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Frozen and saturated Wetterstein limestone – a characterisation of changing rock strength

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Instability of rock faces in high mountain areas is an important risk factor for man and infrastructure, particularly within the context of climate change (Krautblatter et al. 2013). The presence of water in rock leads to a clear rise in rock strength, the effect is intensified with lower temperatures and a higher degree of saturation (Kodama et al. 2013). As reduced rock strength due to phase change from frozen to unfrozen state has a high influence on the rock-ice-mechanical model, this research focused on intact rock bridges (Krautblatter et al. 2013). The indirect tensile strength and uniaxial compressive strength increase inverse with temperature (Kodama et al. 2013).

The aim of this research has been a characterisation of the rock mechanical properties of Wetterstein limestone and quantifying its change in strength due to thawing of saturated and frozen rock. Indirect tensile tests and uniaxial compression tests as well as ultrasonic tests were conducted on continuously frozen and saturated rock samples.

We tested the tensile strength for 30 saturated samples, with a result of 7,2 $\pm$ 1,9 MPa, while for saturated and frozen samples it was 9,0 $\pm$ 1,4 MPa. The uniaxial compression tests were conduced on each 15 saturated as well as 15 saturated and frozen samples. For the saturated samples the uniaxial compressive strength was 91 $\pm$ 27 MPa, for the saturated and frozen samples 109 $\pm$ 25 MPa.

The ultrasonic tests were conduced on dry, on saturated and on saturated and frozen samples. For each phase a number of 30 tests with 3 measurements per sample were made. The dry samples had the lowest P-wave velocity (5735 $\pm$ 195 m/s), as well as the lowest Young's modulus 58 $\pm$ 4,8 GPa. For the saturated samples, the P-wave velocity was 6290 $\pm$ 170 m/s, the Young's modulus 74,7 $\pm$ 6,8 GPa. The saturated and frozen samples had the highest P-wave velocity and Young's modulus with 6715 $\pm$ 80 m/s and 80,2 $\pm$ 3,3 GPa respectively.

In summery a reduction of 20 % in terms of tensile strength was determined for 60 samples at the phase change from frozen to unfrozen condition. The uniaxial compressive strength decreases by 16 % at thawing for 30 samples. The Young's Modulus diminishes from frozen to unfrozen state by 20 %, for frozen to dry even 27 %. Using these mechanical properties for frozen and for saturated samples, a rock-ice-mechanical modelling was conducted for the Zugspitze ridge using UDEC. As proofed by these results, permafrost regression leads towards a decrease in rock strength and favours the development of mass movements.

Kodama et al. (2013): The effects of water content, temperature and loading rate on strength and failure process of frozen rocks. – International Journal of Rock Mechanics & Mining Sciences, 62: 1-13, DOI: 10.1016/j.ijrmms.2013.03.006

Krautblatter et al. (2013): Why permafrost rocks become unstable: a rock-ice-mechanical model in time and space. – Earth Surface Processes and Landforms, 38: 867-887, DOI: 10.1002/esp.3374