Toppling Accelerations of Precarious Rocks on a Profile Perpendicular to the San Andreas Fault for Constraining Strong Motion Attenuation Relationships for Great Earthquakes

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Constraints on dynamic horizontal ground accelerations that could topple precariously balanced rocks can be approximately estimated by measuring the quasi-static toppling accelerations of the rocks in the field (Shi *et al.*, 1996). The quasi-static toppling accelerations of the rocks are determined by the ratio of the quasi-static toppling force, $\vec{F}(N)$, and the estimated mass of the rock (Anooshehpoor and Brune, 1996; 1998). The horizontal quasi-static force is applied at the estimated center of mass of the rock, either by pulling or pushing. The force, monitored by a digital loadcell, is slowly increased until it reaches a maximum value. At this moment the rock begins to rotate about the rocking point and the applied horizontal force decreases in magnitude. The peak magnitude of the force is defined as the quasi-static toppling force. Once it is made sure that there is no secondary resting position for the rock, the test is complete and tipping is stopped to avoid toppling of the rock. The rock would topple when the applied force had reached zero in magnitude. The next step is estimating the mass by the product of the volume and the density of the rock. The volume is estimated by sandwiching the rock between two parallel pegboards. Using a graduated wooden dowel, that fits through the holes on the board, the horizontal distance between the rock surface and the boards at different elevations is measured. Then, using the area of the resulted parallel cross sections of the rock and the distance between them, the volume is estimated. For very large rocks and the hard to reach ones, the toppling acceleration is estimated by directly measuring the angle α between the vertical and the rocking point (αg).

During this year we surveyed and documented 32 precarious and semi-precarious rocks at Lovejoy Buttes, about 15 km northeast of the Mojave section of the San Andreas fault near Palmdale (which ruptured in the great 1857 earthquake), and about 10 balanced rocks in the San Gabriel Mountains. We completed measurements of the quasi-static toppling acceleration of 8 balanced rocks at Lovejoy Buttes (Figure 1). Tabel 1 shows the result of those measurements. The approximate dynamic accelerations, A_d, for a time history with the same shape as the El Centro seismogram are obtained by increasing the quasi-static value by 20%. This is based on a series of numerical tests (Shi *et al.*, 1996). In Figure 1, at the bottom, the locations of the tested rocks at Lovejoy Buttes are shown. The arrows are the vector representations of the toppling accelerations listed in Table 1. The ground accelerations that can topple these rocks are in the opposite direction of these arrows.

The top plot in Figure 2 shows a comparison of estimates of toppling accelerations of precarious rocks in the Mojave Desert with PSHA estimates (from published PSHA maps) and with approximate mean of mean attenuation curves derived by various authors. Numbers in the circles are the number of rocks found to give reliable estimates of toppling acceleration. (Numbers in the black circles indicate the accelerations measured in the field.) The constraint on ground accelerations provided by precarious rocks agrees well with the mean of attenuation relationships, and suggests that the "2% in 50 yr" PSHA maps for the Mojave Desert overestimates the ground accelerations. The bottom plot in Figure 2 shows similar results for the San Gabriel mountains southeast of the San Andreas fault. The three zones of semi-precarious rocks give preliminary estimates of toppling accelerations that are much lower than those provided by PSHA maps.

Figure 3 shows a comparison of estimates of ground accelerations by several authors at a distance of 15 km from large earthquakes with the spectral acceleration curve of Abrahmson and Silva (1997). By extrapolating to shorter periods, assuming a similar spectral shape, they all overestimate the peak ground acceleration constraints ($\sim 0.4g$) obtained from the estimates of toppling acceleration for the precarious rocks found at a distance of about 15 km from the Mojave section of the San Andreas Fault at Lovejoy Buttes, and in the San Gabriel Mountains. The spectral acceleration plot for the N-S component of the 1940 El Centro earthquake is shown as well. We estimated the dynamic toppling accelerations of rocks for a time history with the same shape as the El Centro seismogram by increasing the quasi-static value by 20% (Shi *et al.*, 1996).

We also deployed two portable seismic stations at Lovejoy Buttes and Piute Butte (Figure 1), in conjunction with the LARSE2 passive experiment, for the purpose of investigating any anomalous site effect at these location. These stations have been operating since late October, 1998. We have recorded numerous local and regional earthquakes, but have not analyzed any data yet.

References

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Table 1: Field measurements of the quasi-static toppling accelerations, A_{qs}, for several precariously balanced rocks located at Lovejoy Buttes, California.

Rock I.D.	$\vec{F}(N)$	Direction	Mass (kg)	A_{qs} (g)	A_d (g)
LB1	356	E	154	0.24	0.29
LB2a	89	N75°W	27	0.34	0.41
LB2b		N75°W		0.30	0.36
LB5a	2000	N70°W	471	0.43	0.52
LB5b	3164	N35°E	944	0.34	0.41
LB9	302	S25°E	95	0.32	0.38
LB15a	1293	N60°W	519	0.25	0.30
LB15b	6222	E10°S	1557	0.41	0.49

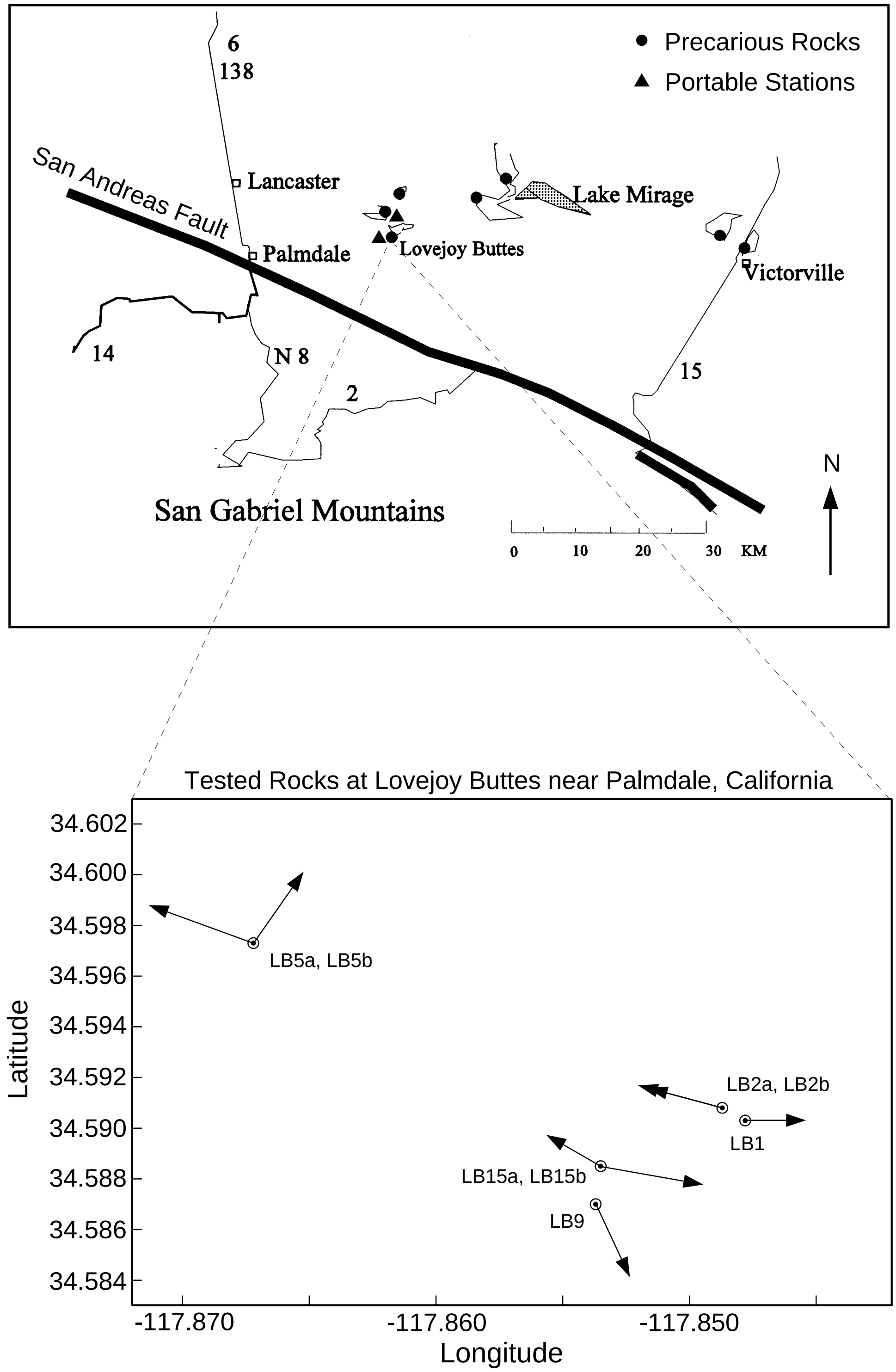
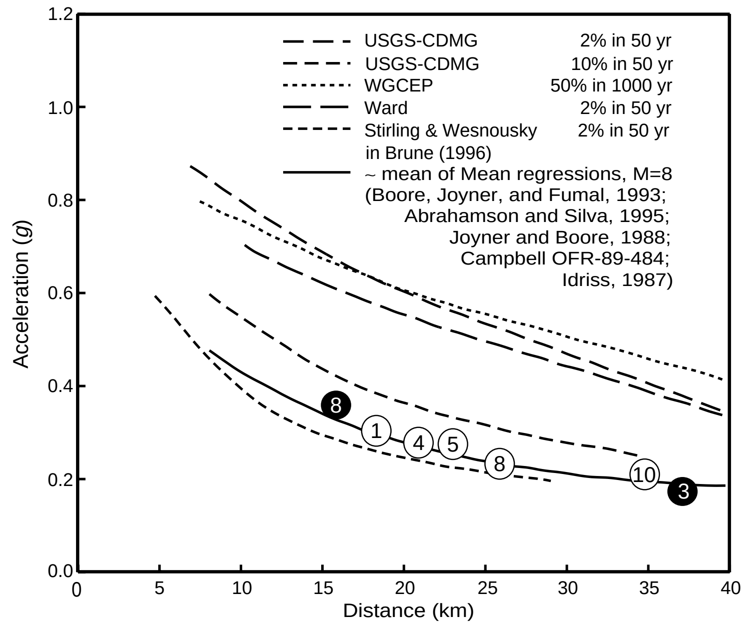
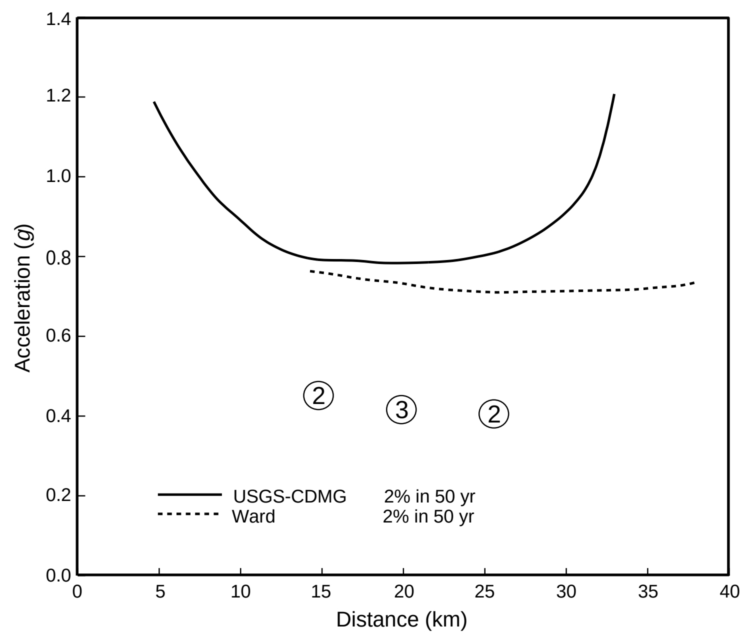


Figure 1: Map showing the locations of precarious rocks near the San Andreas Fault. The map at the bottom shows the locations of the 8 rocks tested in the field. Arrows represent the magnitude and the direction of the toppling accelerations listed in Table 1.



(a)



(b)

Figure 2: (a) Comparison of estimates of toppling accelerations of precarious rocks in the Mojaveh Desert with PSHA estimates (from published PSHA maps) and with approximate mean of mean attenuation curves derived by various authors. Numbers in the circles are the number of rocks found to give reliable estimates of toppling acceleration. (Solid circles indicate accelerations measured in the field.) (b) Same information for San Gabriel Mtns.

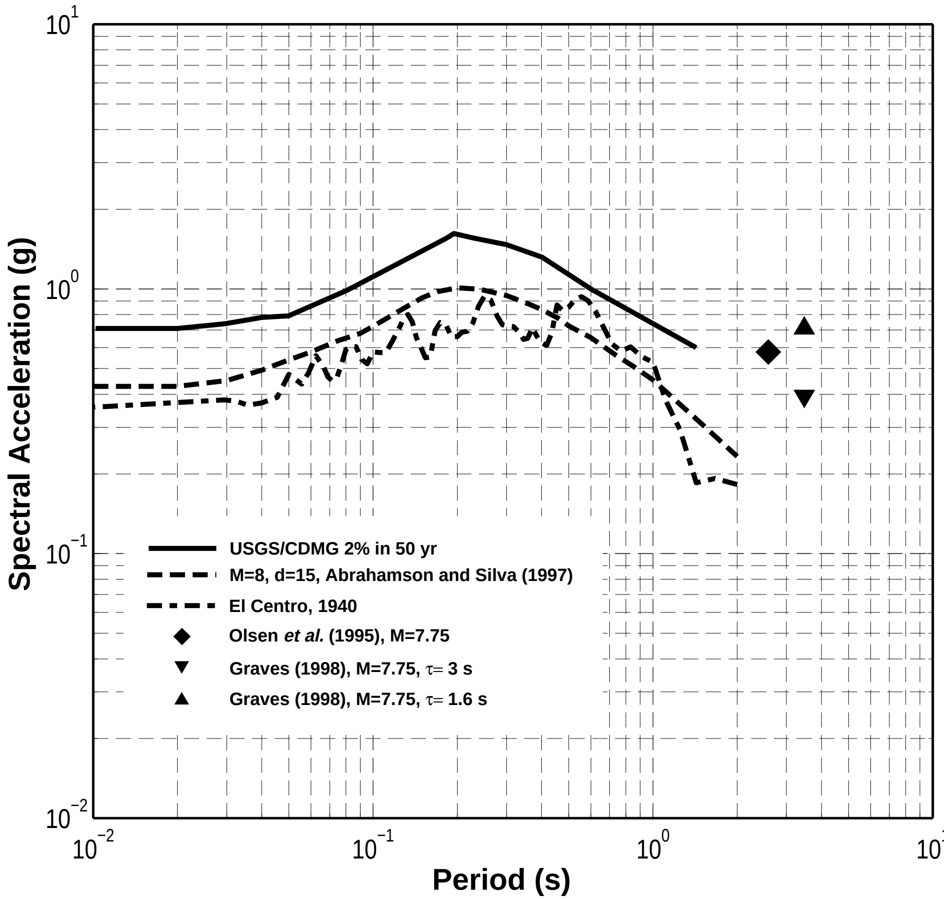


Figure 3: Comparison of estimates of ground accelerations by several authors at a distance of 15 km from large earthquakes with the spectral acceleration curve of Abrahamson and Silva (which is consistent with the precarious rock data). Assuming a similar spectral shape, they all overestimate the peak ground acceleration constraints obtained from estimates of toppling acceleration for the precarious rocks found at a distance of about 15 km from the Mojave section of the San Andreas fault at Lovejoy Buttes, and in the San Gabriel Mountains.