Artificial avalanche release and the probability of triggering secondary avalanches

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ABSTRACT: Today, avalanches are often artificially triggered to protect ski areas and to some extent, transportation routes and residential areas. During avalanche control, unwanted secondary avalanches may also be triggered in adjacent avalanche paths. Damage potential and secondary avalanches are two important factors to consider when evaluating the practicality of artificial release in an avalanche path or elaborating a safety concept. A too high risk of secondary avalanches can be a no-go criterion for the application of artificial release in a specific area. In 2012 we elaborated a guideline with evaluation criteria how to estimate the likelihood of triggering a secondary avalanche. The probability of triggering secondary avalanches can be classified in three classes which are mainly based on topographical features, snow distribution and climatic conditions (main wind direction). Secondary avalanches are most often triggered as a result of crack propagation in the snowpack. Other trigger possibilities are the effect of the air blast wave and of ground vibrations.

KEYWORDS: artificial release of avalanches, secondary avalanches, application of artificial avalanche release, safety concept.

1 INTRODUCTION

Today, avalanches are often artificially triggered to protect ski areas and to some extent, transportation routes and residential areas. Applying avalanche control by explosives requires rigorous safety measures such as closing the exposed area (Stoffel and Schweizer, 2008). McClung and Schaerer (2006, p. 283), for example, pointed out that in deciding the size of the area to be closed, one should consider that explosives may trigger avalanches on adjacent slopes.

Recently, Stoffel and Margreth (2009) developed a guideline that helps to evaluate whether avalanche control can be applied in starting zones above settlements. They suggested that the three most important factors to be considered when evaluating the applicability of artificial release are terrain conditions, damage potential and secondary release of avalanches. However, so far no rules exist how the probability of releasing secondary avalanches during a control operation can be assessed.

Our aim is therefore to provide guidance on how the probability of secondary avalanches can be assessed. The guideline should be particularly useful for avalanche consultants who elaborate safety concepts for avalanche control operations. In the following, we summarize the principal findings; for details the reader is referred to Stoffel and Margreth (2012).

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2 RELEASE OF SECONDARY AVALANCHES

2.1 Overview

As a result of blasting, avalanches can be triggered remotely in secondary starting zones far away from the original detonation point by crack propagation in the snowpack, the effect of the air blast wave and ground vibrations.

2.2 Secondary avalanches due to crack propagation in the snowpack

For crack propagation during new snow conditions a continuous snow cover, a weak layer in the snowpack, continuously existing throughout the area, and a cohesive slab (of new snow) are necessary. We distinguish the following three terrain situations for the release of secondary avalanches: release in adjacent starting zones of similar aspects (separated by minor terrain features), release around broad ridges to starting zones with different aspects and release over a ridge to a starting zone on the opposite side of the ridge.

In the first case, avalanches up to 1 km wide triggered by a single detonation have been observed. Releases around broad ridges can occur due to crack propagation in the snowpack, provided the snowpack is continuous, or due to ground vibrations caused by the detonation itself or by the primary released avalanche. The release to a starting on the opposite side of a ridge is rare, as often the snowpack is not continuous, and is most probably due to ground vibrations.

2.3 Remote triggering by air blast wave

Cases have been reported where no (large) primary avalanche was triggered at the detonation point, but several hundred meters away an avalanche occurred, probably due to the air pressure wave. Such releases may only occur if no obstacles such as ridges lie in between the two starting zones and if the distance is clearly smaller than about 500 m. Air pressure waves can also be reflected from rock faces and then trigger a secondary avalanche.

2.4 Secondary avalanches due to ground vibrations

The ground vibrations in secondary starting zones depend on the type of ground (especially problematic is unfractured rock), the distance from the primary starting zone and the strength of the impact (charge size, size of primary avalanche). The recoil of Gazex tubes leads for example to ground vibrations. Whether a secondary triggering occurs strongly depends on the strength of the vibrations, the snowpack (stability, snow depth etc.) and the slope angle in the secondary starting zone.

3 GUIDELINE

We compiled 20 examples where secondary releases were observed and based on these observations we developed criteria to be considered when evaluating the probability of secondary releases (Table 1). Depending on the triggering scenario (crack propagation in the snowpack, air blast wave, or ground vibrations) criteria are defined (such as topography of starting zone and distance with direct view from detonation point) to assess the probability of a secondary release. Based on these criteria three classes (likely, medium likelihood and unlikely) are suggested.

In addition, a previous analysis showed that blasting rarely triggers large secondary avalanches (<1% to 10% off all positive blasts). The lower value is valid especially for areas with frequent triggering by explosives and the upper value for areas with only occasional avalanche control operations. Whether an avalanche is triggered in a secondary starting zone, strongly depends on snowpack properties (stability, snow depth etc.) and slope angle (more likely on slopes steeper than 35°).

We assume that secondary avalanches due to crack propagation in the snowpack are much more frequently compared to triggering by air blast or ground vibrations. However, the effect of ground vibrations caused by a detonation or a primary avalanche is difficult to quantify. Ground vibrations propagate in unfractured rock relatively well while they are strongly attenuated in loose soil within short distances. The effect of ground vibrations may be large if the distance to the secondary starting zone is small (< 50 m). In starting zones, ground vibrations due to an avalanche are typically small. They are some larger in the avalanche track (Vilajosana et al., 2007). A flowing avalanche can also trigger avalanches in starting zones beside the main avalanche track.

4 CASE STUDY

In the following example we assess whether secondary releases in the starting zones B to E induced by a fictional blasting at location X in the starting zone A are possible (Fig. 1). The prevailing wind direction is northwest. So, the release area A is usually situated in the lee of the ridge.

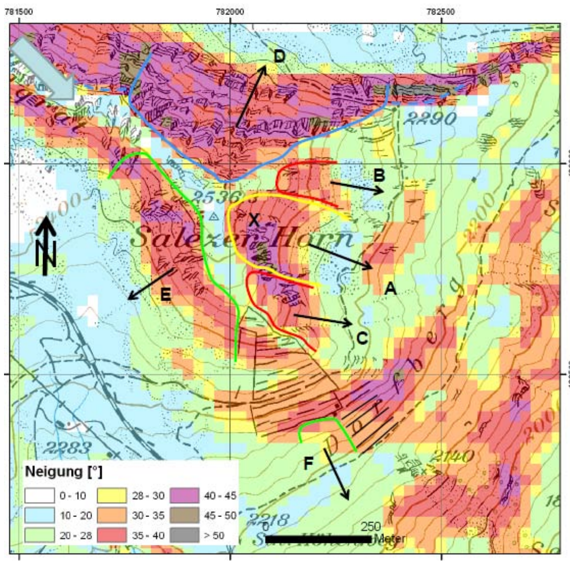

Figure 1. Slope angle map and avalanche path A with detonation point X. Grey arrow (top left) indicates mean wind direction. The likelihood of secondary avalanche releases in the starting zones B-F is evaluated (see text below).

Based on the guideline (Table 1), our assessment is summarized as follows:

- Secondary releases likely, marked with red lines: Release areas B and C have similar aspects and a continuous snowpack is expected. The distances to release area A are very short.
- Secondary releases with medium likelyhood, marked with blue lines: Towards area D a continuous snowpack seems to be possible (with WNW wind). However the area is divid-

ed from release zone A by a relatively broad ridge. There is no effect of the air blast in other areas than area A.

- Secondary releases unlikely, marked with green lines: Area E is separated from the primary area A by a 30-60 m wide wind exposed ridge. In addition, the part of area E towards the areas A and C is wind exposed too.

Table 1. Criteria for the assessment of secondary avalanche releases in adjacent avalanche paths by blasting (to be applied when establishing safety concepts for artificial release operations).

<table>
<tr><td></td><td colspan="3">Criteria</td></tr>
<tr><td rowspan="2">Probability of secondary release</td><td>Crack propagation in snowpack</td><td>Air blast wave</td><td>Ground vibrations due to detonation or primary avalanche</td></tr>
<tr><td>Assessment factors:
Topographical features and wind (exposure and direction)</td><td>Assessment factor:
Distance with direct view from detonation point or Gazex tube</td><td>Assessment factors:
Type of ground, distance to secondary area, strength of impact</td></tr>
<tr><td>Likely</td><td>- Directly adjoining area, similar aspect (in lee) and continuous snowpack.</td><td>- Distance from detonation point less than about 50-100 m, i.e. within about effective range of blasting.</td><td>- Exceptional situation, e.g. detonation point less than 20 m from snow covered ridge.</td></tr>
<tr><td>Medium likelihood</td><td>- Separation of the starting zones by (sloping) broad ridge in lee, especially if the broad ridge is approx. parallel to the main wind direction; continuous snowpack.</td><td rowspan="2">- With direct view secondary releases over distances from 100 m to 500 m from the detonation point cannot be excluded (in particular in the direction of an adverse slope), for large charges detonated above the snow surface.</td><td rowspan="2">- Rocky terrain (primary and secondary release area)

and

- small distance to the secondary starting zone: Probability for triggering increases for strong detonations (charges > 4 kg, Gazex) or large primary avalanches.</td></tr>
<tr><td>Unlikely</td><td>- Separation of starting zones by flat, wind exposed and approx. horizontal broad ridge (width larger than about 20-30 m).
- Very steep and rocky secondary starting zone behind wind exposed, horizontal ridge.
- Secondary starting zone at least partially wind exposed including the connection to the primary starting zone.
- Two adjacent starting zones with same aspect: Separation by pronounced, rocky, sloping ridge or broad wind-ward ridge or by pronounced terrain edge in luv.</td></tr>
<tr><td colspan="4">General remarks:
- With a very unstable snowpack and generally during avalanche danger level 5 large secondary releases can occur (during time periods with danger level 5 artificial triggering by explosives is often not recommended). For such situations, the guideline is not applicable.
- Slope angle steeper than 35° in large parts of the secondary starting zone means an increased probability of secondary releases.
- Situations with detonation points close to ridges must be assessed depending on the situation, independent from this guideline.
- For the evaluation of the wind influence also local wind directions have to be considered. Wind exposed terrain may hinder crack propagation in the snowpack.</td></tr>
</table>

5 CONCLUSIONS

Artificial avalanche release by explosives has become increasingly popular as mitigation measure. When evaluating whether artificial release can be recommended as a measure of risk reduction, assessing the probability of releasing secondary avalanches due to blasting is crucial but complex and involves uncertainties. We propose to mainly base the assessment on the following four evaluation criteria:

- crack propagation in the snowpack (terrain situation and wind direction)
- air blast wave (distance with direct view from detonation point)
- ground vibrations due to detonation or primary avalanche (type of ground, distance to secondary starting zone, strength of impact)
- slope angle of the secondary starting zone (more likely on slopes steeper than 35°).

Based on these criteria, secondary starting zones can be grouped into the three classes "release likely", „release with medium likelihood" and "release unlikely“.

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