Seismic Hazard de-Aggregation and Ground-Motion Sensitivities for Yucca Mountain

by Gabriel R. Toro, Risk Engineering, Inc.

Introduction

This report summarizes the results of additional de-aggregation and sensitivity calculations performed on the Yucca Mountain seismic-hazard models and results documented in CRWMS-M&O (1998, the YMPSHA) and in Toro (2003). The objective is to provide further insights into the seismic sources and expert models that control seismic hazards at very low exceedence probabilities.

These calculations consider peak ground acceleration (PGA) and peak ground velocity (PGV), for annual exceedence probabilities ranging from 10^{-4} to 10^{-8} (which are associated with PGAs of 0.5 and 11g and with PGVs of 50 to 1300 cm/s, respectively). The first value represents the range of interest for the design of surface facilities; the second represents the range of interest for for performance assessment of the repository. For the sake of brevity, this report contains only the most salient graphical results; the complete set of results is contained in the Powerpoint file from the August 23 presentation, which will be distributed by the USGS.

De-Aggregation of Seismic Hazard

These results use finer magnitude and distance resolutions, and extend to lower probabilities, than the de-aggregation results in the YMPSHA. The objective is to provide additional insights into the magnitude-distance-epsilon combinations that dominate seismic hazard for low exceedence probabilities.

Results in the YMPSHA and in the presentation materials indicate that the seismic hazard for 10^{-4} comes from the various seismic-source classes considered (i.e., local faults, local area sources, and regional faults), especially from the first two. For 10^{-8}, on the other hand, most of the hazard comes from local faults.

Figure 1 shows the de-aggregation of the mean PGA hazard for 10^{-4} and 10^{-8}, in the form of joint and marginal distributions. The marginal distributions for 10^{-8} are shown separately for each ground-motion expert. Examining the hazard contributions by magnitude, we observe that the hazard at both 10^{-4} and 10^{-8} comes from the same broad range of magnitudes and that the modal value slightly above magnitude 6. Examining the hazard contributions by distance, we observe that the most of the hazard for 10^{-4} comes from distances between 0 and 10 km. The two spikes at 0.5[1] and 3.5 km, which are associated with the contributions to hazard from the Solitario Canyon and Paintbrush faults[2], are approximately equal. For 10^{-4}, the contribution from Solitario is much greater than the contribution from Paintbrush. This is true for all ground-motion experts

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[1] The contribution shown at a distance of 0.5 km corresponds to contributions from the first distance bin, which extends from 0 to 1 km. All distances shown are closest distance to the rupture (the distance metric used by all YMPSHA attenuation equations).

[2] The YM site is located on the foot wall of Solitario and on the hanging wall of Paintbrush

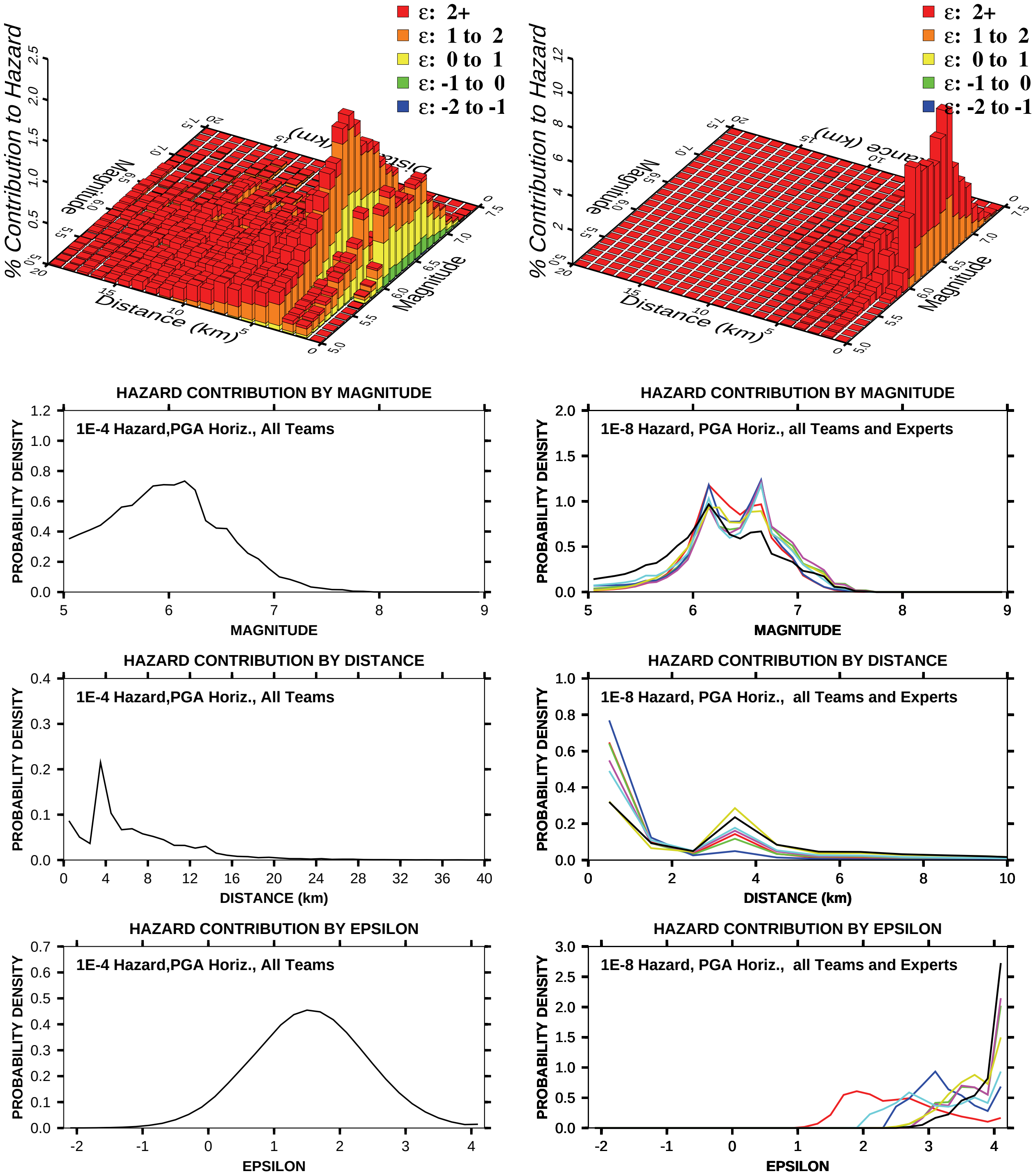

Figure 1. Joint and marginal de-aggregation results for the PGAs with annual exceedence probabilities of 10^{-4} (left, PGA=0.5g) and 10^{-8} (right; PGA=11g). The marginal results for 10^{-8} are presented separately for each expert (red, Anderson; green, Boore; blue, Campbell; magenta, McGarr; yellow, Silva; cyan, Somerville; black, Walck).

except Silva and Walck. Examining the hazard contributions by epsilon[3], we notice that the contributing epsilons shift to higher values as the exceedence probability varies from 10^{-4} to 10^{-8}. For 10^{-8}, we see large differences among ground-motion experts.

In summary, the de-aggregation results for PGA indicate that most of the 10^{-4} hazard comes from earthquakes in the Solitario Canyon and Paintbrush faults, while most of the 10^{-8} hazard comes from earthquakes in the Solitario Canyon fault. Results for PGV (not shown here) exhibit similar trends, except that there are moderate contributions from magnitudes 7 to 8.

Sensitivity to Ground-Motion Experts

Figures 2 and 3 show the mean hazard calculated using the models specified by each ground-motion expert. These results differ from those in the YMPSHA in that they extend to 10^{-8} and that they are averaged over all source-characterization teams.

Each ground-motion expert specified a median attenuation equation, a value of σ, and the expert's estimates of the uncertainty in the median (σ_μ) and uncertainty in σ (σ_σ). All of these quantities were allowed to vary with magnitude and distance.

For PGA, and to a lesser degree for PGV, Anderson's results are significantly higher than those of the other experts. Results for the other experts show moderate scatter, except for Boore's PGV results, which are significantly lower than the others. At 11g (corresponding to 10^{-8} annual exceedence probability), Anderson contributes 70% of the mean seismic hazard.

Examination of the figures in Section 6 of the YMPSHA suggests that the main reason for Anderson's higher results is his estimate of σ_μ, particularly at short distances (see Figures 6-7 through 6-10 of YMPSHA)[4].

Other results, not shown here, indicate that the effect of σ_μ on amplitudes for a given exceedence probability (averaged over all ground-motion experts) is approximately 25% for 10^{-4} and 50% for 10^{-8}. The effect of σ_σ is approximately 5% for 10^{-4} and 50% for 10^{-8}. The latter effect is roughly the same for all ground-motion experts.

In summary, the model specified by one of the ground-motion experts leads to much higher estimates of seismic hazard than the other experts. This difference is due mainly to that expert's estimate of uncertainty in mean hazard (σ_μ). For an exceedence probability of 10^{-8}, the effect of

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[3] Epsilon represents the difference between ln[actual ground-motion amplitude] and ln[predicted (median) ground-motion amplitude], expressed in units of the ground-motion standard deviation σ, Thus, if we take a σ value of 0.5 (which is typical of PGA), an epsilon of 3 implies that the PGA is $\exp[0.5 \times 3] = 4.5$ higher than the predicted PGA. In figure 1, the $\varepsilon = 4$ value contains the contributions from $\varepsilon \geq 4$.

[4] The effect of σ_μ on the mean amplitude for a given exceedence probability is approximately a factor of $\exp[\tfrac{1}{2} \kappa \sigma_\mu^2]$ (relative to the result that would be obtained by ignoring uncertainty in the median), where κ is the slope of the hazard curve in log-log space (typically 3 to 4 at the amplitudes of interest). Therefore, $\sigma_\mu = 0.78$ (Anderson's value for 1-km distance) implies a factor of 2.5 in amplitudes for a typical slope of $\kappa = 3$. In contrast, $\sigma_\mu = 0.4$ (a value typical of all experts except Anderson and Campbell) for 1 km), implies a factor of 1.3. The approximation used here is based on equations in Appendix A of NUREG/CR-6769.

uncertainty in sigma is as important as the effect of uncertainty in the median. The results for PGV show similar trends.

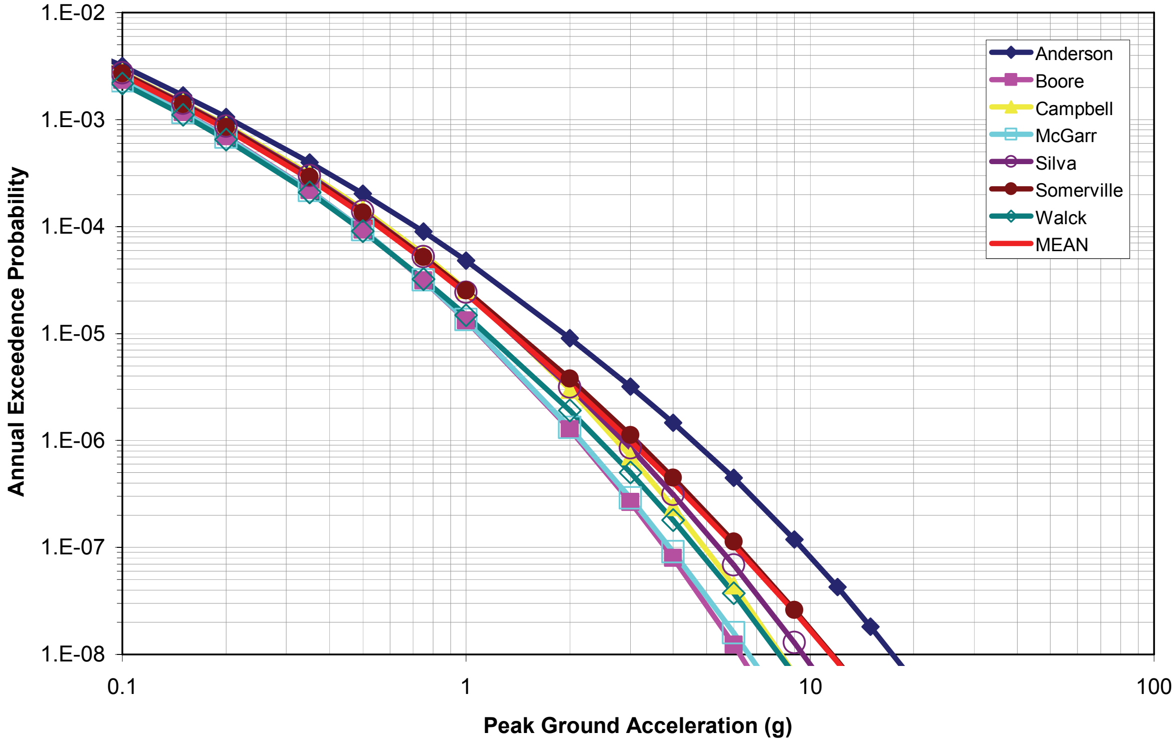

Figure 2. Mean PGA hazard by ground-motion expert.

Recommendations

The first lesson from these results is that SSHAC level-IV PSHA studies need additional feedback to the experts because the effects of unintended differences between expert models may have very large effects on the hazard results for very low exceedence probabilities. In fact, we have extracting additional insights from the de-aggregation information as part of this exercise. All these insights should have been available to the source-characterization and ground-motion experts as part of the feedback.

The high epsilons obtained in the 10^{-8} de-aggregation, together with existing results on the spatial variation of peak ground motions (e.g., Abrahamson and Sykora, 2003), imply that these peak motions may only occur in a small fraction of the repository area.

Ground-motion modelers can take the following two approaches in their effort to improve their inputs to low-probability PSHAs: (1) focus on maximum motions and try to define the maximum motions using physical constraints, or (2) improve their overall models (perhaps including the mechanisms that control maximum motions), in an effort to reduce the aleatory and epistemic uncertainties. The first approach is the one taken by PEGASOS, and may be viewed as the development of attenuation equations for the maximum possible motion (this is likely to be much more difficult than defining an attenuation equation for the median amplitude). The second approach may be more fruitful in the long term, but will probably require a significant research effort. It will also require a shift in emphasis from "getting the median right" (which may turn

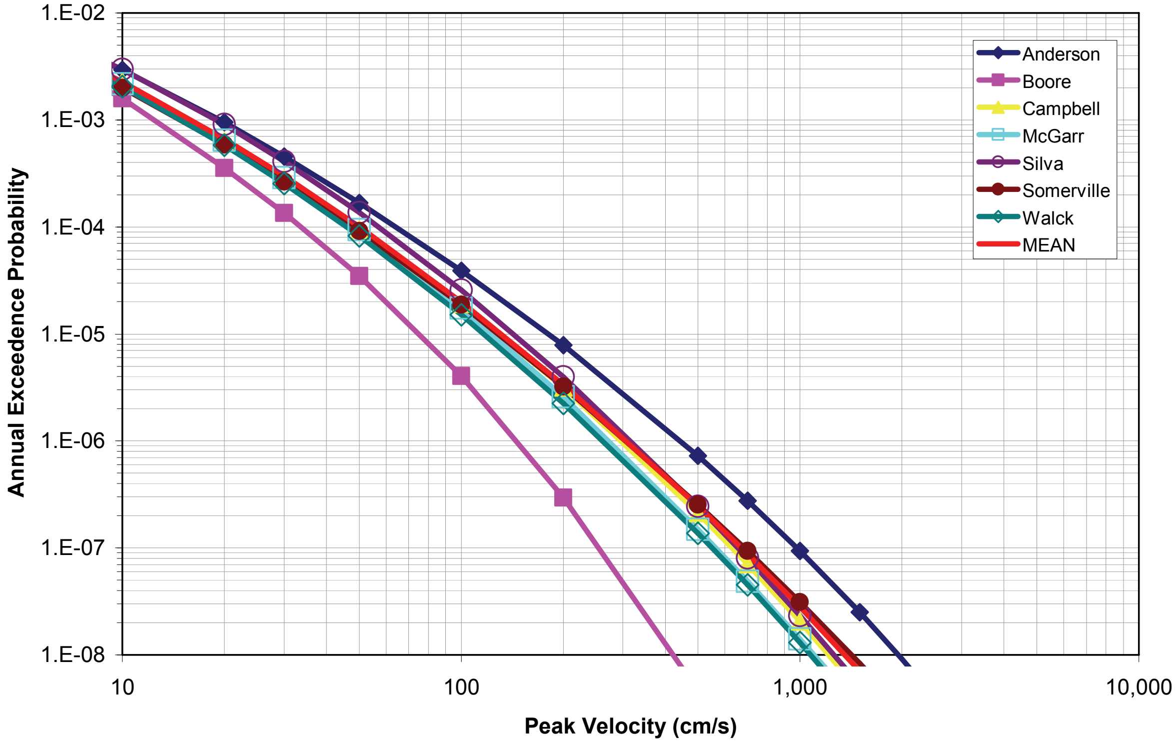

Figure 3. Mean PGV hazard by ground-motion expert.

out to be the easy part) to "getting the uncertainties right." Part of this effort may include the introduction of new explanatory variables. The de-aggregation results presented here indicate that the experts need to concentrate on earthquakes at very short distances (5 km or less).

Information about past ground motions or lack thereof ("Paleseismometric data") may be a very useful tool in our effort to obtain more realistic estimates of seismic hazard. It is important, however, to investigate alternative explanations for these observations and to quantify the associated uncertainties in both the age of the feature and the maximum ground motion that the feature has experienced during its existence. The spatial variability of ground motions (and its physical causes) may also have to be considered. Most of these "observations" provide information in "hazard space," not directly in terms of attenuation equations or source characteristics. Bayes' Theorem provides a rigorous framework for combining existing hazard results with Paleseismometric data, including the associated uncertainties and should be explored. There are precedents in the application of similar techniques to flood analysis (e.g., O'Connell et al., 2002).

The effect of non-ergodic ground-motions (i.e., the lack of independence between the ground-motion residuals of repeated characteristic events; see Anderson and Brune, 1999) should also be considered. Non-ergodic effects may be important in the Yucca Mountain performance assessment as a result of the long performance period. The YMPSHA and Anderson-Brune have explored both end members; reality lies somewhere in between and we should explore the hazard implications of partial ergodicity.

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