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Constraints on Probabilistic Seismic Hazard Models from Unstable Landforms (Precariously Balanced Rocks): Cross Validating the North American Results

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Summary

In the past year my SCEC-funded work has comprised further, more sophisticated studies of New Zealand precariously-balanced rocks (PBRs) than the earlier field-based work (Stirling & Anooshehpoor, 2006). The collaborative work with Matthew Purvance and others at the Nevada Seismology Laboratory has continued to focus on developing PBRs as a criterion for validating the national probabilistic seismic hazard (PSH) model for New Zealand, and a means for cross-validating the otherwise wholly North American-based PBR research. Analysis of toppling probabilities at a precariously-balanced rock (PBR) site close to a major active reverse fault in the Central Otago province of New Zealand has been achieved by way of the newly-developed methodology of Purvance (2006). The analysis shows that median ground motion predictions from recently developed attenuation models for repeated earthquakes on the nearby Dunstan Fault correlate well with the existence and age of the PBRs, but the plus one standard deviation motions do not. Older attenuation models produce median motions that do not correlate with the PBR data. Only when exceptions are made regarding the PBR age and elapsed time since last earthquake can all these discrepancies be resolved. The main implication for PSHA is that the standard application of the ergodic assumption for treatment of aleatory variability in PSHA may produce overly conservative estimates of hazard at near-fault sites when ground motion uncertainties of plus one standard deviation or greater are assumed for the new attenuation models. My SCEC and New Zealand co-funded work in the coming year will be focussed on: (1) reducing the large age uncertainties for the PBRs, and; (2) determining whether similar results are obtained for PBRs at sites that have been subjected to many more earthquakes, such as near the most active faults in the country.

Introduction

In the last year of study we have applied the methodology of Purvance (2006) to one of the near-fault PBR sites in New Zealand studied by Stirling & Anooshehpoor (2006) where cosmogenic age control was obtained for two of the PBRs. The Clyde PBR site is situated on a remnant of the Central Otago peneplain plateau (Cairnmuir Flats; e.g. Brumley et al., 1985) that is studded with numerous schist tors, many of which yield either precarious or semi-precarious rocks (Fig.1). The Clyde site was chosen for our present study due to the near-fault setting of the site to the Dunstan Fault, the most active fault in the Central Otago region, and the focus of detailed paleoseismic investigations in recent years (Van Dissen et al., 2004).

Figure 1: The Clyde 6 precariously-balanced rock (PBR), one of at least 12 PBRs found on the plateau of Cairnmuir Flat, an uplifted remnant of the Central Otago peneplain. Clyde 6 was one of two PBRs that were subjected to dating of the pedestal of the rock (around 30cm above the notebook; see Stirling & Anooshehpoor, 2006)

Earthquake Source: Dunstan Fault

The Dunstan Fault is the most active fault in the central Otago region, and is the closest fault to the Clyde PBR site The fault shows reverse slip and the closest active fault traces to the Clyde site are less than 5km away. Scaling relations predict a moment magnitude (Mw) of about 7 for the fault. For the modelling of ground motions at the Clyde PBR site, the fault is assumed to be 14km wide, based on a seismogenic thickness of 12 km and dip of 60 degrees (default values). The recurrence interval stands at 2,000 to 7,000 years based on the recent results of a seismic hazard re-evaluation of the Clyde hydro dam (work currently in progress and summarised thus far in Van Dissen et al., 2004), and the last event may have been around 9,000 years ago. 5,000 years is therefore an approximation of the average long-term recurrence interval. The Clyde site lies approximately off the southwestern end of the Dunstan Fault, which represents neither a hanging wall or footwall setting in relation to the fault. Our analysis only considers ground motions from the Dunstan Fault, given the overwhelming dominance of the fault in the PSHA for the Clyde site (Stirling & Anooshehpoor, 2006).

Ground Motion Predictions

The choices of attenuation models are the New Zealand model of McVerry et al (2006; referred to hereafter as the McVerry model), and the Next Generation Attenuation (NGA) models of Chiou & Youngs (2006) and Boore & Atkinson (2006). The older Abrahamson & Silva (1997) model (A&S model) is also used for comparative purposes. The following table shows the median accelerations and the associated standard deviations for Dunstan Fault earthquakes at the Clyde PBR site. We simply show the McVerry and A&S model calculations, as the McVerry and NGA models produce very similar results. In contrast the differences in predicted accelerations from Dunstan Fault earthquakes for the McVerry/NGA versus A&S model are very large.

Table 1: Median accelerations and associated standard deviations for Dunstan Fault earthquakes at the Clyde PBR site. The site is assumed to be 5km from the fault and the site conditions are assumed to be for rock.

MODEL	**SIGMA(total)**
McVerry et al (2006); (ESSENTIALLY IDENTICAL RESULTS TO NGA MODELS)	
Median acceleration on rock (NZ rock is approximately 760 m/s)	
PGA=0.49g	0.45
SA(1)=0.31g	0.53
SA(2)=0.16g	0.59
Abrahamson & Silva (1997)	
PGA = 0.75g	0.43
SA(1) = 0.44g	0.59
SA(2) = 0.17g	0.64

Comparison of Earthquake Motions to PBRs

The graphs in Figure 2a-c show application of the Purvance (2006) methodology to the Clyde PBR site. The graphs show the probability of toppling the Clyde 6 PBR due to repeated Dunstan Fault earthquake motions. The four graphs show the toppling probabilities that result from the simple assumption of Dunstan Fault earthquakes recurring every 5,000 years (Figs 2a & c), and the probabilities that result from the additional assumption that no earthquakes have occurred in the last 9,000 years (Figs 2b & d). The graphs should be interpreted as toppling probability (y-axis) as a function of the potential age of the Clyde 6 PBR (x-axis). An age of 10,000 to approximately 50,000 years is given for the Clyde 6 PBR (Stirling & Annooshehpoor, 2006). The two lines on the McVerry/NGA model graphs (Fig. 2a & b) show the cases that result from the standard deviation being set to zero and to one in the model. For the A&S model graphs (Fig. 2c & d) both of these cases produce the same result, giving the single line on the graphs.

The toppling probabilities as a function of age for the Clyde 6 PBR differ greatly for the McVerry/NGA models, depending on whether the predicted motions are set at the median versus the plus one standard deviation level. For the case of simply assuming that the Dunstan Fault earthquakes have occurred with a recurrence interval of 5,000 years, high toppling probabilities are achieved at less than the minimum age of the PBR with the assumption of plus one sigma motions for the McVerry/NGA models. The same is achieved for the median motions from the A&S model. These McVerry/NGA and A&S-derived motions are only consistent with the survival of the Clyde 6 PBR if it is assumed that no earthquakes have occurred in the past 9,000 years (see above) and the age of the PBR is at the minimum estimate of 10,000 years.

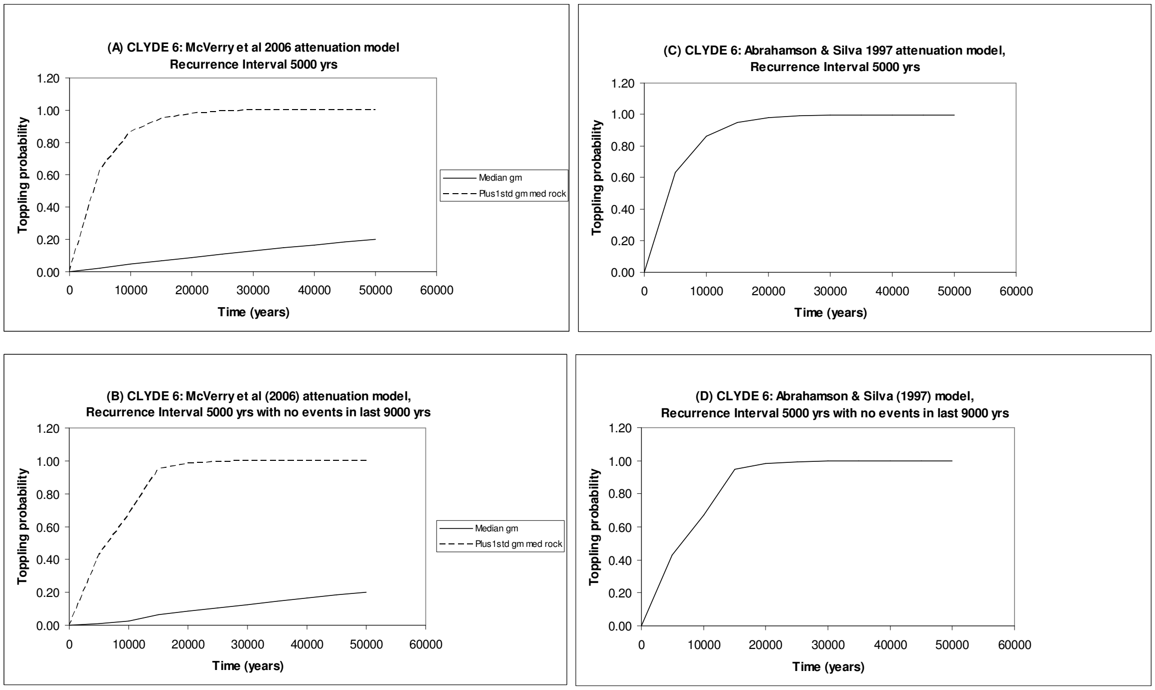

Figure 2: Fragility curves that show toppling probabilities of the Clyde 6 PBR as a function of age and repeated Dunstan Fault earthquakes. The four cases are as follows: (a) use of the McVerry et al (2006) model and assumption of an average recurrence interval of 5,000 years; (b) as for (a) but with the assumption of no earthquakes in the last 9,000 years; (c) use of the Abrahamson & Silva (1997) model and assumption of an average recurrence interval of 5,000 years; and (d) as for (c) but with the assumption of no earthquakes in the last 9,000 years. The solid lines give the toppling probabilities for median ground motions, and the dashed lines give the probabilities for plus one standard deviation motions.

Discussion and Conclusions

Our results indicate that the plus one standard deviation motions predicted for repeated Dunstan Fault earthquakes from the McVerry and NGA models, and median motions from the older A&S model are inconsistent with the fragility and age of the Clyde 6 PBR. An exception to these observations is the case where we assume that the PBR has an age close to the minimum reported estimate of 10,000 years and the Dunstan Fault has not produced any earthquakes over that time period (Fig 2b & d). Reduction of the large uncertainties in the age estimates for the PBRs and confirmation of the elapsed time since the last earthquake on the Dunstan Fault will more clearly define the level of uncertainty that should be built into near-fault motion estimates from the McVerry/NGA attenuation models. In the coming year my SCEC and New Zealand co-funded work needs to be focussed on (1) gaining additional age control on PBRs at the Clyde site and elsewhere to refine the age constraints on the PBRs in the New Zealand environment, and; (2) determining whether similar results are obtained for PBRs at sites that have been subjected to many more earthquakes, such as sites near major active faults like the Alpine Fault. This annual report is a précis of a manuscript that has been recently prepared for submission to the Bulletin of the Seismological Society of America (Stirling et al. in preparation).

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