate of earthquakes for the i^{th} source.

The use of a conservative lower bound magnitude approach has an important negative impact on hazard estimation, causing a bias to high hazard particularly for higher response spectra frequencies. The bias is a consequence of incorporating non-damaging earthquakes into the hazard. These are primarily small magnitude events near the site of interest, which occur with much greater rate than larger magnitude earthquakes because of the exponential increase in the number of earthquakes with decreasing magnitude. As an example, the deaggregation of the 20 Hz spectral hazard for a CEUS rock site, located away from the Charleston and New Madrid source zones, is shown in Figure 1. This example hazard determination used a minimum moment magnitude of 4.6.

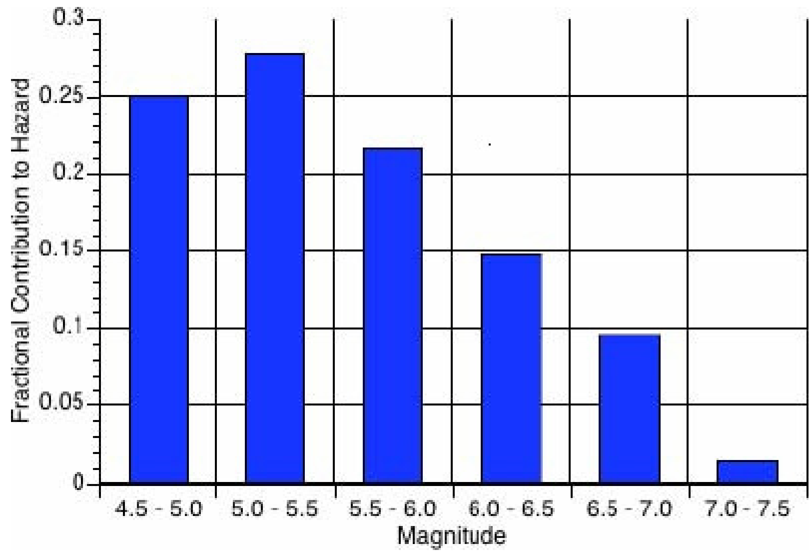

Figure 1. Example of deaggregation for ENA source zones for 20 Hz spectral acceleration. There is a large contribution to the hazard from earthquakes near M=4.6, the lower bound magnitude.

Figure 1 shows that there is a large contribution from events with magnitudes just above the minimum magnitude. If these small magnitude earthquakes are not potentially damaging, then the computed hazard will be biased to high ground motion values and the determination of the controlling earthquake will be biased to smaller magnitudes and closer distances.

As an alternative to using earthquake magnitude to determine non-damaging earthquakes, Reed and Kennedy (1988) proposed using the ground motion measure, denoted as CAV, given by the integral of the absolute value of a ground motion acceleration recording. To make the CAV value representative of strong ground shaking rather than coda waves (small amplitudes that can continue on for a long time after the strong shaking), O'Hara and Jacobson (1991) restricted the integration for computing CAV to 1-second time windows that have amplitudes of at least 0.025g. This definition of CAV is given by:

$$CAV = \sum_{i=1}^{N} H(pga_i - 0.025) \int_{t=t_i}^{t_{i+1}} |a(t)| dt \qquad (2)$$

where N is the number of 1-second time windows in the time series, pga_i is the peak ground acceleration (in g) during time window i, t_i is the start time of time window i, and H(x) is the Heaviside function (unity for x>0 and 0 otherwise).

As shown by O'Hara and Jacobson (1991), a CAV value of 0.16g-sec is associated with a negligible level of observed damage to buildings of good design and construction. Based on the definition in Equation 2, the CAV parameter is a measure of the mean deviation of the strong motion portion of the acceleration record times the duration. Although named the "Cumulative Absolute Velocity", the CAV is not directly related to the ground motion velocity (derivative of acceleration), but it does have units of velocity (g-s). The parameter is denoted by the name Cumulative Absolute Velocity since, if it is noted that $a = dv/dt$, the integral in Equation 2 may be written as $\sum_j |\Delta v_j|$ or the accumulative changes in velocity minima/maxima within each one second time interval.

Watson-Lamprey and Abrahamson (2007) developed the technical basis for establishing the appropriate distribution of low magnitude earthquakes for use in probabilistic seismic hazard computations for nuclear power plant applications. The most direct method for applying the minimum CAV model as part of the hazard calculation is to add an integral over the PGA aleatory variability. This becomes:

$$v(Sa > z) = \sum_{i=1}^{N_{source}} N_i(M > M_{\min}) \int_{M=M_{\min}}^{M_{\max i}} \int_{R=0}^{\infty} \int_{\varepsilon_{PGA}=-5}^{5} \begin{matrix} \{f_{mi}(M) f_{ri}(r,M) f_{\varepsilon}(\varepsilon_{PGA}) \\ P(CAV > 0.16 \mid M, PGA(M,R,\varepsilon_{PGA})) \\ P(Sa > z \mid M,R,PGA)\} d\varepsilon_{PGA} dr dM \end{matrix} \quad (3)$$

where P(Sa>z|M,R,PGA) is given by:

$$P(Sa > z \mid M,R,PGA) = 1 - \Phi(\varepsilon'_{SA}) \quad (4)$$

and

$$\varepsilon'_{Sa} = \frac{\ln(z) - (\ln Sa_{med}(M,R) + b_1 \varepsilon_{PGA} \sigma_{SA})}{\sqrt{1 - b_1^2}\,\sigma_{SA}} \quad (5)$$

Two models for CAV were proposed based on both the ground motion parameter and the earthquake parameters. The first CAV model was developed based on the extensive strong motion data set from the western United States (WUS) in two steps. In the first step, CAV is modeled as a function of the uniform duration, magnitude, peak ground acceleration, and site shear wave velocity. In the second step, the uniform duration is modeled as a function of the peak ground acceleration, magnitude, and site shear wave velocity. Taken together, these two steps lead to a model of CAV that depends on parameters that are available in a standard PSHA. Comparisons with a small set of ground motions from earthquakes in the central and eastern United States (CEUS) and Canada show that the CAV model and the duration model developed from the WUS data sets are also applicable to the CEUS earthquakes.

The 2-step approach found that there was no need to modifiy the duration model for ENA earthquakes. Therefore, a second CAV model was developed using the combined WUS and ECUS/Canadian data sets. The resulting probability of exceeding CAV for the 1-step model is comparable to that from the 2-step model, and is simpler to implement.

Example Application

As an example, the CAV filtered hazard is computed for a CEUS rock site using the USGS (Frankel et al. 2002) smoothed seismicity and the Toro et al (1997) attenuation relation. No fault sources were included. In this example, the CAV filtering is applied inside the hazard integral. The CAV is modeled using the two-step approach from Watson-Lamprey and Abrahamson (2007).

The hazard curves for 20 Hz spectral acceleration are shown in Figure 2 with and without the CAV filtering. The effect of removing the events with CAV less than 0.16g-sec is to flatten the hazard curve at small ground motion levels. There is little effect on the hazard curve for high ground motion levels since these levels will be associated with CAV values greater than 0.16g-sec.

The uniform hazard spectrum for a probability level of 1E-4 is shown in Figure 3 with and without the CAV filtering. At a hazard level of 1E-4, the UHS is reduced by about 10-25% due to CAV filtering. This example is for a site that is not close to either the Charleston or New Madrid sources. For sites close to these sources, the effect of the CAV filtering on the low frequency part of the UHS will be smaller since the ground motions that form these larger magnitude earthquakes will have large CAV values.

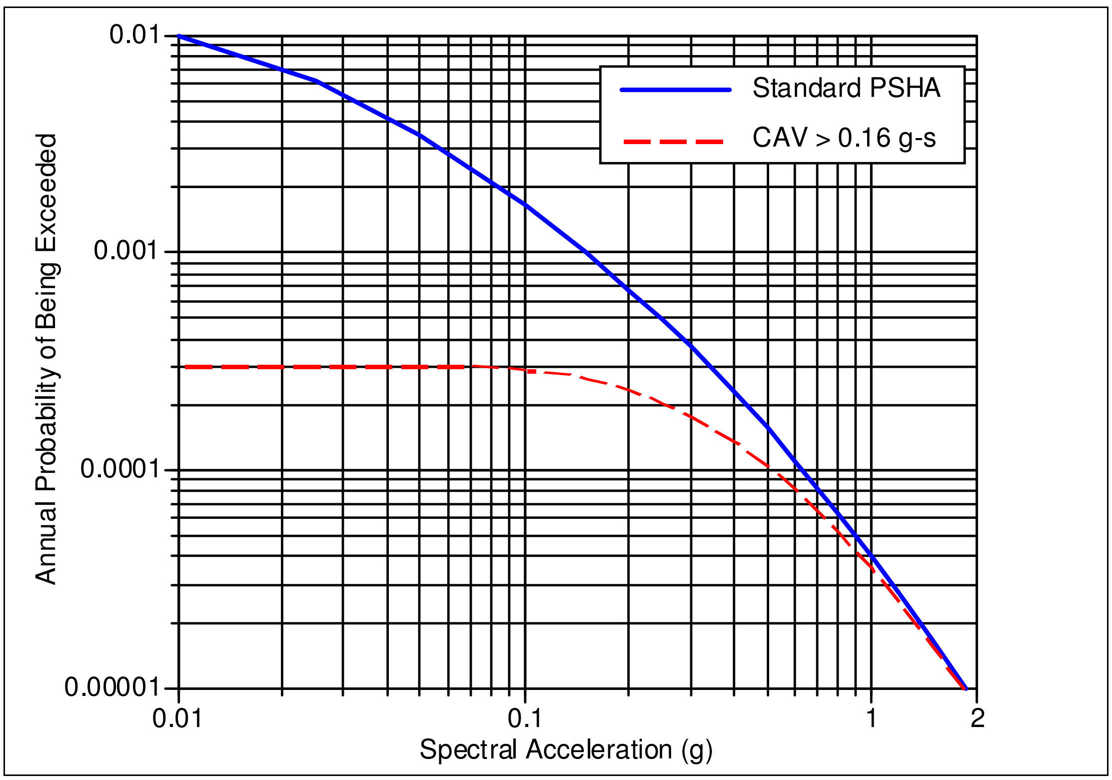

Figure 2. 20 Hz hazard computed with and without CAV filtering.

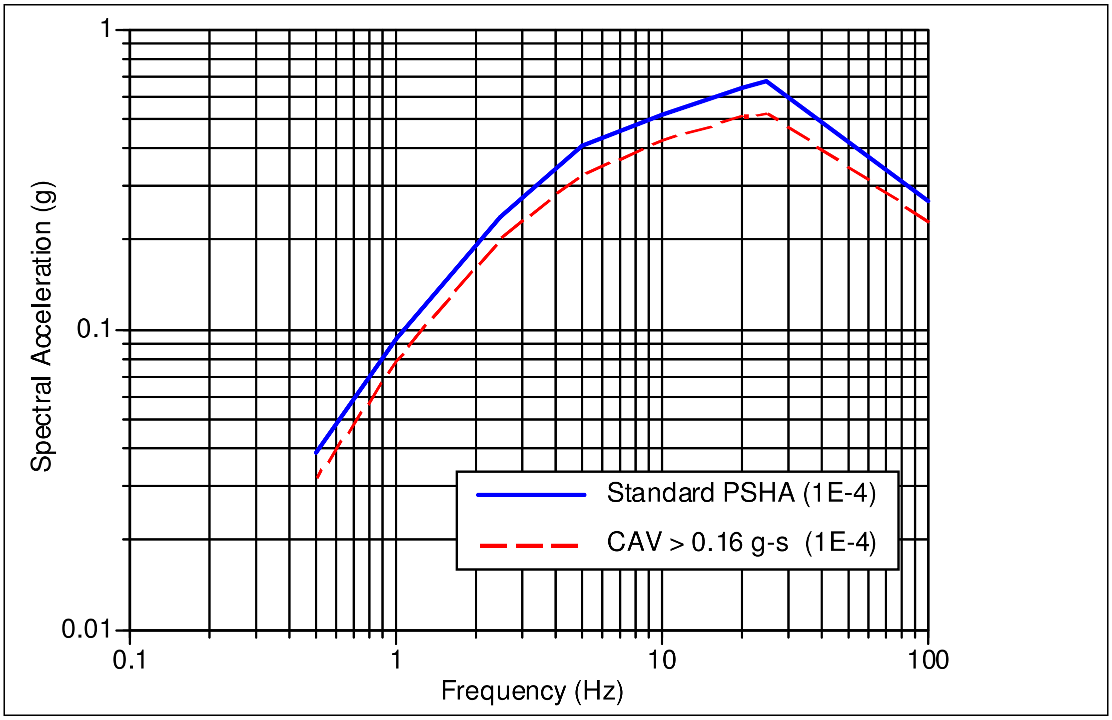

Figure 3. UHS for 1E4 with and without CAV filtering.

The example deaggregation for 20 Hz spectral acceleration for a hazard level of 1E-4 is shown in Figure 4 with and without the CAV filtering. The effect of the CAV filtering is to remove the contribution from smaller magnitudes, shifting the peak in the deaggregation to larger magnitudes and larger distances. For the PSHA using a fixed lower bound moment magnitude of 4.6, there is a significant contribution from **M**4.6-5.0, but these are removed in the CAV filtered hazard.

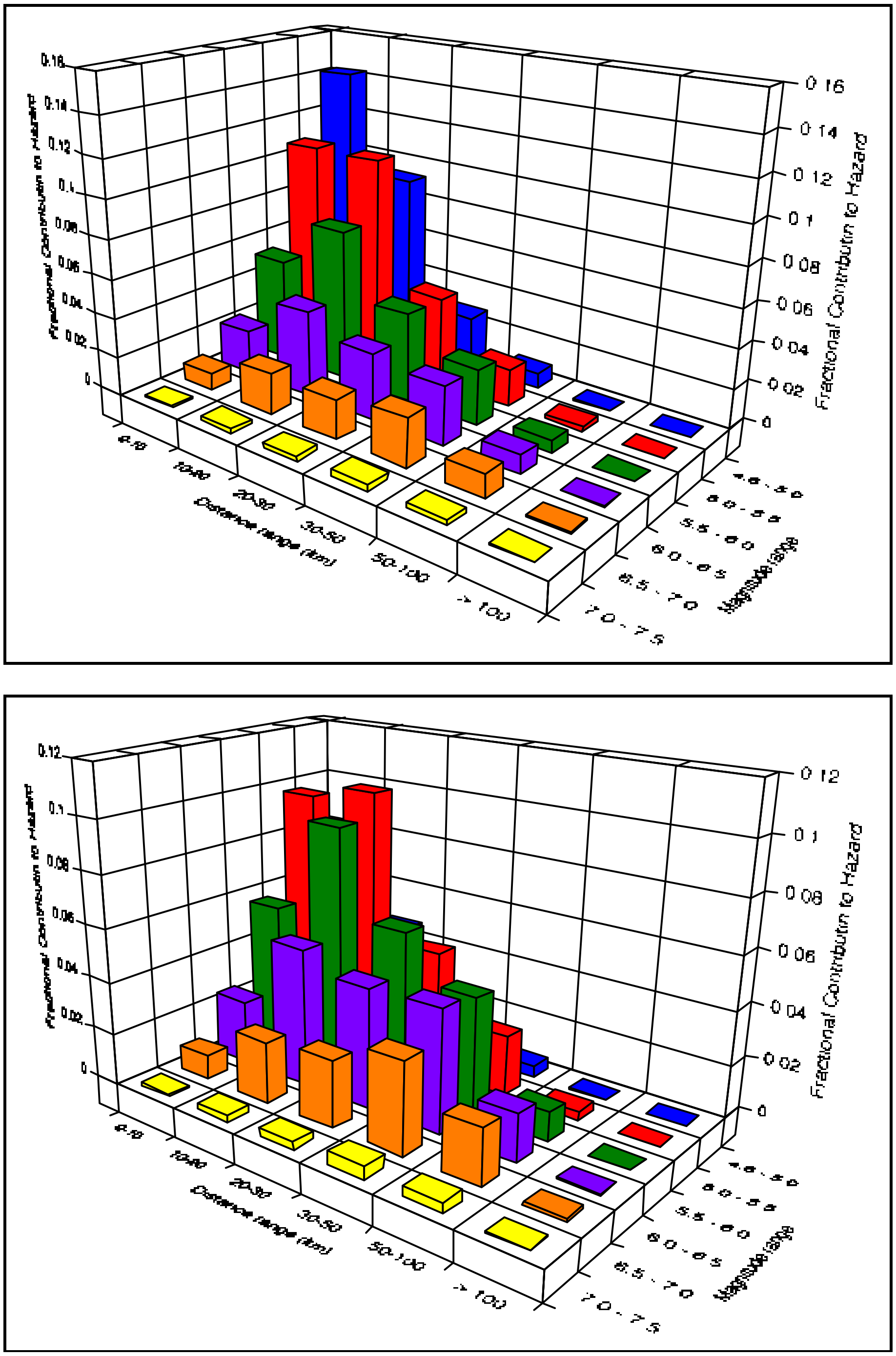

Figure 4. Deaggregation of 20Hz spectral acceleration hazard for 1E4. The upper plot is the standard PSHA. The lower plot is the CAV filtered PSHA.

Conclusions

Current seismic hazard methods generally utilize a lower bound body wave magnitude cut-off value of 5.0 (approximate moment magnitude of 4.6) to integrate the probabilistic seismic hazard. This lower bound magnitude cut-off level was a conservatively defined value based on several past research studies whose objective was to estimate the damage potential of small earthquakes. A much more complete and technically defendable characterization of the damage potential for small earthquakes was determined to be the cumulative absolute velocity (CAV). A CAV value of 0.16 g-sec was defined in past studies to characterize a conservative estimate of the threshold between damaging earthquake motions and non-damaging earthquake motions for well-engineered structures. The application of a minimum CAV value is shown to significantly reduce the contribution of small magnitude earthquakes to the total hazard leads to a controlling earthquake that more correctly represents the contributions of potentially damaging earthquakes to the hazard at a site. At high frequencies, the magnitude of the controlling earthquake increases from near magnitude 5.25 for the fixed lower bound moment magnitude 4.6 to magnitude 5.8 by applying the CAV model.

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