SNOWCATCHER: A new snow avalanche protection measure

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Steel wire rope nets have become common as protection measure against avalanches in Europe by preventing a release in the potential starting zone. A novel approach that has gained much ground through new research is to retard the movement of an avalanche after it has been initiated, that is in its path or run out zone. Such systems have the potential to be more cost efficient than traditional structures such as avalanche protection dams, saving both time and space of installation. In Lech (Vorarlberg - Austria) a Snowcatcher prototype was installed and instrumented with several load measuring pins, which record the dynamic loads caused by an avalanche. 24 avalanche events in 4 years were detected. In addition to the field tests, scaled granular experiments were performed in the laboratory. These tests show that the Snowcatcher leads to a significant reduction of avalanche velocities. Subsequently the calculated Froude numbers decrease, indicating less destructive power of the avalanche. As well, the spreading of the avalanche in the deposition zone decreases downslope of the Snowcatcher.

Key words: snow net, protection measure, granular experiment

1. Introduction

Permanent avalanche protection measures are either constructed in the release zone (e.g. snow bridges) or in the lower avalanche path/run out zone (e.g. dams). One advantage of measures in the run out zone compared to those in the release zone is the reduction of construction lengths. This has important consequences with regards to project implementation, specifically a space and time savings coupled with lower construction costs and often less ecological consequences. Presently, the most common method of retarding an avalanche in motion is the use of an avalanche protection dam (Johannesson et al., 2009). It is proposed herein that a new system using flexible wire rope nets is a viable alternative to avalanche dams for areas endangered by smaller avalanches. But until now there has been little experience with the dynamic loading of steel net structures. However, it has been obsereved that rockfall nets hit by an avalanche could receive remarkable damage (Margreth and Roth, 2006). In an attempt to help fill this gap in knowledge, both field tests and laboratory experiments were carried out.

As part of the field program, a prototype of a Snowcatcher was instrumented with several load measuring pins, which record the dynamic loads caused by an avalanche. The main purpose is to measure nor-

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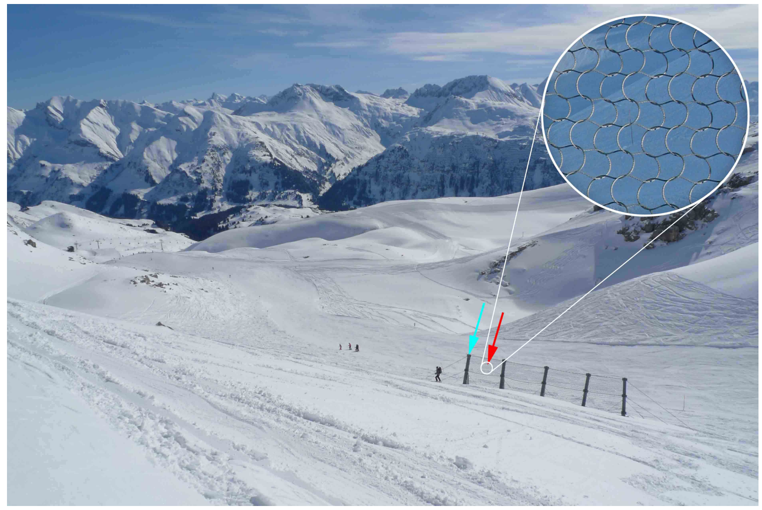
(a) Parts of the Snowcatcher



(b) Test field in Lech. The Snowcatcher with a detail of the omega net.

Figure 1: Pictures of the Snowcatcher test field in summer (a) and winter (b). Red arrows mark the omega net, blue arrows the cables, green arrows the breaking elements, cyan arrows the supporting frame and pink arrows the anchors.

mal and shear forces in the net supporting frame and the cable forces. In the time period between 2008 and 2012 the installed system recorded data from 24 avalanche events. An example of the measured forces is shown in section 3.

A second part of the research was focused on labratory testing. As avalanches in nature are impossible to repeat, approved methods (Pudasaini and Hutter, 2007; Faug et al., 2003) were used to carry out scaled granular experiments to simulate the avalanches. Experiments with varying chute angle, release volume and net mesh size were conducted and front velocities, flow depth and deposition patterns were measured (see section 3, Laboratory experiments).

2. Field tests

2.1. Construction

Based on the information of local experts from the ski area, a selected position for the Snowcatcher was found. The advantage of this site is the possibility of artificial avalanche triggering by explosives. The prototype of the Snowcatcher consists of the following parts (figure 1):

- Omega-Net: This is the structure that catches the avalanche. It is a specially braided net to resist energies in a range of 5000 kJ. The mesh width is in the range of 13 - 18 cm (red arrows on the pictures).
- Cables: Bearing and middle ropes stretch the net and conduct forces from the structure to the lateral anchors (blue arrows).
- Break elements: They expand at a certain force level and limit the load in the cables during an avalanche event (green arrows).
- Support structure: It is constructed as a three-hinged frame in the form of a λ (cyan arrows), exactly called "'Lamda Frame"'.
- Anchors: IBO R51 anchors were used for leading loads from cables and frames into the ground (pink arrows).

Five Lambda Frames are errected at 4 m intervals so that the overall width of the Snowcatcher prototype is 16 m. There are no extra cables on the mountain side to facilitate snow removal by snowcats following an avalanche event.

2.2. Instrumentation

Several load measurment devices are installed in the system to record static forces caused by the snowcover as well as dynamic forces exerted by an avalanche. Two frames of the structure (1 frame in the middle and 1 frame at the edge) are instrumented with load measurement pins. The coloured arrows (figure 2) indicate the direction of the force measurement in the Snowcatcher. Data of all sensors is collected by 2 Campell loggers with a rate of 20 Hz. Since there is no rapid change in the forces due to static loads of the snowcover, even in case of snowfall or snow melting, it is not necessary to continously save all the data. Hence static forces are transferred to a server and plotted on a web page in an interval of 2 hours. In case of an avalanche event the forces in the structure rise rapidly. To measure this fast process the data is collected and saved with a rate of 20 Hz within 3 minutes.

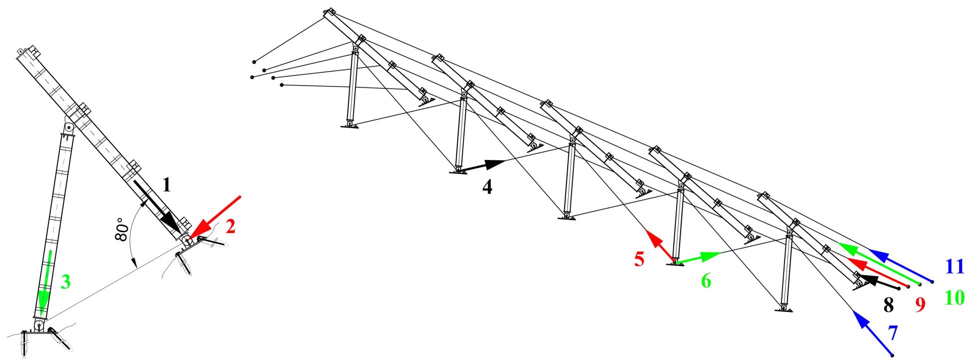
2.3. Avalanche events

Over 4 years 24 avalanches were detected by the measurement system. Some avalanches occurred beside the Snowcatcher, subsequently not triggering the monitoring system and reaching the ski piste below the structure. In contrast, avalanches that did impact the Snowcatcher, did not reach the ski piste. The largest forces were seen during an event on January 21, 2012. Figure 3 shows the temporal evolution of the measured forces in the instrumented frames during this event. The given colours correspond to those in figure 2 (a). In interpreting these forces, it is important to take into account the preceding conditions to the avalanche, that is heavy snow fall during the previous 2 days. Unfortunately this lead to a road closure to the test site due to high avalanche danger, so that there was no possibility to get visual information about this event. Because of the strong precipitation during this winter the Snowcatcher was 70 % prefilled. This event illustrates a force increase of 70 kN in the column of the middle frame, whereas the same force component in the edge frame is increased by 45 kN. The maximum forces in the structure were only a third of the Snowcatcher's design load. The axial force component of the beam (1 in figure 3) in the middle frame is missing because of electric overload during summer 2011.

3. Laboratory experiments

3.1. Experimental set-up

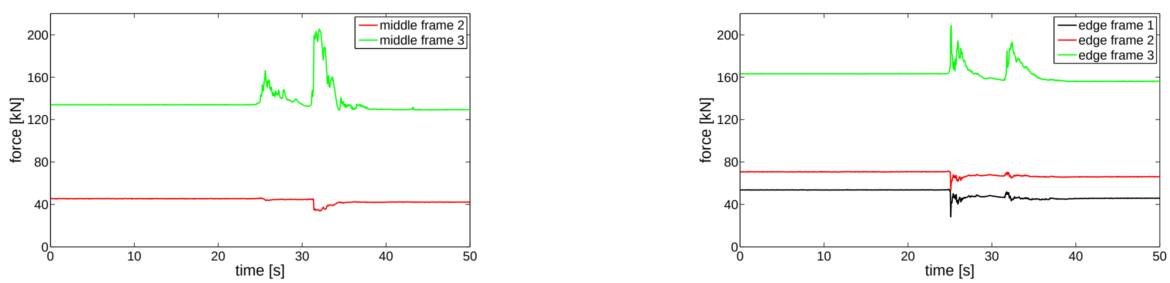
The experiments were performed in a chute consisting of 2 segments (S 1-flow zone and S 2-run out zone) with different inclination angles (Figure 4). Each segment has a length of 2.5 m. The chute inclination α is varied in the experiments between 10° and 15°, while the inclination difference between the 2 segments is 20° in all experiments. To channelize the granular material in the flow zone, the surface of S 1 is concave, whereas the run out zone is planar. The bed of the chute is a smooth aluminium surface. In a pipe with a maximum volume of 30 liter the granular material is stored. With pulling a cotter-pin a flap opens abruptly and the material is released. Polystyrene particles are used in all experiments as a substitution material for avalanche snow. They are coated with a graphite layer to minimize electrostatic forces. The diameter of the particles is in the range of 1.3 - 6.5 mm where the



(a) Measured forces in the frame

(b) Measured forces in the cables.

Figure 2: Force measurement in the system. (a) 1: normal force in the beam, 2:shear force in the beam, 3: normal force in the column. (b) 1-11: traction forces in the cables



(a) Forces in the middle frame

(b) Forces in the edge frame

Figure 3: Forces during an avalanche event in 2 frames. black: normal force in the beam(1), red: shear force in the beam (2), green: normal force in the column (3)

smaller particles are spheric and the bigger ones have a form of ellipsoids. The bulk density of the material is 200 kg/m^3. To better locate the position of the flow during the experiments, the surface of the chute is marked in 5 cm steps. The intersection of S 1 and S 2 is the position of the Snowcatcher and refers to Station 0. Positions on S 1 obtain positive station values whereas positons on S 2 receive negative station values. Experiments were performed with a mass of 2750 g or 6500 g. A model of the Snowcatcher in a scale of 1:15 was installed in the chute. Using 2 different set-ups of the Snowcatcher width (figure 4 right), the influence of the net on the granular flow was determined. In experiments with set-up 1 the angle β of the Snowcatcher net plane was varied, while different mesh sizes were installed in the experiments with set-up 2.

3.2. Measurement devices and measured parameters

Video cameras at different frame rates were used to gain the front velocity v of the flow, which is measured parallel to the flow surface (other velocity components are not considered). Two distance sensors were installed on several positions to measure the flow depth h. With these two parameters it is possible to calculate the Froude number of the flow at a certain position, which gives information on the flow condition.

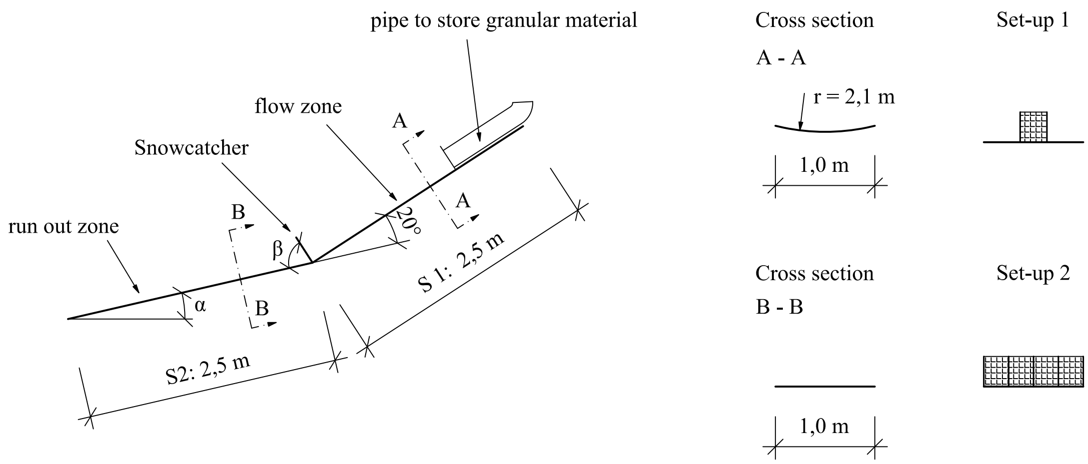


Figure 4: Schematic sketch of the experimental set-up. left: side view of the chute, middle: cross sections of the segments, right: set-ups of the Snowcatcher

$$Fr = \frac{v}{\sqrt{gh}} \tag{1}$$

3.3. Procedure of experiments

First it was necessary to run experiments without the Snowcatcher in order to get a reference avalanche to subsequently determine the effect of the net barrier.

Set-up 1: Lateral flow beside the Snowcatcher is possible. This set-up refers to the edge area of the Snowcatcher. It is the set-up with the smaller Snowcatcher width (figure 4 top right). The experiments were performed with a release mass of 2750 g. The angle β in the experiments was 50°, 60° and 70°, where the angle of 70° corresponds to a rectangular barrier to the flow zone. The Snowcatcher was equipped with a net featuring a mesh width of 10 mm.

Set-up 2: Lateral flow is not possible. This set-up refers to the full scale Snowcatcher prototype (figure 4 bottom right). The release mass of 6500 g was used in this experiments. Mesh sizes of 4 mm, 7 mm and 12 mm were used in the experiments. The angle β was fixed with 70°.

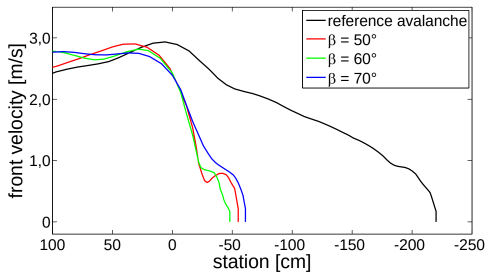
3.4. Results

Results with set-up 1: The experiments show a significant reduction of the run out length in comparison to the reference avalanche. The example with chute inclination α of 12° the run out length is reduced by 70%. Figure 5 (a) indicates higher velocities and a increasing run out length for a β angle of 70° compared to β=50° or β=60°.

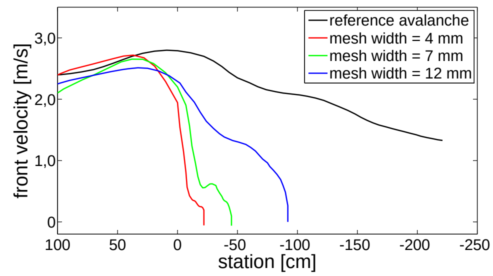
Results with set-up 2: Figure 5 (b) shows the reduction of the run out length with smaller mesh sizes for α=12°. While the front of the reference avalanche exceeds the run out zone, the other avalanches are retarded by the Snowcatcher and come to rest within 100 cm.

3.5. Conclusion

Since there is no recorded event on the Snowcatcher that reached the ski piste the structure seems to fulfill



(a) Different β angles



(b) Different mesh widths

Figure 5: Examples of experiments with 12° chute inclination

the task of retarding avalanches. Moreover granular experiments show a significant reduction of the run out length, which decreases with smaller mesh sizes.

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