NWTRB Perspective on Extreme Ground Motions

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BACKGROUND

On February 24, 2003, the Nuclear Waste Technical Review Board's (NWTRB) Panel on the Natural System and Panel on the Engineered System held a joint meeting in Las Vegas devoted to seismic issues. The NWTRB was set up by the Nuclear Waste Policy Amendments Act of 1987. Its defined purpose is to evaluate the technical and scientific validity of activities undertaken by the Department of Energy (DOE) with respect to various aspects of high-level waste and spent nuclear fuel. It consists of 11 members chosen by the President from a slate provided by the National Academy Science and reports at least twice a year to Congress and the Secretary of Energy. The NWTRB has no regulatory authority.

The Board was interested in the very high ground motions being considered for the evaluation of the proposed nuclear waste repository at Yucca Mountain, Nevada. In order to help in its evaluation, the NWTRB hired four consultants; Alfred (Skip) Hendron (geotechnical engineer-University of Illinois), Peter Kaiser (mining engineer-Laurentian University), Art McGarr (seismologist-U.S. Geological Survey), and Anestis (Andy) Veletsos (Civil Engineer-Rice University). The Board's analysis of the material presented to it by the DOE at the February 2003 meeting, including its perspective on extreme ground motions, was communicated to the DOE in a letter dated June 27, 2003. My presentation at the August 23-25, 2004, workshop is based on that letter, which can be found on the NWTRB web page, http://www.nwtrb.gov, under the heading of "correspondence. Portions of this write-up are taken directly form the NWTRB letter. The individual consultant reports and meeting transcripts can be found on the same web page under the heading of "meetings."

RESULTS OF THE YUCCA MOUNTAIN PSHA

The Yucca Mountain conducted a state-of-the-art probabilistic seismic hazard analysis (PSHA) for ground motion and fault displacement at the proposed Yucca Mountain waste repository. This effort, completed in 1998 and summarized in the professional literature in Stepp et al (2001), was the most extensive PSHA carried out until that time. Originally envisioned as primarily serving as a means for determining seismic design, problems arose when it became apparent that the PSHA would have to be extended to very low probabilities of exceedance ($<10^{-6}$ per year). These low probabilities were needed because the regulations required that events, whose probabilities were as low as one chance in 10,000 over the regulatory lifetime of 10,000 years (10^{-8} per year), have to be considered in assessing the long-term performance of the repository. The ground motions at these low probabilities were extremely large and mean values (the metric of primary interest) reached as high as 11 g for peak ground acceleration (PGA) and 1300 cm/sec for peak ground velocity (PGV) for a hypothetical rock outcrop (see Figure 1). PGV is the primary measure used in evaluating the safety of the underground repository.

The Board views these low probability estimates, which are outside the limits of existing worldwide seismic records or experience, as being generally unrealistic and possibly physically unrealizable. These ground motions may require unrealistic source characteristics (e.g., stress

drops) and unrealistic strains, which may exceed the ability of the rock to sustain without fracturing.

In addition, real records used in the seismic consequence analysis (seismic evaluation) were scaled to reach target levels such as 535 cm/sec PGV at 10^{-7} per year. These target levels were based upon extending the results from the PSHA and modifying them to take local site conditions into account. The scaling technique involved randomly picking one of the two horizontal components, determining how large a scaling factor is needed to reach the target level, and then scaling both horizontal components (regardless of whether it is the larger or smaller of the components) using the same scaling factor. Some of the actual ground motion recordings used were scaled up (increased) by factors higher than 100 to reach the target level of ground motion. In some cases this method of scaling yielded PGA's and PGV's (for example, 20 g PGA and 1790 cm/sec PGV at 10^{-7} per year) well above already unrealistic target levels. Many DOE and DOE contractors at the February 24, 2003 meeting shared the NWTRB's views about the unrealistic nature of the low probability ground motion estimates. However, as discussed below differences of opinion between the NWTRB and the DOE existed on how to proceed given this lack of realism.

TREATMENT OF UNCERTAINTY

Another possible source of error in the ground motion estimates has to do with the treatment of uncertainty in the ground motion models. Anderson and Brune (1999) have questioned the use of the ergodic assumption, i.e., that the distribution of a random variable in space can be treated the same as the distribution of that same random variable at a single point when sampled as a function of time. In ground motion regression analysis this means that the standard deviation from the misfit of multiple earthquake can be assumed to be aleatory (random) uncertainty. If this uncertainty is due to differences in earthquake sources that are not present around the site being analyzed, it could result in overestimating the ground motion at low probabilities, where assumptions about the tails of the distribution control ground motions. In support of this hypothesis, James Brune and his colleagues at the University of Nevada have argued that observations of precarious rocks and other formations in the vicinity of Yucca Mountain imply that ground motions during the past 10,000,000 years, have been substantially less than those estimated in the PSHA.

RECOMMENDATIONS

The NWTRB made several recommendations to the DOE.

1. The very low probability ground motions need to be bounded on the basis of sound physical principles.

2. The results of the DOE studies should be subjected to external peer review. Estimating physical bounds on ground motion will be challenging. Aside from a study in Switzerland, the NWTRB was not aware of any other systematic attempt to address this issue.

3. The DOE should evaluate and consider the work on precarious rocks and its implications.

IMPLICATIONS OF TOO MUCH CONSERVATISM

Finally the NWTRB was concerned that the DOE may find the highly conservative (erring on the side of safety) and physically unrealistic assumptions and results used in addressing seismic issues an attractive option because they can still show regulatory compliance. In this approach, studies carried out to define limits on ground motions would be used to show conservatism rather than as a means of modifying the ground motion estimates themselves. There are inherent problems associated with this approach.

1. High levels of conservatism can lead to a skewed understanding of repository system behavior. This is particularly important when many types of events are considered and priority is determined according to the risk they pose.

2. High levels of conservatism can introduce consideration of events for which there is little or no understanding such as predicting the effects of physically unrealistic ground motions.

3. Compounding conservative assumptions does not always lead to conservative results. For example, the worst case for tunnel stability is not when the horizontal and vertical stresses are both very high.

4. High levels of conservatism may lead to unreasonably high costs and may have a serious effect on the eventual design.

5. Conservatism stemming from a lack of understanding can undermine confidence in the scientific basis of the process under consideration. Physically unrealistic results, inappropriately extrapolated from physically real databases and analyses, could cast unwarranted doubt on much of the truly excellent work carried out this area.

6. If “unacceptable” consequences develop later as a result of the use of unrealistic or unduly conservative ground motion estimates, it may be difficult to justify subsequent reductions in ground motions to make them more realistic.

ADDED NOTE

It is important to note that subsequent to this letter, the DOE embarked upon a serious program (both short and long term) to derive more realistic ground motion estimates and has begun to modify the high ground motion estimates for their use in seismic consequence analysis.

REFERENCES

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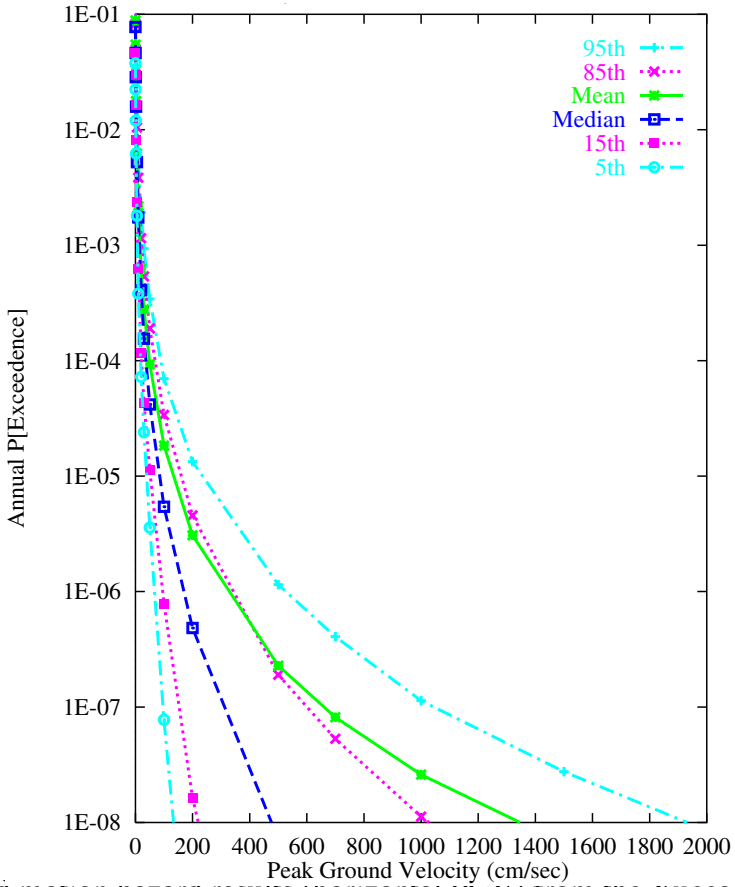

Figure 1. Ground motion hazard results (horizontal PGV) from the Yucca Mountain PSHA (Stepp and Wong, 2003)