DIFFERENT SURVEYS TECHNIQUES TO ASSESS THE SNOW EROSION AND DEPOSITION AT THE PUNTA SEEHORE AVALANCHE TEST SITE

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ABSTRACT: The aim of this paper is to describe the surveys techniques, used at the Seehore avalanche test site located in Aosta Valley (NW Italy), concerning the snow erosion and deposition due to avalanches and the preliminary results obtained during the first operative seasons. The following approaches are used:

- the laser scanner technique: the data recorded during two experiments are analyzed in order to assess the influence of the morphology of the test site (slope angle) on deposition. Analytical models (the cohesive-frictional and Pouliquen ones) are applied to explain the correlation between the slope angle and the snow depth in the runout area;
- the straw test: this new field test is devised to evaluate the net erosion/deposition processes using a very cheap and quick method based on the number and on the position of plastic straws placed within the snow cover. The test is used in the analysis of the eroded and deposited snow along the avalanche track, in particular close to the obstacle, which was built in the experimental site and was impacted by the avalanches;
- the RAMMS simulations: a comparison between the model outputs and the experimental data is made focusing the attention on the eroded areas and on the deposition zones;
- the manual measurements of the snow depth through a probe: they allow the evaluation of the deposition depth and the involved snow volume.

1. INTRODUCTION

Erosion and deposition processes within a snow avalanche flow have been studied in Russia, Norway, Italy, France and Switzerland, with the aid of both laboratory and full-scale test sites and numerical modelling (Sovilla et al, 2007). In the full-scale approach, different techniques are used to evaluate the mass balance of an avalanches. In the beginning, Sovilla (2001) simply used mechanical switches installed on poles placed along the path combined with field measurements. Later, more sophisticated techniques have been used: fotogrammetry (for ex. Vallet et al., 2001), terrestrial (for ex. Prokop, 2008) or aerial laser scanning, FMCW radars (Gubler et al., 1984). The goal of this work is to describe some of the existing survey techniques used to assess the snow erosion and deposition processes occurring within an avalanche flow and to present a new simple test ideated by one of the authors. We refer in particular to the activities made in the avalanche test site of Seehore in Aosta Valley, NW-Italy.

2. STUDY AREA

The test site, called Seehore, is located in Aosta Valley in the North-western Italian Alps. The slope, with an elevation difference of about 300 m (from 2300 to 2570 m asl), has a mean slope angle of about 28° and a NNW aspect. Avalanches are artificially released on a routine basis to secure the ski-runs, as the site is located within a ski resort (MonterosaSki). The site is instrumented with a steel obstacle, which measures the effects of avalanches impacting on it. Fig. 1 shows an overview of the test site, while we refer to Maggioni et al. (in press) and Barbero et al. (in press) for a detailed description of the
test site and of the instrumented obstacle, respectively.

Figure 1. View of the Seehore test site after the avalanche of 27th March 2010.

3. METHODS

3.1 Laser scan technique

In some experiments, before and after the avalanche triggering, terrestrial laser scanner surveys are carried out with a Riegl LMS-Z420 and a Riegl VZ400, in order to get information about the snow erosion and deposition along the track. These estimates are obtained by comparing the surfaces scanned before and after the avalanche release (Prokop, 2008). In this work we analyzed the laser scan data of the events triggered on 27th March 2010 and 5th March 2011. In particular, we used the data from laser scan concerning the difference \( h_\delta \) between the snow height after and before the avalanche event, in order to evaluate the influence of the slope angle on the deposition height \( h_d \).

Since \( h_\delta \) represents the combination of the erosion and deposition processes, the first step consisted on depurating \( h_\delta \) from the contribution of the erosion \( h_e \), in order to keep only the deposition height given by:

\[
h_\delta = h_e + h_d
\]

To explain the relationship between the deposition depth \( d_d = h_d \cos \theta \) and the slope angle \( \theta \) two analytical models (the cohesive-frictional and Pouliquen ones) were applied, following the approach presented in Sovilla et al. (2010).

The cohesive-frictional model is based on the importance of snow cohesion within an avalanche flow, especially in the deposition zone. Cohesion is caused by the continuous contacts between snow particles, which, in the deposition zone, are more frequent due to the plug structure of the flow. Assuming that the gravity force is balanced by a drag force, described with a simple Mohr-Coulomb frictional model with cohesion (Platzer et al., 2007), a characteristic snow height \( h_d \) for which the snow stops, can be found:

\[
h_d = \frac{c}{[\rho g(\sin \theta - \mu \cos \theta)]}
\]

where \( c \) is the cohesion, \( \rho \) the density, \( g \) the gravity acceleration, \( \theta \) the slope angle and \( \mu \) the tangent of the internal friction angle.

The Pouliquen model (Pouliquen, 1999) is based on observation that the granular flow stopped with a thickness of \( h_{\text{stop}} \) corresponding to the clusters size and depending on the slope angle:

\[
h_{\text{stop}} = L \log[(\tan \theta_2 - \tan \theta_1)/(\tan \theta_2 - \tan \theta_1)]
\]

where \( \theta_1 \) and \( \theta_2 \) are angles. For \( \theta < \theta_1 \) no steady flow is possible and deposits of any depth can occur. For \( \theta > \theta_2 \) the flow cannot rest. \( L = \alpha d \) is a length scale, where \( \alpha \) is a coefficient, generally 2-8, and \( d \) is the particle diameter.

3.2 Straw test

The straw test was ideated by E. Bovet and L. Pitet, consultant of the Regione Autonoma Valle d’Aosta, during winter 2010-11, in order to have a simple and cheap method to distinguish, after an avalanche, the avalanche deposit from the undisturbed snow cover. It is based on the analysis of number and position of plastic straws opportunely placed within the snow cover. Only very cheap materials are necessary: plastic straws, a metallic pole with a diameter inferior to that of the straws (a wire straightened up for instance) and resistant thread.

The following steps have to be followed (Fig. 2):

- join the metallic pole with the thread thanks to an adhesive tape at the point A;
- enumerate the straws by an alphanumeric code XY, with X a letter indicating the
position of the test, and $Y$ a progressive number indicating each inserted straw in an ascending order from $B$ to $A$;
- insert the straws from $A$ to $B$;
- join the extremities $C$ and $A$;
- insert the whole structure vertically in the snow cover ($A$ at the top and $B$ at the bottom) leaving some straws to come out of the snow cover, which must be fixed with some snow;
- pull the metallic pole and the thread, holding the upper straw in one hand, from $A$ to $B$ and $C$;
- repeat the above procedure for more locations along the avalanche path.

The analysis of the test is based on the amount of new snow ($HN$) and on the code number of the first straw found near the surface after the avalanche. In this paper, we focus the attention only on some situations that might occur (Fig. 3).

For example, case 2 of Fig. 3 means that before the avalanche the amount of new snow do not bury the straws. Since the straw found at the top after the avalanche has a code number $j$ lower than $i$ (code of the straw at the top before the avalanche), it is possible to conclude that: 1) first the avalanche eroded the snow cover until the straw $X_j$ for the height indicated by the red arrow, 2) then it deposited the height represented by the green arrow.

In order to speed up the retrieval of the straws a compass will be coupled to the meter. Moreover, the number of monitoring points will be increased in order to better describe the zones where both erosion and deposition occurs and where the deposition is prevalent. This will help in evaluating if the supposition of an uniform erosion everywhere is correct (see section 4.1). Finally, in order to avoid the situation of $i=j$ when some information are lost, an higher number of straws will be inserted.

![Diagram](image-url)
3.3 Avalanche dynamics simulations

We used the module avalanche of the program RAMMS developed by the researchers of the WSL-SLF of Davos (CH) to simulate some of the events triggered at the test site. We refer to Bartelt at al. (2012) and Christen et al. (2010) for a detailed description of the model. In particular, we simulate the events of 27th March 2010 and 5th March 2011 when information on erosion and deposition were available from laser scan measurements.

3.4 Field work

Generally, before and after each artificial triggering, physical properties of the snow in the avalanche release, track and deposition zones were recorded. After the event, according to safety conditions, a snow pit and stability tests were made in the release zone. Moreover a GPS survey of the avalanche outline was made, together with measurements of the snow depth in some points around and within the avalanche deposit and track, in order to estimate the snow distribution in the deposit.

4. RESULTS AND DISCUSSION

At the test site several avalanches were triggered in the three operating seasons (from 2009-2010 until present). In this work we refer in particular to the events triggered on 27th March 2010 and 5th March 2011 when laser scan measurements were performed. They were small slab avalanches with release volumes around 300 m$^3$; they were mainly dense avalanches with a little development of a powder cloud.

In the following paragraphs we present and discuss the results we obtained, concerning the evaluation of the erosion and deposition processes within an avalanche flow obtained with the different methods.

4.1 Laser scan technique

Fig. 4 shows the difference between the snow height after and before the avalanche of 27th March 2010 as measured by laser scan.

The erosion depth $h_e$ was estimated supposing that all the new snow available was entrained as found by the analysis shown in Figg. 5 and 6, imaging that on steep slope angles only erosion occurs. The erosion height equal to 17 and 26 cm for the avalanche of 27th March 2010 and 5th March 2011, respectively (Tab. 1), were comparable to the values of the fresh snow measured in the snow pit: 25 and 30 cm, respectively.
We note that for steeper slopes $h_e$ could be lower, maybe due to the fact that the avalanche was not completely developed therefore not all the erodible snow was eroded. The values of erosion (Tab.1) were taken for the whole avalanche area, without taking into account the eventual dependence on the difference in altitude. The deposition height was then evaluated through Eq.1.

For statistical reason and considering the slope angle at which the majority of the mass is deposited, we limited the analysis to a specific range of slope angles (Tab.1). Tab. 1 also summarizes the results of the least square fit (shown in Fig.7), as well as the values reported in the literature (Sovilla et al., 2010) concerning the cohesive-frictional and the Pouliquen models.

Concerning the cohesive-frictional model, we found a higher $\mu$ value in comparison with those reported in other research. This can be explained by the fact that the avalanches considered in this work were smaller than those released for example at the Vallée de la Sionne test site. Also in numerical models, for ex. in RAMMS (Bartelt et al., 2011), smaller avalanches have to be simulated with lower $\mu$ than larger avalanches.

The value obtained for $c$ is lower than the data available in literature. We think that this determination is affected by large uncertainties in the snow density estimation (see Eq.2), which we could not measure.

Our fit is in agreement with the experimental data, even if for high slope angles the accuracy of the fit decreases, as in Sovilla et al. (2010). Nevertheless, we expected this behavior because a characteristic of the cohesive-frictional model is that cohesion is never null even for large values of the slope angle.

As Pouliquen fit concerns, if we take $d = 10 \text{ cm}$ (De Biagi et al, 2012), the value of $\alpha$ is in the correct range.

We found higher values of $\theta_1$ and $\theta_2$ than those reported in the literature. It might be related to the size of the avalanches. In fact, a small avalanche, as in our case, generally stops before a bigger one, having lower mass, velocity and momentum.
Figure 8. 5th March 2011: relationship between the snow deposition height and the curvature.

4.2 Straw test

In winter 2010-2011 four monitoring points were used in proximity of the obstacle (Fig. 9).

![Figure 9: Distances of the 4 straw tests from the obstacle (in meters).](image)

After the avalanche recorded 5th March 2011, we found the situation n. 7 reported in Fig. 3 where we set the test A (Fig. 9). At the set-up time two straws of 13.5 cm each one, for a total height of 27 cm, were left out of the snow cover. The code number of the top straw was A12. Before the triggering, about 30 cm of new snow fell. After the avalanche, we found the straw A11 on the surface. This findings means that at point A about 17 cm of snow were eroded and no deposition processes occurred. Therefore, at least at 2.10 m upwards the obstacle, the shape of the snow accumulated (Fig. 10) was due to the erosion and not to the deposition process.

![Figure 10. Shape of the snow upwards the obstacle after the avalanche of 5th March 2011. The arrow indicates the location of the straw A.](image)

4.3 Avalanche dynamics simulations

The simulated avalanches of 27th March 2010 and 5th March 2011 match well with real data. We tried different simulations to fit the model to the real events - see Maggioni et al. (this issue) for details.

In this work, we simply compared, in a GIS, the output of RAMMS related to the erosion of the top layer with the laser scan measurements.

In the analysis of the laser scan data, we kept in mind that the laser scan technique gives information only on the net erosion/deposition, but it is not able to determine the real erosion and deposition depths. This means that it is not able to describe exactly the areas where both erosion and deposition occur.

Considering the 27th March 2010 avalanche, RAMMS identified the most eroded areas at elevations ranging between 2420 and 2380 m asl, while the real events generated most of the erosion between 2460 and 2410 m asl. The eroded snow depth was in a range of 15-20 cm as measured by the laser scanning and around 20-25 cm as calculated by RAMMS.

Concerning the 5th March 2011 avalanche, RAMMS identified the maximum erosion between 2460 and 2390 m asl with most of the values between 20 and 40 cm. The laser scan measurements showed the same pattern: the most eroded area resulted between 2460 and 2410 m asl with values around 20-40 cm. Also the maximum values, though not so significant as localized on very small portions, were consistent: 45 cm for RAMMS and 60 cm for the laser-scanning.

Considering both events, the shape of the eroded areas were quite similar, while the shape of the deposits were slightly different. RAMMS was able to reproduce the real dual-lobe shape but the calculated deposits were more elongated.
in the cross direction, while the real deposits followed the down-slope direction.

4.4 Field work

The distribution of the snow depth measured in specific points after the artificially triggered events is shown in Fig.11, together with the frequency of the avalanches. The highest values were found in the two lobes where usually the avalanches deposit.

Figure 11. Avalanche frequency distribution at the test site. The points indicate the snow depth measurements: dark blue corresponds to high values (max of more than 331 cm), light one to lower ones (min of 40 cm).

5. CONCLUSIONS

In this work we presented different methods to approach the topic of snow erosion and deposition processes. In particular, we showed the potentiality of the new straw test to measure the real eroded snow in small avalanches. The combination of the straw test and the laser scan technique could probably help extending the punctual information of the straw test to a larger area.

Thanks to the laser scan data, we showed that the dependency between the deposition depth and the slope angle can be explained by both a cohesive-frictional model and the Pouliquen model.

Future work will focus the attention on the new interesting findings concerning the possible dependency between deposition depth and slope curvature.

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7. REFERENCES


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