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Characterization of unstable rock slopes using ambient vibration analysis

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Earthquake-induced landslides can have serious social impacts, causing many casualties and significant damage to infrastructure. They are the most destructive secondary hazards related to earthquakes. The impact of strong seismic events is not limited just to triggering of catastrophic slope failures, it also involves weakening of intact rock masses and reactivation of dormant slides. Hazard mitigation of potentially catastrophic landslides requires a thorough understanding of the mechanisms driving slope movements and seismic response.

We present an overview of the investigations on more than 25 instabilities. The results show that ambient vibration measurements allow for a rapid and objective characterization of potential slope instabilities. It is possible to distinguish unstable from stable areas, to identify slope eigen-frequencies, local amplification levels due to weak excitation, local deformation directions and properties of the internal slope structure. The ambient vibration techniques include single-station H/V ratios and polarization analyses, site-to-reference spectral ratios, array methods to identify surface-wave dispersion curves, and/or normal mode analysis using enhanced frequency domain decomposition. We analyse the seismic response of the rock slopes in different frequency bands together with its spatial and azimuthal variability, which is a fingerprint of the slope's internal structure at different scales (tenth of meters to hundred meters). Normal mode behaviour is typically observed in structures with distinct sub-volumes, where the wave field at the resonance frequencies is oriented perpendicular to the deep persistent fractures. These structures show maximum amplification at their resonance frequency. Normal mode behaviour is also observed for rock towers, similar to what can be observed for buildings. In contrast, a highly fractured rock mass without dominant cracks is characterized by an S-wave velocity gradient with shear-wave velocity being significantly reduced close to the surface. Generally, normal modes do not develop, but surface waves propagate in such structures, which can be used for the determination of the S-wave profile. This is typical for large deep seated landslides with a layered structure. Without strong S-wave velocity contrast at depth, H/V spectral ratios show no clear peak and are not conclusive to characterize structures with highly fractured material. However, frequency-dependent ground-motion amplification from standard spectral ratios is directly related to the S-wave velocity profile and damping. Therefore, wave amplification can be a measure for the disintegration of the rock.

Repeated measurements on slopes allow for the detection of possible changes in their properties. Semi-permanent installations on instabilities of interest allow for a continuous assessment of the dynamic response in order to understand variations due to weather conditions and potential long-term changes. This includes the measurement of site-amplification during earthquakes derived from empirical spectral modelling. When measuring in the same season and weather condition, the seismic response of rock instabilities in general remains unchanged over years, as long a no external trigger affects the instability, including a strong earthquake, partial failure of the slope or permafrost degradation.