Measuring acoustic emissions in an avalanche starting zone to monitor snow stability

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ABSTRACT: Evaluating snowpack stability still involves time-consuming and labour-intensive manual tests; in dangerous or remote areas performing such tests might not even be possible at all. In other natural, heterogeneous materials such as wood, limestone, or ice, monitoring the acoustic signals emitted by cracks forming and growing within the material has proven a valuable tool for failure prediction. In an exploratory field study we tested the acoustic emission method for monitoring snow stability and possibly predicting avalanche release. We performed several preparatory laboratory studies in order to evaluate the optimal sensor frequencies and coupling of the sensors to the snow. The resonant (30 kHz) sensors, which were coupled to thin aluminium plates with silicone and protected by a plastic housing, were placed in a potential avalanche slope close to a weak interface (old snow - storm snow) within the snow cover. We then measured acoustic emissions and seismic signals and compared those to the slope stability which was assessed by the success of avalanche control by explosives. Preliminary results are shown and discussed with respect to their practical relevance for avalanche prediction.

KEYWORDS: snow avalanche, avalanche release, snow stability evaluation, acoustic emission, precursor

1 INTRODUCTION

A prerequisite for dry-snow slab avalanche release is a weak snow layer (such as buried surface hoar, faceted or depth hoar crystals) beneath an amply cohesive slab. A macroscopic crack in the weak layer (size 10 cm or more) might propagate across and up and down slope ('crack propagation') thus leading to the release of an avalanche. The formation of such a macroscopic ('initial') crack is due to the accumulation of damage processes (microscopic cracks) within the weak layer (Schweizer et al., 2003). Cracking on a microscopic scale is always happening within snow but not always does this lead to a macroscopic instability where larger cracks form.

According to the theory of critical phenomena (Johansen and Sornette, 2000) there exists an analogy between the failure of inhomogeneous materials (such as snow) and a phase transition. The material can be considered in a stable state (microscopic cracks form but do not coalesce to form a macroscopic crack that will propagate) and an unstable state (catastrophic failure highly possible). Since cracking within a material is accompanied by the release of elastic energy generating elastic waves (acoustic signals), recording acoustic emissions (AE) can be used for detecting cracks and crack growth (e.g. Lockner, 1993). For other materials AE is a very common method to test stability and imminent failure (Grosse and Ohtsu, 2008). Within natural hazards AE has been used to investigate and predict a glacier break-off (Faillettaz et al., 2011), cliff collapse (Amitrano et al., 2005; Got et al., 2010), or earthquake occurrence (Niccolini et al., 2011). Girard et al. (2012) set up an acoustic sensor network in order to predict rupture within rocks and permafrost.

Our aim is to test whether acoustic signals can indicate instability of a snow slope.

2 METHODS

2.1 Laboratory experiments

In a set of laboratory experiments we evaluated optimal sensor coupling to the snow and a suitable sensor frequency in view of field use. The central measurement element was a six

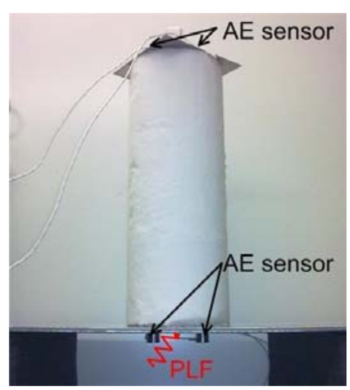

Figure 1. Snow column for measuring frequency response of snow and evaluating the best sensor coupling.

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channel acoustic measurement system manufactured by Physical Acoustics Corporation. The system consisted of wide band piezoelectric AE transducers (20 kHz - 1 MHz, ultrasonic region), preamplifiers (with maximally 60 dB gain), band pass filters, digitizers, a personal computer, and the recording and analysis software AEwin. For the experiments we sent an acoustic reference signal (pencil lead fracture, PLF) through a 45-cm high snow column (Fig. 1). The PLF signal has a flat frequency distribution (measured by the AE sensors at the bottom of the snow column). Evaluation of the signal after having traveled through the snow column (sensors at the top) shows which frequency is transmitted best. The energy of the incoming signal for different sensor couplings (we used Plexiglas, aluminum, and foam plates) shows which sensor coupling works best.

2.2 Field experiment

In order to assess snowpack stability and detect precursors to avalanche release by measuring acoustic emissions we had two acoustic sensors installed in a potentially unstable slope (often cross-loaded by wind, north-eastern aspect, about 35° steep) throughout the winter season 2012-2013. For analysis we used the acoustic activity measured during the night (no skiers, ski lifts, hardly any snow cats). The slope was regularly tested with explosives, and the success of blasting provided a measure of slope stability. Within our reference slope and also the slopes next to it, avalanches often release at the interface between wind-blown snow and old snow.

The sensors were placed in protective plastic housing and attached to thin aluminum plates with silicone. The acoustic measurement system was a portable version of our laboratory system, using AE nodes (from MISTRAS) and a laptop with the software AE in for data acquisition. The laptop and the USB AE nodes were placed in the station of the ski lift. A similar system was used by Girard et al. (2012) for monitoring the stability of frozen rock-walls.

For data evaluation we computed the exponent β of the complementary cumulative event energy distribution

$$p(> E) \sim E^{-\beta}\,, \qquad (1)$$

a detailed description of the procedure can be found in Faillettaz et al. (2011).

3 RESULTS AND DISCUSSION

The laboratory measurements with the snow column revealed the best coupling of the AE sensors to the snow column could be obtained by attaching the sensors with silicon to a 1 mm thin aluminum plate which was frozen onto the snow. Within the frequency range studied we found the least attenuation at 30 kHz, suggesting this a suitable frequency for recording AE within snow.

Analysis of the acoustic data revealed mostly good data quality and also the conditions for a true power law distribution (Clauset et al., 2009) were mostly fulfilled. The values of the exponent β were surprisingly constant with a value of approximately 3.5 for nights with stable snow conditions but also for nights when avalanche triggering by explosives was successful the following morning. In the night of 11-12 December 2012, a spontaneous avalanche released on the slope next to our sensors (Fig. 2), meaning that the slope was truly in an unstable (critical) state. In this night we measured acoustic data of high quality and computation yielded an exponent β of 2.5.

Figure 2. Spontaneous avalanche (right) and artificially released avalanche (left). The cross marks our sensor positions.

4 CONCLUSIONS

We calculated the exponent β of the complementary cumulative event energy distribution (Faillettaz et al., 2011) of acoustic events within the snowpack and compared them to slope stability.

We found a significant change in exponent β for the night when a spontaneous avalanche released. So far we only had one spontaneous avalanche on our test slope, and therefore cannot verify this finding.

It seems apparent, though, that for estimating avalanche danger with respect to artificially triggered avalanches, calculation of β alone will not yield useful information.

Concerning spontaneous avalanches – at least according to our initial results from the first winter of data – the exponent β seems to be a suitable indicator for predicting slope instability. This is consistent with the theory of critical phenomena, where a critical state (which is characterized by a change in exponents) is defined as a state when the system reaches an unstable state by itself (Johansen and Sornette, 2000).

We will continue with our field measurements in the coming winter season and hope for more spontaneous avalanches to verify the theory that a change of exponent β hints towards an increased probability of spontaneous avalanche release in a given slope.

ACKNOWLEDGEMENTS

Special thanks go to the Parsenn ski area for logistical support, in particular to Romano Pajarola, Andrea Studer, and René Frey. We thank Christian Simeon, Lino Schmid, and Christoh Mitterer for help with the field work.

REFERENCES

Amitrano, D., Grasso, J.R. and Senfaute, G., 2005. Seismic precursory patterns before a cliff collapse and critical point phenomena. Geophys. Res. Lett., 32(8): L08314.

.Clauset, A., Shalizi, C.R. and Newman, M.E.J., 2009. Power-law distributions in empirical data. SIAM Rev., 51(4): 661-703.

Faillettaz, J., Funk, M. and Sornette, D., 2011. Icequakes coupled with surface displacements for predicting glacier break-off. J. Glaciol., 57(203): 453-460.

Girard, L., Beutel, J., Gruber, S., Hunziker, J., Lim, R. and Weber, S., 2012. A custom acoustic emission monitoring system for harsh environments: application to freezing-induced damage in alpine rock walls. Geosci. Instrum. Method. Data Syst., 1(2): 155-167.

Got, J.L., Mourot, P. and Grangeon, J., 2010. Pre-failure behaviour of an unstable limestone cliff from displacement and seismic data. Nat. Hazards Earth Syst. Sci., 10(4): 819-829.

Grosse, C.U. and Ohtsu, M., 2006. Acoustic Emission Testing. Springer, Berlin, Germany, 400 pp.

Johansen, A. and Sornette, D., 2000. Critical ruptures. Eur. Phys. J. B, 18(1): 163-181.

Lockner, D., 1993. The role of acoustic-emission in the study of rock fracture. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 30(7): 883-899.

Niccolini, G., Carpinteri, A., Lacidogna, G. and Manuello, A., 2011. Acoustic emission monitoring of the Syracuse Athena temple: Scale invariance in the timing of ruptures. Phys. Rev. Lett., 106(10): 108503.

Schweizer, J., Jamieson, J.B. and Schneebeli, M., 2003. Snow avalanche formation. Rev. Geophys., 41(4): 1016.