ANNUAL REPORT 2007

Validation of a Petascale Cyberfacility for Physics-based Seismic Hazard Analysis using Precariously Balanced Rocks

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INTRODUCTION

Precariously balanced rocks (PBRs) are fragile geomorphic features which can be destroyed by low to moderate levels of ground motion. Brune and Whitney (1992) first recognized the importance of PBRs for constraining ground motions and identified a number of PBRs on Yucca Mountain. Subsequently PBRs have been located in a plethora of tectonic environments including near to the Mojave section of the San Andreas fault (Brune 1999), asymmetrically distributed with fault distance on the footwall and hanging wall sides of the White Wolf thrust fault (Brune et al. 2004), close to trans-tensional strike-slip faults (Brune 2003), within a few hundred meters of the traces of normal faults on the footwall sides (Brune 2000), and equidistant (~15 km) between the San Jacinto and Elsinore faults (Brune et al. 2006). This progress report documents our efforts to further refine the ground motion constraints in Southern California provided by PBRs through field testing and careful shape estimation. In addition, this report presents comparisons between PBRs and ground motions produced by the ShakeOut scenario (Graves et al. 2007).

FIELD TESTING PBRS – FORCED TILTING AND SHAPE ESTIMATION

As shown in Purvance et al. (in press), the contact conditions between a PBR and the pedestal upon which it rests strongly affect the fragilities. Figure 1a shows an example of a PBR with simple basal contact conditions and a restoring force versus tilt curve. Figure 1b, on the other hand, depicts similar information for a PBR with a pronounced basal bump. The bump allows the PBR to initiate rocking motion at lower PGA, reducing the PBR's overturning resistance. In fact, the presence of basal bumps reduced the PGA associated with overturning by ~ 50% during a set of shake table experiments. As a result, a concerted effort is underway to measure the forced tilting responses of PBRs in Southern California. In 2007, field testing was focused on PBRs at three sites important for seismic hazard in Southern California, namely Perris, Pinyon Crest and Pioneer Town (Figure 2). Examples of measured forced tilting responses are shown in Figure 3.

We have also developed a method to accurately determine the PBR shapes which further reduces the uncertainty in PBR fragility estimation. We have recently acquired photogrammetry software that facilitates accurate estimates of the PBR masses and the center of mass locations. This method utilizes coded targets and a digital camera to develop an accurate digital representation of each PBR; future initiatives may use the 3D shapes to simulate the rocking and overturning responses on a 3D simulation platform. We have applied this method to all PBRs that have been field tested in 2007 (see Figure 4 for an example). This method has been validated through mass estimation of objects with known masses, finding that our current mass estimates are within 5-10% of the true masses.

COMPARISON BETWEEN PBRS AND THE SHAKEOUT SIMULATION

In 2008, NEHRP will oversee a massive multi-hazard response exercise based on the damage inflicted by an M=7.8 rupture scenario on the Southernmost San Andreas Fault. Vital aspects of the Great Southern California ShakeOut exercise are the realistic depictions of both the spatial distributions and intensities of damage resulting from strong ground shaking produced by such an event. In this vein, simulated ShakeOut ground motions provided by Graves et al. (2007) have been compared with PBRs at 20 sites in Southern California (Figure 5). The simulated ground motions cover a broad frequency range (0-10 Hz) and incorporate effects of complex fault rupture and 3D wave propagation. Purvance et al. (in press) developed PBR fragilities that depend on a vector of ground motion intensities (e.g., PGA and either PGV, Sa(1), or Sa(2)). As the ShakeOut simulation produced broadband ground motions, it is straightforward to calculate the PBR fragilities and estimate the overturning probabilities. As shown in Figure 6, PBRs at only two sites overturn with greater than 50% probability given the ShakeOut ground motions. The broad agreement between the ShakeOut ground motions and the PBR constraints suggests that the ground motions are not unrealistically intense.

During the 1952 Kern County Earthquake, a number of transformers were overturned due to intense shaking. This analysis can also be extended to assess the loss of electric transformers given the ShakeOut ground motions. As shown in Figure 7, a number of electric substations exist in the region influenced by a ShakeOut type earthquake. Using these ground motions, a number of electric substations near to the San Andreas Fault may experience significant damage in terms of transformer overturning from such an event. These findings are critical for emergency responders as resources may have to be allocated to deal with the loss of power in these areas. This is especially important should a ShakeOut type event occur in the heat of the summer as air conditioning is a necessity for survival in Mojave Desert towns.

CONCLUSIONS

We have continued in 2007 to refine PBR based ground motion constraints through force tilting tests in the field and careful shape determination via the photogrammetry technique. This information is vital for the rigorous testing of seismic hazard estimates in Southern California such as those that will be provided through the PetaSHA initiative. We have also compared the PBRs for consistency with the ShakeOut ground motions produced by the Graves et al. (2007). The PBRs generally survive the ShakOut scenario with high probability suggesting that the model does not produce unrealistically intense ground motion. In addition, this analysis has been extended to estimating the overturning probabilities of transformers at electric substations throughout the Mojave. A number of substations may experience loss of power transmission due to transformer overturning from a ShakeOut type of event; this type of information is vital for emergency responders.

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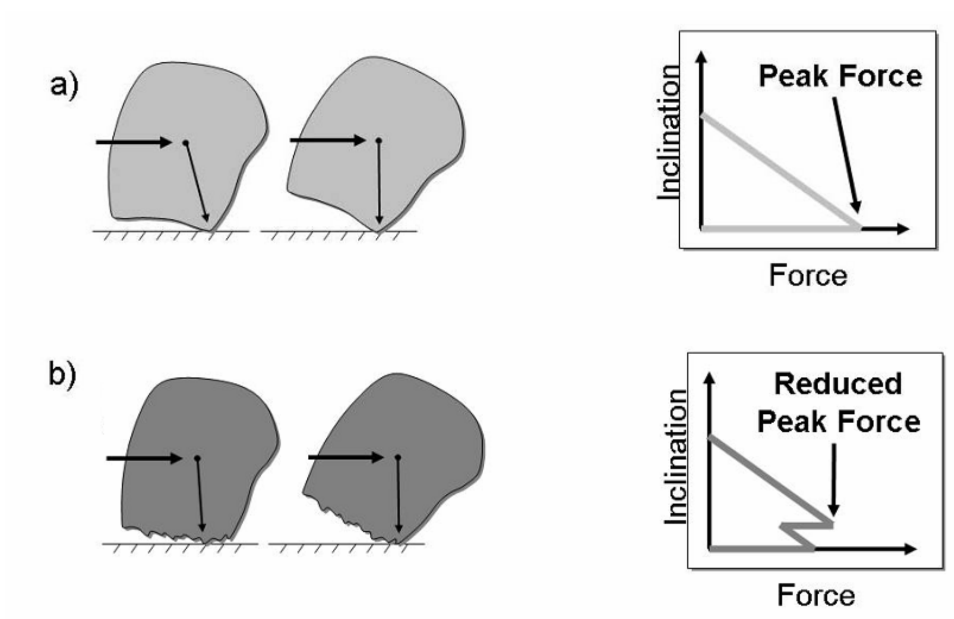

Figure 1. Examples of forced tilting responses of objects with simple basal contact conditions (a) and multiple basal bumps (b) along with the corresponding restoring force versus inclination curves.

Figure 2. Map of locations of field tests and examples of tested PBRs.

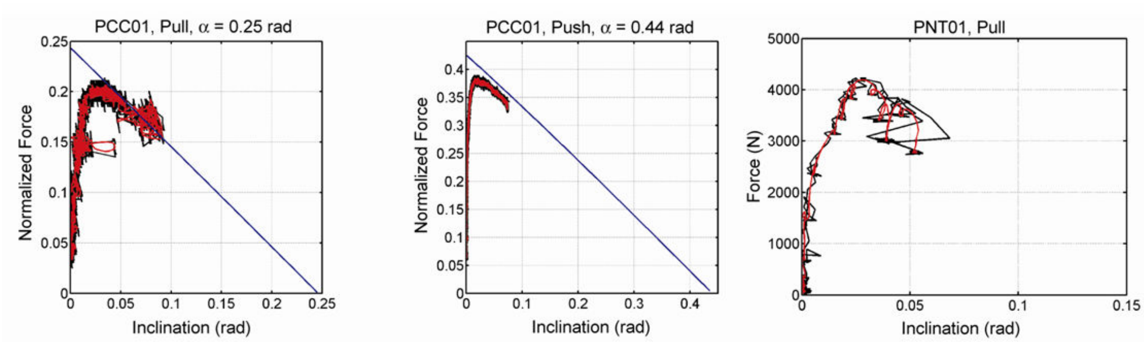

Figure 3. Examples of data produced by forced tilting tests.

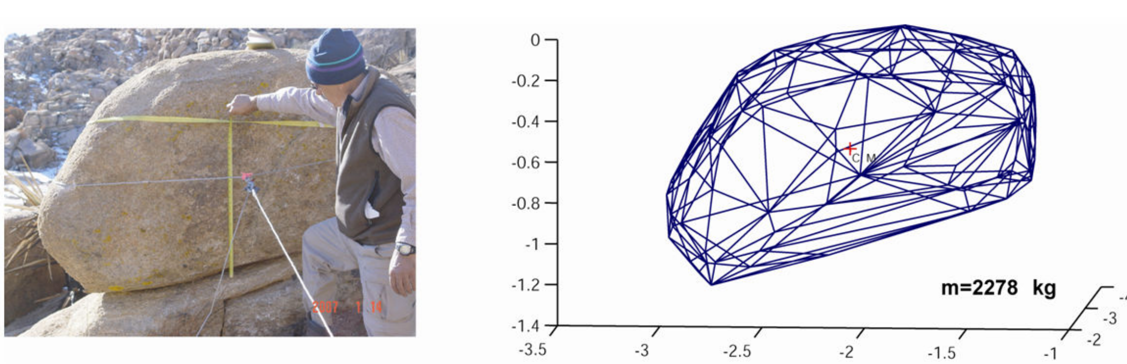

Figure 4. 3D digital representation of a PBR at Pioneer Town as determined via the photogrammetry method.

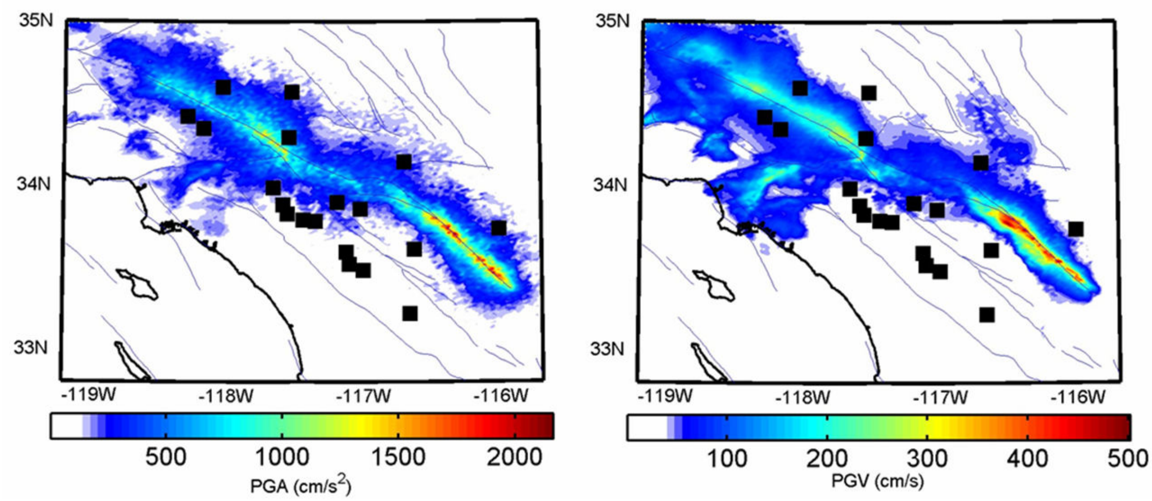

Figure 5. ShakeOut ground motions with PBR locations (black squares).

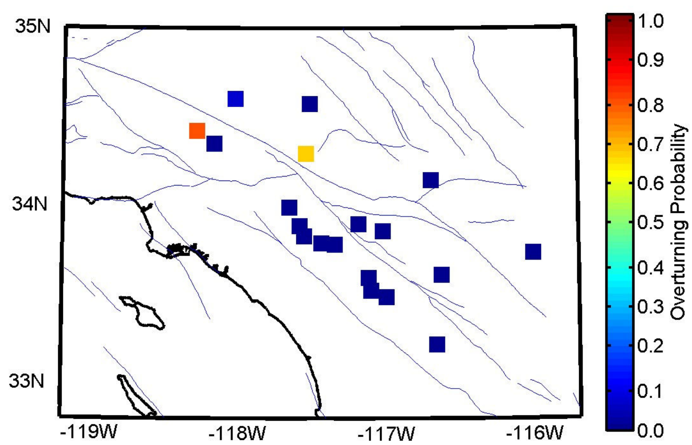

Figure 6. Overturning probabilities of the PBRs given the ShakeOut ground motions.

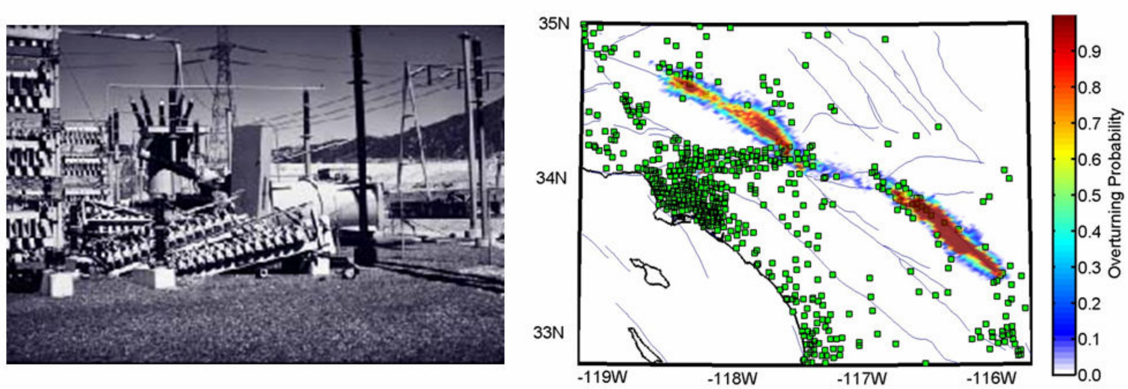

Figure 7. Picture of overturned transformer from the 1952 Kern County Earthquake along with contours of overturning probability for transformer shaped objects and the transformer locations in Southern California.