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Does low magnitude earthquake ground shaking cause landslides?

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Estimating the magnitude of coseismic landslide strain accumulation at both local and regional scales is a key goal in understanding earthquake-triggered landslide distributions and landscape evolution, and in undertaking seismic risk assessment. Research in this field has primarily been carried out using the ‘Newmark sliding block method’ to model landslide behaviour; downslope movement of the landslide mass occurs when seismic ground accelerations are sufficient to overcome shear resistance at the landslide shear surface. The Newmark method has the advantage of simplicity, requiring only limited information on material strength properties, landslide geometry and coseismic ground motion. However, the underlying conceptual model assumes that shear strength characteristics (friction angle and cohesion) calculated using conventional strain-controlled monotonic shear tests are valid under dynamic conditions, and that values describing shear strength do not change as landslide shear strain accumulates.

Recent experimental work has begun to question these assumptions, highlighting, for example, the importance of shear strain rate and changes in shear strength properties following seismic loading. However, such studies typically focus on a single earthquake event that is of sufficient magnitude to cause permanent strain accumulation; by doing so, they do not consider the potential effects that multiple low-magnitude ground shaking events can have on material strength. Since such events are more common in nature relative to high-magnitude shaking events, it is important to constrain their geomorphic effectiveness.

Using an experimental laboratory approach, we present results that address this key question. We used a bespoke geotechnical testing apparatus, the Dynamic Back-Pressured Shear Box (DynBPS), that uniquely permits more realistic simulation of earthquake ground-shaking conditions within a hillslope. We tested both cohesive and granular materials, both of which displayed ductile behaviour under standard strain-controlled monotonic shear tests. We applied dynamic stresses of varying amplitude, frequency and sequence, and monitored the resultant strain response to determine which factors, when combined, create significant deviations from standard monotonic shear behaviour. Critically, we demonstrate that multiple dynamic stress/shaking events that are largely insufficient to cause permanent strain accumulation (and hence are conventionally deemed geomorphologically ineffective) can, under favourable though limited conditions, affect material stiffness such that the future behaviour of the sediment/landslide differs considerably from that observed in standard monotonic shear tests. In other words, low-magnitude ground shaking events can be effective precursory geomorphic processes. Our results have important implications for studies of long-term landscape evolution, in which modelled hillslopes are repeatedly subjected to multiple earthquake events but that currently lack appropriate empirically-constrained strength parameters.