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Earthquake hazard assessment uncertainty reduced by fragile geologic features in coastal Central California

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Probabilistic seismic hazard analysis (PSHA) models typically provide estimates of ground motions for return periods that exceed historical observations. It is therefore important to develop quantitative methods to evaluate and refine ground motion estimates for long return periods, especially in proximity to major earthquake sources where estimates can be very high. Here we provide empirical constraints over 10,000s years on ground motions from onshore and offshore seismic sources in central California using the distribution, age and fragility (probability of toppling given an intensity of ground shaking) of fragile geologic features.

The fragility is estimated for seven precariously balanced rocks (PBRs) formed on uplifted marine terrace palaeo-sea stacks. The site is <10 km from the Hosgri fault, a major offshore fault considered part of the San Andreas fault system. PBR 3D models were constructed using photogrammetry and used to define normalized geometric measures that could be combined with empirical models to estimate the probability of toppling (i.e., fragility), over a range of vector ground motions (PGA and PGV/PGA). Using vector hazard and the fragility, the likelihood of survival was then computed. The PGA associated with a 50 percent chance of survival varies from ~0.4-1.3 g for the selected PBRs.

We obtain fragility ages (time that each PBR achieved its current geometry) using Be-10 cosmogenic surface exposure dating. Extremely low Be-10 concentrations (~5000 at/g) in modern high-stand samples demonstrates minimal inheritance and reliability of chert age estimates. Additionally, the volume of colluvium surrounding the palaeo-sea stack outcrops, determined from LiDAR, combined with alluvial fan surface dating (using Be-10 and soil profile development indices) indicates low erosion rates (~2.5 mm/ky) and long-term stability. Exposure ages that bound the fragility age by approximating the removal of surrounding blocks range ~17-95 ky. The similar age distributions of block removal events around all of features suggests that all PBRs

share a common evolution, and we interpret ~21 ka as the most defensible fragility age estimate of all seven PBRs, with negligible change to their fragility between that time and now. Despite the lack of constraints on the recurrence behaviour of the Hosgri Fault, the slip rate is such that the PBRs have almost certainly experienced multiple large-magnitude, near-field earthquakes, and therefore provide rare constraints on low frequency ground motions.

Each estimate output from the PSHA model is evaluated against the ground-motion corresponding to the 95% probability of survival of the most fragile PBR over the 21 ka fragility age. The logic tree branches that produce estimates inconsistent with the survival of the PBR are removed from the PSHA model. From the consistent logic tree branches a new PSHA model is produced that has reduced mean ground-motion levels and reduced uncertainty between the estimates. At the 10^{-4} hazard level, the mean ground motion estimate is reduced by ~30% and the range of estimated 5^{th}-95^{th} percentile ground motions is reduced by ~50%.