THE RELATIONSHIP BETWEEN MEASURED SNOW HARDNESS AND SHEAR STRENGTH

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ABSTRACT: Snow hardness is an important parameter in avalanche forecasting; however, hardness has not that relevance as the shear strength of snow. On the other hand hardness measurements are easier to operate and they are more suitable for practitioners. The snow hardness correlates approximately with the shear strength of snow; low hardness may be an indicator for weak layers (e.g. depth hoar).
This study aims to quantify the shear strength with data of hardness measurements. For that purpose both, traditional hand hardness observations and objective hardness measurements were carried out.
The snow hardness was measured in horizontal direction with a digital push-pull gauge.
The shear strength was measured with a shear frame (size 0.05m^2).
All measurements were done at intervals of 10cm vertically.
The analysis of the scattering data allows an interpretation of the relationship between the snow hardness and the shear strength. Especially lower hardness levels (up to 100kPa) show a clear correlation.

KEYWORDS: snow hardness, shear strength, push-pull gauge

1. INTRODUCTION

Snow hardness was first determined using the Swiss rammsonde (Bader and others, 1939). Several other measurement techniques, like the snow resistograph (Bradley, 1966), the digital resistograph (Dowd and Brown, 1986), modified by Brown and Birkeland (1990), and the electric cone penetrometer (Schaap and Föhn, 1987), have also been developed. At the end of the 1990s the Swiss SnowMicroPen (SMP) was introduced by Schneebeli and Johnson (1998).
The hand hardness test, unlike the rammsonde and the SMP, is carried out in a horizontal direction. It was introduced by de Quervain (1950), is used regularly by practitioners and can be applied without special equipment. It is a subjective penetration test (Pielmeier and Schneebeli, 2002) and involves pushing objects of different dimensions into snow. According to the International Classification of Seasonal Snow on the Ground (ICSSG-1990, Colbeck and others, 1990; ICSSG-2009, Fierz and others, 2009), snow hardness is divided into five levels (without ice); the hand hardness test provides only an index value of snow hardness.
Horizontal measurements of snow hardness were carried out by Takeuchi and others (1998) using a push–pull gauge. They used one attachment with a diameter of 14mm (which corresponds to the size of a finger). Höller and Fromm (2010) applied also a digital push-pull gauge but they used five attachments to quantify the hand hardness test.
Shear strength measurements can be done by applying shear vanes (Keeler and Weeks, 1968) which were originally used to determine the shear strength of soil. The shear frame - introduced by Roch (1966a, 1966b) - was used by many researchers to determine the shear strength of snow (Perla et al.,1982; Perla, 1983; Föhn, 1987; Jamieson, 1995; Jamieson and Johnston, 2001).
A relation between snow hardness and shear strength was found by Keeler und Weeks (1968).
Höller and Fromm (2008) investigated the relation of the shear strength and the human hand hardness test. The present study incorporates the quantification of the hand hardness test with a push-pull gauge equipped with different attachments (Höller and Fromm, 2010).

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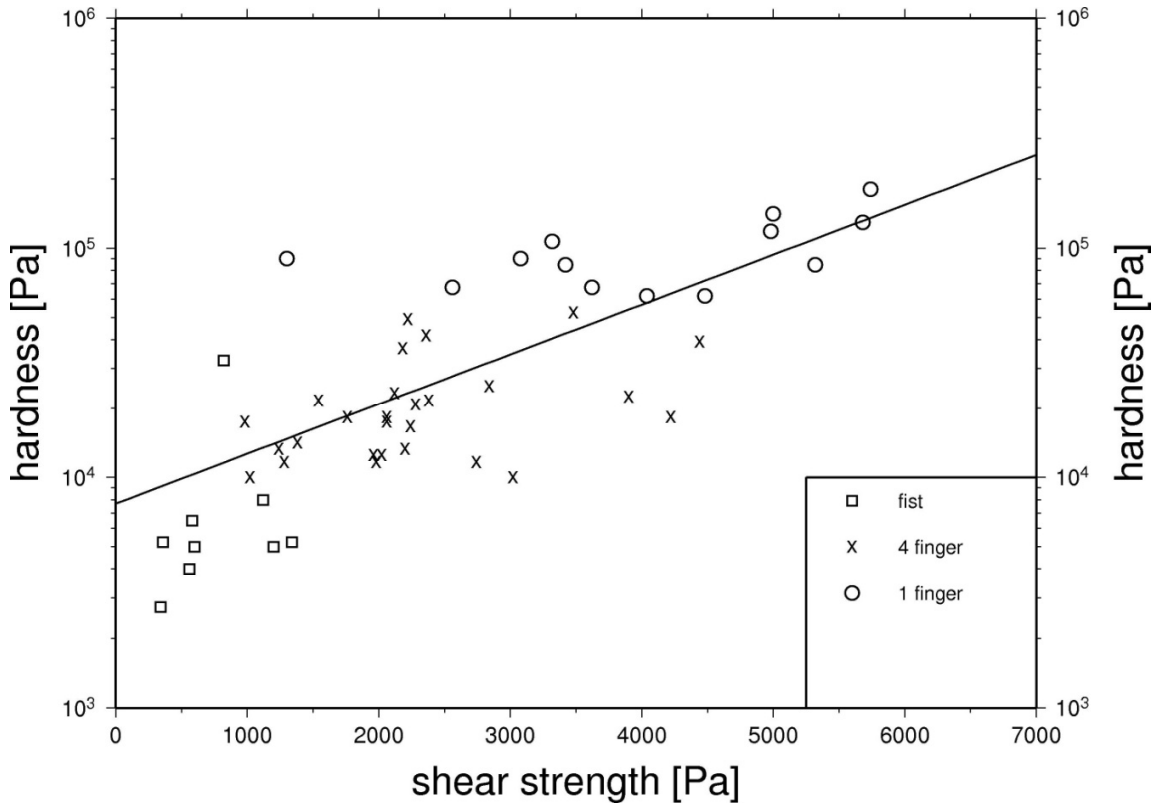

Figure 1: Measured snow hardness with different attachments versus the corresponding measured shear strength.

2. METHODS

The data acquisition of this study was carried out in the Tuxer Alpen, Austria (47°09'56"N, 11°38'02"E). Measurements were done every two weeks and contained complete snow pit observations with special consideration to hardness and shear strength.

A precise description of the push-pull gauge and its attachments was given by Höller and Fromm (2010). In principle the 5 attachments correspond to the shape and size of the human hand test (fist: 4 10^{-3} m^2; 4 fingers: 1.2 10^{-3} m^2; 1 finger: 1.77 10^{-4} m^2; pencil: 3.85 10^{-5} m^2; knife: 1.4 10^{-5} m^2).

The shear strength was measured with a shear frame [size 0.05m^2 (Föhn, 1987)]. Both, the hardness values and the shear strength values were made every 10cm vertically and were converted to Pa units.

3. RESULTS

The shear strength data of snow and the hardness quantified by the push-pull gauge were collected at the same positions of the snow pits. The presented investigations are based on these data and their relationships.

The scatter plot shows the increase of the snow hardness with higher values of the shear strength (Fig. 1). The symbols specify the applied attachments which were selected on the basis of the human hand test. This data set does not contain any data for harder snow (pencil and knife). It shows that the classification of the snow hardness is possible with the human hand test. However, it is a difficult task to relate the snow hardness to the corresponding shear strength. An estimation of the snow hardness Σ as a function of the shear strength R is given by eq. (1).

$$\Sigma = a \; exp\,(b\,R) \qquad (1)$$

The parameters a = 9041 and b = 4.86 10^{-4} represent the best fit to the data set (r^2 = 0.76).

For practical applications the human hand test may be used to estimate the shear strength of snow (Fig. 2). The numbers correspond to the ICSSG classification (1 = fist, 2 = 4 finger, 3 = 1 finger, no higher values were observed); the sub classes were used to represent data in between.

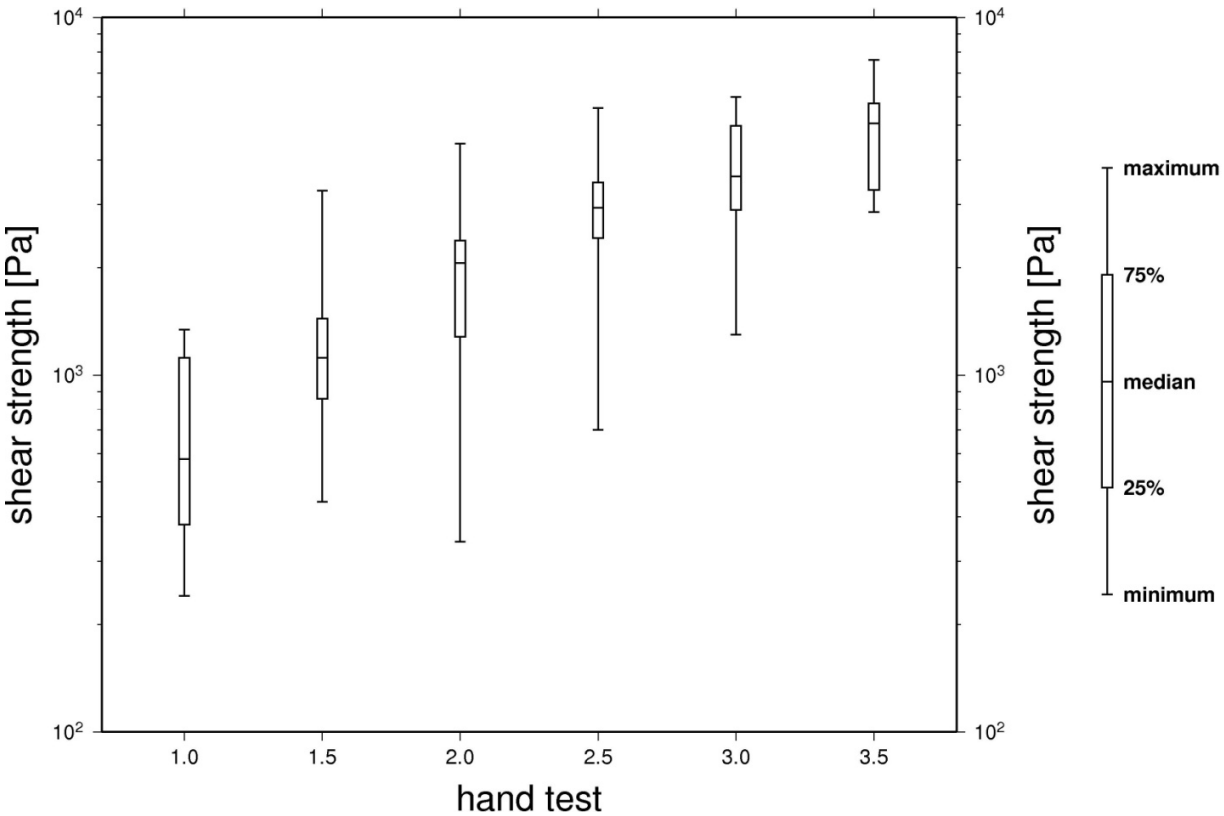

Fig. 2. Boxplot of the shear strength for different hand hardness levels.

Each hand test level covers a certain range of shear strength. The ranges overlap to a great extent, so that a clear classification is limited.
It can be assumed that (at least 50% of) the shear strength data are between 380Pa and 1120Pa for the hand test level 1 (fist). For the hand test level 2 (4 fingers) at least 50% of the data are between 1280Pa and 2380Pa and for the hand test level 3 (1 finger) the data are between 2900Pa and 4980Pa.

4. DISCUSSION AND CONCLUSIONS

The snow hardness has been quantified with a push-pull gauge which was equipped with five attachments. Shear strength measurements were carried out at the same positions.
Although the data show a strong variation, basic findings are possible. Ranges for the shear strength can be determined for each hand hardness level (except pencil and knife).
The vertical resolution of the measurements of 10cm does not allow an overall conclusion to the mechanical stability of the snowpack. Fragile thin layers, which are often the weakest point of a snowpack, are smaller than the attachments of the push-pull gauge.

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