# Peak Ground Velocities for Seismic Events at Yucca Mountain, Nevada

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The objective of this study is to bound credible peak horizontal ground velocities (PGV) for the repository waste emplacement level at Yucca Mountain. Results are presented as a probability distribution for horizontal PGV to represent uncertainties in the analysis. The analysis is used in conjunction with a probabilistic seismic hazard analysis (PSHA) and ground motion site-response modeling to provide input to an abstraction of seismic consequences. The abstraction input consists of values of horizontal PGV at the waste emplacement level for various annual probabilities of exceedance, based on the PSHA and site-response modeling, and a bound to horizontal PGV from this analysis. The seismic consequence abstraction, in turn, feeds the seismic scenario class of the total system performance assessment (TSPA).

The bound on horizontal PGV at the repository waste emplacement level developed in this analysis complements ground motions developed from PSHA results. In the PSHA, ground motion experts characterized the epistemic uncertainty and aleatory variability in their ground motion interpretations. To characterize the aleatory variability they used unbounded lognormal distributions. As a consequence, as seismic hazard calculations are extended to lower and lower annual exceedance probabilities, the ground motion level increases without bound, eventually reaching levels that are not credible. To provide credible seismic inputs for TSPA, in accordance with 10 Code of Federal Regulations (CFR) 63.102(j), this complementary analysis is carried out to determine reasonable values of horizontal PGV at the waste emplacement level for very low annual exceedance probabilities. For each realization of the TSPA seismic scenario, the results of this analysis provide a constraint or bound on the values sampled from the horizontal PGV hazard curve for the waste emplacement level.

This analysis depends largely on predictions of rock deformation that would be caused by large ground motions at the waste emplacement level at Yucca Mountain and the fact that such deformation is not observed. The lack of such deformation is used to conclude that lithophysal rocks of the Topopah Spring Tuff have not experienced ground motions large enough to cause the predicted deformation during the approximately 12.8 million years since their deposition. Analysis limitations include the following:

- The 12.8 million years age of the Topopah Spring Tuff does not preclude the possibility that ground motions large enough to cause rock deformation occurred at the Yucca Mountain site prior to its deposition.

- The lack of observations of the type of rock deformation that would be expected if Yucca Mountain had experienced large ground motion levels is limited to those portions of the mountain that are exposed in the Exploratory Studies Facility (ESF) and the Enhanced Characterization of the Repository Block (ECRB) cross-drift.

- Geologic studies of fracture distribution, genesis, and characteristics in the ESF and ECRB cross-drift were not carried out specifically to look for deformation predicted to be associated with large ground motion levels.

- Testing of lithophysal rock samples to provide information on the shear strains associated with fracture generation is carried out on laboratory-scale samples. It represents an approximation to in situ behavior.

- Shear strains at which lithophysal rock of the Topopah Spring Tuff exhibits systematic macro-scale fracturing is modeled using a two-dimensional particle flow code.

- Modeling to determine the shear strains that would be induced in the rock at the waste emplacement level by large ground motions employs a one-dimensional equivalent-linear approach.

Because of uncertainties in the data, analyses, and modeling, and the limitations listed above, the value for bounding horizontal PGV is provided as a probability distribution.

Rock testing data, geologic data, and ground-motion site response data are combined to determine the bounding distribution. The analysis consists of four steps. First, laboratory testing and numerical simulations of lithophysal rock deformation are used to determine the shear-strain threshold for rock failure. Second, the results of the numerical simulations are combined with geologic observations in the ESF and ECRB cross drift to conclude that the Topopah Spring lithophysal zones have not experienced shear strains exceeding the threshold for failure. Third, ground-motion site response data are used to assess the level of horizontal PGV that would be required to generate shear strains exceeding the shear-strain threshold for failure. Fourth, it is concluded that such a level of horizontal PGV has not been reached at Yucca Mountain since the rocks were deposited 12.8 million years ago.

Given the uncertainties in the available data, the bounding horizontal PGV is expressed as a probability distribution. Two approaches are taken. In one, a distribution on the bound to horizontal PGV is assessed directly. In the second approach, a probability distribution is assessed for shear-strain threshold, which is then transformed into distributions for horizontal PGV on the basis of the ground-motion site-response modeling results.

Based on laboratory test results, rock mechanics modeling, and the site-response modeling, the first approach characterizes the bound to horizontal PGV at the waste emplacement level as a uniform probability density function. The lower and upper limits for the distribution are assessed at 150 and 500 cm/sec, respectively, based on the range of shear-strain increments from the combined laboratory testing and numerical simulations and the corresponding horizontal PGV values. This is the distribution used in the seismic consequence abstraction for the seismic scenario class of the TSPA.

For the second approach, the testing and modeling results are used to assess a triangular probability density function for shear-strain threshold, with maximum and minimum values of 0.09% and 0.25%, respectively, and a modal value of 0.16%. (Note: The distribution illustrated in the workshop presentation has a maximum value of 0.35%. It was reassessed following the workshop and now has a lower maximum value.) The range is based on the range of peak strains determined from the laboratory testing results. The mode is assessed on the basis of the mean values determined for the laboratory samples with length-to-diameter ratios greater than 1.5, which are considered to provide the most representative results. The range and mode determined from the laboratory testing results are consistent with the results from the numerical simulations.

To translate the triangular shear-strain threshold probability distribution into a distribution for horizontal PGV at the waste emplacement level, the results of the ground-motion site-response modeling are used to determine PGV levels that correspond to specified peak shear strains. Using this relationship, the assessed distribution on shear-strain failure threshold is mapped to a distribution on PGV. Eight bounding horizontal PGV distributions are developed to account for the epistemic uncertainty in site-response modeling and the use of two response-spectrum frequency ranges. The resulting distributions for horizontal PGV depart slightly from a triangular shape because the relation between shear-strain threshold and horizontal PGV is not linear. These distributions fall into two groups, depending on the assumed dynamic properties of the tuff rock that comprises Yucca Mountain. For the case where the tuff is assumed to respond with a high degree of nonlinearity (i.e., with considerable strain softening and increased damping) to the input ground motions), the PGV distributions range from about 100 to 250 cm/sec and have a mode of about 175 cm/sec. In the second group, in which little nonlinearity is assumed, the distributions range from about 200 to 500 cm/sec and have a mode of about 335 cm/sec. (Note: The workshop presentation shows a combined average of the two groups.) The directly assessed uniform distribution that was used as input to the TSPA conservatively brackets the high end of the range of these results.

It is recognized that the lack of rock-failing ground motions in the last 12.8 millions years does not *prove* that such ground motions would not occur in 100 million years and, therefore, that they have less than one chance in 10,000 of occurrence over 10,000 years, the threshold for exclusion from the TSPA per § 63.102(j). However, as there is no evidence that rock-failing ground motions can or will occur at Yucca Mountain, the 12.8 my geologic record is considered to provide a reasonable basis for identifying what earthquakes are credible at Yucca Mountain. Specifically, it is reasonable to consider that earthquake ground motions that exceed what has been experienced in the last 12.8 my are not credible and can reasonably be excluded from the Yucca Mountain TSPA.