The PEGASOS Project, Methods and Results

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Introduction

The PEGASOS project was a SSHAC level 4 seismic hazard study conducted for Swiss nuclear power plants. Mulitple experts developed models for the PSHA inputs: source characterization, rock ground motion, and sites response. Based on the Yucca Mountain experience, PEAGSOS required that the characterization included maximum ground motions on rock and and soil. The rock maximum ground motions were regional values, whereas the soil maximum ground motions were site specific.

Rock Ground Motion Characterization

The PEGASOS project had five ground motion experts. They developed ground motion models for spectral acceleration for hard-rock site conditions (Vs=2000 m/s). A kappa value was not specified for the site. The experts assigned weights to the candidate models, rather than point estimates as was done for Yucca Mountain. The weights were assigned to the median and the aleatory variability. The epistemic uncertainty was determined by the distribution of weights. In general, the distribution is asymmetric.

The maximum ground motions were considered in two ways: absolute threshold which is a function of magnitude and distance, and a deviation of the shape of the log-normal distribution.

To reduce the number of branches in the logic tree, a composite model was developed for each expert. The epistemic uncertainty in the median ground motion and the aleatory variability was discretized into seven discrete levels: -3σ, -2σ, -1σ, 0σ, 1σ, 2σ, and 3σ.

An example of the epistemic uncertainty in the median ground motion for peak horizontal acceleration for a magnitude 6 earthquake is shown in Figure 1. An example of the epistemic uncertainty in the standard deviation for a magnitude 6 earthquake at a distance of 10 km is shown in Figure 2.

Approaches to Maximum Ground Motions

Four approaches to estimating the maximum ground motions were considered in the PEGASOS project: statistical truncation (e.g. deviation from log-normal), maximum historical observations, limits on seismic source properties, and limits due to wave propagation and site response. Geologic observations were not used in PEGASOS.

For the rock ground motions, maximum values were developed as a function of magnitude and distance, rather than a single limiting value. For the soil ground motions, the maximum values were developed in terms of single limiting values based on the strength of the soils.

Empirical studies were conducted to find the largest historical ground motion at a given magnitude and distance and to evaluate any deviations from a lognormal distribution. The empirical studies are summarized in Bommer’s presentation. Numerical simulations were conducted to find the limits due to source effects and soil strengths.

Maximum Ground Motions on Rock

The ground motion experts had to provide a technical basis for their maximum ground motions. To provide this technical basis, the primary approach used for limiting the ground motion on rock is numerical simulations. In this approach, the "limiting: source properties are used and the ground motion is simulated at a range of sites distributed around the source. The difficulty is determining the limits on the source properties.A key issue is the combination of the source parameters. Are there combinations of source parameters that are physically impossible? This was a recurring difficulty faced in the PEGSOS project.

In this past, numerical modelers have focused on modeling past earthquakes and on modeling "median" future earthquakes. They had little experience with extreme cases and were uncomfortable with some of the results. In some cases, the ground motion experts forced the modelers to consider source parameters combinations that the modelers felt were "extreme". This lead to a recurring difficulty: what is a maximum ground motion in contrast to a very rare ground motion. For example, when the ground motion experts asked if a certain combination of source parameters was possible, the modelers replied, "yes, but it is "very unlikely" or "extremely unlikely". Table 1 lists some of the words used by the modelers and a rough definition. While the ground motion experts asked for the maximum ground motions, the modelers provided estimates of "very unlikely" ground motions.

Table 1. Terminology for "Maximum"

Term	**Meaning**
Unreasonable ground motion	Small chance of a larger ground motion occurring
Unlikely ground motion	Very small chance of a larger ground motion occurring
Very unlikely ground motion	Very very small chance of a larger ground motion occurring
Extremely unlikely ground motion	Really small chance of a larger ground motion occurring
Maximum ground motion	Zero chance of a larger ground motion occurring

Maximum Ground Motions on Soil

Quantifying the maximum ground motion on soil sites was a much easier problem than quantifying the maximum ground motion on rock sites. Soil strength limits the ground motion that can be transmitted. This is a straight forward problem for geotechnical engineers since soil failure is a common problem. While the limited soil strengths can limit the ground motions, it implies soil failure which leads to other problems that must be addressed: e.g. what are the consequences of the soil failure?

Summary

The maximum ground motion means that the probability of a larger value occurring is zero, not that it is unlikely. Maximum ground motions require a physical basis, not a statistical basis, but statistics can be used to constrain the rate of occurrence of very large ground motions. Other than soil failure, this is difficult to defend using currently available models.

Maximum ground motions should be addressed in the context of probability. That is, focus on the probabilities of extreme source parameter combinations, rather than absolute limits on the source parameters. The distribution of the rock ground motion should be modified based on the joint distribution of source parameters and wave propagation.

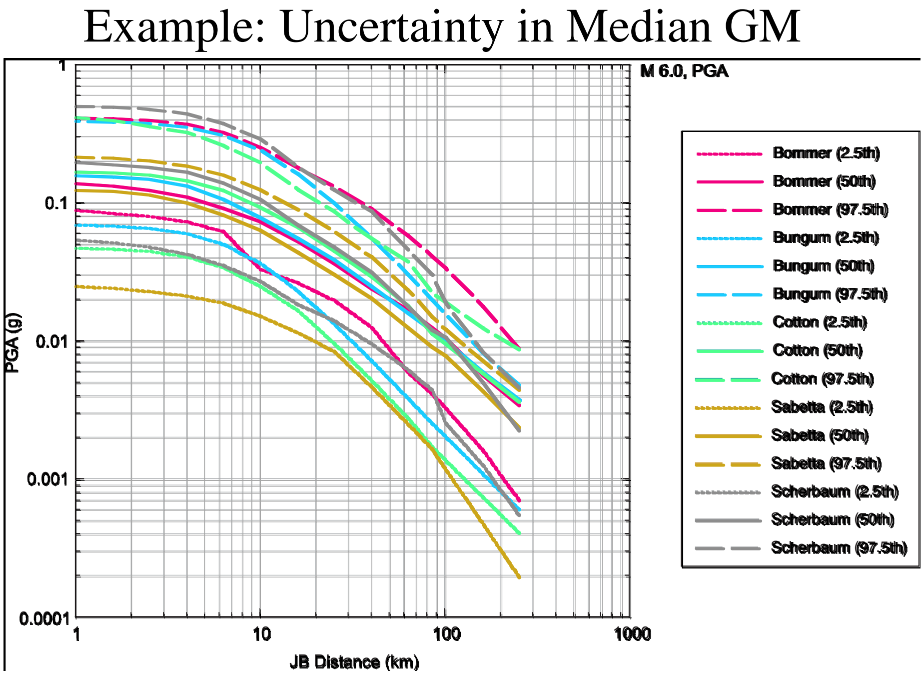

Figure 1. Example of the epistemic uncertainty in the median ground motion: M=6, PGA.

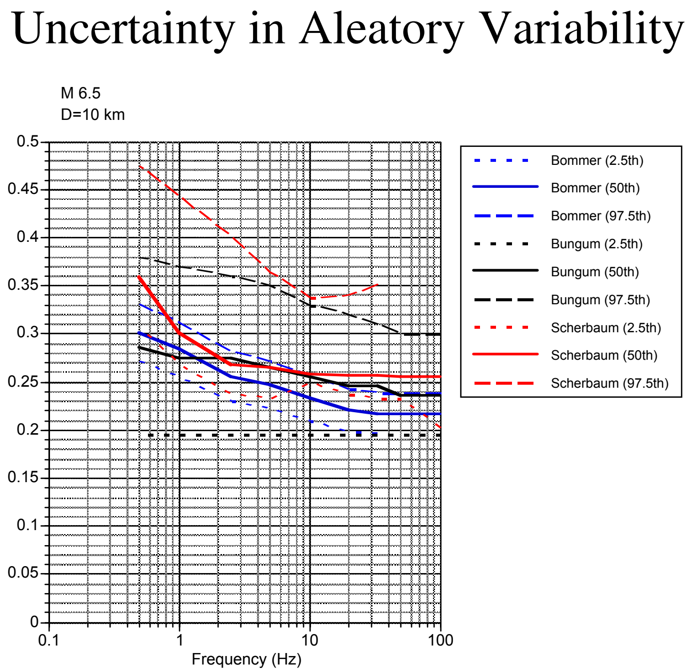

Figure 2. Example of the epistemic uncertainty in the aleatory variability: M=6, R=10 km.