Bounds on PGV at the Yucca Mountain Repository Based on Earthquake Source Constraints

A. McGarr

Summary of presentation at Workshop on Extreme Ground Motions at Yucca Mountain on Monday, August 23, 2004

According to the PSHA for the nuclear repository at Yucca Mountain, summarized by Stepp et al. (2001), the design level PGV's for AEP's of 10^{-7} and 10^{-8} are about 7 m/s and 13 m/s, respectively at Point A. It seems to be generally agreed that the most likely source of such high PGV is an earthquake of M6.5 to M7 on the Solitario Canyon fault, which crops out along the western edge of Yucca Mountain.

Because this fault crops out immediately west of the repository, the maximum ground motion affecting the facility would presumably be that associated with the adjacent fault slip rate. Here I argue that the maximum slip rate is unlikely to exceed 4 m/s and so the corresponding bound on PGV, half the peak slip rate, is 2 m/s. The basis for this argument is the observation that maximum PGV's worldwide are associated with near-fault ground motion. The peak slip rate, in turn, is related to the stresses loading the fault to cause seismic slip. Interestingly, the peak slip rate and the near-fault PGV are independent of earthquake magnitude or moment (McGarr and Fletcher, 2003).

Figure 1 shows near-fault PGV as a function of seismic moment. As seen here, over many orders of magnitude, there is no systematic variation in PGV with M_0. The highest point, 2.6 m/s for the Chi-chi earthquake (Silva and Wong, 2003) is the highest PGV ever recorded, but this datum is probably not relevant the assessment of PGV's that might affect Yucca Mountain because the recording site, TCU068, is on the immediate hangingwall of a thrust fault. The ground motions for the other three major earthquakes were all recorded within several km of the causative fault where substantial surface slip was observed. In each case, the fault parallel displacement, from the twice-integrated accelerograms, is close to half the nearby observed fault slip. The near-fault PGV for Izmit is probably an underestimate because the fault normal (north) component of the accelerograph was not functioning at the time of the earthquake.

The near-fault PGV for the M4.4 mining-induced earthquake is based on the velocity seismogram shown in Figure 2 together with the observation that the maximum slip along the causative fault, several km below the recording site, was 0.2 m. The S wave velocity pulse is well approximated by a single cycle of sine wave of duration of 0.16 s, especially as seen on the vertical component (Figure 2). Dividing this duration (rise time) into the maximum slip gives a lower bound for the average slip rate of 1.25 m/s and a peak slip rate of 2.5 m/s, or a near-fault PGV of 1.25 m/s (Figure 1). This estimate is a lower bound because the duration of the S pulse (Figure 2) may be representative of a broader portion of the fault zone than the high-slip patch, which might have had a shorter rise time.

Stick-slip event 9 was typical of the experiments reported by Lockner and Okubo (1983) and was emphasized by McGarr and Fletcher (2003). As seen in Figure 3 of Lockner and Okubo (1983), the maximum slip rate for event 9 is 0.1 m/s. To relate this maximum slip rate to those anticipated for crustal earthquakes we multiply by a stress adjustment factor of 41, which is based on the differences between the stresses loading the laboratory granite sample and the deepest available in situ stresses, which were measured at a depth of 6.8 km at the KTB site, Germany (Brudy et al., 1997). This adjustment procedure was described in detail by McGarr and Fletcher (2003). It turns out that the adjusted peak slip rate for an equivalent crustal earthquake is predicted, from event 9, to be 4.1 m/s and so the adjusted PGV is half of this, or 2.05 m/s (Figure 1). The stress-adjusted seismic moment of event 9 is 3.2×10^{10} N-m (McGarr et al.. 2004).

The main conclusions are:

1) The near-fault PGV is controlled by the loading stresses.
2) The near-fault PGV is independent of M or M_0.
3) The laboratory results and earthquake observations covering a broad range of earthquake magnitude suggest that near-fault PGV exceeding 2 m/s in the extensional tectonic regime of Yucca Mountain (Point A) is quite unlikely.
4) The PSHA results for postclosure AEP's should be revisited.

Recommendations:

1) More laboratory experiments to simulate near-fault PGV's under controlled conditions.
2) Investigate earthquakes for which one can infer slip rise time and the maximum fault slip to estimate lower bounds on near-fault PGV's
3) Compare ground motion recorded in deep boreholes to slip models developed for the same nearby earthquakes.

Figures

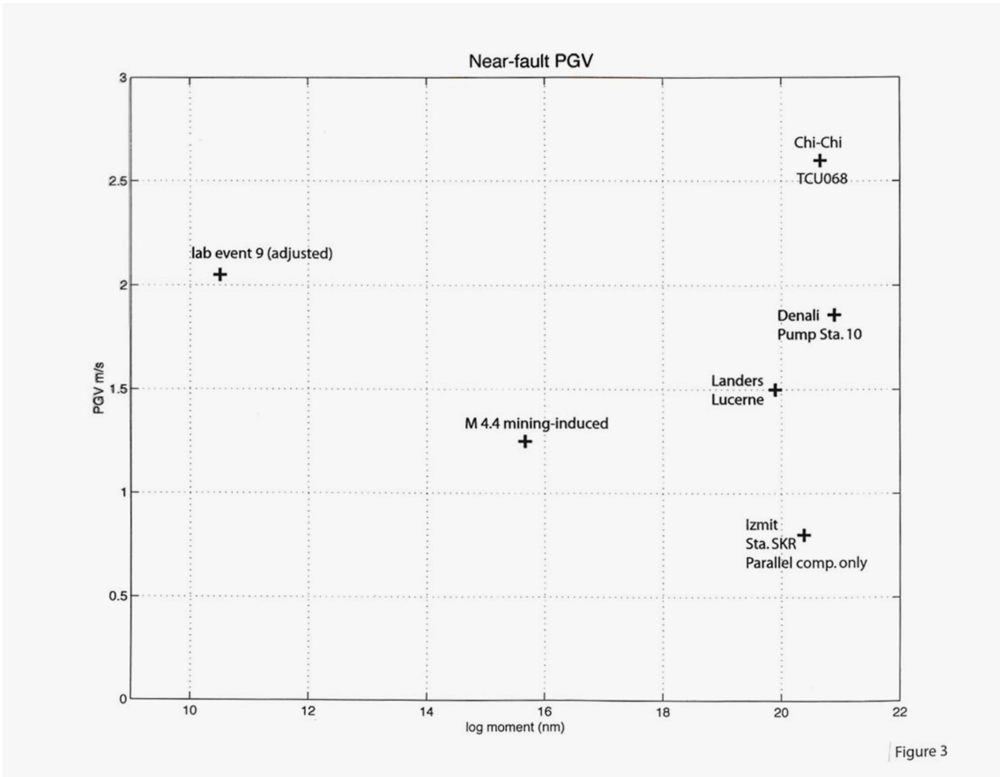

Figure 1. Peak ground velocity (PGV) as a function of seismic moment measured or inferred adjacent to the causative fault.

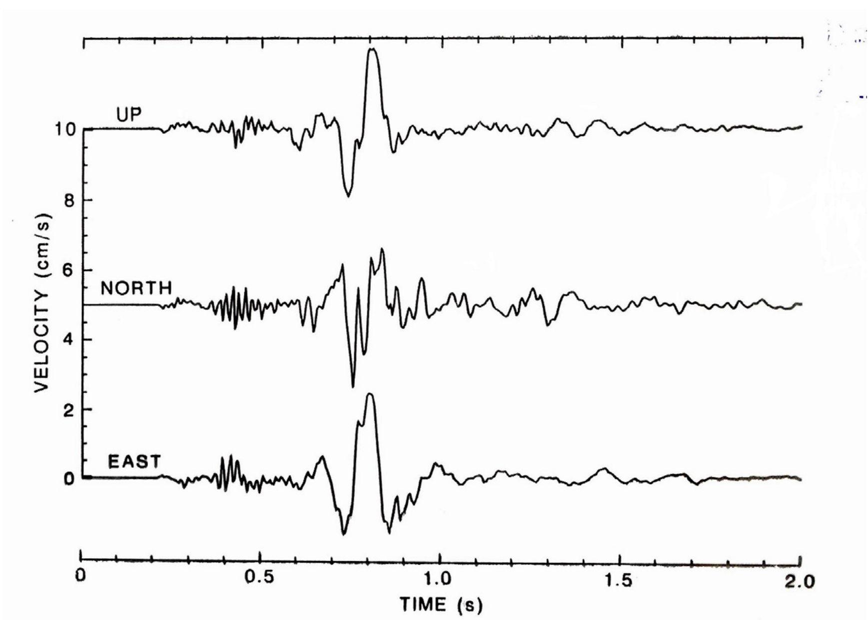

Figure 2. Ground velocity recorded at a bed rock site on the surface about 2 km above a M 4.4 mining-induced earthquake.

References

Brudy, M., M. D. Zoback, K. Fuchs, F. Rummel, and J. Baumgartner, Estimation of the complete stress tensor to 8 km depth in the KTB scientific drill holes: implications for crustal strength, *J. Geophys. Res.*, **102**, 18,453-18,475, 1997.

Ellsworth, W. L., M. Celebi, J. R. Evans, E. G. Jensen, D. J. Nyman and P. Spudich, Processing and modeling of the Pump Station 10 record from the November 3, 2002, Denali fault, Alaska earthquake, preprint 11th International Conference on Soil Dynamics & Earthquake Engineering, Berkeley, CA, January 7-9, 2004.

Lockner, D. A. and P. G. Okubo, Measurements of frictional heating in granite, *J. Geophys. Res.*, **88**, 4313-4320, 1983.

McGarr, A., Observations constraining near-source ground motion estimated from locally recorded seismograms, *J. Geophys. Res.,* **96**, 16,495-16,508, 1991.

McGarr, A. and J. B. Fletcher, Maximum slip in earthquake fault zones, apparent stress, and stick-slip friction, *Bull. Seismol. Soc. Am.*, **93**, 2355-2362, 2003.

Sekiguchi, H. and T. Iwata, Rupture process of the 1999 Kocaeci, Turkey, earthquake estimated from strong motion waveforms, *Bull. Seismol. Soc. Am.,***92**, 300-311, 2002.

Silva, W. and I. G. Wong, Proposed ground motions for postclosure analysis, presented to Nuclear Waste Technical Review board, Joint Meeting of the Natural system and Engineered System Panels, Los Vegas, NV, 24 February, 2003.

Somerville, P. G., N. F. Smith, R. W. Graves and N. A. Abrahamson, Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity, *Seismol Res. Lett.* **68**, 199-222, 1997.

Stepp, J. C., I. Wong, J. Whitney, R. Quittmeyer, N. Abrahamson, G. Toro, R. Youngs, K. Coppersmith, J. Savy, T. Sullivan and Yucca Mountain PSHA Project Members, Probabilistic seismic hazard analyses for ground motions and fault displacement at Yucca Mountain, Nevada, *Earthquake Spectra*, **17**, 113-151, 2001.