Assessing weak layer failure and changes in snowpack properties due to avalanche control by explosives

Stephan Simioni* and Jürg Schweizer
WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

ABSTRACT: Avalanche control by explosives is among the key temporary preventive measures and today fixed avalanche control installations are widely used. Hitherto, little is known about the effect of a blast onto the snow cover. In order to optimize charge location and type it is important to know what the processes caused by an applied load from an air blast wave onto the snow cover are and whether a weak layer is likely to fracture. In the winter 2012-2013 we performed first field experiments on a flat site with a rather uniform snow cover. Cameras located in snow pits capturing the pit wall allowed for recording the blast wave and detecting possible weak layer failure. Accelerometers were used to record the waves penetrating and propagating through the snowpack. Accelerations were strongly attenuated with depth within short distances in the wet snow cover. Consecutive tests did not influence acceleration amplitudes. The video images suggest that the crack initiated near the detonation point and propagated from there to the location of observation (snow pit). The weak layer did not appear to fracture due to the direct impact of the air pressure wave penetrating the snowpack at the snow pit location.

KEYWORDS: snow properties, avalanche control, explosives, weak layer failure

1 INTRODUCTION

Avalanche control by explosives is among the key temporary preventive measures. An explosion may trigger an avalanche due to the air pressure wave penetrating the snowpack or by ground motion. A weak layer can fail due to one of these mechanisms. Past experiments show that blasts above the snow surface are most effective in triggering avalanches (Gubler, 1977). With a charge position above the snow cover, accelerations within the snowpack increase significantly with increasing height of the detonation point as reported by Bones et al. (2012) for short distances from the blast. An air pressure wave reaching the snow surface is partly transferred into the snowpack. Biot's theory indicates that there exist different types of waves within the snow cover and that impedance of a snow cover and the adjacent atmosphere have similar values for low density snow (Johnson, 1982). Air pressure waves penetrate a dry snow cover almost unchanged whereas amplitudes are strongly attenuated under wet snow conditions (Gubler, 1977). Recent numerical modelling confirms past experimental findings such as blast height influence and provide insight into probable snowpack response and failure mechanism (Miller et al., 2011).

*Corresponding author address:
Stephan Simioni
WSL Institute for Snow and Avalanche Research SLF, Flüelastrasse 11,
CH-7260 Davos Dorf, Switzerland;
tel: +41 81 4170354; fax: +41 81 4170110;
email: simioni@slf.ch

The effectiveness of avalanche control depends on the stresses and strain rates caused by the penetrating waves and on snow stability, i.e. the slab and weak layer properties at the time of applying the control method.

van Herwijnen et al. (2008) showed that particle tracking velocimetry allows to record and characterise fracture behaviour of a weak layer.

The aim of this study was to characterise weak layer failure and wave propagation within the snowpack caused by detonation of an explosive charge and to improve our understanding of the processes that cause fracture. We installed video cameras, if available with high speed recording, within snow pits at different distances from an explosion in a plane in order to record possible weak layer failure by avalanche control during two test days in February and April with dry and wet snow conditions, respectively. In addition, we used accelerometers to characterise the waves penetrating the snowpack.

2 METHODS

2.1 Study site

The avalanche control experiments were performed at the military firing range in Hinterrhein (Switzerland) at an elevation of 1680 m a.s.l. (Fig. 1). The plane, level field was chosen to allow repeated measurements under similar snow conditions. The study site is suitable for performing experiments with different avalanche control methods in parallel with short time delay.

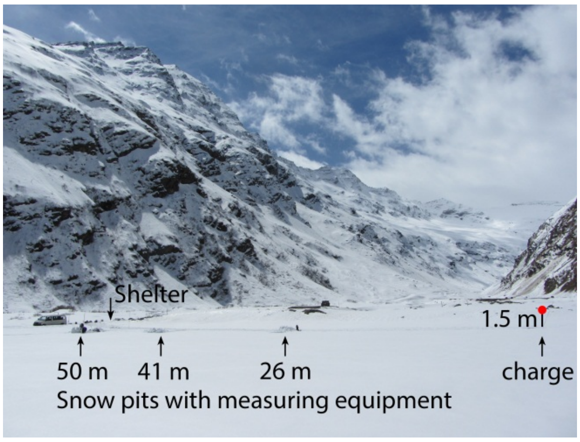

Figure 1: Overview of the study site at Hinterrhein showing distances of the snow pits from the detonation point and height of the charge above snow surface. The snow pit at 15 m is not shown since it was dug after the first experiment.

Inclined slopes would not allow for such tests because of the avalanche danger when entering the site to install measuring equipment and because of the potential loss of measuring equipment in the case of triggering an avalanche.

During winter 2012-2013, snow depth at the nearby observation station Splügen usually was below average and reached 70 cm on the test days at the firing range. Manual profiles including density measurements were taken on the days of the experiments, as well as SMP profiles.

2.2 Explosive charges, detonator and triggering

A widely employed explosive in avalanche control in Switzerland and in particular in fixed avalanche control installations was used for this tests (Tab. 1).

Table 1: Explosive characteristics

Explosive name	Alpinit
Explosive type	Slurry
Explosive mass (kg)	4.25
Explosion heat (kJ/kg)	5610
Detonation velocity (m/s)	4900

Electric detonators were used for these experiments for safety reasons instead of pyrotechnic detonators that are otherwise commonly used.

Charges were mounted on a pole approximately 1.5 m above the snow surface which is below the height of best effectiveness for explosions above the snow surface (Gubler, 1977; Johnson et al., 1994).

2.3 Measuring equipment

Snow pits were dug at different distances from the detonation point, slightly offset in order to not disturb wave propagation caused by the preceding snow pit.

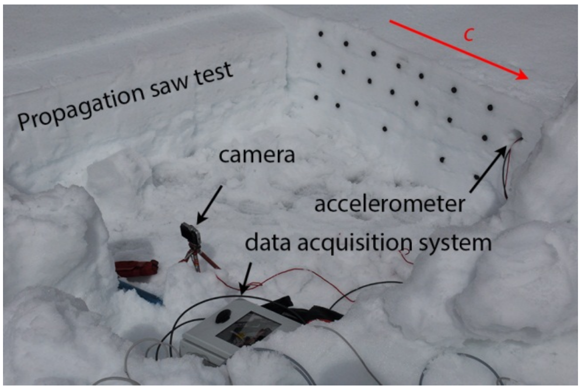

Figure 2: Snow pit showing measuring equipment, direction of air pressure wave with velocity *c* and a stability test to assess crack propagation propensity.

Commercially available SLR and compact cameras with acquisition rates between 24 and 250 frames per second were installed in snow pits aiming at the pit wall parallel to the direction of the propagating pressure wave (Fig. 2). The cameras were triggered manually.

Acceleration sensors or geophones were buried at different distances from the detonation point at different depths within the snow cover to measure snow accelerations or snow displacement velocities, respectively. A microphone was used for one series of experiments to measure air pressure at the snow surface. Data acquisition was performed with National Instruments cDAQ systems (Fig. 2).

Snow micro-penetrometer (SMP) measure-ments (Schneebeli and Johnson, 1998) were performed before and after the experiments along a line starting from the detonation point in a certain interval. However, due to mal-functioning of the instrument and possibly effects of small scale spatial variability, no results can be reported here.

2.4 Processing of the data

The movies allowed to qualitatively assess weak layer fracture and its cause.

Displacements, displacement velocities, accelerations and frequency contents were determined from the accelerometer and geophone data.

3 RESULTS AND DISCUSSION

During winter 2012-2013, a total of six tests were performed, mainly to evaluate the measuring layout and equipment.

Three tests were performed under dry snow conditions using geophones for all tests and video acquisition with one camera for one test. Geophones were placed at 50 m and a camera at 25 m from the explosion for one test.

Three tests on one day were performed under wet snow conditions using accelerometers, a microphone and three cameras placed in snow pits at distances ranging from 26 to 50 m from the blast. These tests were performed consecutively at the same position.

3.1 Snow accelerations

Accelerations from the tests under wet snow conditions showed decay of the amplitude with depth within the snow cover following a power law and were strongly attenuated which is in agreement with results reported by Gubler (1977). Amplitudes were attenuated by as much as 88% within a distance of 0.3 m (Fig. 3).

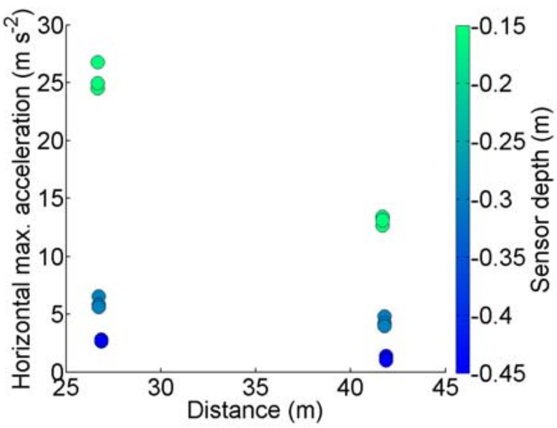

Figure 3: Maximum horizontal accelerations at different distances and depths for the experiments under wet snow conditions. The strong attenuation with depth within the snow cover is clearly visible.

Consecutive testing at the same detonation point did not have a significant influence on the measured accelerations within the snow cover at distances between 26 and 50 m in agreement with Gubler (personal communication). A blast 1.5 m above the snow surface only produced a small crater of a few centimetres in depth close to the detonation point. There was no visible plastic deformation at the distances of the snow pits and accelerometers. The snowpack at these distances did not experience plastic deformation that could influence the signal of consecutive blasts. There was large plastic deformation in case of a weak layer fracture, but this could not be seen in the signal.

3.2 Weak layer failure

The acquired video for dry snow conditions at a distance of 26 m from the blast revealed that the weak layer did not fracture due to the direct impact of the air pressure wave on the snow surface which caused the loose snow on the surface to be blown away. The weak layer fractured with a time delay after the arrival of this wave. We assume that the stress wave penetrating the snowpack near the detonation point caused the fracture of the weak layer which then propagated along the weak layer. In other words, we assume that the fracture observed in the snow pit was not caused by direct impact of the stress wave penetrating the snowpack at the location of the snow pit but by crack propagation through the weak layer. Typical crack propagation velocities in snow are 20 to 40 m/s (Birkeland and van Herwijnen, 2012) whereas the air pressure wave travels at supersonic speed close to the detonation point and as an elastic wave at sonic speed at distances at which our measuring equipment was installed.

For the tests under wet snow conditions three cameras were installed at distances ranging from 15 to 50 m from the detonation point (Fig. 1). The effect of fracture time delay after the arrival of the air pressure wave could not be shown for these experiments since the arrival of the air pressure wave did not cause any visible snow transport (due to the wet snow conditions) and the microphone that was installed in one of the snow pits was not synchronised in time with the camera. The videos only allow for a qualitative interpretation whether the weak layer had fractured at this distance or not.

The first explosion caused a slab fracture at 25 m and no fracture at further distances. The second explosion caused a fracture (resulting in the collapse of the weak layer) at 15 m and no fracture at larger distances. No camera was installed at 15 m for the first test. The weak layer did either not fracture during the first test, the slab changed within the delay of one hour from first to second test due to wetting, the weak layer did not collapse totally during the first test or the missing support of the slab at the side of the snow pit for the second test had an influence on fracturing.

Particle tracking velocimetry could not be applied possibly due to movement of the camera and distortion of the picture, and due to snow particles blown into the visual field of the camera.

4 SUMMARY

We installed accelerometers, geophones and cameras within snow pits in order to characterise wave propagation and weak layer failure within the snow cover on a flat study plot.

Accelerations were strongly attenuated with depth within short distances in the wet snow cover. Consecutive tests did not influence acceleration amplitudes.

The video images suggest that the crack initiated near the detonation point and propagated from there to the location of observation (snow pit). The weak layer did not appear to fracture due to the direct impact of the air pressure wave penetrating the snowpack at the snow pit location.

In the future, we plan to monitor changes in snowpack properties, in particular in density and snow layer thickness before and after an explosion.

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