Extreme Ground Motion at Yucca Mountain: A Statistical Result

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Introduction

The most comprehensive probabilistic seismic hazard analysis (PSHA) completed in 1998 suggested that an extreme ground motion, 10.0g PGA, might have to be considered for seismic design for the nuclear repository at Yucca Mountain. This extreme high ground motion has created much interest and became a special topic for discussion at the annual meeting of the Seismological Society of America. A special project has also been funded to study the extreme ground motion.

Basic Earthquake Statistics

The Gutenberg-Richter and ground-motion attenuation relationships are the foundations of PSHA. The Gutenberg-Richter relationship describes a statistical relation between occurrence frequency (*N*) and earthquakes exceeding a specific magnitude (*M*) (**Fig. 1, step 2**):

$$\tau = \frac{1}{N} = e^{-2.303a + 2.303bM} \qquad (1)$$

where τ is the recurrence interval of earthquakes with magnitude exceeding *M,* and *a* and *b* are constants. The ground-motion attenuation relationship describes a statistical relation between ground motion (*Y*), source-to-site distance (*R*), and earthquake magnitude (*M*) (**Fig. 1, step 3**):

$$\ln(Y) = f(M, R) + E(n\sigma_{\ln,Y}) \qquad (2)$$

where *E* is the uncertainty (error) term measured as a number of standard deviations ($\sigma_{ln,Y}$) from the median ($n\sigma_{ln,Y}$). As shown, the Gutenberg-Richter relationship describes a temporal relation of earthquakes, while the ground-motion attenuation relationship describes a spatial relation of earthquake consequences (ground motion) at a site.

PSHA Formulation

The basic equation for hazard calculation can be expressed as a triple integration over magnitude (*M*), source-to-site distance (*R*), and ground motion uncertainty (*E*) (Cornell, 1968, 1971):

$$\gamma(y) = \sum v \iint \{1 - \int_0^y \frac{1}{\sqrt{2\pi}\sigma_{\ln,y}} \exp[-\frac{(\ln y - \ln y_{mr})^2}{2\sigma_{\ln,y}^2}] d(\ln y)\} f_M(m) f_R(r) dm dr \qquad (3)$$

where $\gamma(y)$ is annual probability that ground motion (*y*) is exceeded, and ν is the activity rate. Ground-motion uncertainty (*E*) was treated as an independent variable in the development of equation (3). However, ground motion uncertainty is not an independent variable, but a dependent of magnitude and source-to-site distance. Therefore, equation (3) is not valid (Wang and Zhou, 2007). This invalid hazard calculation could result in calculation of extreme high ground motions, such as 10.0g PGA or greater. This is demonstrated in **Figure 2** for a single characteristic earthquake.

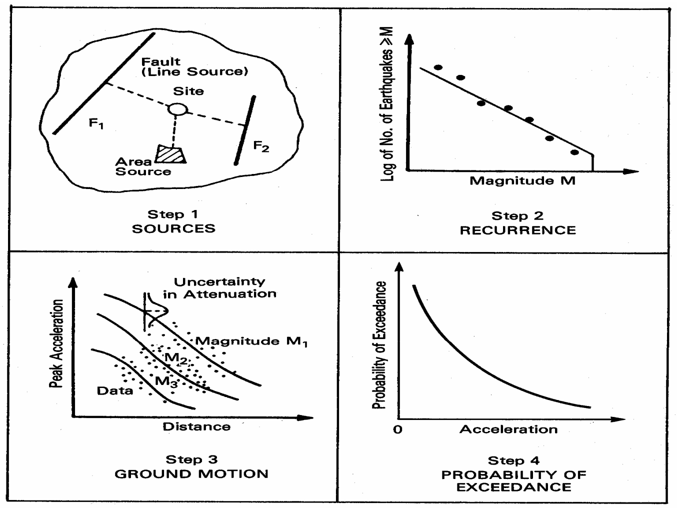

Figure 1. Basic elements in PSHA (Reiter, 1990).

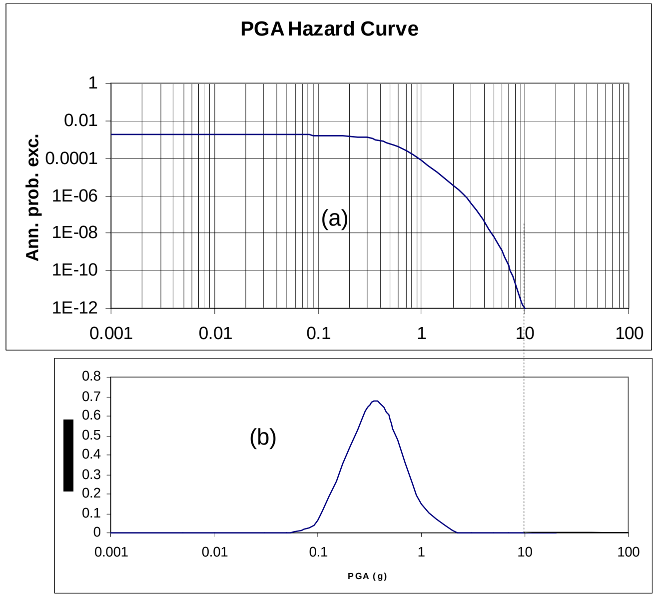

Figure 2. PGA hazard curve (a) and probability density (b) for a site at 30 km from a characteristic earthquake with M7.5 and 500 years recurrence interval. The annual probability of exceedance (10^{-12}) for 10.0g PGA is equal to earthquake rate (0.002) time exceeding probability (0.0000000005 – shaded area).

Conclusion

1.The basic formulation for hazard calculation in PSHA is not valid.
2.This invalid formulation could result in calculation of extreme high ground motion, 10.0g PGA or larger.
3. This invalid formulation also results in mixing temporal measurement (earthquake occurrence in time) with spatial measurement (ground- motion uncertainty in space), or the ergodic assumption (Anderson and Brune, 1999).

Reference
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