Experimental analysis of snowpack effects induced by blasts

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ABSTRACT: An experimental snowfield has been realized in Gressoney La Trinité (Italy) to analyse the response of snowpack to explosives and the induced artificial triggering of avalanches. Two different explosives have been tested (dynamite and emulsion); 24 charges were separately detonated at different elevations from the snowpack (on the snow surface, at 0.5 m, 1 m, and 0.5 m below the surface). The aim was to define the relationship between charge and delay, elevation and air blast. The energy propagation from blasts on the snowpack and the air blast were monitored by passive seismic sensors and sound devices, respectively. The geophysical investigation of the test site (georadar and seismic) was aimed to i) estimate the mechanical properties of the snowpack; ii) detect changes of the snowpack properties before and after the blasts. The georadar survey has permitted to estimate the snowdepth in the range of 0.6 to 1.5 m; the snow density has been evaluated by the conversion of the electromagnetic wave velocity using mixing rules; the density is in the range of 200 – 300 kg/m^3.
The analysis of the craters induced by the different blasts has been performed; the correlation between the crater parameters and the passive seismic and sound data collected in different fixed stations permitted to assess the blast performances. The results agree with previous studies, especially as far as the geometry of the craters obtained from different blasts is concerned.

KEYWORDS: Snowpack, Explosives, Air Blast.

1 INTRODUCTION

Within the Operational programme ’Italy - France (Alps - ALCOTRA)’, Project “DynAval - Dynamique des avalanches: départ et interactions écoulement/obstacles”, the response of snowpack to explosions that induces artificial triggering of snow avalanche is analysed.

Understanding the influence of artificial impulsive overloads is essential to improve the knowledge on the dynamical behaviour of the snow cover and, from technical and practical point of view, to enhance the efficiency of the avalanche release devices (with gas or explosives trigger). To try to evaluate the effects of the induced overpressure on snowpack, an experimental snowfield has been realized during the Winter 2010 in MonterosaSki resort – Gressoney La Trinité (AO- Italy). The first goal of the test is to study the behaviour of the snowpack under dynamic overloads and set up a procedure for evaluating the snowpack alteration after an explosion. The aim is to evaluate the critical explosive charge analysing the results of some blasts caused by two types of explosive employed, different charges and detonation height with respect to the snow surface and mass.

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In this first experiment, to pursuit these goals, the issue were: (i) the individuation of the snowfield; (ii) the design of the plan of the explosions; (iii) the essential devices and tests; (iv) the arrangement of the contemporary surveys on the snowpack (pre and post-explosions) with different devices.

In particular, the chosen surveys were :

(i) pre-explosion (in the undisturbed snowpack):
- traditional survey in the snowpack (height of snowpack along the explosion lines and n. 2 profiles inside and outside of the explosion lines);
- georadar survey along the explosion lines;
- seismic survey along a specific line inside the explosion lines;

(ii) during the blasting tests:
- seismic survey along a specific line inside the explosion lines;
- acoustic survey inside and outside of the explosion lines;
- vibration survey with tri-axial geophones inside and outside of the explosion lines;

(iii) post-explosion:
- the measure of the dimensions of craters given by explosions in the snowpack;
- traditional survey in the snowpack (measure of density and collection of snow samples);

- georadar survey along the explosion lines.

In this paper, the experimental snowfield is described: the master plan of the blasting and the pre – during and post blasts surveys are illustrated. At this stage of the data processing we only discuss some preliminary results.

2 EXPERIMENTAL SNOWFIELD

The test site is located near the lake Gabiet - Gressoney La Trinité (AO- Italy) in an isolated and flat area at an altitude of 2.363 m a.s.l. with dimension about 80 m x 200 m, 1 km from the cableway of Staffal (figure 1).

The experiment was done from 7 a.m. to 5:30 p.m. of the 31st March 2010. During the first 3+½ hours the explosion lines were marked and the tests of the devices and the pre-explosions surveys were performed. In the following hour, the charges were prepared and at about midday the blast tests were performed with related surveys. From about 2 to 5:30 p.m. the post-explosions surveys were carried out.

The campaign was performed under unstable weather conditions: clear sky in the morning, washes in the late morning / early afternoon (with a slight snowfall) and a return to clear sky in the late afternoon. The air temperature was variable from about -11 °C at 7 a.m., to +3 °C at 11 a.m., to -4 °C at 5:30 p.m. . During the night between the 30th and 31st March, a snowfall left about 50 cm of fresh snow (data from Gabiet station at 2.379 m a.s.l., given by Centro Funzionale – Regione Autonoma Valle d'Aosta).

In the snowfield, the snowpack presented a total height from 60 cm to 150 cm. The two snowpack profiles characterised the snowpack with total height about 1 m and a melt-freeze crust after 30 cm of the fresh snow on the surface (given by the snowfall with 70 kg/m^3 of density). At -50 cm, a sandwich crust with a with maximum thickness of 5 cm was presented. The presence of the sandwich crust was confirmed over the entire snowfield from measurements with the steel probe.

The rest of the snowpack was characterised by uniform snow with density between 220 and 290 kg/m^3. The bottom of the snowpack was composed by a strong layer of ice.

3 EXPLOSION TESTS

The explosives employed in the survey had been chosen between the commercial and the ones used for artificial release of avalanches. We tested two types of explosives: the dynamite and the emulsion, both characterized by high detonation velocity and excellent strength. Compared to dynamite, the emulsion develops 5% more of the volume of gas (this is considered as a positive factor for artificial avalanche release); in Table 1 the properties of the explosives used are listed.

Table 1 – Main properties of the explosives employed to perform the experimental blasts.

Type		Emulsion	Dynamite
Commercial name		Premex 3300	Goma 2 Eco
Density	[kg/m^3]	1200	1450
Energy release	[kJ/kg]	3850	4100
VOD in free air	[m/s]	4900	6100
Gas Volume	[dm^3/kg]	935	895
Charge Mass	[kg]	0.992	0.953

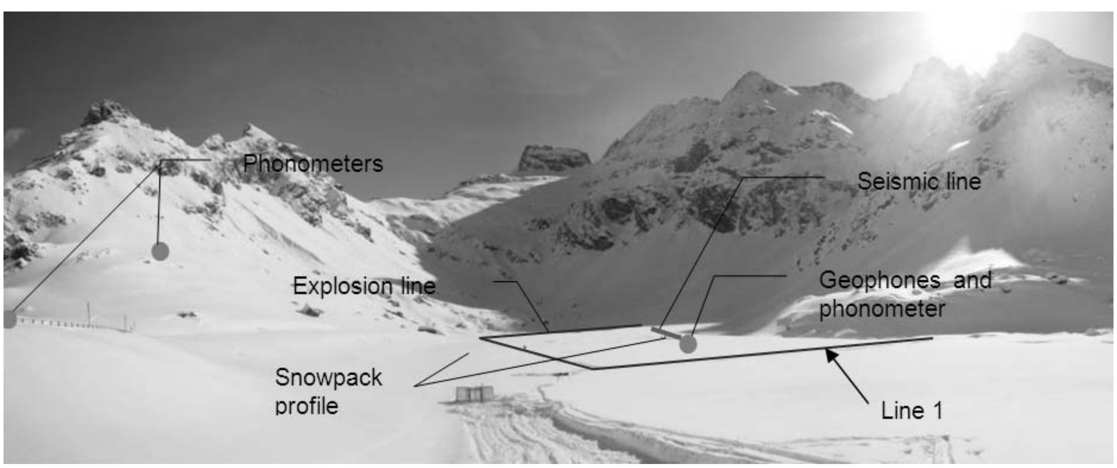

Figure 1. Overview of the experimental snowfield Lago Gabiet - Gressoney La Trinité (AO - Italy).

To test the effect of different charges, 24 shots have been done (12 for dynamite and 12 for emulsion) with 1, 2 and 3 kg of explosive, respectively located at detonation height 0 m, +0,5 m , +1 m and -0,5 m from the surface of the snowpack.

To avoid the superimposition of the effects given by the explosion of adjacent shots and taking into account the assumptions in Cardu et al. (2007), the design of the master plan of blasts presented two explosion lines (one for each types of explosives). Each line had two branches (L shape) with length 75 m and 90 m. The charges were spaced 15 m and the sequence of the shots was based on the height of the explosion and the mass of charge, respectively. For example, the first set of charges was dynamite at -0.5 m of the surface of snowpack (inside the snowpack) with a sequence of 3 kg, 2 kg, 1 kg, on the Line 1 (figure 2). The next sets increased the height of the explosion (0 m, +0,5 m and 1 m from the snowpack) and the same procedure was adopted for the emulsion. The minimum timing of the blast was 1 min between each shots. The fire trigger of each charge was given by 50 cm of safety fuse.
The charge positions were photographed and all detonations were video recorded.

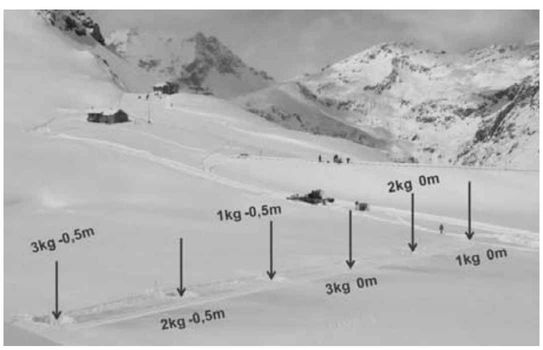

Figure 2. First two set of charges at -0,5 m and 0 m height (Dynamite - Line 1). The sequence of shots is controlled by the height of the explosion and by the weight of the charge.

4 SURVEY DEVICES

In this section, the devices used to evaluate the effect of the impulsive overload induced by blast during our experiment are presented. Both, the effects of the blast on the snowpack and the overpressure given by the air blast were monitored respectively by: (i) snow, georadar and seismic surveys (for pre and post-blast) and (ii) vibration and acoustic surveys.

4.1 Snow survey

The profiles have been carried in the natural snowpack and, after blasts, in the radial cross-section of each crater generated by explosions. The pre-blast survey provided two snowpack profiles in the morning and located inside (near the seismic line) and outside the explosion lines. Besides, for each point of shot of the explosion lines and each 5 m of the seismic line, the measure of the height of the snowpack and the depth of the sandwich crust were noticed. For each crater (with the exclusion of the craters generated by a 2 kg charges), the post-blast survey provided the measure of: the dimensions of the crater (maximum and minimum diameter and depth, figure 3), section shape, snow density and temperature, snow samples for chemical analysis.

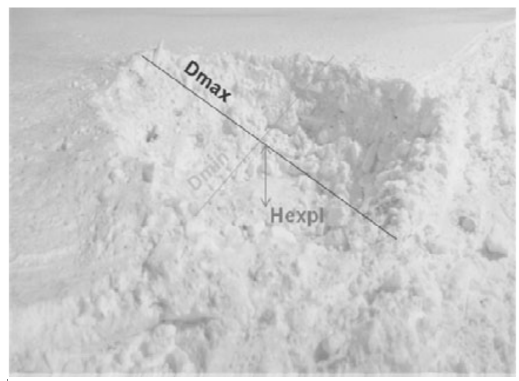

Figure 3. Crater dimensions.

4.2 Georadar survey

The georadar survey was performed on natural snowpack and, after the blasts, along the passage closer to the craters. For the comparison with a seismic survey, a single georadar trace was performed along the seismic line. The survey aimed to estimate the snow electrical properties and detect changes of the snowpack properties before and after the blasts (e.g. the variability of the density and of the snowdepth).

The data acquisition process was conducted in two different ways: (i) single reflection mode to acquire a profile series with a length from 75 m to 100 m before and after blasts, closer to the blast source (profiles n. 1, 2, 3, 4, 5 in figure 4); (ii) WARR (Wide angle refraction and refraction) procedure to acquire some profiles along a 30 m line, for estimating the dielectric properties of the snowpack and indirectly the density of the snow (profiles n. 6 in figure 4).

Surveys were performed using a IDS georadar system with a GSSI antenna operating at the main frequency of 900 MHz, controlled by a laptop. In the snow, the wave length at 900 MHz was about 20 cm. This permitted to obtain a vertical resolution of about 10 cm.

The acquisition with a 900 MHz antenna permits to carefully identify the snow-bedrock interface as the dry snow is a low-lossy material in which the radar signal is weakly attenuated (Godio, 2008).

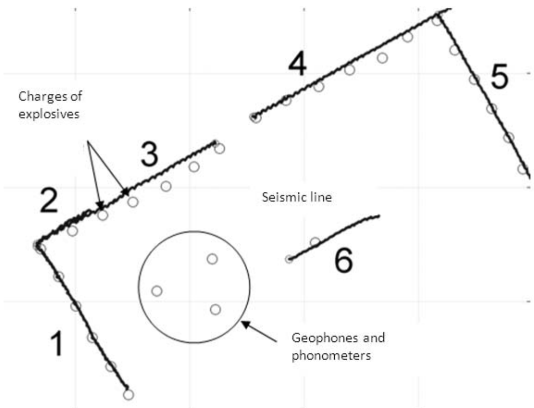

Figure 4. Position of georadar traces with respect to the shots and fixed instruments (geophones and phonometers). The numbers are the ID of the radar traces. The spacing between each charges of explosive is equal to 15 m.

The radar traces were referenced by GPS real time acquisition, that guarantees a theoretical spatial accuracy in the order of few meters. A GPS-Topcon 2 directly connected to the acquisition system was adopted. This GPS system is able to receive the differential corrections given by EGNOS and, consequently, to carry out the localisation in RTK with a metric accuracy. The radar traces were geo-referenced in WGS84 system and UTM coordinate.

The elaboration of the pre-blast georadar data in single reflection mode permits to evaluate the layering of the natural snowpack and calibrate the value of the electromagnetic waves velocity in the snowpack with a comparison between the signal travel time and the snow depth measured by hand probes.

The WARR georadar measures were elaborated by interpreting the dispersive events in the radargramms caused by the wave propagation inside the snowpack. This data analysis is finalised to define a vertical profiles series of electromagnetic waves velocity.

4.3 Seismic survey

The seismic survey aimed to estimate the mechanical properties of the snowpack and of the ice-layer (i.e., the shear modulus and the Poisson ratio).

The pre-blast data acquisition was carried only on a specific seismic line (profile n. 6 in figure 4) with the following characteristics:

- a seismic line with 24 vertical geophones with 30 Hz frequency and 0.5 or 1 m of spacing;
- giving energy with a 1.5 kg hammer on a Teflon plate (0.5 m x 0.5 m), shot points were placed at both ends of the line.
- data acquisition with Geode seismograph (Geometrics) with 24 cannels.

During blasting, the propagation of the wave field generated by the explosions of some charges was registered, in this case geophones spacing was 1 m.

4.4 Vibration survey

To register the vibrations induced by explosions, two stations of seismic and acoustic monitoring have been used. Each station was equipped by a three component geophone and an external microphone (Table 2).

Table 2 – Main properties of employed geophones.

Monitoring station		THOMAS VMS 2000	NOMIS Mini SUPERGRAPH
		GEO1	GEO2
Amplitude range	[mm/s]	± 228	± 260
Frequency range	[Hz]	2-250	2-400
Sample rate		1024	1024

The instruments were located closed to the explosion lines (at a distance of 56 and 180 m). The correct coupling between geophones and snow was guaranteed by three steel spikes on a single geophone. In this way, the horizontal position of geophones and the correct acquisition of the seismic waves was assured.

The particle motion at the snow surface of the three seismic components plus the acoustic one induced by single blasts were acquired (figure 5). Because of the low temperature, one of the station could not acquire the vibrometric data.

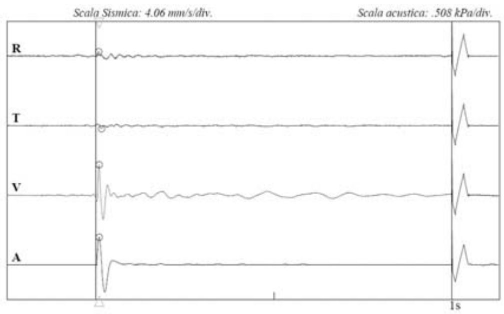

Figure 5. Shot n. 5 (2 kg dynamite). Registration of the vibrations with the three seismic components and acoustic one (GEO1 station).

4.5 Acoustic survey

The acoustic survey aimed to evaluate the overpressure induced by blast in air, to have a comparison with the interference on the snowpack.

For the sound acquisition data, two Modular Precision Sound Analyser Bruel & Kjaer, Type 2260 were used. They were calibrated at the Modulo Uno S.p.A. Centre on 03/04/2008 (Table 3) and calibrated again before and after the surveys.

The collected data were elaborated with a Sound Analysis Software BZ 7210/BZ7219 and Enhanced Sound Analysis Software BZ 7260. For the data elaboration, the chosen indicator was the acoustic linear peak level.

Table 3 – Main properties of employed phonometers.

Monitoring station	2260 B&K
Application	BZ7206 Version 2.1
Numbers of peaks	140 dB
Field	51,6-131,6 dB
Sampling rate	1 ms
Parameters in broadband	All
Spectrum parameters	All statistic
Input	Microphone
Level of calibration	94,0 dB
Sensibility:	-25,5 dB

5 RESULTS AND DISCUSSION

Some of the data processing are still in progress to find a correlation between the different types of information obtained by the experimental tests.

In particular, from the snow survey, the relationship between pre and post-blast density and blasting energy is still under research. Regarding the size of the induced craters, it seems that the crater dimension (width and depth) grows with the increase of the mass charge and decreases with the shot height.

Instead, the georadar survey has permitted to estimate the snowdepth in the range of 0.6 to 1.5 m; the snow density was evaluated by the conversion of the electromagnetic wave velocity using mixing rules; the density is in the range of 200 – 300 kg/m^3. These results were confirmed by snowpack profiles.

Figure 6 shows the georadar section acquired along profile n. 1 (figure 4) pre and post-blasts. Note that the snowpack presents a marked deformation closed to the shot also at deeper level in the snow in depth, caused by explosions.

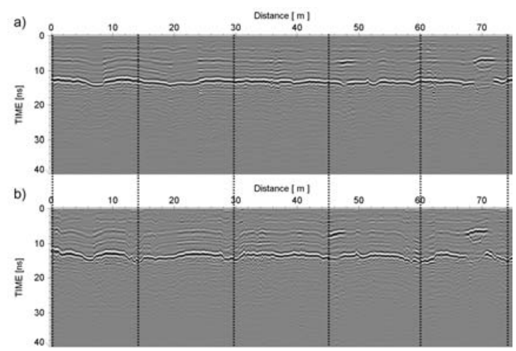

Figure 6. Radar section of profile 1: a) pre-explosion; b) post-explosion. The position of shots corresponds to 0 m, 15 m, 30 m, 45 m, 60 m, 75 m coordinate – Line 1 (figure 2). The most intense reflection (with corresponding signal travel time about 12-14 ns) represents the interface between ice/snow and bedrock. The figure puts into evidence the layers of the snowpack: the reflection at 5-6 ns refers to the presence of a centimeter single layer of ice-crust. The vertical lines indicate the blast positions.

Figure 7 shows the electrical permittivity profiles resulting from the analysis of the WARR acquisitions along the seismic line.

The elaboration of the guided waves shows the presence of a basal ice layer with a thickness of about 0.4 - 0.5 m. By the analysis of the guided waves, the mean velocity of the snowpack is estimated about 0.245 - 0.26 m/ns, corresponding to an electrical permittivity equal to 1.4 - 1.45 (typical for the dry snow). Ice layer permittivity is a little bit underestimated, the value retrieved is about 2.4.

The seismic survey was focused to estimate the shear modulus and the Poisson ratio of the snowpack by compressional wave and surface wave investigation along a selected profile in the test area. Unfortunately, it seems that the mechanical properties cannot be estimated due to the reduced snow depth (about 1 m), too small compared with the resolution of the survey.

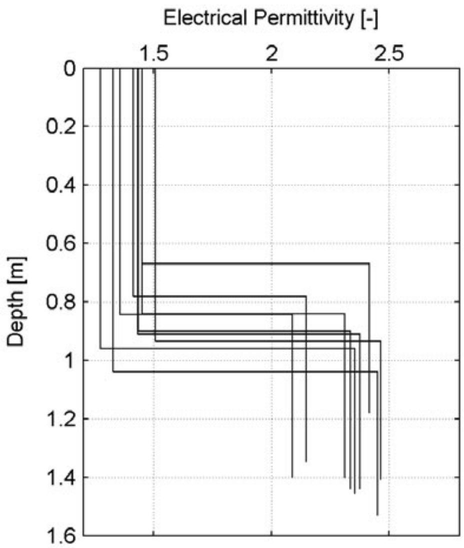

Figure 7. Electrical permittivity profiles achieved from the WARR survey. The interface at the depth between 0.8-1 m separates the snow cover from the basal ice.

As far as the seismic and acoustic surveys are concerned, theirs results cannot be coupled together and cannot yet be integrated with the wind and weather data.

6 CONCLUSIONS

The paper presents a description of the experimental snowfield and its related surveys to detect the effects on the snowpack induced by blasts. The first conclusion of this campaign is to understand which classical device can be applied to detect the induced changes of the snowpack and the performances of the explosives during the artificial avalanche release. The second one is to check which of the snow properties better reflects the changes of the snowpack induced by blasts (compaction or density ??) and, for the snow survey, to understand which types of measures should be made pre and post- explosions.

About the performances of different blasts used for artificial avalanche trigger, the campaign with other types of blasts will be repeated next winter.

We're still working on the relationship between the crater parameters and the vibrations and sound data to assess the blast performances.

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8 REFERENCES

Binger C., Nelsen J., Olson K.A., 2006. *Explosive shock wave compression in snow: effects of explosive orientation and snowpack compression*. In Proceedings of the International Snow Science Workshop, Telluride, Co, October 2006. 592-597.

Cardu M., Chiaia B., Chiaravallotti L., Cornetti P., Frigo B., 2007. *Modello meccanico per l'innesco delle valanghe di neve*. GEAM - Geoingegneria Ambientale e Mineraria. XLIV. 1: 23 – 34.

Cresta R., 2000. *L'esplosivo e la neve*. CAI Ed. pp. 147.

Colbeck S., Akitaya E., Armstrong R., Gubler H., Lafeuille J., Lied K., McClung D., Morris E., 1985. *The International classification for seasonal snow on the ground*. NTIS (Springfield, Virginia) and USACRREL (Hanover), pp. 37.

Godio A., 2008. *Performance and experimental evidence of GPR in density estimates of snowpack*. Bollettino di Geofisica Teorica e Applicata, 49, 279-298.

Koh G., Yankielun N.E., Baptista A.I., 1996. *Snow cover characterization using multiband FMCW radars*. Hydrol. Process. 10, pp. 1609–1617.

Harper J.T., Bradford J.H., 2003. *Snow stratigraphy over a uniform depositional surface: spatial variability and measurement tools*. Cold Reg. Sci. Technol. 37, pp. 289– 298.

Sand K, Bruland O., 1998. *Application of georadar for snow cover surveying*. Nordic Hydrology 29, pp. 361–370.