Proceedings, International Snow Science Workshop, Breckenridge, Colorado, 2016

# ARTIFICIAL AVALANCHE RELEASE: FLAT FIELD EXPERIMENTS USING A GAS EXPLODER

Stephan Simioni[1]*, Jürg Dual[2] and Jürg Schweizer[1]

[1] WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland
[2] Institute of Mechanical Systems, ETH Zürich, Switzerland

ABSTRACT: Fixed avalanche control installations are frequently used today due to their various advantages to artificially trigger avalanches. Gas mixtures or explosives are ignited to create the required overpressure on the snowpack which is then transferred to the snowpack and may cause weak layer failure. Hitherto, extensive research has been conducted on explosives. However, comprehensive gas exploder experiments have so far been lacking and the detailed effect of gas explosions on a snowpack is poorly known – although it is no question that gas exploders are successfully operated throughout the world. We performed experiments with a mobile prototype gas exploder on a flat level study site. In total, 35 experiments with different gas quantities consisting of propane and oxygen were conducted. Similar to previous experiments, we measured surface air pressure with microphones at different distances from the point of explosion and snowpack accelerations at different depths within the snowpack and different distances from the explosion. Measurements were performed along two different axes to consider the effect of a directed explosion. As it is the case with explosives, air pressure and accelerations within the snowpack decay strongly with distance from the point of explosion and depth within the snowpack. The test procedure is well suited as a standard procedure to compare different avalanche release methods. Our findings will help to better understand the effect of different fixed avalanche control installations.

KEYWORDS: avalanche control, gas exploder, avalanche formation, experiments

## 1. INTRODUCTION

The artificial release of avalanches is a key active control measure in avalanche mitigation. Hundreds of fixed avalanche control installations have been installed during the last decade – and are successfully operated. Still, a number of questions on the effectiveness remain unanswered.

To release avalanches artificially, an explosion is either caused by explosives or a gas mixture. In the snowpack, the explosion leads to peak stress and strain within a fraction of a second and might cause the failure of a weak layer. A subsequent avalanche release is probable if the snowpack is prone to crack propagation. Within the scope of this research, we focus on gas explosions.

Different studies were performed on the effect of explosions on snowpacks, many of them investigated the effect close to the point of explosion, i.e. within the shock region, and showed the strong attenuation of waves within a snowpack (e.g., Frigo et al., 2012; Johnson et al., 1993). Tichota et al. (2010) and Binger and Miller (2016) developed a measurement setup to record air overpressures above and accelerations within the snowpack at short distances from the explosion and showed a strong decrease of the measured parameters with distance from the point of explosion and depth within the snowpack.

At larger distances, more relevant for the effectiveness of artificial release, Gubler (1977) performed an extensive study with explosives used for artificial avalanche release. He showed, among other findings, the influence of charge placement and the increased effect of a charge elevated above the snowpack. Other studies observed the effect of a snowpack on the propagation of acoustic wave above the snow surface (e.g., Albert and Hole, 2001). Simioni et al. (2014) recorded a weak layer failure caused by an explosion. Also using explosives, Simioni et al. (2015) performed extensive field studies to study the impact on a snowpack and reported that air pressures decayed strongly, proportional to $x^{-1.6}$, where $x$ is the distance from the explosion. Snowpack accelerations decreased significantly with depth within the snowpack and distance from the explosion.

Liebermann et al. (2002) described the principle of a fixed avalanche control system working with gas. Berthet-Rambaud (2009) performed first investigations on this kind of release systems. The effect of ground motion induced by a gas exploder at far distances was investigated by Suriñach et al.

---

* *Corresponding author address:*
Stephan Simioni, WSL Institute for Snow and Avalanche Research SLF, Flüelastrasse 11, CH-7260 Davos Dorf, Switzerland;
tel: +41 81 417 03 54; fax: +41 81 417 01 10;
email: simioni@slf.ch

(2011). They concluded that ground motion caused by a gas exploder was not sufficient to trigger avalanches at distances greater than 120 m.

Many of the studies on the impact of explosions were performed at short ranges and with explosives only. Only one study was particularly dedicated to gas exploders, however at large distances (>120 m) (Suriñach et al., 2011). We are not aware of any published studies investigating the effect of gas explosions on a snowpack.

The aim of this work was to assess the impact of a directed gas explosion on the snowpack. We used a mobile prototype gas exploder and measured air pressures above and accelerations within the snowpack.

## 2. METHODS

### 2.1 Study site

We performed the experiments at the military firing range in Hinterrhein (Switzerland) (Simioni et al., 2015). Snow depth at the level study site was between 70 and 80 cm; the snowpack was predominately dry and spatially rather uniform.

### 2.2 Measuring equipment

The measurement setup was similar to the one used by Binger and Miller (2016). Microphones were installed above the snow surface to measure the air pressure and accelerometers within the snowpack to measure snowpack accelerations (Simioni et al., 2015). The instruments were installed at different distances ranging from 11.6 to 49.2 m from the point of explosion. Measurements were performed along different axes from the point of explosion to account for the fact that the effect of the directed gas explosion is not radially symmetric.

### 2.3 Mobile gas exploder

A mobile prototype gas exploder, provided by TAS, the manufacturer of the Gazex® system, was used to perform the experiments. The gas exploder consists of a steel tube open on one side (length: 2.5 m, inner diameter: 80 cm); it is suspended from a crane and anchored to the ground with steel wires to absorb the recoil. The two gases (oxygen and propane) are stored in tanks at a pressure of 6.5 and 1.4 bar, respectively). The gas then flows for a certain period of time from the tanks into the gas exploder where it is mixed. A plastic lid prevents the gas from flowing out of the tube before the explosion. This is required since the oxygen-propane mixture is heavier than the ambient air. The gas mixture is ignited using spark plugs.

Fig. 1: Gas exploder during explosion.

The gas exploder was installed at different elevations from the snow surface and angles between the snow surface and the exploder.

### 2.4 Gas quantities and scaling

The released gas quantity $m_G$ (in kg) is calculated using the ideal gas law:

$$m_\mathrm{G} = \frac{\Delta p_G \, V_\mathrm{tank}}{R_s \, T}$$

where $\Delta p_G$ is the pressure difference between before and after releasing the gas from the tank (Pa), $V_\mathrm{tank}$ is the volume of the pressure reduction tank ($m^3$), $R_s$ is the specific gas constant of the respective gas (J $kg^{-1}$ $K^{-1}$) and $T$ is the gas temperature (K).

The gas volume is calculated from the gas mass using air temperature and the ambient air pressure.

For explosives, the influence of the charge mass is usually considered by scaling the distances from the point of explosion with the cube root of the charge size (Cooper, 1996). For a directed gas explosion, this relation might not hold true. Therefore, the scaling factor was determined from the air pressure results. The scaling factor was varied within a certain range and the best fit of the air pressure vs. the scaled distance was chosen.

$$x' = x \, m_\mathrm{G}{}^{-c_\mathrm{G}} \quad (\mathrm{m\ kg}^{-c_\mathrm{G}})$$

where $c$ is the scaling factor and the subscript $\mathrm{G}$ stands for gas.

The acceleration data were integrated with time to obtain displacement velocities and displacements. In addition, an energy equivalent was calculated by integrating the square of the displacement velocities with time, similar to the air pressure energy equivalent.

Air pressure data were fitted against scaled distance with a power law relation, e.g.:

$$p_{\max} = 10^{\mathrm{a}}\, x'^{-\mathrm{b}}$$

where $\mathrm{a}$ and $\mathrm{b}$ are the coefficients of the power law. The coefficient $\mathrm{b}$ describes the magnitude of the decay of a certain parameter with distance or depth.

Accelerations and derived parameters were first fitted with depth within the snowpack. This fit was used to calculate the decay with distance at a certain depth within the snowpack – again with a power law.

## 3. RESULTS AND DISCUSSION

We performed 35 gas exploder experiments above dry and partly moist snowpacks during the winters 2014-2015 and 2015-2016.

The angles between the axis of the gas exploder tube and the second measuring axis ranged between 23 and 37° above snow and 89° above bare ground. The elevation of the tube bottom edge and the snow/ground surface was between 1.4 and 1.8 m.

The quantities of the gas mixture were between 0.4 and 1.45 kg. Exact gas quantity measurements were only performed during the winter 2015-2016. The quantities of the first season were determined using the air pressure measurements and the scaling factor from the second season.

### 3.1 *Scaling factor*

The best scaling factor $c_{\mathrm{G}}$ was 0.65 for experiments above snow and 0.4 for experiments above bare ground. This shows the influence of two different surfaces on air pressure propagation.

### 3.2 *Air pressure*

The maximum air pressure decayed on average with $x'^{-1.67}$. This is in good agreement with or slightly higher than reported by earlier studies that, however, all used explosives (Albert and Hole, 2001; Gubler, 1977; Ingram, 1962; Mellor, 1973). Up to the maximum angle of 37° from the exploder axis, no lateral decrease was observed. The maximum derivative of the air pressure decreased similarly as the maximum air pressure. The energy equivalent decreased stronger than the air pressure with distance. This is plausible, since the energy of a wave decays following the square of the amplitude decay.

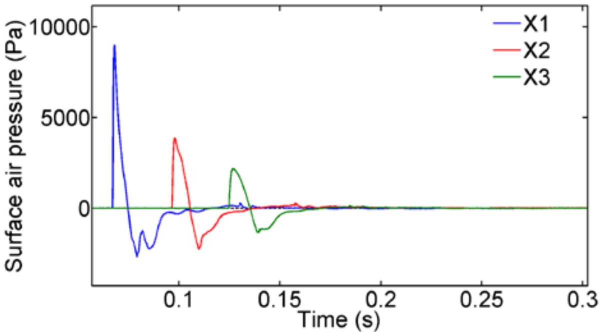

Fig. 2: Example of the air pressure signal at the three measuring locations on the x-axis, data from 18 Feb 2016, experiment 5. Distances for X1, X2 and X3 are 16.0, 25.6 and 34.9 m, respectively.

### 3.3 *Acceleration, displacement velocity and displacement*

The accelerations decreased strongly with depth proportional to $z^{-0.9}$ to $z^{-1.4}$. This is in the same range as observed in other studies using explosives (Binger et al., 2006). Displacements were small ranging from $10^{-3}$ m to $10^{-6}$ m and were in good agreement with previous results by, e.g., Gubler (1977).

The incline and the elevation of the gas exploder did not have a significant effect on the measured quantities. Compared to the distances at which we measured, the slight change of elevation and the change of incline within a range of only 10° are expected to have a minor influence. The incline was not changed to more extreme values as the tested inclines were similar to those for operational gas exploders.

The strength of the air pressure decay was similar to the decay of the maximum vertical accelerations. This finding means, that the behavior of the air pressure can be used as an approximation for the behavior within the snowpack. The propagation speed of the air pressure wave never exceeded the speed of sound in air for locations larger than approx. 11 m. At shorter distances, no measurement was possible to prove the existence of a shock wave with higher speeds.

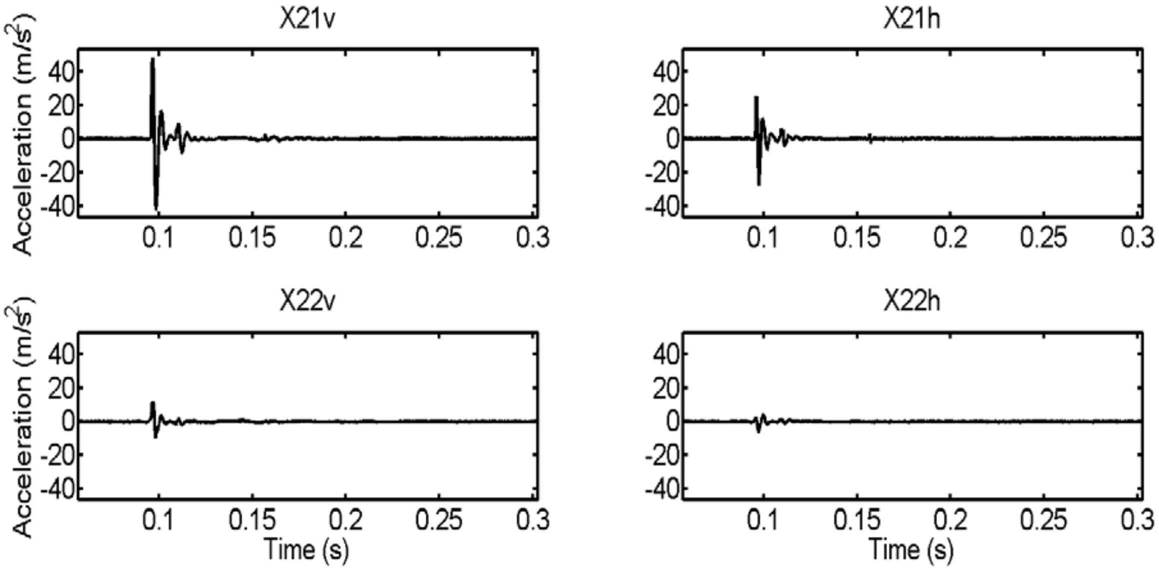

Fig. 2: Example of the vertical (left) and horizontal (right) accelerations at two depths (top: 14 cm, bottom 38 cm) within the snowpack at 25.6 m from the gas exploder. Data from 18 Feb 2016, experiment #5.

## 4. SUMMARY AND OUTLOOK

We performed the first extensive measuring campaign with a mobile gas exploder to investigate the effect of gas explosions on a snowpack.

We observed an air pressure of 1 kPa at approx. 57 m with 1.8 kg of gas which is similar to what we observed with a 4.5 kg explosive charge. This shows that the impact of a gas exploder is cle-comparable to the impact obtained with solid explosives.

Within an opening angle of approx. 70° no lateral decay of the impact was observed. However, it is expected that the decay will be different at larger angles due to character of the directed explosion. Slight changes of incline and elevation of the gas exploder had no influence on air pressures above and accelerations within a snowpack. The snowpack accelerations decreased similarly as the maximum air pressure or the air pressure derivative with distance from the point of explosion. The decay of the latter parameters might therefore be useful as approximations to assess the behaviour within the snowpack.

All the relevant quantities are clearly sufficient to trigger an avalanche – as far as our understanding goes. In particular at close distances the impact is extremely high. The size of the resulting avalanche might rather be related to crack propagation propensity than a high impact at large distances.

These results help to understand the effect of a directed gas explosion on snowpacks. The findings might be used to assess differences in the effect of different explosions.

## 5. LIMITATIONS

Our results obtained with a prototype gas exploder cannot directly be compared to an operational Gazex®. The gas masses and volumes measured during the experiments do not correspond to the size of an operational gas exploder given in m$^3$.

## CONFLICT OF INTEREST STATEMENT

None of the authors has any affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

## ACKNOWLEDGEMENTS

The study was partly funded by the Swiss Federal Office for the Environment (FOEN). We thank the Swiss Armed Forces for logistical support. Our thanks go to TAS for providing the mobile gas exploder and operating supplies. We thank Lino Schmid, Matthias Heck, Achille Capelli, Bettina Richter and Alec van Herwijnen for help with the field work.

## REFERENCES

Albert, D.G. and Hole, L.R., 2001. Blast noise propagation above a snow cover. Journal of the Acoustical Society of America, 109(6): 2675-2681.

Albert, D.G. and Orcutt, J.A., 1990. Acoustic pulse propagation above grassland and snow: Comparison of theoretical and experimental waveforms. Journal of the Acoustical Society of America, 87(1): 93-100.

Berthet-Rambaud, P., 2009. Comparison of shock waves provoked by various artificial avalanche release techniques, and of their effects on the snowpack. In: J. Schweizer and A. van Herwijnen (Editors), Proceedings ISSW 2009. International Snow Science Workshop, Davos, Switzerland, 27 September - 2 October 2009. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, pp. 328-329.

Binger, C., Nelsen, J. and Olson, K.A., 2006. Explosive shock wave compression in snow: effects of explosive orientation and snowpack compression. In: J.A. Gleason (Editor), Proceedings ISSW 2006. International Snow Science Workshop, Telluride CO, U.S.A., 1-6 October 2006, pp. 592-597.

Binger, J.B. and Miller, D.A., 2016. Soft and hard slab snow dynamic response to explosives used in avalanche hazard mitigation. Journal of Cold Regions Engineering, 30(2): 04015003 (17 pp.).

Bones, J., Miller, D. and Savage, S., 2012. An experimental dynamic response study of hard slab seasonal snow to explosive control, Proceedings ISSW 2010. International Snow Science Workshop, Anchorage AK, U.S.A., 16-21 September 2012, pp. 142-148.

Cooper, P.W., 1996. Explosives engineering. Wiley-VCH, New York, 480 pp.

Frigo, B., Chiaia, B. and Cardu, M., 2012. Snowpack effects induced by blasts: experimental measurements vs theoretical formulas, Proceedings ISSW 2012. International Snow Science Workshop, Anchorage AK, U.S.A., 16-21 September 2012, pp. 943-947.

Gubler, H., 1977. Artificial release of avalanches by explosives. Journal of Glaciology, 19(81): 419-429.

Ingram, L.F., 1962. Air blast in an arctic environment. Technical Report no. 2-597, US Army Waterways Experiment Station, Vicksburg, MS, U.S.A.

Johnson, J.B., Solie, D.J., Brown, J.A. and Gaffney, E.S., 1993. Shock response of snow. Journal of Applied Physics, 73(10): 4852-4861.

Liebermann, E., Schippers, J. and Liebermann, S.C., 2002. The "Gazex" avalanche release system. In: J.R. Stevens (Editor), Proceedings ISSW 2002. International Snow Science Workshop, Penticton BC, Canada, 29 September-4 October 2002, pp. 46-48.

Mellor, M., 1973. Controlled release of avalanches by explosives. In: R. Perla (Editor), Advances in North American avalanche technology: 1972 Symposium. USDA Forest Service, General Technical Report RM-3, pp. 37-49.

Simioni, S., Schweizer, J. and Dual, J., 2014. Field experiments on weak layer failure and crack propagation due to explosions. In: P. Haegeli (Editor), Proceedings ISSW 2014. International Snow Science Workshop, Banff, Alberta, Canada, 29 September - 3 October 2014, pp. 185-188.

Simioni, S., Sidler, R., Dual, J. and Schweizer, J., 2015. Field measurements of snowpack response to explosive loading. Cold Regions Science and Technology, 120: 179-190.

Suriñach, E., Vilajosana, I., Kleemayer, K. and Rammer, L., 2011. Study of the wavefield generated by a gas exploder used for artificial avalanche release. Cold Regions Science and Technology, 66(1): 17-29.

Tichota, R.G., Miller, D.A., Larson, R. and Richmond, D., 2010. An experimental investigation of explosives and snowpack dynamic response, International Snow Science Workshop ISSW, Lake Tahoe CA, U.S.A., 17-22 October 2010, pp. 418.