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Testing a new shear loading apparatus for *in-situ* studies of weak snow layers

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ABSTRACT: Here we show preliminary results of shear tests carried out with a new shear test apparatus designed and constructed by Politecnico di Torino, DISEG (Italy). The ultimate objective of the work is to develop an instrument for in situ measurements of the mechanical properties of weak snow layers. At the present, it is a portable force-controlled apparatus with adjustable shear-loading rate and normal pressure for specimen dimensions 0.16 m × 0.16 m × 0.08 m. The first series of cold laboratory experiments were focused on calibration, experimental methodology, and, in particular, on sintering (conducted at CEN / Météo-France). As an illustration of the instrument's performance, here we show a set of tests dedicated to sintering effects on snow interface strengthening with time. The protocol of experiments could be briefly described as follows: two snow blocks were placed on top of one another and immediately subjected to rapid horizontal loading at a constant rate of about 19 N s^{-1} (i.e., effectively cutting the sintering time to zero); then the same samples were left for four hours and re-tested; finally, the same procedure was repeated after 16 more hours. For each test, shear displacements and force were recorded with high-frequency gauges. Interfacial strength evolved rapidly under constant normal pressure, air temperature and relative humidity (about 0.1 kPa, −10 °C, and 70 %, respectively) and corresponded to an increase of failure load by an order of magnitude (about 0.3 kPa h^{-1}; that is comparable to field measurements by Birkeland et al*.,* 2006). Following further cold laboratory testing with various types of snow and, possibly, some technical modifications, we intend to continue the development of the instrument for its future usage in the field at slab avalanche release zones.

KEYWORDS: snow, mechanics, instrument, weak layer, avalanche.

INTRODUCTION

Three decades ago Perla and Beck (1983) noted that the shear frame was "a useful tool for gathering statistical data on strength distributions ... until a more fundamental technique is developed". For in situ tests on alpine snow mechanics, and in particular on mechanical properties of snow weak layers, multiple instrumental methods have being developed since the 1930s. Examples, temporal evolution, usage and popularity of such tools are presented at Fig. 1. This figure shows that, despite the remark by Perla and Beck (1983), still the most common tools are shear frames and shear vanes (Fig. 1b), both of which are manually-controlled. More recently, the Snow-Micro-Penetrometer became a widely used tool (Fig. 1b); however, it does not give full records of failure behaviour of weak layers.

In this study we introduce and present a newly built shear-cell instrument and the first series of cold laboratory experiments focused on its approbation and testing. This portable apparatus was designed and constructed by DISEG, Politecnico di Torino (Italy) for in situ measurements of snow weak layer failure properties (Barbero et al., 2013). Here we present the motivation for introducing such an instrument (Fig. 1) and on-going bi-lateral joint work between Politecnico di Torino, IRSTEA (UR ETGR) and Centre d'Etudes de la Neige (CEN / Météo-France) aimed at further development and testing of this new device.

METHODS

The testing of the instrument was conducted in a cold laboratory of CEN (Meteo-France) at air temperature -10ºC and relative humidity approximately 70%. In its current form the shear-loading apparatus presents a portable direct force-controlled shear-box (for detailed descriptions refer to Barbero et al., 2013). It consists of the main steel frame with a lower half-box and horizontally movable upper half (Fig. 2). The inner volume of the apparatus corresponds to 16 x 16 x 8 cm^{-3}. Thus the area of shearing (256 cm^2) is comparable to standard shear frame tests. Three intermediate fins may be installed into the upper box for work with low density snow. A pneumatic actuator produces horizontal displacement of the upper box relative to the lower part (Fig. 2). Creation of compressed air

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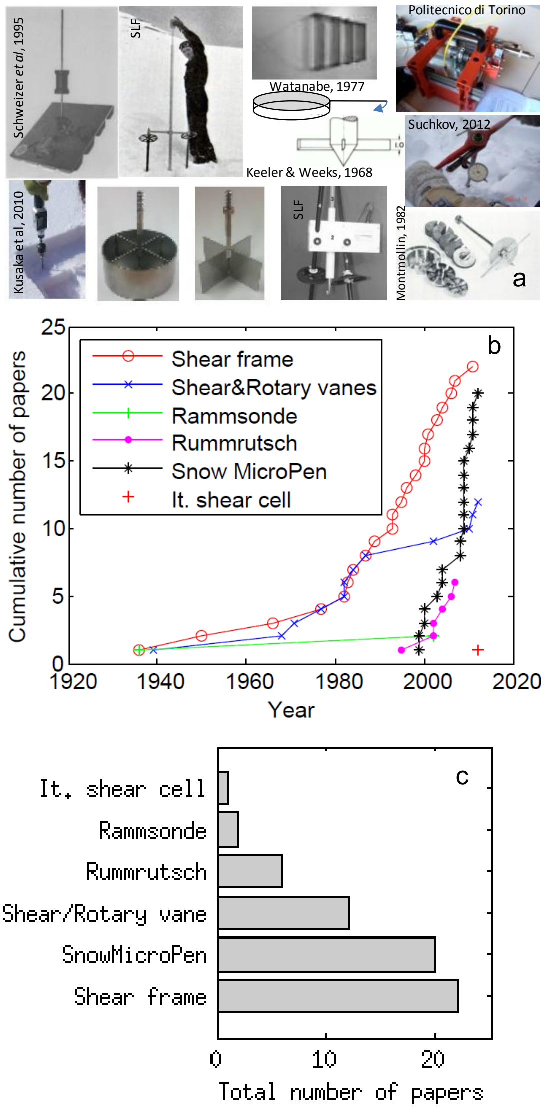

Figure 1. a) Illustrations showing main existing instruments (clockwise from the upper left corner: Rummrutsch, Rammsonde, shear frame/vanes, Italian shear cell, shear vane, rotary vane, SMP, shear vanes). See full references for reproduced illustrations at the end of the paper (SLF photos were adapted from SLF web-page); b) cumulative number of papers by each method; c) total number of papers by each method (until 2012).

pressure inside the actuator is supported by an electric air-compressor or a portable tank supplying compressed air. The normal pressure is controlled through the inflation of a rubber membrane, which is located in the upper part of the shear-box. The associated horizontal force, normal pressure and horizontal displacements are recorded with high frequency gauges. Recording and operation of the apparatus are performed and controlled by an operator, staying in a warm room with a data-logger, a notebook computer (with LabVIEW environment) and the air-compressor (with a maximum output pressure up to 7 bars); while snow sample preparation and instalment is conducted by operators in the cold chamber (Fig. 3).

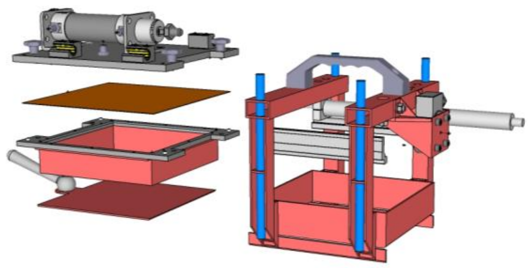

Figure 2. A model of the shear apparatus indicating its main functional parts (a photograph of the assembled instrument is shown in Fig. 1a & Fig. 3).

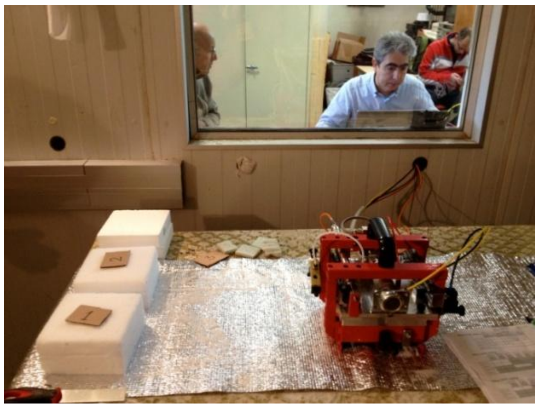

Figure 3. Cold laboratory working conditions: snow samples and the cell are on the table, all instrument cables and tubes are connected to data-logger, PC and air compressor in the operator's room, which is behind the glass.

The natural snow samples, used in cold laboratory tests, were collected in the French Alps or in St.-Martin-d'Heres and stored at temperature -20ºC for 10-100 days before experiments. Since transportation required up to two hours of driving and keeping samples in thermo-insulated boxes, we could not work with very fragile snow weak layers, and had to limit this series of tests to homogeneous blocks of mid-density snow slabs (between 250 and 400 kg m^{-3}). In order to work with interfacial failure, we created artificial potential failure planes by the following procedure. Each snow sample was cut in the middle by a thin wire into two pieces and consequently these we left one on top of each other for sintering (at time scales of less than one minute, 4, 16 and 23 hours; or in a few tests for about two months). Sintering driven strengthening of the interface gave higher

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strength and an opportunity to localize failure along the separation plane of the instrument. Thus it allowed the study of failure properties of these weak-zones of samples and also gaining an insight into the poorly known sintering rates of snow interfaces. Additionally, we also measured snow density, sample weights, Specific Surface Area (by DUFISSS), and shear resistance by shear-rotary vane, and we took microphotographs of snow grains.

RESULTS AND DISCUSSION

About 100 shear tests were performed with different snow types, at various normal pressures (~0.1–1.0 kPa), and at constant loading rates (19 N s^{-1}). Since analysis is still in progress, here we show only illustrative material. Each shearing test corresponded to a failure of a sample along the interface. Examples of records are provided at Fig. 4. In particular, Fig. 4b shows the evolution of interfacial strength with time: the test performed immediately after cutting resulted in much lower strength than tests performed after 4 or 16 hours of sintering.

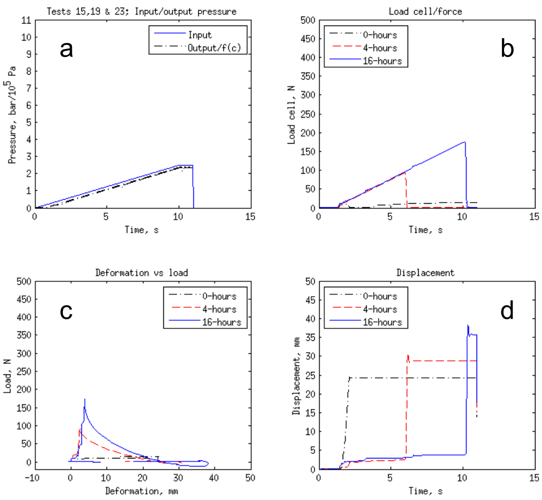

Figure 4. Examples of records produced for three tests made after 0, 4 or 16 hours of sintering (with 0 normal pressure): a) prescribed and real pressure from the air-compressor directed to the actuator; b) Signal from load sensor with peak corresponding to failure; c) Load vs. absolute deformation; d) temporal evolution of deformation.

The corresponding increase of the failure load due to sintering was up to an order of magnitude. In terms of strengthening rates we obtained a similar order of magnitude to that which was reported by Birkeland et al. (2006) for in situ measurements of post-fractured weak layers.

CONCLUDING REMARKS

Following further technical modifications and cold laboratory testing, the instrument will be tested in the field in the French and Italian Alps during the 2013/14 winter season. More detailed descriptions of tests and performance of the apparatus will be published elsewhere in the nearest future. Since the instrument remains in a constant process of development and modification, we are open for ideas and collaboration.

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