Seismic-Hazard Deaggregations in Ground-Motion Bands: Another Way of Looking for the Design Earthquake

Introduction

Probabilistic seismic-hazard deaggregation involves determining earthquake parameters, principally magnitude and distance, to consider in seismic-resistant design. These parameters may be used to define a controlling-event response spectrum and/or to select strong-motion records for use in dynamic structural analysis. In the early era of seismic-hazard deaggregation (roughly corresponding to the 1980s), users generally defined a controlling earthquake from the mean magnitude and distance, or **mbar, dbar,** computed at a specific spectral acceleration level, SA, for a specified oscillator period, T, that usually corresponds to the fundamental period of building response. Later, many users came to prefer the most likely magnitude, distance pair, or mode, or **mhat, dhat**, as a most appropriate choice for design purposes, because the mode represents a relatively likely source in the seismic-hazard model, whereas the mean may represent an unlikely or even unconsidered source.

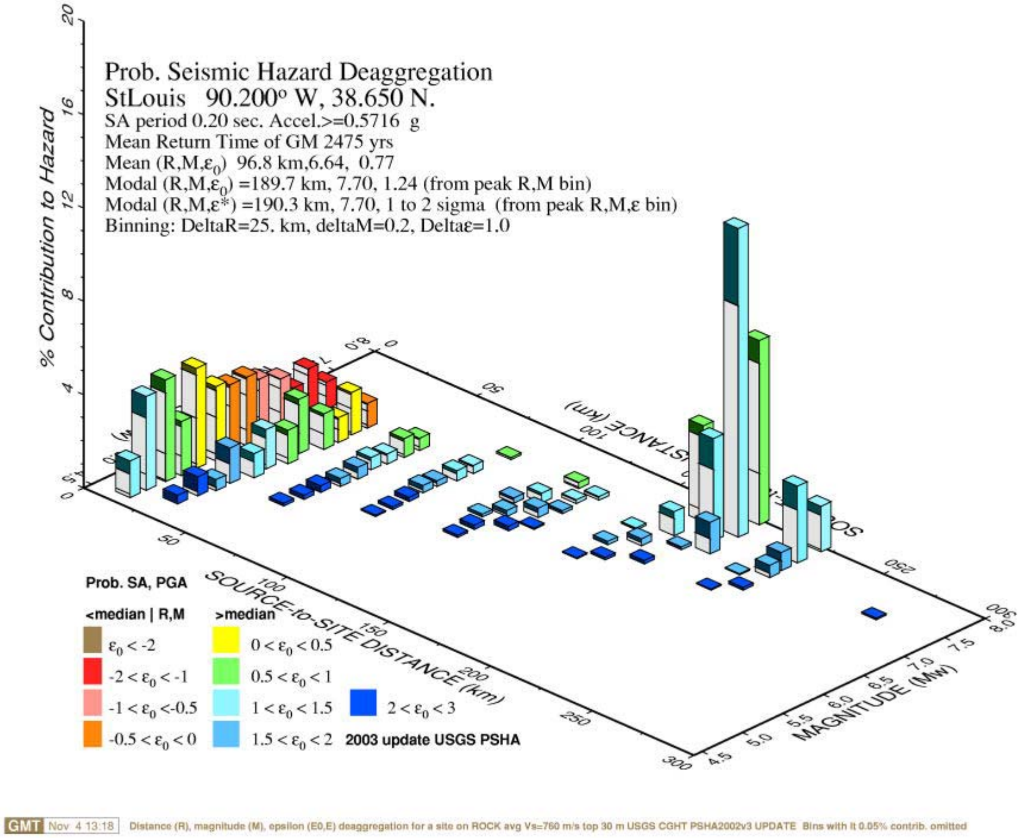
The 1996 and 2002 deaggregation web sites deaggregate the USGS seismic-hazard models. In particular, they perform calculations to determine the statistical mean and modal sources for any given U.S. site, and for a range of spectral periods and probabilities of exceedance or PE. Figure 1 below is a graph of the deaggregated sources that contribute to *f*=5-Hz or T=0.2-s spectral acceleration at a rock site in St. Louis, Missouri for the 2% in 50 year PE, using the data of the 2002 PSHA. 2% in 50 years corresponds to a mean return time of about 2500 years. Note in fig. 1 that the distribution of hazard sources is bimodal, with concentrations of relatively small-M sources at near-site distances and large-M sources at relatively large distances. The latter correspond to main shocks in the New Madrid seismic zone. However, the mean distance and magnitude, 97 km and **M**6.6, respectively, correspond to a source that has relatively low likelihood.

A third dimension of deaggregation sources is shown in figure 1; this is the parameter ε. The definition of ε (Greek letter "epsilon") is

$$\varepsilon(SA \mid S) = \frac{\ln(SA) - \ln(\mu_S)}{\sigma_S}$$

where μ_S is the median ground motion at the magnitude and distance of source *S*, and σ_S is the standard deviation of the logged ground-motion distribution at oscillator period T. T is implied but omitted in the above equation. ε_0, the value of ε at SA=SA_0, is indicated in fig.1 by column color. The range of ε, which corresponds to exceedances of SA_0, is indicated by rectangles on the face of each column in fig. 1. In fig.1, SA_0 is 0.5716 *g*. For further discussion, see the readme at the 2002 deaggregation web site.

Fig. 1 below



Alternate Approach for Computing the Modal Event

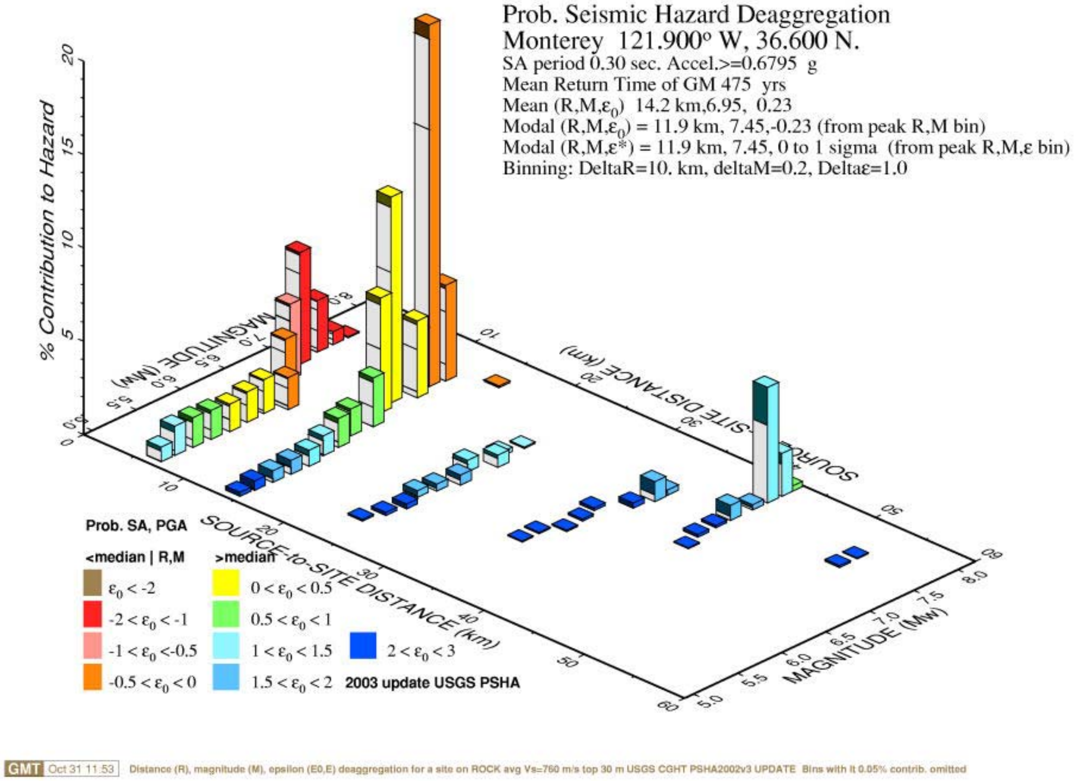
In probabilistic seismic hazard assessments a mean rate of exceedances is computed for each SA or PGA. A particular SA(T), call it $SA_0(T)$, may be associated with seismic-resistant design provisions. At the 1996 and 2002 deaggregation web sites, the analysis determines the sources that contribute to the aggregate hazard curve at various SA values, in particular, at SA_0 corresponding to the 10% in 50 year PE and 2% in 50 year PE. That is, the resulting deaggregation bins contain information on sources that contribute to exceedances of SA_0. The distribution's mode is the most likely event to generate $SA \geq SA_0$. The mode is determined without regard to *by how much* this anticipated event's ground motion is likely to exceed SA_0 at the building site. However, the provisions of the building code have not asked the seismic resistant design measures to protect against motions considerably above SA_0, only to motion that is less than or equal to SA_0. Thus, it appears plausible, and McGuire (1995) suggests, that the design earthquake – whose parameters are frequently taken from the modal event - should be determined based on consideration of ground motions that are close to SA_0, or in the limit, that equal SA_0.

The web site you are looking at now, launched in November, 2005, is an initial attempt to provide a comprehensive deaggregation of the seismic hazard in SA or PGA bands. Without knowing in advance what the seismic provisions will require of the builder in any specific instance, we cannot perform a detailed deaggregation at all ground motions, but we can and do perform deaggregations of sources whose motions contribute to limited bands of ground motions. For the most part, SA bands that are defined at this web site are at a central ground motion ±10 percent approximately, for example SA_0=0.65 ± 0.05 *g* or SA_0=0.225 ± 0.025 *g*.

An Example that Shows Contrasting Modes

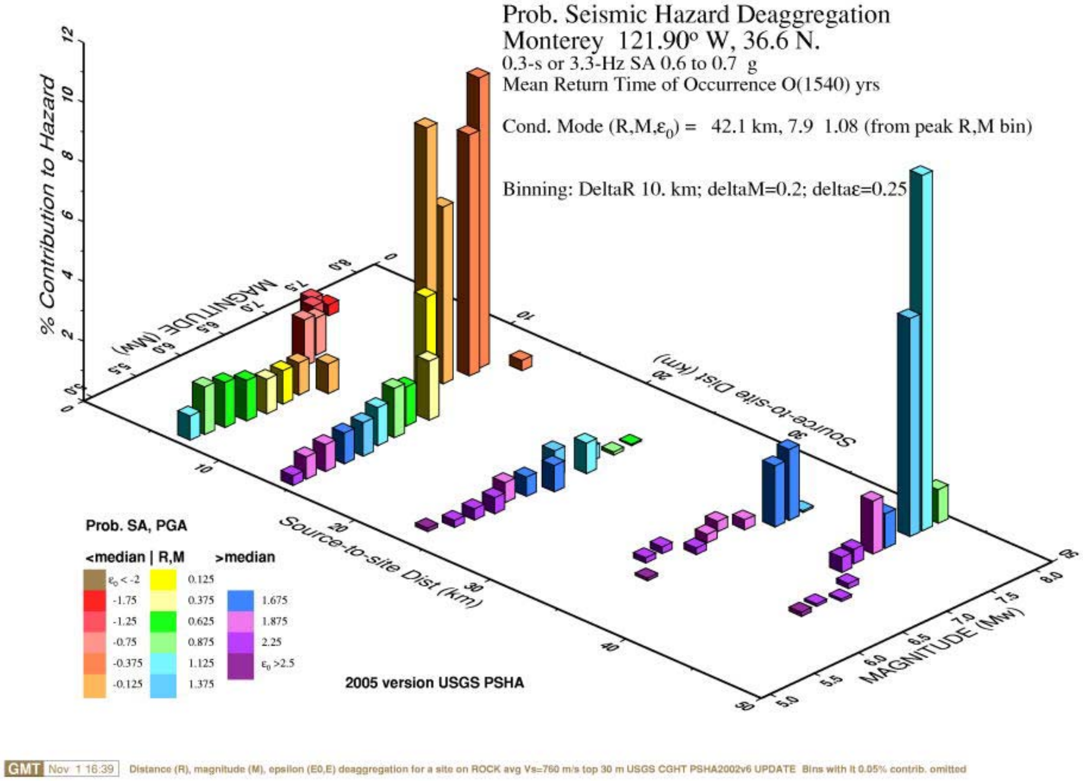
The investigator may find many instances where the most likely event that is estimated from deaggregating exceedance rates is about the same as the most likely event that is estimated from deaggregating occurrence of motion within a ground-motion interval that narrowly covers or brackets SA_0. There are also many instances where the most likely event or events is/are quite different. A good example of a site that exhibits the latter instance of divergent modal events is Monterey, California, for the 475-year SA at T=0.3 s. Let the site coordinates be 36.6ºN and 121.9ºW. A standard deaggregation of the seismic hazard at the 2002 deaggregation web site is presented in Figure 2. In fig. 2, the modal-event magnitude and distance, whether estimated from a M,D deaggregation, or from a M,D,epsilon deaggregation, has **M** 7.45, and D=11.9 km. This source corresponds to a characteristic earthquake on the offshore San Gregorio fault. Note in fig. 2 that the modal event's ε_0 is negative, -0.23, indicating that SA_0 = 0.68 *g* at the site in Monterey is below the median for this event. When ε_0 is negative, it is highly probable that the sampled ground motion in any future instance of this event will be substantially above SA_0. Thus, the San Gregorio characteristic event, in spite of its modal contribution in fig. 2, may not be the best candidate to select for seismic-resistant design in Monterey.

Figure 2 below.



At this new web site, you may perform the T=0.3-s SA source deaggregation at this location in Monterey – or anywhere else in the U.S.A. - for ground motion in bands. The bracketing band that is available for the above 0.68 *g* SA is 0.6 to 0.7 *g*. The deaggregated source data corresponding to rates of occurrence within this SA band are plotted in Figure 3, below. In fig. 3, note that the most likely earthquake to produce 3-hz SA in the 0.6 to 0.7 *g* interval occurs at a distance of about 42 km and has **M** 7.9. This event corresponds to a San Andreas-fault source, similar in location and magnitude to that of the devastating1906 main shock. San Gregorio source contributions are not by any means reduced to insignificance, but no single binned San Gregorio source contributes more than 10% to this particular band of 0.3-s hazard. The main SAF source contributes 12% to the hazard. There are several San Gregorio source scenarios in the PSHA model, corresponding to different fault segmentation models and to magnitude uncertainty. Bin boundaries are always somewhat arbitrary; in this instance many scenario events have been binned into adjacent or nearby bins. Alternate binning strategies may easily cause the contribution of "the" San Gregorio fault source to dominate the hazard at Monterey.

Figure 3 below.

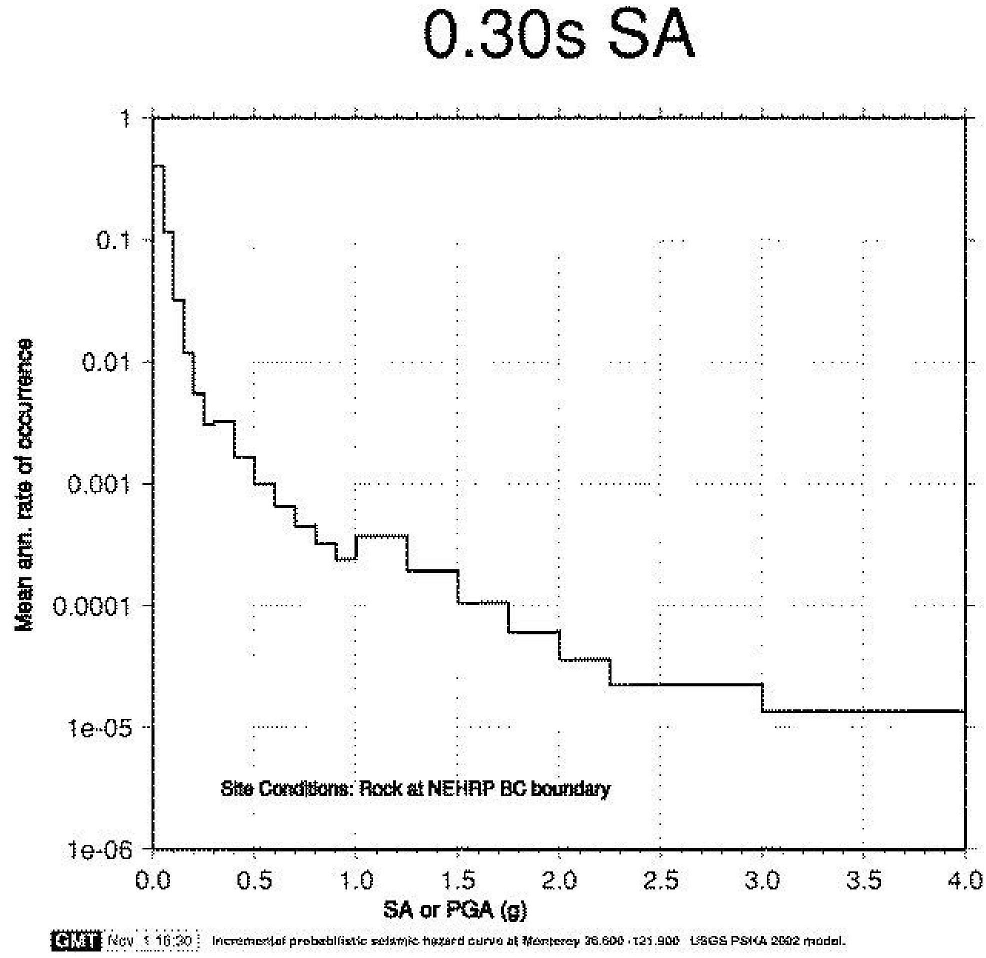


When using this modal-source information to compute the expected response spectrum as a function of magnitude, distance, and ε_0 at period T_0, empirical evidence indicates that spectral amplitudes are strongly correlated to the target value when T is near T_0, and are less correlated for other T. The resulting shape of the expected response spectrum can be an important consideration when selecting seismograms for use in seismic-resistant design applications.

We frequently find that more distant, larger events in the banded deaggregation are promoted in importance (contribution to hazard) relative to the nearer, often smaller events when comparing these newer source distributions to the more familiar distributions that are based on SA exceedance. The more distant source also has a significantly larger ε_0 than the secondary mode. In the CEUS, for example, when comparing contributions from the New Madrid Seismic Zone (NSMZ) to contributions from more local sources at sites that are at regional distances, say 100 to 300 km from NMSZ, we find that the NMSZ main shock mode is even more prominent for the deaggregation of bracketing ground motion than it is for the deaggregation of ground-motion exceedance. The NMSZ contribution at St. Louis, in the banded-deaggregation analog to fig. 1 above, for 5-hz SA close to 0.57 g, is even greater than it is in fig. 1.

While the above graph (fig. 3) is not automatically generated at this web site, another graph is generated. This graph is the hazard curve for rate of occurrence of acceleration within pre-defined SA or PGA bands (the conventional hazard curve shows the rate of exceedance of the given ground motion). Figure 4 below shows the graph that is output for the above 3-hz analysis at Monterey. Corresponding to each step in fig. 4, the text file that is served up contains a reasonably complete deaggregation of the mean seismic hazard. Figure 3 was prepared from the textfile data corresponding to 0.6 to 0.7 *g*. While the conventional seismic hazard curve monotonically decreases, the steps of fig. 4 are not necessarily always down. The main reason is that the SA-interval changes. The interval is initially 0.05 *g*, then 0.1 *g*, then 0.25 *g*. Finally, a 0.75-*g* interval and an all-remaining-SA interval are deaggregated to complete the hazard calculation. A second reason can be noted. It is mathematically possible for the banded rate to locally increase with SA even when the interval size is uniform.

Figure 4 below. The Y-axis label could read “mean rate of occurrence of SA within each X-interval corresponding to a constant Y-value.” Here, brevity wins over clarity.



This web-site analysis changes the SA interval at 0.3 *g*, 1.0 *g*, 2.25 *g*, and 3 *g*. These are the ground motions where you are most likely to see local “bumps” in the hazard graph.

Summary and Caveats

This banded ground-motion deaggregation web site provides an alternate approach to that at the 1996 and 2002 USGS deaggregation web sites for estimating earthquake parameters for sources that might be used in various seismic-resistant design procedures. The resulting distribution of sources from ground motion in bands is often similar to, but can be considerably different from, the distribution of sources from ground-motion exceedances. If the latter is the case, variations in the statistical mode can lead to considerably different ideas of response spectra and strong-motion seismograms that are most appropriate to consider in some engineering applications. Estimates of the mode are frequently influenced by somewhat arbitrary bin-boundary definitions; for this reason and because seismic-design procedures should be conservative, one should examine secondary modes as well as the primary mode when making decisions about specific earthquake scenarios to consider in seismic-resistant design.

There may be other practical uses for the information at this web site. Users are encouraged to provide information on applications.

Future Enhancements

We will add an option to deaggregate (or dis-aggregate) at SA_0 that the user inputs if the approach that was implemented at this new web site is found to be useful. Usefulness will be determined by feedback from users of this web site and/or from changes in seismic-resistant design provisions of building codes (which currently tend to be silent on deaggregation). We expect that the deaggregation will be performed in a narrow interval around SA_0, on the order of $SA_0 \pm 2\%$. A graph should accompany the table.

One of the seismic-hazard deaggregation products that we want to provide is a set of seismograms for use as input to inelastic demand studies. We believe that this set may be strongly influenced by or perhaps determined by the banded-deaggregation modal event at $SA_0(T)$.

Reference:

McGuire, Robin, 1995. Probabilistic Seismic Hazard Analysis and Design Earthquakes: Closing the Loop, *Bull. Seism. Soc. Am.*, **v** 85, p1275-1290.