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Modelling vibration-induced stresses in tall (11 to 40 m) rock columns partially supported by interstitial ice

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The emergence of alpine rock slope instabilities during periods of strong warming or abnormally high temperatures has been linked to the degradation of interstitial ice and permafrost through a number of mechanisms. Studies seeking a causative link typically suggest the instability results from an increase in driving stress due to the development of high joint water pressures, a loss of rock mass cohesion as interstitial ice melts from joints, or a combination of the two effects. Here, we investigate the potential for critical tensile stresses to form at the base of large (meter-scale) vertical rock columns in response to a combination of increased geometric freedom as ice melts out of a pre-existing fracture separating the column from the stable rock mass, and seismic excitation due to a) ambient seismic noise, or, b) a magnitude Mw 6 earthquake at a focal distance of 60 km.

Using a 2D finite element model, we evaluate eigenfrequencies for a range of equivalent rock slope geometries with ice-backed column thicknesses ranging from 2 m to 7 m, heights ranging from 40 m to 11.5 m (respectively), and 100 different ice occupation configurations. Selecting the excitation frequency that produces the largest deformation at the base of the column, we then run two time dependent simulations (for excitation by ambient noise, or an earthquake) for each geometric configuration in order to assess the maximum tensile stress generated at the tip of the fracture separating the column from the stable rock slope. Modelled displacements compare favourably with observations derived from unstable rock columns in the field, while maximum tensile stresses typically increase with a thinning of ice toward the base of the fracture (allowing the column to sway more freely). The maximum tensile stress generated behind a 40 m high, 2 m wide column is 19 MPa when a couple of meters of ice is present near the base of the fracture, while a similar configuration with ambient vibration produces peak tensile stresses of just 1.5 MPa. When ice fills the rear crack, the peak tensile stress for both excitation conditions is just 0.4 MPa.

While our model results suggest that ambient vibration is unlikely to generate damage in intact rock at the base of such columns, fatigue may play a role, and reducing the volume of ice behind rock columns may reduce the lifetime of tall, thin columns composed of weak rock. On the other hand, modelled tensile stresses induced by seismic loading are in the range of typical tensile strength estimates for strong rock, and although further work is required, our results suggest the simple increase in geometric freedom due to a reduction of ice in such rock slopes may lead to an increase in earthquake-triggered rock slope failures.