Systematic derivation of anchoring forces in permafrost affected bedrock

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Abstract

Warming rate in the European Alps is twice the average global rate since the 19th century. Warming-related permafrost degradation is closely linked to changes in mechanical system behavior of rock slopes in high alpine regions. These affect slope stability itself as well as structures built on permafrost-affected bedrock in a potentially stability-relevant manner. It is, however, very difficult to gain insight in the in-situ mechanical system behavior of such permafrost-affected bedrock. However, despite the frequent use of anchoring systems, very little long-term monitoring data on the mechanical behavior of rock anchors in permafrost-affected bedrock and annual changes is available. This study uses measurements of forces on rock anchors in combination with borehole temperature data of different depths to deduce determining factors for mechanical system behavior.

Keywords: high alpine permafrost; rock anchors; mechanical system behavior; infrastructure.

Motivation

Climate warming has considerable consequences for sensitive high-alpine environments. In the European Alps warming has been twice as high as the global average rate (EEA 2009), affecting bedrock properties, and potentially altering the stability of high-alpine constructions. However, mechanical system behavior and the magnitude of stability-relevant changes is widely unexplored (Fischer et al., 2006). The overall aim of this study is to identify the predominating factors of the mechanical system by using continuous measurements of anchoring forces and temperatures.

Study site

The study site is located around the summit station of the Kitzsteinhorn cable car (3029 m a.s.l., Austria). Its immediate vicinity is home to an interdisciplinary Open-Air Lab (OpAL), where the consequences of climate change, based on a long-term surface, subsurface and atmospheric monitoring are investigated (Hartmeyer et al., 2012). It encompasses the north-oriented rock wall of the Kitzsteinhorn, which consists of calcareous micaschists. The foliation of the micaschists is inclined roughly in line with the slope, at angles between 39° and 52°. Until the mid-20th century most parts of the rock wall were covered by a permanent ice face. However, the current surface of the glacier is now located approximately 100 m lower. The summit station first built in 1965/66, has since been reconstructed twice.

Data and methods

Site investigations

Near-surface properties of the rock wall were investigated during the geotechnical mapping of the study site (Geoconsult ZT GmbH 2010).

Load Cells, Anchoring Forces

Two rows of 15 pre-stressed rock anchors were installed directly beneath the summit station in November 2015. The 25 m long anchors were drilled with an inclination of around 3° and a grouted section of 7 m length. Three of these rock anchors were equipped with continuously measuring anchor load cells.

Boreholes, Temperatures

Within the framework of OpAL two deep boreholes (22m & 30 m) are providing continuous rock temperature time series in 11 depth steps in close vicinity to the rock anchors (Fig 1.).

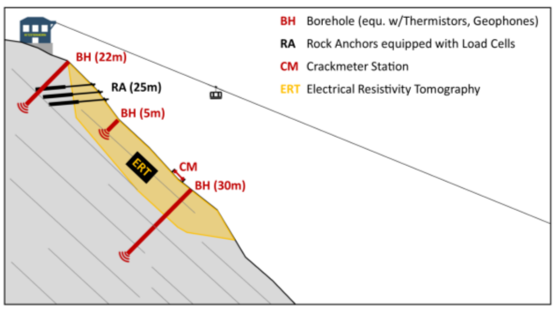

Figure 1. Existing monitoring OpAL (Hartmeyer et al., 2017).

Results

Anchor loads significantly vary between summer and winter. During the entire measuring period of two years, load values reach their maximum around December and stagnate until the end of May. From May on values decrease on average by 120 kN (22%) below their maximum. Specific load values are shown in Table 1.

Table 1. Anchor Load Values.

Load cell	Min	Max	Variability abs	Variability perc
#9	400	585	185	32%
#12	386	492	106	21%
#15	506	580	74	13%

Combining datasets on load values and temperature at anchor head and different depth steps in boreholes an annually recurring pattern is clearly discernible (Fig. 2.).

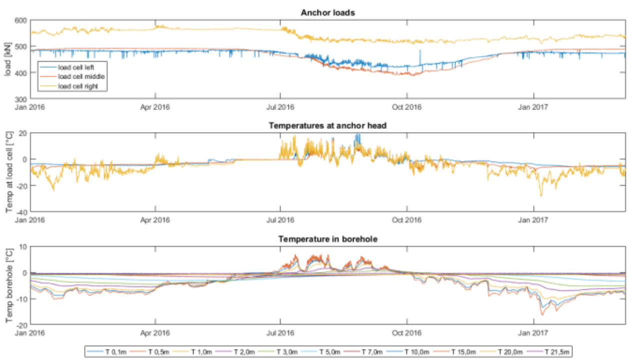

Figure 2. anchor loads and temperatures.

Discussion

Annual changes in anchor loads correlate with temperatures at anchor head and borehole temperatures. To determine plausible physical explanations for observed annual changes, an engineering model of the mechanical system, based on information on joint sets obtained from geological mapping as well as logs on anchor drilling comprising anchor and surrounding rock, was set up (Fig. 3).

Measuring load variations at the anchor head is tantamount to integrating relative displacement over the volume of influence of the anchor (free stressing length). Steel and the bedrock clearly exhibit similar coefficients of thermal expansion, which is why differential thermal strain can be rejected as reason for relative displacements. With known stress-strain behavior of steel and free stressing length a requisite displacement for the measured differential loads is determined. Resulting displacements can therefore be assumed to result from joints only. Regarding water and ice content in joints, ice segregation appears to be the primary driving force within the rock-anchor-joints system.

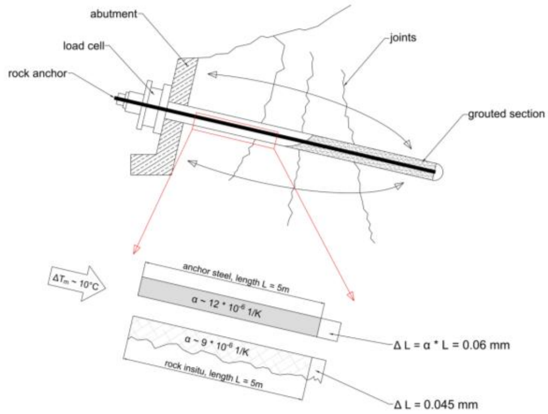

Figure 3. System sketch engineering model.

Conclusion and outlook

This is the first study to demonstrate systematic variations in anchoring forces in permafrost rocks. Ice segregation seems to have the greatest influence on mechanical system behavior. Thus, integrating these findings in the understanding of cyclic anchoring stress variations is crucial to a better design of high alpine infrastructure in future.

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