STRESS MEASUREMENTS IN THE SNOWPACK DURING COMPRESSION TESTS

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ABSTRACT: The snow compression test is a well-known and widely used snow stability test where an isolated column of snow is progressively loaded by tapping on it to induce failure in a possible weak layer. The test result provides valuable information about the existence of possible weak layers and consequently the propensity of failure initiation within the snowpack. As the test is performed manually by tapping, different persons might tap with different force and thus reduce the reproducibility of the test results. The aim of this work was to quantify the influence of different test persons and different snowpacks on snow compression test results. Moreover, we compare our stress measurements to measurements performed previously by others and discuss the comparability of different measurements and different snowpack tests. As far as different persons are concerned, we let 62 persons tap on a stress measurement plate during a workshop of the European Avalanche Warning Services. In the field, we performed stress measurements during 116 snow compression tests with 13 persons at eight different locations in the Alps. Our results show that the stresses that reach a weak snow layer due to tapping are influenced by both the snowpack as well as different persons. Still, the data's scattering is surprisingly small for lower loading steps and decreases with depth. Therefore, we can deduce that, especially when avalanche conditions are particularly dangerous, snow compression test results are quite reproducible. Moreover, since the compression test and the extended column test share the same loading steps, the results are equally relevant for the extended column test, which is frequently used by snow and avalanche experts in the field.

KEYWORDS: snow stability test, compression test, snow strength, avalanche, weak layer, snow

INTRODUCTION

Snow stability tests are a very effective and widely used tool for assessing snowpack stability and hence for gaining valuable information from the field in terms of avalanche danger by both recreationists and professionals. The quickest and easiest snow stability test is the snow compression test – commonly referred to as compression test (CT), and first introduced by Jamieson and Johnston (1997). It is a mechanical test where an isolated column of snow is manually loaded by tapping on it with progressively increasing load to induce failure in possible weak snow layers. Based on when, where and how a fracture initiates, an indication of the snowpack's stability is gained. However, to include stability test results into operational procedures for avalanche warning, quantitative information about test results as well as information on their reproducibility is needed (Techel and others, 2020). For a better understanding of the influence of different snowpacks on stress levels during a CT, and to understand how person-caused differences in tap forces interact with the snowpack, we performed several measurements. In the field, we measured the forces for different persons performing a CT at two burial depths of the force sensor. Under no-snow conditions, we directly measured the tapping forces of 62 persons, each tapping directly on the measurement device.

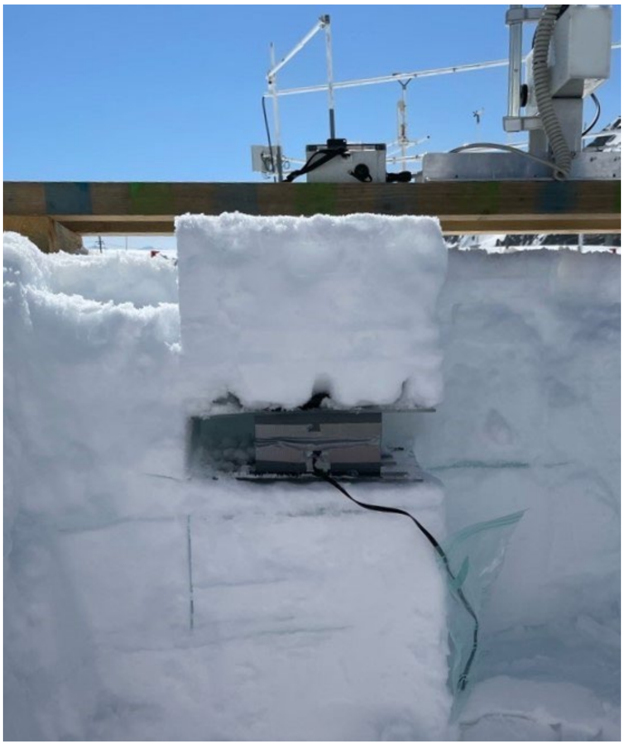

Figure 1: CT block with measurement plate, ready to be loaded. Picture: Weissfluhjoch, March 2022.

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METHODS

When performing a compression test (CT) a block of 30 cm × 30 cm is isolated for progressive loading (see Fig. 1). A shovel is placed on the top of the column and loaded consecutively with ten taps out of the wrist, ten taps out of the elbow and ten taps out of the shoulder. A possible weak layer within the snowpack can be deduced by a slope parallel fracture of the column. A low number of taps needed to induce the fracture indicates low stability.

We developed a device that measures forces over the area of the CT column (see Fig. 1). For the force measurements we used a capacitive pressure pad by SingleTact which covers forces up to 450 N at a sampling frequency of 100 Hz.

In the field, we conducted 116 compression tests, at eight different locations, with 13 persons, and at two different snow depths, namely 20 cm and 50 cm, with an average snow density above the measurement device of 300 kg/m^3. When measuring forces directly, i.e. in an indoors setup without snow, we placed the measurement device on a table during a conference of the European Avalanche Warning Services (EAWS) in Davos, Switzerland, in June 2022. We then let 62 persons, most of them professional avalanche forecasters, simulate a CT.

RESULTS AND DISCUSSION

The median stresses for different tap numbers at a depth of 20 cm are shown in Figure 2. The gray shading indicates the interquartile ranges of the measured stresses. There is a pronounced difference in stress levels between hand taps (red), elbow taps (yellow) and shoulder taps (blue). Moreover, we see a statistically significant stress increase from tap to tap even within the single loading steps. A similar picture is found for stress levels at a depth of 50 cm, see Figure 3.

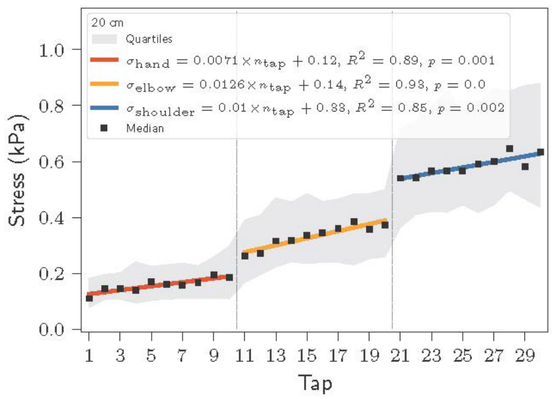

Figure 2: Median stress levels and their interquartile ranges for the measurements at 20 cm depth.

The rising trend of the stresses in the snow can be explained by a gradually increasing compaction of snow with progressing tap number. During the first taps, the snow is deformed plastically, absorbing a lot of energy (e.g. Kronthaler and others, 2018; Schweizer and others, 1995). But with each new tap, the plastic deformation decreases and the already compacted snow transmits stress more easily (Thumlert and others, 2013). Considering a CT and also an extended column test (ECT), this indicates that the tenfold repetition of the taps with the same loading step is appropriate, as the stress that actually reaches the weak layer does increase from tap to tap and might therefore induce a fracture that could not have been induced beforehand. Also Boone (2018) states that once a tap surpasses the strength of the weak layer, plastic deformation of the weak layer begins. Each additional tap then contributes energy towards the failure of the weak layer, with the final tap being critical for the final failure.

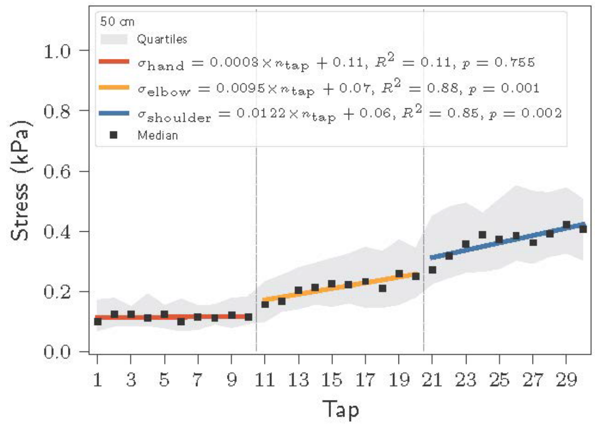

Figure 3: Median stress levels and their interquartile ranges for the measurements at 50 cm depth.

Moreover, it can be seen that measured stresses are slightly lower for a snow depth of 50 cm compared to the shallower depth of 20 cm. As the snow block for the compression test is free-standing, the decrease of stress with increasing snow depth cannot be attributed to bridging effects. We assume that a loss of energy due to plastic deformation in the snow block above the measurement device is the reason for the decrease of stress with increasing snow depth.

The stress levels for different taps in the setup without snow (at the EAWS conference) are shown in Figure 4. As expected (e.g. Sedon, 2021), stress levels vary between different persons. Still, especially for hand taps, stress levels scatter closely around a specific value. Lower stress levels for the very first and higher stress levels for the very last tap of the respective loading step cause a rising trend within distinct loading steps, although not statistically significant ($p > 0.05$). We attribute this rising trend under no-snow conditions to people tapping with less force at the very first, and with greater force at the very last tap of each step; in between, forces are roughly the same. Data scattering is lower for measurements with snow than without, see Figures 2, 3 and 4, even though different people as well as different snowpack conditions were involved. Moreover, the scattering decreased with increasing snow depth and for lower tap numbers. Apparently, differences are smoothed out by the overlying layers of snow.

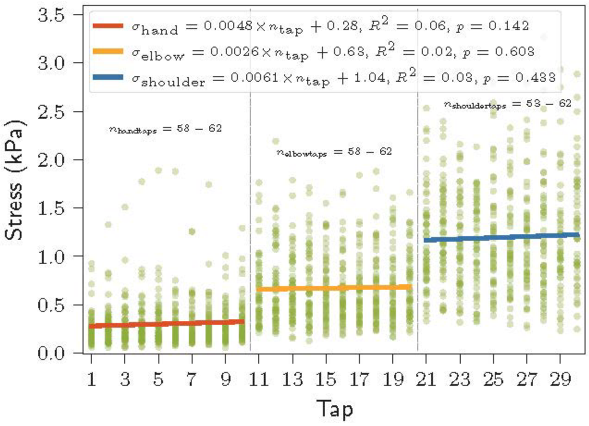

Figure 4: Stress levels for the different taps by different people in the setup without snow.

CONCLUSIONS

We performed force measurements during compression tests to assess the reproducibility with respect to different test persons. We could show that these differences were surprisingly small, especially for low loading steps, which are most relevant for instable conditions. We have thus shown that compression test (CT) results seem to be fairly similar between different people, especially when the snowpack is quite unstable. This facilitates the communication of test results between people and across avalanches forecast regions. It also shows that, at least for low loading steps, a standardized interpretation of CT results is legitimate. What is also relevant is that these conclusions about the CT also apply to the widely used extended column test (ECT) with different persons, as the ECT has the same loading steps as the CT.

Moreover, we found an increase of stress between single taps within one loading step due to increasing snow compaction, which underlines the importance of being concise in performing every single tap of a loading step.

ACKNOWLEDGMENT

We here want to note that the presented conference proceedings paper is a short version of the recent, open-access, peer-reviewed paper Griesser et al. (2023). Moreover, we thank all our colleagues and friends who volunteered as tapping persons. Without them this research would not have been possible.

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