COMMENT & REPLY

Comment on "Comparison Between Probabilistic Seismic Hazard Analysis and Flood Frequency Analysis"

PAGE 303

Despite providing an exceptionally clear example of the basics of probabilistic seismic hazard analysis (PSHA), *Wang and Ormsbee* [2005] nevertheless conclude that "…using PSHA for risk analysis is not only confusing, but is also inappropriate." I argue here that (1) the results of a PSHA analysis are not confusing and have physical meaning, and (2) the authors' basis for declaring PSHA "inappropriate" is misguided. I note in passing that the authors consistently confuse "risk" with "hazard." Both PSHA and flood frequency analysis provide estimates of hazard. Risk is the product of hazard, vulnerability, and exposure. This discussion is only concerned with hazard.

The authors reveal the basis for their confusion about a physical interpretation of PSHA in the statement, "Because it is impossible for the three earthquakes to occur at exactly the same time (1.5×10^{-19} probability at the same hour), the predicted PGA [(peak ground acceleration) at a point of interest] corresponding to the total annual probability of exceedance is a statistical measure and does not have a clear physical meaning" (words in brackets are mine). The total annual probability of exceedance (P) from PSHA is not conditioned on all three earthquakes occurring at once. Using the authors' example, it is the sum of the independent probabilities that any one of the three faults will cause PGA to exceed 0.97*g*. Summing the probabilities simply produces the annual probability that the PGA will be exceeded in a year. It does not imply the three earthquakes are concurrent.

The physical interpretation of the ground motion in their example is that 0.97*g* is the PGA with a 2500-year return period, which is the inverse of its total annual probability of exceedance, 0.0004. In fact, the authors provide the annual probability (0.000086, 0.000147, and 0.000167) that each fault (A, B, and C) will generate a PGA greater than 0.97*g*. The interested reader will note that these probabilities sum to 0.0004. An alternative way to physically interpret this is that we expect 25, 12.5, and 5 earthquakes in 2500 years from faults A, B, and C, respectively, and at least one of these earthquakes will generate a PGA greater than 0.97*g* at the point of interest [see *Wang and Ormsbee*, Figure 1].

The PGA with a 2500-year return period is conceptually analogous to the flood with a 100-year return period, which is the peak discharge that is expected to be exceeded on the average every 100 years. To the extent that the 100-year flood has physical meaning, the 2500-year PGA has physical meaning. Is this PGA guaranteed to occur in 2500 years? No, just like the 100-year flood in the next 100 years, it has a probability (p_t) of 0.63 of occurring within the next 2500 years ($p_t = 1\text{-}e^{-Pt}$, where t is time in years).

To understand the basis of the authors' conclusion that PSHA is "inappropriate," it is helpful to review how the annual probability of exceedance for each of the three faults is computed in their example. The contribution by each fault to the annual probability of exceedance is the product of two probabilities: (1) the annual probability that the earthquake will occur and (2) the probability that PGA will exceed a given value.

The annual probability that the earthquake will occur is simply the inverse of the earthquake return period given in Wang and Ormsbee's Figure 1. The probability that the PGA will exceed a given value is the area under the upper tail of the lognormal probability density function. This distribution arises because earthquakes of the same size do not always produce the same PGA. The lognormal distribution describes the range of possible PGA at a point of interest that can be expected for each earthquake at least to within a few standard deviations of the median PGA. Note in Wang and Ormsbee's Figure 2 that the lognormal distribution predicts very high PGA with low probabilities (several standard deviations from the mean) because it is unbounded. Thus, these upper tails become extremely important when estimating low probability ground motions. At annual probabilities of exceedance of 4×10^{-4} and larger, where PSHA is commonly applied such as in building codes, it is quite unnecessary to sample these low probability tails.

Thus, the authors' conclusion that PSHA is "inappropriate" is a red herring. It is based on the technical challenge of applying PSHA to estimate extremely low annual probability, 10^{-8}, ground motions at the Yucca Mountain nuclear waste repository. The 4×10^{-4}/yr ground motion estimates are all within two standard deviations of the median ground motion, which is well within the range where the lognormal distribution captures the uncertainty. There is nothing inappropriate here.

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Reference

Wang, Z., and L. Ormsbee (2005), Comparison between probabilistic seismic hazard analysis and flood frequency analysis, *Eos Trans. AGU, 86*(5), 45, 51–52.

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Reply to Comment by T. L. Holzer

PAGE 303

Risk discussed by *Wang and Ormsbee* [2005] may differ from that of Holzer. Although there are some different definitions of risk among different professions, it is quantified by three terms: probability, hazard (loss or others), and exposure. For example, in health sciences, risk is defined as the probability of getting cancer if an average daily dose of a hazardous substance (hazard) is taken over a 70-year lifetime (exposure). In the financial world, risk is defined as the probability of losing a certain amount of money (loss) over a period of time.

Wang and Ormsbee defined seismic risk as the probability of a structure being damaged one or more times (at least once) in t years (exposure) by an earthquake or ground motion (hazard) generated by the earthquake. This definition is consistent with that of *Cornell* [1968]. This is also consistent with those used in building codes, such as the International Building Code [*ICC*, 2000].

Probabilistic seismic hazard analysis (PSHA) and flood frequency analysis are being used to characterize the hazards, ground motion for earthquake and peak flow for flood, and their frequencies of occurrence at a point or region of interest. Although they have been used in engineering risk analyses in the same way, Wang and Ormsbee demonstrated that PSHA and flood frequency analysis are clearly different; i.e., the annual probability of exceedance (P_f) defined in flood frequency analysis is a direct statistical inference, whereas the annual probability of exceedance (λ) defined in PSHA is the sum of the product of the individual annual probabilities of earthquake (also a direct statistical inference) and the probability that ground motion will exceed a given value if the earthquakes occur.

In other words, the annual probability of exceedance defined in PSHA is a statistical measure [*Wang and Ormsbee*, 2005]. This is also clearly recognized by Holzer. Our conclusion was based on these comparisons, not on "the technical challenge of applying PSHA to estimate extremely low probability."

Although it does not depend on all earthquakes occurring at once, the total annual probability of exceedance (λ) or the associated ground motion from PSHA does not have a clear physical meaning. This was recognized by the Aki committee [*National Research Council*, 1988], which indicated that "the aggregated results of PSHA are not always easily related to the inputs."

Holzer offered an alternative way to interpret the physical meaning of the PGA of 0.97*g* with total annual probability of exceedance of 0.0004 (or 2500-year return period), which was the example given by Wang and Ormsbee. Holzer stated that "we expect 25, 12.5, and 5 earthquakes in 2500 years from faults A, B, and C, respectively, and at least one of these earthquakes will generate a PGA greater than 0.97*g* at the point of interest."

As shown by Wang and Ormsbee, the probabilities (*Pe*) that PGA will exceed 0.97*g* are 0.0086, 0.0294, and 0.0835 if the characteristic earthquakes of *M*6.5, *M*7.0, and *M*7.5 occur on faults A, B, and C, respectively. Because occurrence of an individual earthquake on a single fault follows a Poisson probability distribution [*Cornell,* 1968] and occurrence of an earthquake on one fault does not affect the other faults, the probabilities (*p*) that PGA exceeds 0.97*g* at least once after 25 earthquakes on fault A, 12.5 earthquakes on fault B, and five earthquakes on fault C are 0.194, 0.311, and 0.353, respectively ($p = 1 - e^{-nPe}$). Total probability that PGA exceeds 0.97*g* at least once in 2500 years is 0.858. The event in which PGA exceeds 0.97*g* may not occur at least once in 2500 years because the probability is less than 1.0.

These calculations also show that the 2500-year return period cannot be used to describe an independent event because of the aggregated nature of PSHA. As shown by Holzer, the probability of PGA exceeding 0.97*g* at least once in 2500 years is 0.63 if the 2500-year return period is assumed for an independent event.

The calculations and analyses above show that the PGA with a 2500-year return period is not conceptually analogous to a flood with a 100-year return period. The PGA with a 2500-year return period is not a physical event, but a mathematical extrapolation from the time domain characteristics of earthquakes and the spatial characteristics of ground motion.

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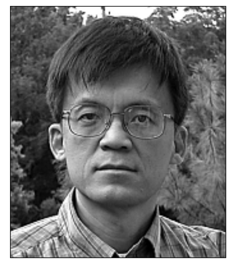

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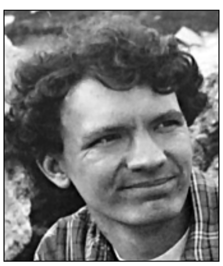

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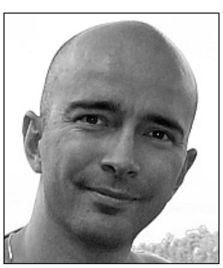

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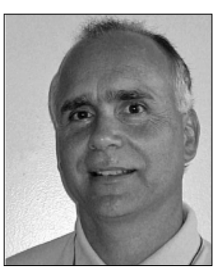

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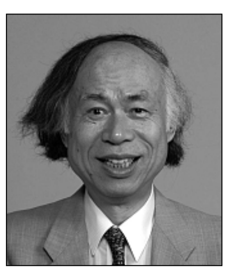

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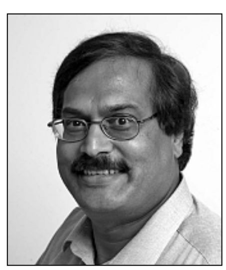

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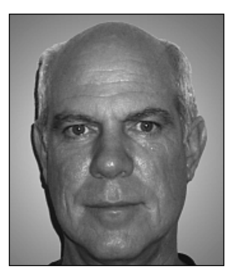

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