GEOMATIC APPROACH IN SNOW AVALANCHES MONITORING: THE VARAITA VALLEY (CUNEO - ITALY) CASE STUDY

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ABSTRACT:

This paper presents an integrated measurement procedure with the employment of geomatic methodologies and in particular it describes the avalanche deposit measurement carried out by GPS receivers in RTK mode. To estimate the deposit volume surveys have been executed on the avalanche deposit and after its complete melting to measure bare soil morphology; surfaces obtained by the interpolation of the two surveys have allowed computing the snow deposit volume. The computed volume has been useful to determine the input parameter for the avalanche dynamics model used to reproduce the event.

The numerical model AVAL-1D, developed by the Swiss Federal Institute for Snow and Avalanche Research WSL-SLF of Davos (CH), has been used to simulate the event in both its components: FL-1D for the dense part of the avalanche and SL-1D for the powder one. The simulations gave outputs of velocity, impact pressure, flow height and run-out distances that were compared to the one estimated from field surveys.

The RTK mode has allowed the execution of each survey campaign in only one day assuring centimetric precision: the results, already processed in real time, have been immediately available to the following analyses.

The described methodology has allowed compiling an operative protocol that aims to guarantee a fast measurement execution, a reduced permanence in deposit zone – increasing the operator safety – and a high precision avalanche data, necessary for specific researches, such as numerical modeling or the determination of solid material amount transported by avalanches.

1. INTRODUCTION

1.1 Avalanches

According to UNESCO (UNESCO - International Commission on Snow and Ice, 1981) an avalanche can be defined as a snow mass, with a volume greater than 10 m³ and a minimum length of about 50 m moving downhill. Generally, avalanches consist of three zones (Figure 1): the zone of origin (starting zone) characterized by the manner of starting, the transition zone, where the avalanche is independent from the starting mechanism and the run-out zone, where a natural deposit is produced by the loss of energy due to friction.

Factors causing an avalanche are related to terrain morphology, meteorological parameters and snowpack characteristics (Colbeck et al., 1990; Schweizer et al., 2003). On slopes of inclination between 28° and 60°, the accumulated snow might reach a volume that induces an instability within the snowpack between the gravity and the resistance forces and therefore releases as an avalanche (Mc Lung and Schaerer, 1993). Among the meteorological factors, the wind may contribute in snowpack accumulation by snow drifting (Daultier et al., 1995; Lehning et al., 2000).

Layers in the snowpack play a basic role in its stability, as they may act as sliding planes and contribute to avalanche triggering (Pielmeier and Schneebeli, 2003). Snow and air temperatures may influence snowpack stability, too (Barry et al., 2007; Regonda et al., 2005)

Avalanches are well known since ancient Greeks and Romans and during, past and recent, history have been recognized as the cause of several casualties, e.g. in the First World War, in year 1916, at least 6000 soldiers have been killed by avalanches within 48 hours (Schaffhauser et al., 2005).

Avalanches are classified according to McClung and Schaerer (1993) in two typologies:

1. Loose snow avalanches: the avalanche trigger happens on snowpack surface or on upper layers. They involve a small, punctual, starting zone and then expand during the flow assuming a typical triangular shape while increasing their volume;
2. Slab avalanches: it is caused by a fracture inside the snowpack and forms rectangular shaped blocks that completely releases due to the fracture propagation.

Moreover, avalanches are classified, among other criteria, also according to the flow type (powder or dense avalanche). A dense avalanche presents high density (200-300 kg/m^3) and flows closed to the ground, while a powder avalanche is made by a saltation layer with a density of about 50 kg/m^3 and a suspension layer with a flow height up to hundreds meters and low densities (1-10 kg/m^3). Recently, scientist started to speak about mixed avalanches which present both components (for ex. Bartelt et al., 2000).

The destructive power of an avalanche may result impressive as it can reach, in its maximum recorded values (Schaffhauser et al., 2005), velocities of up to 350 km/h and exert a pressure of up to 500 kPa, thus being able to damage reinforced concrete structure or to completely uproot big trees.

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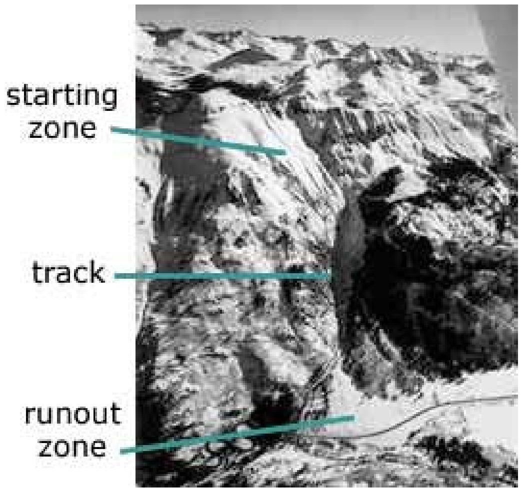

Figure 1. - Subdivision of avalanche track (Source, National Snow and Ice Data Center, http://nsidc.org)

1.2 Geomatic

Geomatic may be a main factor in the monitoring of avalanche and generally cryospheric phenomena, as recommended by the UNEP report, encouraging the employment of remote sensing and geo-informatics, with the purpose of keeping track of changes and to assess their impacts (United Nations Environment Programme, 2007).

According to current monitoring methodologies, geomatic may offer a support in measurement and in data analysis, optimizing the work flow or may provide innovative techniques with the aim of introducing new methodologies. The results of these experiment should still be validated with previous methods in order to asses their methodological feasibility.

Avalanche events are studied through different approaches: experimental sites, hazard zoning and modelling.

The comprehension of avalanche physical parameters is achievable by the event simulation in experimental sites. The measurement of artificial triggered avalanche, during and after the event, may provide useful data in the phenomena understanding. Amman (1999) has defined the main parameters to measure in a site:

- Initial conditions of the snowpack in the starting zone;
- Area, volume and density of released snow;
- Change of snow flux in the track due to snow entrainment;
- Topography of the track;
- Dependence of friction on snow properties and snow mass, terrain characteristics, vegetation;
- Vertical profiles of averaged flow velocities along the track and in transverse direction;
- Flow and deposit depths;
- Run-out behaviour, deceleration characteristics;
- Lateral spreading of the avalanche flow during run-out;
- Interaction of the avalanches with various types of obstacles.

In addition, for powder-snow avalanches:

- Erodability and suspendibility of the snow;
- Velocities and concentrations in the suspension layer as a function of time and space;
- Boundary conditions at the lower surface (velocity of the dense-flow avalanche, velocities and pressures in the saltation layer, snow entrainment);
- Run-out behaviour, sedimentation rates.

Geomatic techniques may offer a fundamental contribution in the measurements of these parameters and particularly in the survey of the topography of the track and on the deposit volume. In order to estimate avalanche volume and to test its dynamic with simulation models, the topography of the area should be carefully measured. GPS may be employed in avalanche deposit volume survey. According to Schaffauser et al (2005) direct measurement may be hazardous for the operators, but the differential approach may assure a fast execution of the survey, improving operator safety while keeping the accuracy of the final result and reducing the instrumentation costs.

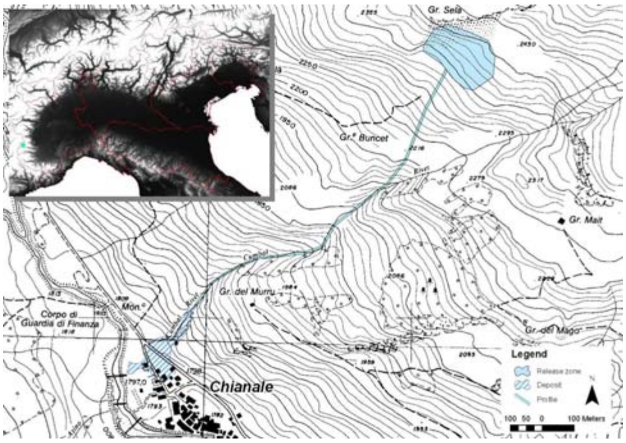

Figure 2. – Study area

2. MATERIALS AND METHODS

The study area is located in Cuneo province in the municipality of Pontechianale, particularly in a small village called Chianale (44° 38' 51.024" N 6 59' 51.475" E). The site is situated in the upper sector of the Varaita valley at 1797 m a.s.l. and it is crossed by the main road connected to France (Figure 3). In the last winter the village has been endangered by several avalanche events. In this paper we focus on the avalanche that released on December 15th and caused remarkable damages to three building, nearly destroying one of them, uprooted several trees (Figure 3) and the deposit caused the interruption of the main road.

Figure 3. – Uprooted trees in the avalanche deposit (Photo courtesy A. Pagliero)

The study of the avalanche event has been performed with different approaches in order to acquire the higher amount of data to describe and analyze the phenomenon.

Firstly, an historical research has been carried out in order to determine past events in the same area. The main data source has been the "*Monografia militare delle valanghe*"(Figure 4), a map produced by the Alpini Corps – Meteomont Service (Tecilla, 2007).

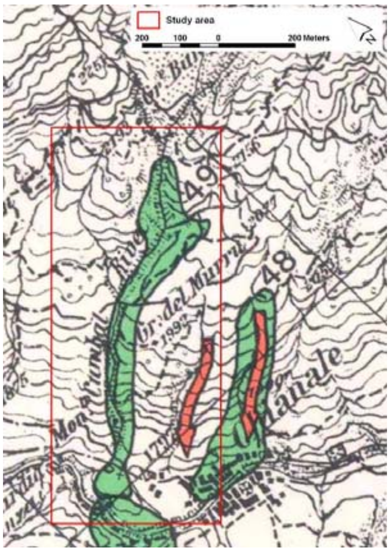

Figure 4 - Study area represented in the Monografia Militare delle Valanghe.

According to the report, in the '80s several events have been observed with light damages to the village houses and the interruption of the main road. Other documentary sources, as the Capello's inventory (1977) have not provided additional results. Maps as the CLPV - Probable Avalanche Location Map (Nevini e Sani, 1991) does not exist in the area.

The following phase has then been characterised by field inspections and surveys. Main goals of these operations have been the recognition of the avalanche zones, the damages and the GPS measurement of the avalanche volume. The avalanche survey has been fulfilled in three steps (Freppaz et al., Submitted, 2009; Godone et al., 2009): first, a reference point has been placed in the village and its position has been measured in static mode; then, in RTK mode the avalanche deposit has been measured after placing a receiver on the previously defined reference point. The same procedure has also been adopted in the bare soil measurement. The reference benchmark positioning has been carried out by measuring its position relatively to the Savigliano reference station in two 1h-session in order to assure redundancy in the post processing phase. Data downloaded from the two receivers and from the reference station website has been processed by building up the two baselines and thus computing the reference position. Those coordinates have then been employed in the following two surveys. The base station has been, in fact placed on the benchmark and the computed coordinates have been employed to compute the differential correction coefficients transmitted by the radio modem to the rover instrument performing filed measurements.

The point cloud obtained from the two survey sessions have been employed in the interpolation of two surfaces (deposit and ground) with the purpose of computing avalanche volume. The process has been performed employing the "Triangulation with Linear Interpolation" in Surfer™ (Guibas and Stolfi, 1985; Lawson, 1977; Lee and Schachter, 1980). Data have been exported from the Leica Geo Office™, which has been employed to manage GPS data, in ASCII xyz format and inputted in the "Grid" tool of the software.

The two surfaces (Figure 5) has then been processed in the "Volume" tool: it requires the definition of their reciprocal positions, i.e. upper and lower surface, and then it calculates the volume inside the two features by first integrating over the grid columns to get the areas under the individual rows, and then integrating over the rows to get the final volume (Press et al., 1988).

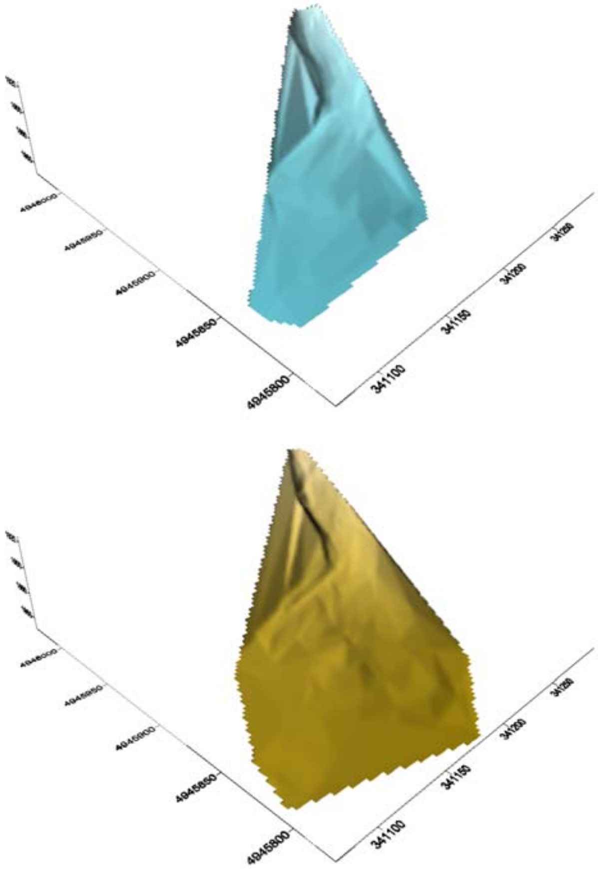

Figure 5. – Interpolated surfaces of the avalanche deposit (above) and of bare soil (below)

During the surveys, also data about the damage to trees along the path and to buildings in the run-out zone have been recorded in order to describe the intensity of the avalanche, that developed both a dense and a powder part.

The analysis of the event has also been carried out by numerical simulations with the model AVAL-1D developed by the WSL-SLF of DavosAVAL-1D is a numerical model which includes FL-1D for the simulation of dense flows and SL-1D for powder ones (Christen et al, 2002). In this work both components has been used to reproduce the event of December 15th.

FL-1D is a numerical, depth-averaged, quasi one-dimensional, continuum model, which tracks the motion of an avalanche from initiation to runout. The fundamental differential equations are based on the principles of conservation of mass and momentum. One of the main hypothesis is that the avalanche mass is constant and no entrainment processes are modelled; the model is one-dimensional, but the user can give the width of the path, over which the calculated flow height is averaged.

SL-1D consists of a suspension layer and a so called saltation layer (fluidized part). The latter is only a few meters deep and is modelled by depth-averaged mass and momentum balances. In the suspension layer, the mass and momentum balance equations for the mixture are supplemented by the snow mass balance and the transport equations for turbulent kinetic energy and dissipation. Mass and momentum exchange between the two layers is determined by particle settling, turbulent diffusion against the concentration gradient, and aerodynamic shear forces. The net erosion or deposition rate is a function of the kinetic energy of the impacting particles.

3. RESULTS AND DISCUSSION

The used approach to study the avalanche event brought us to a complete description of the event, including volume measurements and estimation of the impact pressure.

The volume calculation has been computed with the employment of high precision GPS receivers and, moreover, the methodologies employed in field survey and post processing phases has assured the conservation of the precision for the next processing phases

3.1 GPS surveys

The reference mark position has been measured with high precision, as shown in the following table.

Sd N (m)	**Sd E (m)**	**Sd Hgt (m)**
0.0042	0.0048	0.0094

A (m)	**B (m)**	**A/B**	**Phi (°)**
0.0055	0.0033	1.7	52

Table 1 – reference benchmark positioning precision and error ellipse

These values have allowed the employment of the benchmark in the following measurement phases. The avalanche area has been surveyed twice in the year, with the deposit and when the complete melting has occurred. Both she surveys have given similar accuracy results and respectively 182 and 221 points have been measured.

The amount of data have allowed interpolating the two surfaces and thus computing a volume of 68431 m^3

At the time of the measurement of the avalanche deposit, there was about 1 m of snow at ground. It might be that the computed volume overestimates the avalanche deposit; on the other side, the measurement was done not immediately after the event but one month later, therefore the two facts could compensate. Moreover, the GPS measurements were done for the dense and fluidized parts, neglecting the area of influence of the powder cloud.

3.2 Avalanche dynamics calculations

The use of the numerical model AVAL-1D allowed the calculation of some dynamical variables, such as flow height, velocity and run-out distance for the two components of the avalanche. In the following we described the two simulations.

3.2.1 Dense avalanche

The avalanche has been classified as extreme with a return period of 100 years.

The input for the fracture depth was equal to 2.15 m and the release volume about 56.000 m^3. The friction parameters were derived from SLF (1999) for a medium size avalanche: $\mu = 0.207$ and $\xi = 1815$ m/s^2 in the release and deposition zones where the avalanche is unchannelled, $\mu = 0.267$ and $\xi = 1200$ m/s^2 between 2150 and 1830 m asl where the avalanche is channelled, and $\mu = 852$ and $\xi = 0.337$ m/s^2 for a small section (1900 - 1850 m asl) where it flows in a gully.

The simulated avalanche stops at an altitude of 1971 m asl with a deposition depth of 2.8 m at that point. As the model is one-dimensional it is not possible to describe the avalanche deposit distribution and we could not compare the calculated deposit with the measured one, but in some points. The calculated maximum velocity is 31.92 m/s (Figure 6). The pressure of 15 kPa (limit between the high and medium danger zones) occurs at 1798 m asl.

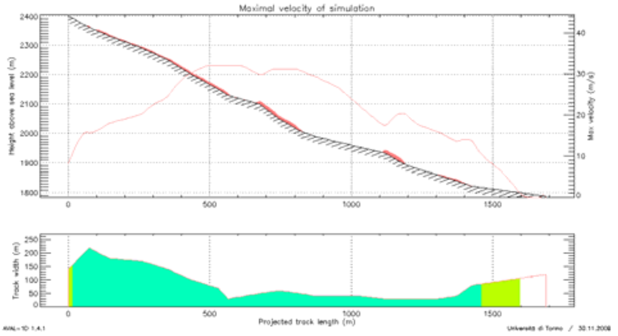

Figure 6. - Maximal velocity calculated by AVAL-1D for the dense avalanche.

3.2.2 Powder avalanche

The input for the powder avalanche in the release zones are: fracture depth of 2.15 m (as for the dense avalanche) and density of 200 kg/m^3. The coefficient that determines which percentage of the dense avalanche passes to the powder part is the degree of suspension, which is taken equal to 0.2. The erodible snow along the path is taken equal to 1.5 m and the erodibility coefficient is chosen according to SLF (1999).

The output shows that the avalanche develops a saltation and a suspension layers that are respectively 0.8 and 50 m deep in the run-out zone (below 1820 m asl); it can reach velocity of 20 m/s in the saltation layer and up to 40 m/s in the suspension layer. The maximum pressure in the run-out zone occurs in the saltation layer with values around 3 kPa.

At the altitude where the avalanche flows out of the channelled part at 1830 m asl, the powder avalanche present a saltation layer of about 70 cm with a density of 20 kg/m^3 below a suspension layer up to 62 meters with a density of 2 kg/m^3.

The event was a mixed avalanche with a well-developed powder part, which probably generated most of the damage. A powder avalanche is made by a saltation layer plus a suspension layer; we think that most of the damages in the run-out zone were made by the saltation layer, while during the path the suspension component was the more destructive one, especially concerning trees.

4. CONCLUSIONS

The employment of different methodologies has contributed to deepen the knowledge of this event dynamic; however, in order to define an operative protocol, to be used in case of similar events, further analyses are needed. When dealing with such complex phenomena, a high detail in investigations is mandatory. On the other hand is necessary to, contemporarily, employ different approaches in order to study each phenomenon's aspect with the purpose of carrying out a multidisciplinary analysis, as suggested in this research.

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