INVESTIGATIONS ON SNOW HARDNESS AS A MEASURE TO DETERMINE SHEAR STRENGTH

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ABSTRACT: The shear strength plays an important role in avalanche formation. However, investigations on shear strength in the field are time-consuming, in particular these measurements require experienced avalanche professionals.
Main objective of this study was to estimate shear strength by using indirect methods which are more user-friendly than the traditional tests.
We assumed that hardness and density of snow must be the two most appropriate parameters. Three different methods were implemented to determine snow hardness: the conventional hand hardness test, measurements with the Swiss Rammsonde, and a method with a digital force gauge where we measured hardness in horizontal direction (to find out hardness ranges in the different layers of the snowpack). The snow density was measured with the common standard cylinder and the shear strength was determined with a shear frame.
The results indicate a encouraging relationship between snow hardness and shear strength; however, the strong scattering of the data requires further investigations to specify these relations.

KEYWORDS: Snow hardness, shear strength, snow density

1. INTRODUCTION

Several studies and investigations were done to determine shear strength by the use of alternative snowpack parameters.
Keeler und Weeks (1968) found a relation between snow hardness and shear strength.
Takeuchi et al. (1998) investigated the snow-hardness distribution by the use of a digital push-pull gauge; they identified a relation between hardness and density.
Investigations on the relationship between snow density and shear strength were done by Perla et al. (1982). Conway and Wilbour (1999) also used a power law which is similar to that proposed by Perla et al. (1982).
Jamieson (1995) and Jamieson and Johnston (2001) have adopted Perla's (1982) equation; they determined the relevant empirical variables for different classes of grain shapes.

However, as shear strength decreases with increasing water content this parameter was also included by several authors.
Bhutiyani (1994) showed a correlation between \`wet snow density´ and shear strength.
Yamoni und Endo (2002) developed a function which allows to calculate shear strength by the use of density and water content of the snowpack.

In this study we investigated not only the relation beween density and shear strength but also between density and hardness and between hardness and shear strength. The idea was to find the varying interconnections that may exist between the several parameters.

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2. MEASUREMENTS

Our measurements took place at the experimental site of the Department for Natural Hazards in the Wattener Lizum which is located approximately 25 km south-east of Innsbruck, Tyrol.
The observation site is situated in about 2000 m a.s.l. and is not affected by skiers.
Measurements were done every two weeks and contained complete snow pit observations with special consideration to snow density, hardness and shear strength.
Density measurements were done with a standard cyclinder (500 cm^3). The snow hardness was determined with three different methods: (i) the hand hardness test, (ii) the Swiss Rammsonde and (iii) a digital push-pull gauge; the diameter of the cone end of the gauge was 1.5 cm (7.1 10^{-4} m^2). The shear strength was measured with a shear frame [size 0.05 m^2 (Föhn, 1987)]. Both, the hardness values and the shear strength values were converted to Pa units.
All measurements were done at intervals of 10 cm vertically, except investigations with the Swiss Rammsonde.

It can be seen that a hand hardness of 2 (4 fingers) and 3 (1 finger) corresponds to a measured hardness of less than 100 kPa. A hand hardness of more than 3 (pencil and knife) on the other hand, means that the measured hardness exceeds the value of 100 kPa in a couple of cases.

Hand hardness versus shear strength yields the following results:
While a hand hardness of 1 (fist) corresponds to very low shear strength values (below 1 kPa), a hand hardness of 2 implies shear strength values from 1 kPa to 4.5 kPa. This indicates, however, a broad variation. A hand hardness of 3 means that shear strength values up to 6 kPa are possible (variation from 1.5 kPa to 6 kPa).

A sligth trend can be identified between hand hardness and density. However, most of the hand hardness levels correspond to densities between 200 kg m^{-3} and 400 kg m^{-3} which does not allow a significant regression.

3. RESULTS

The results are shown in Fig. 1. It is obvious that with increasing density hardness and shear strength increases too. The upper part of Fig. 1 (left side) illustrates the relationship between density and hardness derived from the measurements with the push-pull gauge; the continuous line shows the most suitable regression determined by our data; the dashed line gives the equation which was found by Takeuchi et al. (1998).
On the right side of Fig. 1 the dependence of shear strength on density is shown [continuous line is a regression derived by our data; the dashed line corresponds to the findings of Conway and Wilbour (1999)].

The relationship between hand hardness and measured hardness as well as between hand hardness and shear strength and hand hardness and density is shown in the lower part of Fig. 1

4. DISCUSSION AND CONCLUSIONS

The relation between hand hardness and measured hardness is adequate. The findings correspond with the hardness scale published by Colbeck et al. (1990).

The relation between density and measured hardness can be described by a simple root function. However, the regression determined by our data gives higher density values than that from Takeuchi et al. (1998). It can be assumed that they have not applied an adequate number of density data in the range of 400 kg m^{-3} .

The investigations furthermore indicate an encouraging relationship between hand hardness and shear strength. However, it seems that there is an opposite trend (shear strength decreases with increasing hardness level) in the upper hardness levels (level > 3). We assumed that this relates to the fact that

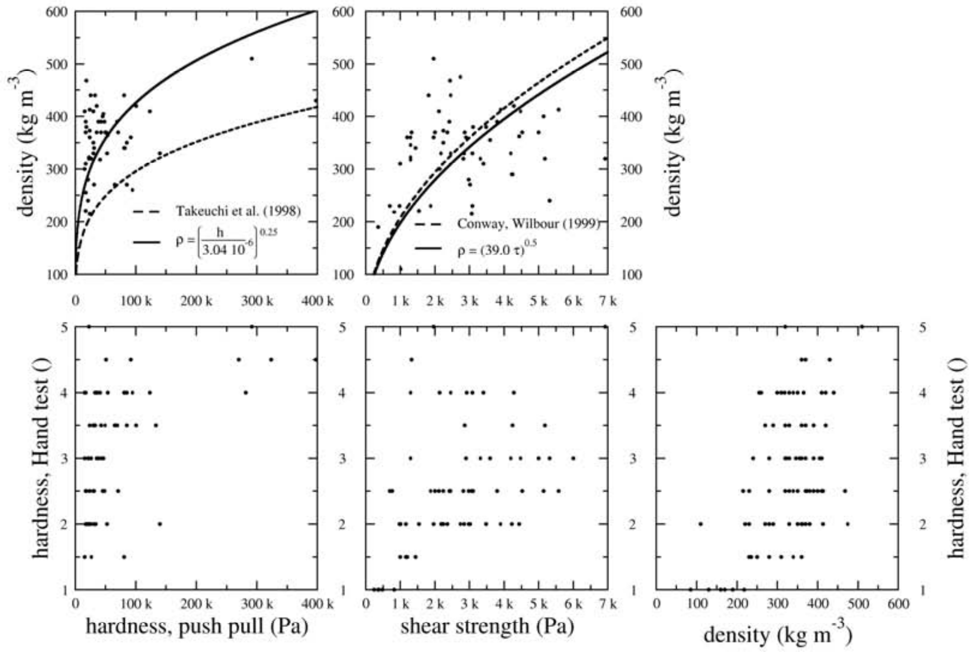

Figure 1: Upper row: density (kg m^{-3}) versus measured hardness (Pa) and density versus shear strength (Pa); ρ…..snow density (kg m^{-3}), h ….measured hardness (Pa), τ…. shear strength (Pa). Lower row: hand hardness (acc. to Colbeck et al. (1990)) versus measured hardness (Pa), hand hardness (acc. to Colbeck et al. (1990)) versus shear strength (Pa) and hand hardness (acc. to Colbeck et al. (1990)) versus density (kg m^{-3}).

hard layers are regularly less than 1 cm. While a pencil or knife can be easily inserted in such a thin layer, it is difficult to meet them exactly with the shear frame. The incorrect use of the shear frame means, however, that the shear strength quite often was underestimated.

The calculated regression between density and shear strength is adequate and agrees well with the findings of Conway and Wilbour (1999).

It can be summarized that several interconnections exist between snow hardness, shear strength and snow density; however, the strong scattering of the data requires further investigations to specify these relations.

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