REZONING AFTER INSTALLING AVALANCHE MITIGATION MEASURES: CASE STUDY OF THE VALLASCIA AVALANCHE IN AIROLO, SWITZERLAND

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ABSTRACT: The catastrophic Vallascia avalanche struck the village of Airolo in the southern Swiss Alps on 12 February 1951. The accident was one of the most severe disasters during the catastrophic avalanche cycle of winter 1951. Shortly afterwards, one of the largest avalanche defense projects in Switzerland was initiated to prevent further catastrophic avalanches. In approx. 60% of the potential release area supporting structures were built. In 2016 the existing hazard map was re-evaluated in view of the extensive mitigation measures. The well documented 1951 avalanche allowed a comprehensive back-analysis. We determined the reduced hazard zones based mainly on the avalanche history, simulations with the 2D dynamics model RAMMS and expert judgment. A special focus was put on assessing the effectiveness of the mitigation measures. Calculating the runout area was not straightforward since several rows of houses brake the avalanche flow. The case study of Airolo is well suited to demonstrate the different facets and the complexity of such an analysis.

KEYWORDS: avalanche disaster, mitigation measures, hazard map, risk management

1. INTRODUCTION

In Switzerland the guideline PROTECT was developed to assess the effectiveness of mitigation measures in hazard maps (Romang, 2008; Margreth and Romang, 2010). The procedure includes three main evaluation steps. The first step is investigating whether the effect of the measures may be relevant in any way to the hazard assessment or not. In the second step, the mitigation measures are evaluated technically by assessing their reliability, which is defined in terms of structural safety, serviceability and durability. The third step involves the quantification of the effectiveness of the mitigation measures, taking into account their reliability. Finally, the hazard zones can be adapted based on an adjusted scenario. The consideration of mitigation measures such as snow supporting structures in hazard maps is a very difficult task, and of growing importance. The described case study of Airolo demonstrates the different facets and the complexity of such an analysis (SLF, 2017).

2. AVALANCHE SITUATION

The Vallascia avalanche endangers the village of Airolo situated in the southern Swiss Alps. The mostly south-facing starting zone is huge, with a surface area of 110 ha. The elevation difference is more than 1300 m, from 2500 to 1100 m ASL. The release area consists of a western and eastern terrain bowl with similar sizes (Fig. 1). Avalanches merge at an elevation of 1600 m ASL in a narrow and steep gully that ends at 1300 m ASL on a debris cone with a mean incline of 14°. The distance to the settlement area is 500 m. The endangered part of the village consists of several rows of multi-level houses without large free interspaces.

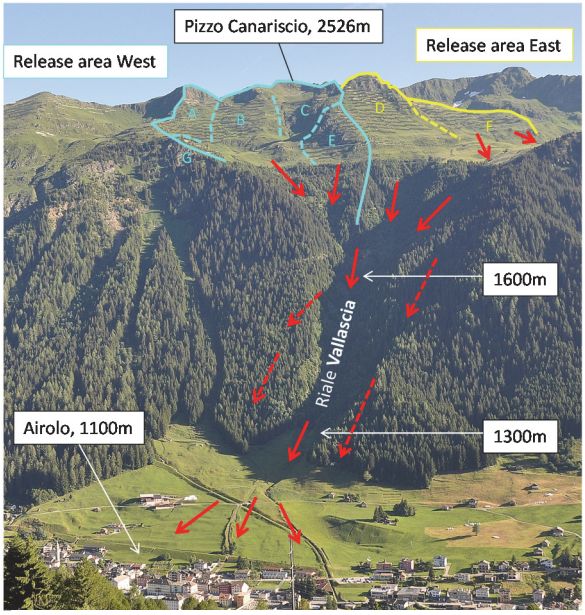

Fig. 1: Overview avalanche path Vallascia, Airolo (Photo S. Margreth).

3. SNOW AND WEATHER SITUATION

The southern Swiss Alps belong to the snow-richest areas of Switzerland. Especially southerly storms can cause very high snowfall intensities with a high avalanche activity. However,

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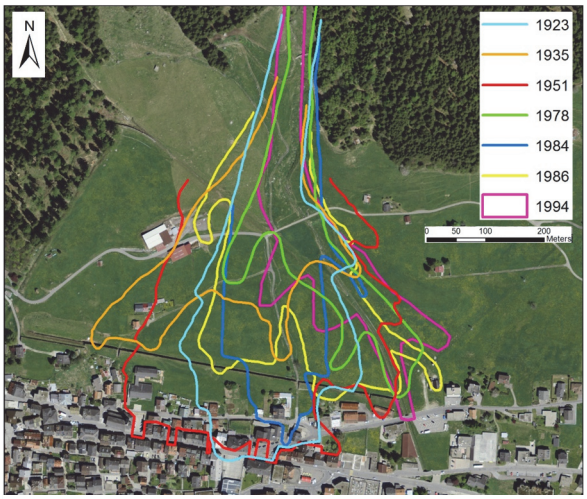

Fig. 2: Runout of historical avalanches in the avalanche path Vallascia.

NW-conditions can also cause avalanche cycles. The 100-year snow depth is 530 cm in the release area of the Vallascia avalanche and the 300-year snow depth increase in 3 days, i.e. the base value for the definition of the release depth for avalanche simulations is 235 cm.

4. AVALANCHE HISTORY

Many historical events of the Vallascia avalanche are documented. In the last 160 years the avalanche reached the settlement 4 times and stopped close to the settlement 6 times (Fig. 2). In 1877 a fire destroyed nearly the entire village of Airolo. The village was rebuilt farther eastward and thus more in the area influenced by the Vallascia avalanche. For the analysis of the avalanche history it is important to consider that the ongoing development of the mitigation measures in the release area influenced the avalanche activity. We assume that without the effect of mitigation measures the Vallascia avalanche might hit the settlement area every 40 years.

The largest and most disastrous avalanche, which caused 10 casualties and destroyed 30 houses occurred on 12 February 1951. The accident was one of the most severe disasters in the winter 1951 catastrophic avalanche cycle (Laternser and Ammann, 2001). The well-documented avalanche allows a comprehensive back-analysis of the event, which is important for the understanding of the characteristics of the Vallascia avalanche. The 10-day sum of new snow height before the catastrophic avalanche was around 330 cm, which corresponds to a return period of 50 years. The snowpack was relatively stable which resulted in large fracture depths. The day before the catastrophic avalanche it rained in the runout area. The avalanche was a combined powder and dense flow avalanche. The damage in the village was mainly caused by the slowly

Fig. 3: Deposit area of 1951 avalanche in Airolo. Three rows of houses were overflown by the avalanche (Photo SLF).

flowing dense part. We think that the moist snowpack at lower elevations increased friction and slowed down the flowing snow masses to less than 10 m/s.

The structural analysis of the destroyed buildings demonstrates that the primary reason for the damage were vertical overloads caused by the up to 20 m high avalanche deposits and not the avalanche impact (Fig. 3). The avalanche volume was estimated between 420'000 and 660'000 m^3. The powder part destroyed major forest stands lateral to the main avalanche track. We performed back-calculations with the two-dimensional dynamics model RAMMS (Christen et al. 2010) for different conditions: wet-snow and dry-snow avalanches, eastern and western release area as well as with and without the braking effect of buildings in the runout zone. The braking effect of the buildings could best be reproduced by assuming increased friction parameters (μ = 0.275 and ξ = 400 ms^{-2}) at the locations of large houses in the second and third rows and a "no flux" area in the village square with continuous multi-level houses. We assumed a fracture depth of 1.5 m and a release volume of 420'000 m^3. The simulated avalanche entrains 150'000 to 170'000 m^3 of snow in the track. The simulation shows that the 1951 avalanche most likely released in the eastern release area. We estimate that the volume of the 1951 avalanche corresponds to a return period between 100 and 300 years. As the moist snowpack in the runout zone slowed down the avalanche, we assume that the impact pressure in the settlement might correspond to a return period of only 50 years. The simulations also demonstrate that the runout of the 1951 avalanche would have been 350 m longer without the braking effect of the houses.

Fig. 4: Mixed steel-wood structures combined with modern steel bridges (Photo S. Margreth).

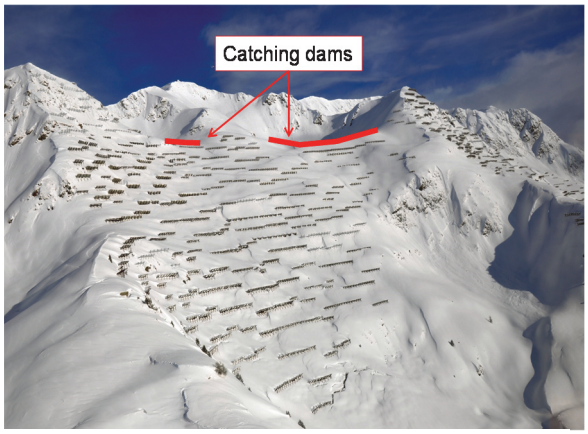

Fig. 5: Overview western release area Vallascia in 2014 (Photo M. Hauser).

5. EFFECT OF MITIGATION MEASURES

Step 1: General assessment

The main goal of the first step according to the PROTECT procedure is to decide whether the effect of the mitigation measures may be relevant for the hazard assessment or not. The wide variety of structure types in the release area is typical for serious avalanche paths with a long avalanche and mitigation history. First stone walls, with a total length of 3.6 km were built between 1886 and 1906 in combination with afforestation. After the catastrophic avalanche of 1923, 1 km of stone walls and nearly 3 km of earth terraces were added. The structural heights of the stone walls and earth terraces are absolutely insufficient. Their effect is therefore not relevant for the hazard assessment. The 1951 avalanche demonstrated that the previously installed mitigation measures were not sufficient to provide Airolo with a sufficient safety level. 5 km of snow bridges consisting of steel, concrete, aluminium and mixed steel-wood structures were added (Fig. 4). After the last large avalanche in 1984, a comprehensive mitigation project was initiated that included nearly 10 km of supporting structures, two catching dams and 54 ha of afforestation. The project ended in

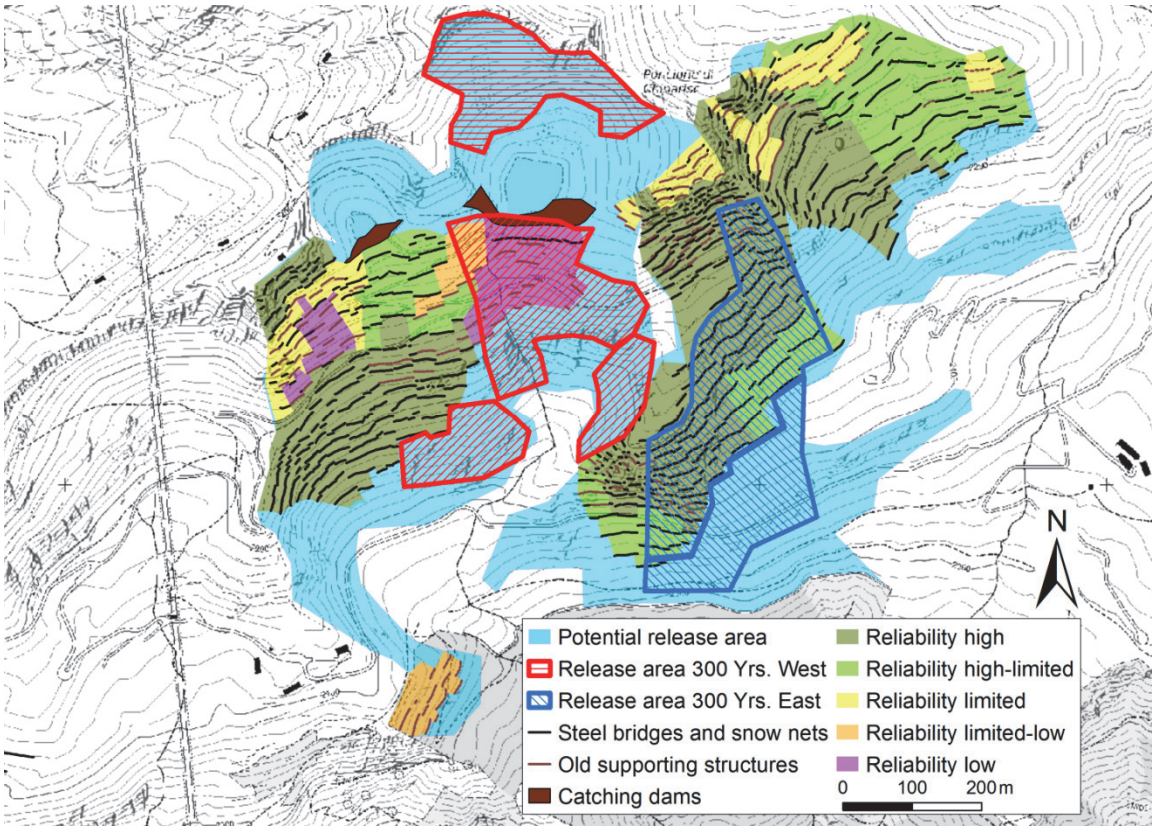

Fig. 6: Release area Vallascia avalanche with structure layout and reliability of structures. The release areas of the 300-year scenarios “West” and “East” are also shown.

2012 (Fig. 5). Today 60% of the potential release area is secured with supporting structures.

Step 2: Assessment of mitigation measures

The goal of the second step is to evaluate the supporting structures technically by determining their reliability. The reliability was assessed based on the structural safety, serviceability and durability. The state of all structures was evaluated based on field investigations and an analysis of a database of all structures, which is the base of the maintenance concept. The state of invisible components such as anchors was assessed with the observational method (Spross and Johansson, 2017). If no deformations of the structural geometry were visible, we assumed that the structural safety of the anchors is fulfilled. For the application of the observational method, a monitoring and maintenance concept is fundamental. The structure height D_k varies between 3 and 5 m. The structure height should be at least 4 m to be in accordance with the 100 year design snow height. The first structures were typically built in the most critical release zones with the highest release probability. These structures mostly do not fulfil the current design guidelines (Margreth, 2007). If necessary, faulty structures were exchanged or reinforced in course of time. In some sectors the effective height was increased by an elongation of the supporting plane. Critical points in the assessment of the reliability especially included too low effective heights of the older structures, too long distances between lines of structures, the only partly fulfilled structural safety of the structures built before 1984 and the insufficient durability of the structures with wooden cross beams. Two terrain bowls in the topmost part of the release area are secured with 16 m high catching dams. The 300-year avalanche can overflow the eastern catching dam and destroy the supporting structures situated below. Therefore, the reliability of those structures is considered to be low. In total 78% of the installed structures have a high or limited to high reliability (Fig. 6). 8% of the structures have a low reliability. To simplify the definition of the release scenarios with the effect of the structures we determined the reliability for zones larger than approximately 1 ha.

Step 3: Assessment of effectiveness

The third step, one of the key-points in the PROTECT procedure, includes the hazard assessment, considering the mitigation measures with respect to their reliability. If the reliability is high, a good functioning of the mitigation measure can be expected. In scenarios with limited reliability, the mitigation measures will only be partly effective. In Switzerland hazard maps are based on scenarios with a theoretic return period of 30, 100 and

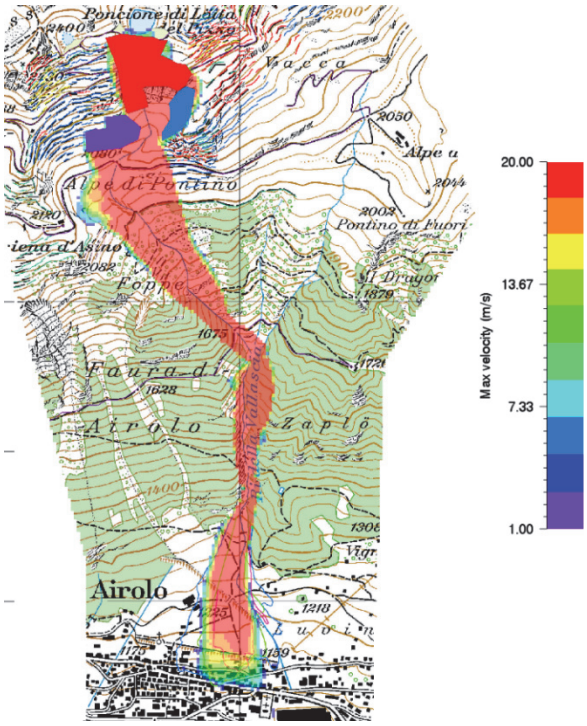

Fig. 7: Maximal velocity of RAMMS simulation of scenario 300 years “West”.

300 years as well on an extreme scenario representing an overload of the mitigation measure. In the present case, the 300-year scenario is decisive for the extent of the hazard zones. We calculated the runout area of the avalanches with the two-dimensional dynamics model RAMMS for two independent release scenarios (Fig. 6).

Scenario 300 year “West”: An avalanche releases in the starting zone above the eastern catching dam. The avalanche overflows the catching dam (Fig. 5) and triggers a large secondary avalanche in the non-protected zone and in the zone with the structures with a low or limited reliability. The release volume is 145’000 m^3. The avalanche entrains 100’000 m^3 of snow along the track. At the border of the settlement, the velocity is 15 m/s and the flow height 1.2 m. The avalanche stops on the main road (Fig. 7).

Scenario 300 year “East”: An avalanche with a volume of 75’000 m^3 releases between the lines of structures and triggers a secondary avalanche with a volume of 50’000 m^3 in the non-protected zone below the controlled perimeter. We considered the retarding and braking effect of the lines of structures with a reduction factor of 0.7 for the fracture depth and an increased friction (μ = 0.18 instead of 0.155 and ξ = 400 ms^{-2} instead of 3000 ms^{-2}). The avalanche entrains 85’000 m^3 of snow along the track. At the border of the settlement the velocity is 14 m/s and the flow height 1.2 m. The avalanche also stops on the main road.

The simulated avalanche intensities at the edge of the settlement are higher than in 1951. A 300-year avalanche without any mitigation measures has a velocity of 29 m/s and a flow height of 2.1 m there.

6. HAZARD MAPS

The elaboration of the adapted hazard map of Airolo was especially challenging due to the buildings in the runout zone. We carefully analyzed size, position and structure of the houses in view of possible braking effects and destruction. The calculated width of the endangered area was too small in comparison with the historical avalanches. We determined the reduced hazard zones based on the insights of the 1951 event, an analysis of the topography and buildings' structure, simulations with the two-dimensional dynamics model RAMMS and expert judgement. The currently valid hazard map dates back to 1982. Due to insufficient documentation, it was unclear which assumptions that hazard map was based on. Especially the red zone was even smaller than the one on the newly elaborated 2017 hazard map without the effect of the mitigation measures. This problem occasionally occurs: the extent of hazard zones in old hazard maps not considering mitigation measures is smaller than on newly adapted hazard maps taking into consideration mitigation measures. Such conflicting assessments are difficult to understand for non-professionals. In such cases we propose to elaborate an updated hazard map without considering the mitigation measures, in order to have a well-defined basis for comparison. In the case of Airolo the difference between the updated "old" hazard zones and the "new" hazard zones which include the effect of the mitigation is 20 to 100 m (Fig. 8).

7. CONCLUSIONS

In Switzerland the effect of permanent mitigation measures is considered in hazard maps. Hazard zones are typically re-evaluated every 10 to 15 years to consider new insights from avalanche events or climate change, changes in the topography, further developments of simulation models or new mitigation measures. The reduced extent of hazard zones mainly depends on the reliability of the mitigation measure. High-risk avalanche paths such as the Vallascia avalanche typically have a long mitigation history. The oldest supporting structures that often do not meet the state of the art are often situated in the main release zones. A detailed analysis of the reliability of the supporting structures is essential. The verification of the state of invisible components such as anchors is particularly difficult. The development of the structural state of the structures can be determined based on the observational method. For this, a sound monitoring and maintenance concept is essential. If necessary, unreliable structures have to be replaced in time. In the present case the analysis of the 1951 avalanche was very helpful to understand the characteristics of the avalanche path and to define the reduced scenarios. A precise calculation of the runout area was nevertheless impossible because several rows of houses brake the avalanche flow. In the present case the extreme scenario, which is characterized by a remarkable overload of the mitigation measures and considered as a residual risk is covered by the original hazard map without considering measures. The residual risk of a failure of mitigation measures is typically not shown in hazard maps. In cases leaving room for interpretation a secondary independent evaluation can be helpful. The consideration of mitigation measures in hazard mapping is a very difficult task, and of growing importance.

Fig. 8: Hazard map Airolo with and without the effect of mitigation measures. In the red zone the impact pressure of a 300-year avalanche is more than 30 kPa. In the blue zone the impact pressure decreases from 30 to 0 kPa.

REFERENCES

Christen, M., J. Kowalski, and P. Bartelt, 2010: RAMMS: Numerical simulation of dense snow avalanches in three-dimensional terrain. Cold Reg. Sci. Technol., 63: 1-14.

Laternser, M., Ammann, W., 2001. Der Lawinenwinter 1951. Schweiz. Z. Forstwes. 152, 1: 25-35.

Margreth, S., Romang, H., 2010. Effectiveness of mitigation measures against natural hazards. Cold Reg. Sci. Technol. 64:199-207.

Margreth, S., 2007. Defence structures in avalanche starting zones. Technical guideline. FOEN Federal Office for the Environment, Bern, WSL Institute for Snow and Avalanche Research SLF, Davos.

Romang, H., 2008. Wirkung von Schutzmassnahmen. National Platform for Natural Hazards PLANAT, Bern, p. 289. http://www.planat.ch/resources/planat_product_de_1103.pdf.

Spross, J. and Johansson, F., 2017. When is the observational method in geotechnical engineering favourable?, Structural Safety, 66: 17-26.

SLF, 2017. Überprüfung der Lawinengefahrenkarte Airolo. SLF Expert report G2016.03, Author: S. Margreth. Davos, (unpublished technical report).