MONITORING FORCES IN STEEL WIRE ROPE NETS: EVALUATION OF SHORT AND LONG TERM INFLUENCES

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ABSTRACT: Flexible steel wire rope nets are used as mitigation measures in avalanche starting zones. The purpose of these measures lies in the prevention of an avalanche release. Net systems are loaded by the uphill snowpack which results in pressure, tensile and shear forces in various parts of the structure. At the "Hafelekar" test site close to Innsbruck (Tyrol, Austria) at 2.254 m a.s.l. forces acting on the strut in the middle and the strut at the edge of the snow net were measured from 2006 to 2017. Furthermore two automatic weather stations provide continuous measurements of air temperature and snow height in the test site.

The recordings provide the temporal evolution of forces over each winter period. Hence maximal values of forces per year and overall were determined. Since mitigation measures are dimensioned to withstand extreme values, a comparison between characteristic forces and the measured forces is given. With regards to the meteorological parameters the measurements indicate additional loading by precipitation events. Melting and sublimation processes lead to a reduction of the snowpack and therefore to decreasing forces acting on the structure. Beside seasonal variations throughout the winter period, the measured forces also indicate a diurnal variation. While resulting stresses in the structure increase during the night, they decrease during the day, if no precipitation event occurs. These fluctuations are observed in a range of $\approx 10\,\%$ of the load and are correlated with heating and cooling of the snowpack which is associated with different bonding states in the snow cover.

Keywords: steel wire rope nets, avalanche mitigation, design load, diurnal variation, mitigation measures, monitoring

1. INTRODUCTION

Snow nets are flexible supporting structures built in the starting zone of avalanches in order to prevent the failure of the snow cover. Over the past decades these structures have become more commonly used. Their linear and modular shape leads to a flexible adaption to specific topographic conditions. Further steel wire rope nets are less sensitive to rockfall compared to classical snow bridges. Since the acceptance of mitigation measures regarding preservation of nature is of gaining importance, mitigation measures with a low apparent impact are desired. Therefore snow net systems, which are made of galvanized steel, are sometimes favoured against snow bridges, which massive constructions are often brown due to corrosion and as a consequence very noticeable. Figure 1 shows the test site on the Hafelekar near Innsbruck. Figure 1 (a) highlights the inconspicuousness of the nets compared to snow bridges.

The development and dimensioning of snow nets was basically empirical and up to now only a few approaches have been made to improve the design of the snow net system (e.g. Nicot et al., 2002; Boutillier et al., 2004; Margreth and Roth, 2007). In 1954 Haefeli proposed a simple method for the design of snow nets which is still the most recognized basis for calculating these flexible structures. Margreth (1995) worked on the validation of Haefeli's proposal by field measurements.

Herein we show the time evolution of forces over two winter periods with surpassing snow depths, highlighting the maximal values of each period. The construction of steel wire rope nets is still afflicted with open questions regarding design forces. Therefore we compare forces calculated on the basis of guidelines and measured forces in the structure. Finally we depict a thaw period and examine the amplitudes of the diurnal fluctuations.

2. GUIDELINES VERSUS FORCE MEASUREMENTS

Rainer et al. (2008) proposed a comparison of force measurements and theoretical calculations considering subpar snow heights. However mitigation

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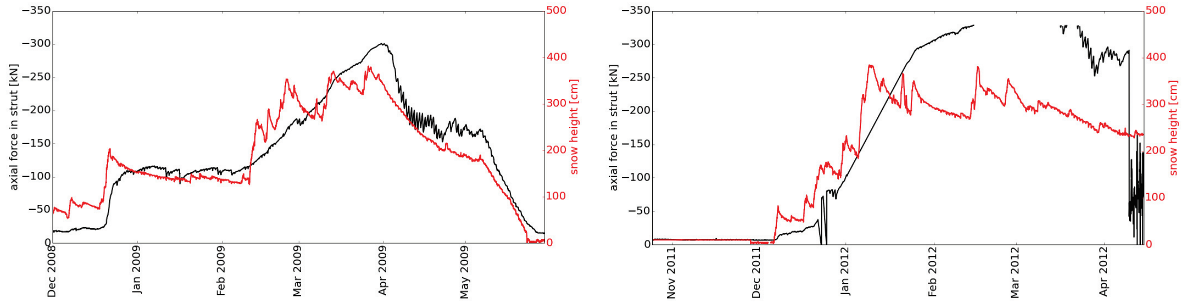
(a) Location of the Test site

(b) Test site and instrumented system

Figure 1: Test site at the Hafelekar.



(c) 2008

(d) 2011

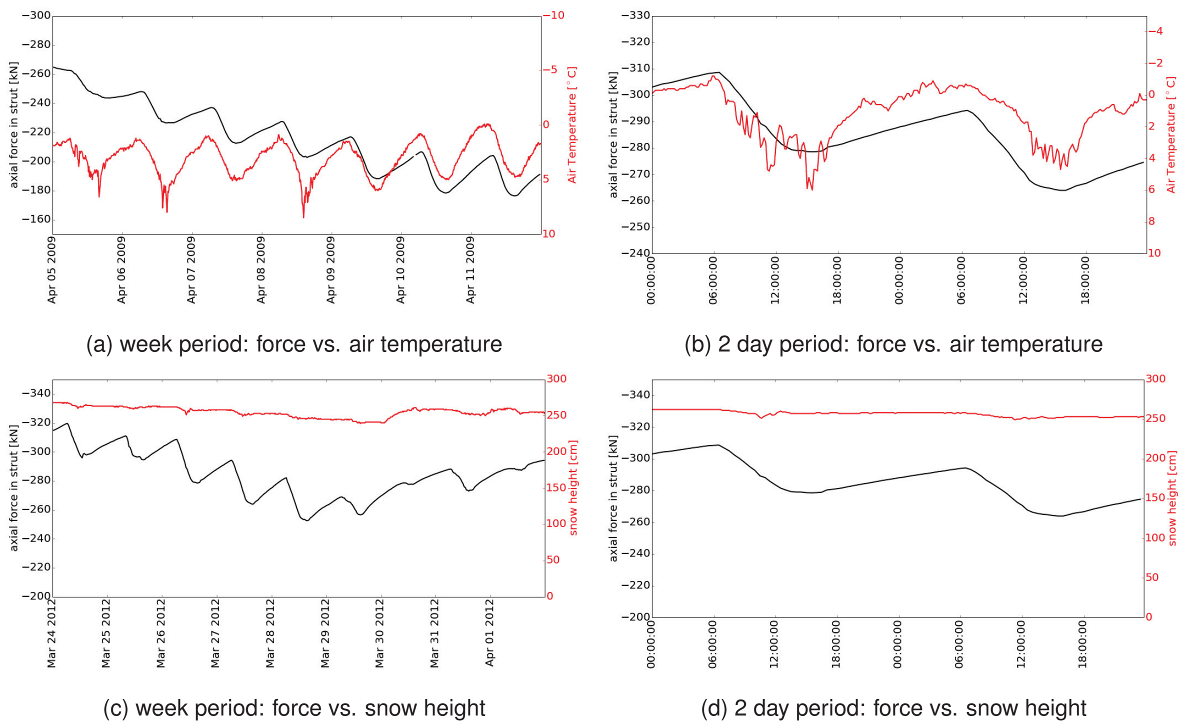
Figure 2: course of snow height and resulting forces in the edge strut of the snow net system.

measures are dimensioned to withstand extreme values. Herein we deploy the dimensioning methods according to Haefeli (Haefeli, 1954) and the Swiss guidelines “Lawinenverbau im Anbruchgebiet” (Margreth, 2007), which is referred by the Austrian guidelines (ONR-24805, 2010; ONR-24806, 2011). In the Austrian guidelines the design event statistically occurs once in 150 years.

A distinction is made between two load cases in the guidelines (Margreth, 2007). Load case 1 is attributed to a snow depth value similar to the effective height of the snow net (DK), and to a snow density of $270\,kg/m^3$. The snow depth for load case 2 is 77% of load case 1 and the snow density is $400\,kg/m^3$. The guidelines set the load case 2 to a standard for dimensioning flexible net structures. For the net type that is installed at the Nordkette with an normal height of 3.5 m (DK$= 3.5$) and a mean slope inclination of 38°, the guidelines yield an axial charakteristic force of 360 kN in the edge strut and 170 kN in the middle strut of the constructed snow net.

From 2006 to 2017 axial forces of the struts in the middle and at the edge of the snow net were measured. Furthermore two automatic weather stations provide continuous measurements of air temperature and snow height from the test site. Although there are measurements from several years, just a few of them highlight snow depths reaching values to be called extreme values. Therefore only selected recordings are relevant to be compared to the theoretical values obtained from the guidelines. The periods with highest accumulated snow depths and therefore the highest recorded force values are the winter periods of the years 2008/09 and 2011/12. In these periods the net structure was fully covered by the snowpack. Figure 2 shows the evolution of the axial force in the edge strut of the structure, due to the load of the snowpack. The height of the snow pack is obtained from a nearby weather station located at the Seegrube at 1.921 m a.s.l. Although the weather station is on a lower altitude and the measurements of snow heights may not be exactly the same on the test site, due to the small spatial distance between test site and weather station occurrence and duration of precipitation events are similar.

Precipitation events lead to a continuous increase in the axial force of the strut. The maximum force is reached in spring when the melting period starts. The maximal force measured in the edge strut is 300 kN in 2008/09 and 330 kN in 2011/2012. Unfortunately there is a absence of the measurement



(a) week period: force vs. air temperature

(b) 2 day period: force vs. air temperature

(c) week period: force vs. snow height

(d) 2 day period: force vs. snow height

Figure 3: Diurnal variations of forces, air temperature and snow height

in March 2012. This period supposed to be the time of the highest loads and therefore an underestimation of the maximal force in 2011/12 in the structure is likely. The calculation according to the guidelines (load case 2) provides a force of 243 kN as dimensioning value, which seems to underestimate the measured values. A calculation according to load case 1 however reveals a dimensioning value of 360 kN, which is in better agreement to the measured forces. Measurements of axial forces in the middle strut indicate a maximal value of 169 kN which is almost equivalent to the calculated value according to load case 2.

3. DIURNAL VARIATIONS

Beside seasonal variations throughout the winter period, the measured forces also indicate a diurnal variation. While resulting stresses in the structure increase during the night, they decrease during the day although the snow height remains almost constant. This variations typically occur with the start of the melting period in spring, leading to the assumption that melting and freezing processes in the snowpack result in different loadings of the mitigation structure. Figure 3 (a) depicts the period of a week in March 2012 highlighting the axial forces in the edge strut of the snow net system. Figure 3 (b) shows a 2-day interval in detail. Comparing forces in the strut and the air temperature obtained from the nearby weather station at the Hafelekar (2.270 m a.s.l.), an analogy between both courses is obvious. The forces show a daily peak just where air temperature is minimal. This effect is notable in spring where air temperatures are around the freezing point. Figure 3 (c) and (d) indicate that this fluctuations are independent from the related snow height. An explanation for this fluctuations might be, that cohesion, sintering and feezing as bonding processes in the snowpack lead to a larger snow volume acting as load on the mitigation measure. Melting processes lead to a loss of junctions between snow grains and therefore the load of the snow pack to the structure decreases. The magnitude of this effect is about 30 kN of the axial force in the strut, which is approximately 10 % of the overall force in the strut.

4. CONCLUSIONS

The presented work shows the time evolution of forces in the struts of an instrumented snow net system on the “Hafelekar” test site near Innsbruck. Measurements of two surpassing winter periods highlight maximal forces in the struts. Comparing these forces with theoretical characteristic forces from guidelines a good accordance regarding the middle strut of the system has been observed. The measurements in the edge strut indicate higher forces compared to the force obtained from guidelines. However, calculating the forces in the edge strut according to an adverse load case (load case 1 in the swiss guidelines) leads to a good agreement with the measured force.

Furthermore the continuous measurements indicate a diurnal variation of the forces in the struts of the snow net. Therefore snow heights and air temperatures of the elected time periods were analysed and compared to the force measurements. The observed effect is independent from snow height but shows a strong correlation to the air temperature, particularly in spring. We assume this effect occurs due to melting and freezing processes in the snowcover.

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