Title: Studying overturning and large displacement processes of precariously balanced rocks for ground motion estimation

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Abstract: Studying the overturning and large-displacement processes of precariously balanced rocks (PBRs) facilitates ground motion estimation. Using a physics engine and robotic tools, we developed a virtual shake robot (VSR) to simulate the dynamics of PBRs for the study of overturning and large-displacement processes. We applied the VSR to investigate a PBR at a study site of Double Rock, located close to the critical infrastructure of the Diablo Canyon nuclear Power Plant. Our overturning experiments demonstrated that the ground motion orientation and lateral pedestal support were important factors that affect PBR fragility. Large-displacement experiments estimated rock trajectories (post overturning) for various ground motions. Ground motions positively correlated with large displacement statistics such as mean trajectory length, mean largest velocity, and mean terminal distance. The overturning and large displacement processes of PBRs may provide complimentary constraints to refine ground motion estimation: fragile configurations of existing PBRs indicate an upper-bound ground motion constraint; large displacements of toppled PBRs suggest a lower-bound ground constraint.

Studying overturning and large displacement processes of precariously balanced rocks for ground motion estimation

GAGE/SAGE 2023 Community Science Workshop

EarthScope Consortium

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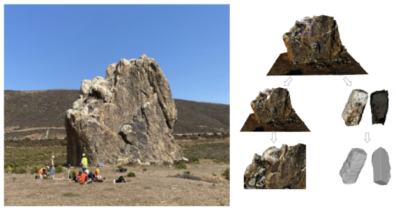
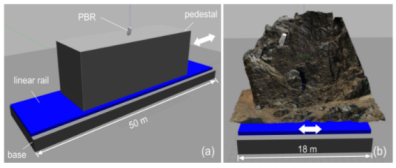
Precariously Balanced Rocks and UAV Mapping



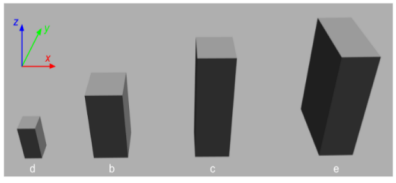
Precariously balanced rocks (PBRs) at Double Rock, located close to the critical infrastructure of the Diablo Canyon nuclear Power Plant. 3D geometric modeling of terrain and PBR was mapped by unpiloted aerial vehicle (UAV) and structure from motion (SfM).

Virtual Shake Robot

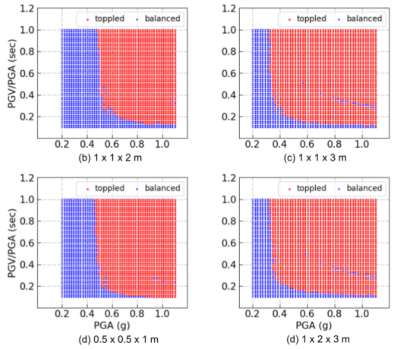


Using a physics engine and robotic tools, we developed a virtual shake robot to simulate the dynamics of PBRs.

Fragility and Geometric Dimensions

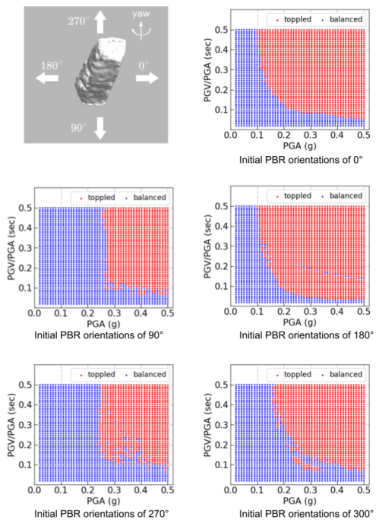


(a) Cuboids with different dimensions



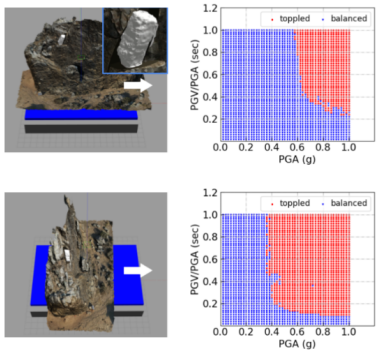
- same height-width ratio: smaller PBR, more fragile
- same width: taller PBR, more fragile
- same height-width ratio: length does not affect fragility

Fragility Anisotropy



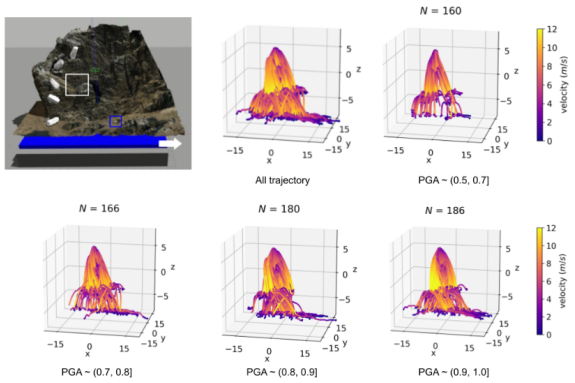
From the opposite directions, the same single-pulse cosine ground displacements produced different overturning responses. The PBR was less fragile to the 90° ground motions than 0° or 180° ground motions.

Niche Studies

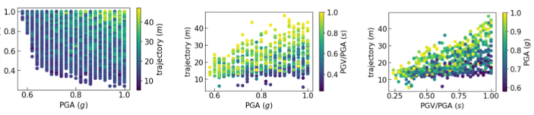


The effects of the surrounding pedestals varied from different ground motion directions. When the ground motion was along the yaw 0° direction, the surrounding pedestals largely reduced the PBR fragility. When the ground motion was along the 90° direction, the surrounding pedestals only slightly reduced the PBR fragility.

Large Displacement Studies



As PGA increases, the number of trajectories and the ratio of trajectory number to ground motion number also increase. Comparing the trajectory plots gives an intuition of how trajectory and velocity change with PGAs.



Concurrently large PGA and PGV/PGA result in a long trajectory. Only one large value in either PGA or PGV/PGA is not sufficient to produce a long trajectory. Trajectory length tends to increase with PGA or PGV/PGA. The trajectory data points around 6 m represent the situations where the overturned PBR lands on the niche position shown as the white box.

Correlation between Large Displacement and Ground Motion

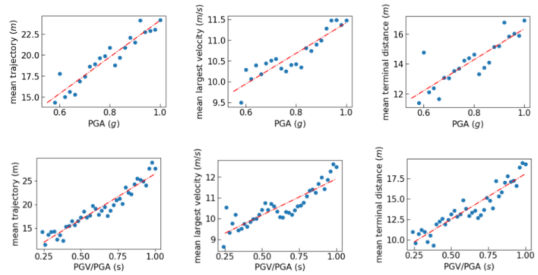


Table 1 Large displacement property and ground motion correlation statistics

R^2	PGA	PGV/PGA	p-value	PGA	PGV/PGA
mean trajectory	0.90	0.92	mean trajectory	2.3×10^{-11}	3.2×10^{-22}
mean largest velocity	0.82	0.78	mean largest velocity	5.5×10^{-9}	1.0×10^{-13}
mean terminal distance	0.73	0.87	mean terminal distance	3.5×10^{-7}	3.9×10^{-18}

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