CONTROLLED AVALANCHE RELEASE FOR PROTECTION OF TRAFFIC INFRASTRUCTURE: TOWARDS A NEW PERSPECTIVE

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ABSTRACT: Permanent measures, like supporting structures, dams and tunnels have been the classical technical measure for mitigation of avalanche danger in the last decades. Recently, for protection of traffic infrastructure, such as roads and railways, temporary measures, like remotely controlled avalanche release and detection systems have become increasingly important. This is due to two main reasons: i.) The technological developments of release systems improved significantly and lead to an increase in effectiveness and reliability, and ii.) For economic and ecological reasons. The latter one refers to the comparable small environmental impact of release systems in terms of foundation and visibility in comparison to permanent measures. Moreover, with the limited financial resources for avalanche mitigation, controlled release, presents an attractive alternative also from an economical point, as only a fraction of the money is needed. Experiences over the last 13 years in Austria and Switzerland showed, that controlled avalanche release can cause a risk reduction of up to 92% and closure times of traffic infrastructure could be reduced to a minimum during the release activities.

KEYWORDS: Avalanche Release, Road Protection, Avalanche Towers

1. INTRODUCTION

Over the last decade artificial avalanche release has experienced a tremendous popularity in alpine regions. Avalanche towers are nowadays used not only for ski resorts but also to protect traffic infrastructure and in some cases to protect endangered villages (Kogelnig et al. 2012). Switzerland has been among the first countries to use fixed installations for controlled avalanche release for road protections. In Austria the first pilot project was launched in 2011 and has proven its success, then others followed. Most of the major avalanche problems have been mitigated using permanent measures such as snow supporting structures, dams and tunnels. However, in recent years, the financial resources for avalanche control are limited and on the other hand traffic steadily increases. The political and economical pressure to keep the roads open is high and puts a lot of pressure on the local avalanche control team.

With this background artificial avalanche release, often in combination with detection systems can present an economical and ecological attractive alternative. In this paper two major avalanche projects from Switzerland (Gonda) and Austria (Ischgl) will be presented.

2. GONDA AVALANCHE

2.1 Introduction Gonda

The Gonda avalanche in Lavin was one of the last avalanches in Switzerland that on a long-term average endangered a main road every winter and buried it every 5th winter. Moreover the adjacent avalanche paths of Urezza and Punia to the west also endangered the RhB railway line in more rarely occurring situations (Fig. 1).

Due to the topographical features, the only realistic construtional solution to this danger would have been a road tunnel and lengthening the railway tunnel with a gallery. A preliminary project for eliminating this danger assumed costs of around 40 million CHF. Hence, the major project has not proceeded beyond the planning stage due to limited financial means and other building projects with higher priorities.

Up to and including the winter of 2000/01, safeguarding against avalanches was done using a 12 cm mortar. In the avalanche winter of 1999, the road that had been protected in this manner, was buried under the Gonda avalanche, which killed one person and injured three.

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In the case of the avalanche accident, a result of this was that even small quantities of new snow following the final firing were sufficient to set off a large avalanche with a break on the ridge of Piz Chapisun. Triggering from the helicopter was only permitted in isolated cases following the accident in the winter of 1999.

In 2001 a preliminary project was submitted for a fixed installation with three avalanche towers of type Wyssen in the main avalanche starting zone of the Gonda avalanche. Together with the Swiss Federal Institute for Snow and Avalanche Research (SLF), the construction and operation of the installation was evaluated as a scientific project over a period of three winters (2001-2004). The installation proved to be functional after a few defects had been rectified. In particular the explosive effect within the effective range of the avalanche tower was found to be very good.

The experience in the three test winters and also in the winter of 2005/06 showed that the residual risk, taken over the whole region, was still inadmissibly high. The large avalanche-starting zone of the Gonda avalanche was not sufficiently covered with three avalanche towers. Avalanches from the side regions that were not covered with the towers and are not accessible for the mortar, had twice come threateningly close to the road. For this reason it was intended to extend the number of avalanche towers so that the whole starting zone of the Gonda avalanche and the neighboring Urezza avalanches could be actuated with the towers. To evaluate economic sustainability of the investments and find the best solution a cost analysis study was conducted. The goal was to reduce the risk to an acceptable level and make the actions for artificial avalanche release safer and simpler.

2.2 Concepts for Solutions

The following chapter summarizes the concepts analysed; A detailed description can be found in Kindschi et al. (2008).

With the experiences made and the limited financial resources three extension options came into account. Basically it must be said that in all the options discussed, closing the transport systems at risk will remain one of the measures. However, the number of necessary days of closure per winter will vary according to the alternative.
In all three extension options an avalanche detection system was also demanded. The avalanche paths and the areas of deposition at higher elevations of all avalanches are not visible for topographical reasons, or when the visibility is poor, or at night. Therefore the success of artificial avalanche release often cannot be verified without a delay unless technical aids are employed. Since the certainty of success of an artificial triggering action is indispensable for assessing the residual risk, it is proposed to install a detection system.

Option Zero

The status of 2004 with closures, three avalanche towers and the 12 cm mortar is designated as the Zero alternative. However, this alternative was not considered as a long term option. The 12 cm mortar weapon system had been already fairly old and thus production and supply of spare parts was uncertain. In exceptional cases following extraordinary snowfall, the triggering in portions from the helicopter in consultation with the municipality of Lavin is possible. This option will also be kept opened in future as a complementary measure (e.g. failure of the other blasting methods, additional triggering of slopes without success).

Option 1

The first and minimum extension option was designated as a partial extension of the avalanche tower installation with three additional towers in the starting zone of the Gonda avalanche and keeping two mortar targets in the avalanche starting zone of the Urezza avalanches.

Option 2

The second extension option provides for the complete extension with five additional avalanche towers in both of the Gonda and Urezza avalanche paths. The mortar can then be dispensed with in future. This option is more durable due to the discontinuation of the mortar. Even though technical systems are also limited in their life time due to mechanical parts and the electronics, thanks to the modular construction, the continued existence of the system and above all the steel towers is very likely, even in case of further development or for a replacement of the blasting magazine.

Option 3

In the third extension option following the full extension of five additional avalanche towers installation, also a solution for the Val Punia avalanche was planned. Artificial avalanche release is not possible there, due to the danger of destroying protective forest underneath. Initial assessments of the starting zone allowed an estimate of the costs for the construction of avalanche fences on the basis of the gradient maps. Since the starting zone has an area of around 9 - 10 ha with an average slope of > 35°, at least 2,000 m of steel barrier must be anticipated. The necessary costs for this would have been at least CHF 4 million.

Fig. 2: Polarity profile of the utility analysis.
In order to find an objective basis to compare the different options an utility-value analysis was conducted. The utility-value analysis can be visualized with the aid of a polarity profile (Fig. 2) Here the assessment criteria are listed on the x-axis, and the grading scale on the y-axis, graded from unfavorable (low value for weighting*grade) to favorable (high value for weighting*grade). The polarity profile clearly shows that the alternatives with complete avalanche tower extension (Option 2 and 3) are better with respect to protective effect and durability, but if costs and feasibility are taken into account, Option 2 is the most favorable solution.

Further improvements to the Option Zero could not be justified on the grounds of cost-effectiveness alone, since this solution was already a huge improvement with regard to risk reduction and cost-effectiveness. Apart from the operative advantages already mentioned, it is particularly the aspect of the closure days and their contribution to the total costs, which speak for Option 2 (Table 1).

But even with the extension of the avalanche towers, it is clear that closures will continue to be necessary in exceptional situations. Experience has shown, however, that the blasting efficiency of the avalanche tower system is substantially better than that of the 12 cm mortar. For this reason it was clear that the further extension of the avalanche tower system will reduce the number of closure days. Temporary road closures for triggering the avalanches were not taken into account, since in the vast majority of cases this is done at times when there is little traffic and such closures will lie within the limits of short-term delays expected on winter roads.

With the total-costs method presented in Table 1, the number of potential closure days is included in the cost calculation. Although the method does not take the economic value of a closure days into account, a value is introduced instead that is calculated from the additional costs of totally reducing the closure days by constructing a tunnel/gallery.

This analysis shows that with Option 2, the complete extension with avalanche towers, the optimum is reached. The total costs (0.235 million CHF/year) can be reduced to a minimum, which are actually below the original costs using the mortar (0.359 million CHF/year). The residual risk (0.011 fatalities/year) is just slightly higher in comparison to the cost intensive construction of a tunnel or gallery (0.004 fatalities/year).

2.3 Summary Gonda
Summing up it can be said that the installation of the first three avalanche towers in 2001 as well as the realization of the extension with five more avalanche towers in 2009 has reduced the number of closure days as well as the residual risk significantly. Moreover although investments had to be made the total cost are relatively low.

Prior to 1999, firing of the Gonda bowl with mortars only took place after large snowfalls of around 80 cm at the meteorological station in the valley. After the avalanche accident at the beginning of February 1999, firing was already carried out after medium snowfalls of around 50 cm in the valley. With snow height information only from the valley the analysis of avalanche risk as well as choosing the right timing for the blasting was quite difficult for the avalanche control team. Especially the low release percentage of only 50% of the mortars was not very efficient and left a high residual risk (0.025 fatalities/year), which was not acceptable.

With the complete extension of avalanche towers in 2009 in combination with a meteorological station near the starting zone, the residual risk could be reduced significantly (0.011 fatalities/year).

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The controlled release can now be conducted under every weather situation at the right timing considering the data of the meteorological stations. Blasting is carried out after new snow accumulation of more than 30 cm in the valley or more than 50 cm at the new mountain station. The fact that using the avalanche towers, the detonation is above the snow cover, leads to a very high blasting efficiency (90%). In summary less personal is needed for avalanche control work and the blasting is faster, safer and simpler.

Now with over 5 years experience with this final setup, and 13 years in total, the road had never to be closed due to avalanche danger, except for the time of the blasting, which can be done in less than 30 minutes.

3. ISCHGL

3.1 Introduction

The Austrian state road Silvretta Strasse B188 is located in the avalanche-exposed Paznaun valley. Several sections of the road have to be closed regularly due to high avalanche risk. As the main economic activity of the Paznaun Valley is winter tourism and the Silvretta Strasse B 188 is a very important transport link, closing times of the B188 are very expensive for the region, since the villages of See, Kappl, Ischgl and Galtür and their ski resorts are dependent on it.

In the last decade several permanent mitigation measures such as supporting structures, deflecting dams, snowsheds and tunnels have been constructed to minimize the risk. Nevertheless the road had to be closed several times per winter. In order to minimize the closure times, the community of Ischgl decided in Summer 2011 to initiate a pilot project. Two of the biggest avalanche paths (Grosstal and Hoher Zug), endangering the road at the western periphery of the town every winter and burring it every 10th winter should be mitigated. They not only endanger the B188, but also a local road, a cross-country track and in very rare, extreme situations the edges of the town.

It is well known that permanent mitigation measures have very low residual risk but on the other hand high investment and maintenance costs and constitute a significant impact on the landscape. In recent years the development of new technologies in artificial avalanche release and avalanche detection, enabled attractive alternatives for integral risk management (Rudolf-Miklau and Sauermoser, 2011).

Helicopter-bombing was conducted in the winter seasons 09/10 and 10/11 in order to get first experiences with artificial avalanche release. Small avalanches could be released and therefore the risk for the road reduced.

Fig. 3: Grosstal and Hoher Zug avalanches. Starting zones (blue), track (yellow) and runout zone (red) are indicated. The endangered Silvretta Strasse B188 as well as the village of Ischgl are marked (Source: Google Earth).

3.2 Artificial release and avalanche paths

Due to the above-described reasons the community of Ischgl together with the Federal Road Administration of Tyrol decided to use fixed installed systems for artificial avalanche release. The goal was to reduce the avalanche risk to an acceptable level and have a safe, fast and weather independent releasing method.

The Großtal avalanche path, in the north of the Silvretta Strasse (B188), has a starting zone of about 16 ha. Figure 4 gives an overview of the potential release areas with the position of the five avalanche towers and the effective range marked in different colors. The main avalanche-starting zone is a huge concave cirque with some steeper gullies in the west. Above Grosstal Tower 1 to 3 the terrain forms a bench with lower incline and consequently no avalanches are expected from this area. The open slope around Tower 1 to 3 allows full development of the effective range (5kg, r = 130 m). The narrow gullies in the west (Tower 4 and 5) are separated by ridges, which produce a natural barrier for the stress waves generated by the explosion.
Consequently, the avalanche towers have i) to be placed closer together, ii) to be placed on the ridge to have a clear line of sight on both sides and iii) higher tower heights in order to cover all areas without shadow zones. Besides analysing the slope inclination, exposition and snow drift, the position of the towers has also been chosen according to experiences made with helicopter bombing in previous years. Pictures taken from the starting zone, after the avalanches released, facilitate the determination of the tower positions. The avalanche track, is a narrow channel, followed by the run out zone down in the valley bottom harming the Silvretta Strasse (B188).

Additionally an avalanche radar was installed down in the valley bottom facing the Grosstal avalanche path. The monitored area is marked in orange in Figure 4. The radar is used for verification of the artificial release during the night or bad visibility and for information about spontaneous avalanche activity. For more information about the avalanche radar the reader is referred to Kogelnig et al. (2012).

On the opposite side, southerly, is the release area of the Hoher Zug avalanche (Fig. 3). The two main starting zones (1.5 ha and 3.5 ha), confluence to a single channel further downs the mountain. One avalanche tower is placed in each of the starting zones.

3.3 Summary Ischgl

The winter 2011/2012 was characterized by remarkably high snowfalls in Austria, and therefore an evaluation of the installed systems was possible. The towers were operating dependable and the realising concept proved to be fairly good. Also the avalanche radar provided important information about the release success, helping the avalanche control to quickly open the road again. In the three winters since the installation of the towers, the road had never been closed due to avalanche danger.

Fig. 4: Overview starting zone Grosstal avalanche. The location of the avalanche towers and roughly the effective range are indicated. The red arrow marks possible avalanche danger for Tower 3 from the area of Madeleinspitze, therefore it is a reinforced version with a second foundation. Tower 5 is 2 m higher (h=10m). The orange area marks the monitored zone of the avalanche radar.
4. EXPERIENCES MADE WITH ARTIFICIAL RELEASE

The following chapter presents i.) Experiences made with artificial avalanche release at the above-mentioned projects and ii.) A comprehensive summary of the most important facts for artificial avalanche release, from Gubler et al. (2011).

4.1 Controlled Release with Avalanche Towers

Most important at the beginning, the locations for the installation of the systems have to be chosen. The best spots are the ones with the weakest stability, meaning the ones with the highest probability to release an avalanche (Gubler et al. 2011). As this is almost impossible to know in advance or can change over the winter, the whole potential starting zone must be covered with the effective range of the systems. Locations, which are shielded from the direct air pressure wave, experience insufficient additional stress. To do this in an economic way and with a minimum of charges and/or installations, release systems with a big effective range are necessary and the triggering should start at locations known for their weak snow layers. Due to practical experience (e.g. Stoffel 2013) but also based on scientific studies (Gubler, 1977) it is known that explosions above the snow cover, with high detonation velocities, score the highest release rate. With 5 kg of explosive detonating above the snow cover an effective range of 130 m is reached (Gubler, 1983; Stoffel, 2001).

4.2 Choosing the right timing

If an avalanche can be released artificially is highly depending on the right timing (Stoffel, 2013). Avalanche control work should be carried out whenever possible during or immediately after heavy snowfalls or heavy snow drifting events, before the stability of the snow cover increases (Gubler et al, 2011). If avalanche size (run-out) is critical and has to be limited, protection work should be carried out at regular intervals during the snow fall or drifting phase at least on steeper slopes within the release area.

If the run-out distance (size) of particular avalanches could be critical, timing of the protection work is very important. Blasting too early can give negative results, and blasting too late may result in too much snow being released. Generally it is possible to unload steep slopes with appropriate methods several times during a storm to produce smaller avalanches. But it should not be assumed that a heavily loaded slope can be unloaded in portions by using smaller charges or by special placements of the charges. Usually if fracture propagation has started, it no longer depends on its initialization (Gubler, 1977). Information from weather stations located closely to the release zones can be very helpful. Slopes with extreme radiation conditions, i.e., slopes with a southerly exposure, should be released before slopes with insignificant radiation. Radiation accelerates snow metamorphosis as well as settling in the layer close to the surface (snow slab). These processes cause a decrease in stability for a limited period of time, but subsequently an increase of stiffness of the slab without affecting the weak layer. Therefore the conditions for initial fracturing and the start of fracture propagation are enhanced before strength of the slab and eventually the weak layer increase by settling and strengthening.

The experiences of the last 15 years have shown that with explosives also wet avalanches can be triggered (Stoffel, 2013). In wet snow the effective range is generally very restricted (often limited only to an extended crater zone). Wet snow slabs are not easily released due to their strongly sintered structure and limited period of instability (Johnson J., 1980). In consequence, the timing of the detonation is very difficult to determine, because stability changes much faster in wet snow than in a dry snow pack. Experience has shown that the probability for triggering wet snow avalanches is highest if blasting is carried out shortly after the highest temperatures have been attained and cooling after sunset has set in.

4.3 Residual risk after avalanche control work

A residual risk will always remain, if using temporary measures to mitigate an avalanche problem. If a major avalanche has been released within a given release zone, the zone including the corresponding avalanche path and run-out areas can be regarded as being safe. Normally very distinct changes of weather conditions are necessary to decrease stability of the remaining snow in the release zone and therefore increase the danger again. However, it should be noted, that remaining deposits in the avalanche path could again become mobile in the case of warming.

If no avalanche has been released (negative result) in the potential starting zone, the residual risk of an unforeseen avalanche can be assumed as small, if the following rules of Gubler et al. (2011) have been applied:
• The complete potential starting zone has to be covered with the effective ranges of the individual explosions
• Reduction of effective ranges by pressure wave shadowing has been taken into consideration
• The explosion may only be considered as an stability test for dry snow cover
• Detonations must be verified either by the bang heard by an operator or by means of electronic monitoring
• After negative tests it is recommended to wait at least 15 minutes at high snow temperatures and up to one hour at very low temperatures before the zone can be classified as safeguarded (time for mechanical relaxation of the snow cover)

However, the development of snow and weather parameters has to be carefully assessed in order to recognize in good time any possible increase of danger.

If working with artificial avalanche control methods, secondary avalanches, i.e. avalanches triggered by an artificially released avalanche, have to be considered. The appearance is depending on topography, snow stability and propagation of seismic waves in the ground (Stoffel, 2001). A comprehensive summary about secondary avalanches can be found in Stoffel et al. (2012).

5. CONCLUSIONS

Temporary measures, such as artificial avalanche release and detection are nowadays widely used for protection of roads, railways and ski-slopes. The two-presented projects are just examples from the numerous installations realized e.g. in Austria and Switzerland.

It was shown that, also on a long term, with experiences in Gonda of 13 years and Ischgl of three years, the residual risk can be reduced significantly and road closures are minimized. Controlled release of avalanches has also proven to be very effective during the three periods of heavy snow fall in February 1999. In many cases big avalanches could be prevented, by releasing snow in small portions (Stoffel, 2001).

Key subject of such release actions are well-planned concept of operations, including i) Definition of minimum and maximum snow heights for artificial release, ii) Involved agencies (e.g. avalanche control team, police, community, etc. iii) Exposed areas and necessary roadblocks, evacuations etc. and iv.) Residual risk of the measures.

The success of the triggering actions is highly depending on the right location and timing of the measures. Therefore an avalanche control team with experience and knowledge is needed supported by data from metrological stations and local observers.

CONFLICT OF INTEREST

The first and second author of this paper are employee of Wyssen Avalanche Control AG and are involved in the development and sales of avalanche control products such as avalanche towers and detection systems.

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