AVALANCHE SAFETY CONCEPT FOR A RAILWAY STATION IN AUSTRIA

TECHNICAL AND TEMPORARY MEASURES – A HAZARD ANALYSIS

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ABSTRACT

The Tauernbahn is a railway line crossing the eastern part of the 'Hohe Tauern' range with a tunnel of 8.6 km length. On its northern end in the narrow Anlauf valley a railway station is located. The whole area of the railway station can be considered as an avalanche prone area. From the south-west exposed slope the Feuersang avalanche has reached several times the area of the railway station.

A safety concept for the affected area is presented. Starting from the actual technical measures in the starting zone of the avalanche new potential release areas are selected.

Wind has a great influence on the snow deposit in the starting zone. Therefore a detailed analysis of the snow cover distribution has been done. Investigations ended up in calculating run-out distances and deposit heights of the Feuersang avalanche for selected release zones using new avalanche simulation techniques.

Technical and permanent measures have been compared with each other to develop an optimized hazard management. A decision support for the avalanche warning commission is presented.

Keywords: Avalanche protection, rail way, infrastructure

INTRODUCTION

The railway station Böckstein, situated in the Anlauf valley (Gastein, Salzburg), is part of a very important traffic line to ensure the north-south connection in central Austria for both, the transport of cargo and the passenger transportation. The area of the railway station is endangered by the 'Feuersang' Avalanche. Therefore technical measures have been set up in the release area since the opening of the railway line in 1905.

In Austria the safety of railway infrastructure is regulated by law. The railway company is fully responsible for carried passengers and cargo (Rachoy, 2004). Due to this reason the Austrian Federal Railway Company uses a multifunctional avalanche control system for their tracks and railway stations. Temporary and permanent measures are combined. Technical control measures are set in the starting zones and in the run out areas. In addition to that special trained employees are organized in avalanche warning commissions.

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The latest technical measures projected by Rothuber (1995) and their ongoing realization are used to work out a safety concept for the railway station according to proposed analyses (Wilhelm 1997; Wieshofer 2003; BUWAL 1999).

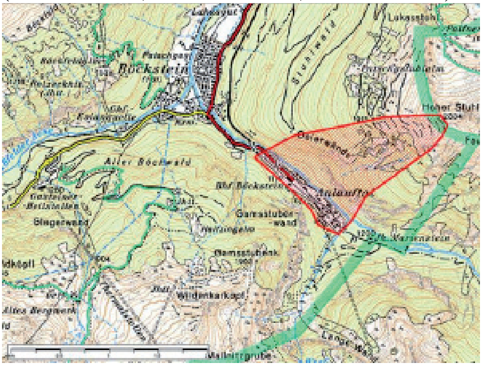

Fig. 1: The project area in the Anlauf-valley, close to Bad Gastein (Salzburg, Austria) Map taken from Austria Map, Federal Austrian Cartography Institute

The potential release area of the ‚Feuersang' Avalanche covers an altitude range between 1900m and 2330m with a main exposition of SW. It is located in the lee side of a steep ridge. If wind is blowing from the north important snow drift and deposition can be observed in the release area. The mean inclination of the whole project area is about 38° with an average width of about 250m.

Several avalanches have been observed since the opening of the railway line. Two of them (winter 1922 and 1970) reached the railway station and were responsible for important damages of the local infrastructure. Local people described them as powder snow avalanches. A big dense snow avalanche was observed in springtime 1975. The avalanche destroyed parts of the defense structures in the release area and reached the bottom of the valley without damaging the local infrastructure.
In the last years on the one hand new technical countermeasures were constructed and at the other hand intensive maintenance work has been done to ensure the functionality of older measures like stone walls or snow supporting structures. These efforts lead to a more detailed investigation regarding the avalanche risk for the exposed railway station.

MOTIVATION

The motivation for the avalanche safety concept is first of all a better understanding of both, the avalanche hazard and the essential actions for the local railway authority in case of danger of avalanches. According to the actual avalanche danger level different types of actions should be set avoiding victims or damage on infrastructure.
To achieve a higher security standard key parameters have to be investigated more in detail.

Wind influence: Observations have shown that during the winter season the snow height varies a lot over the whole project area. This can easily be explained by wind drift and the different expositions of the affected areas. For a detailed investigation we have to quantify this influence and to study the snow cover distribution in the release area. The goal of this investigation was to correlate the wind speed with the snow deposit and thus get a map with the adequate snow heights for the affected area.

Mode of functioning of technical measures: The set-up of technical structures in the release area started immediately with the opening of the railway line. Most of these old structures have been rebuilt or intensively maintained in the last years. Due to the strong wind influence in the release area the mode of functioning for those structures should be investigated in order to adapt future work according to the meteorological conditions.

Close to the railway station a huge catching dam was started to be built in order to prevent flowing snow masses to reach the infrastructure of the Austrian Federal Railways. Due to the huge amount of necessary building material the dam is still under construction. Nevertheless the influence of the deposition of avalanching snow masses should be investigated.

New defense structures in the release area: Most of the potential release area is already covered with technical defense structures to prevent snow masses to slide down the slope. Despite the effort there are still some critical areas without any technical measures. The investigation should outline potential future areas for further constructive measures.
Beside technical permanent measures also temporary actions should be considered in the investigations. Two main points should be highlighted. First the mode of functioning of such a measure and second, a comparison between temporary and permanent actions regarding the price and the safety level reached with the particular measure.

Historical events and numerical simulation: Historical events have already been mentioned above. An additional goal of the investigation is to compare these events with numerical simulations. We expect to better estimate the order of magnitude for a future event and to precise the forecast for pressure-, snow depth or velocity distributions in the affected area.

Decision support for the avalanche warning commission: The experts of the warning commission get informations about meteorological data from observation stations located in the avalanche starting zone. Wind speed, snow height, air temperature, precipitation and humidity of air is recorded and transferred to the commission. The investigations should combine collected data with knowledge about the snow cover distribution to develop a decision support system for the responsible persons.

METHODS

For further analyses we first identified key parameters responsible for the avalanche hazard. As stated above the wind influence on snow deposit in the project area seems to be a major challenge (HÜBL et al. 2006 [1]).

Fig. 2: Example of a permanent meteorological station in the release zone

Local snow cover distribution: Therefore we studied meteorological parameters like wind speed, air-temperature, humidity of air and parameters of the local snow cover like snow height, snow cover distribution and snow density.
We used both, permanent meteorological stations (see Fig. 2) and mobile stations. Wind has a great influence on the snow cover distribution in the release area. Main wind directions are from the north and the south (see Fig. 3).

Where no direct access was possible technical measures have been used to determine the snow height in the project area. Steel supporting structures have horizontal bars enabling snow height measurements with a telescope. This type of remote measurements can be done with an accuracy of 10cm. Snow height measurements in accessible areas have been done with a common probe, 250cm long. Remote measurements as well as in situ observations have been done on predefined locations indicated in Fig. 4.

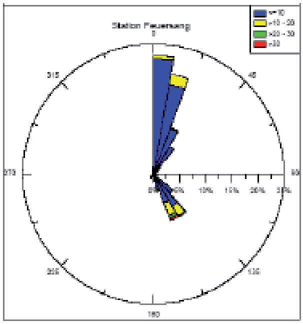

Fig. 3: Wind direction and wind speed of winter 2004/2005 of a permanent station. Colours are indicating the wind speed: stronger wind is blowing from the south.

Recorded data from our field observations have been used to classify the snow height distribution in the release area according to the sensitivity of the wind influence. In a next step we correlated the hand-made measurements in the release area with measurements from a permanent meteorological station on the windward side of the project area. This should enable the authorities to estimate more reliable snow height distributions at the Feuersang slope including also the wind influence.

An example for this type of correlation can be seen in Fig. 5 where the forecasted snow height is plotted for a measured value of 1.0 m at the permanent meteorological station. Wind influence has been taken into account for the calculations.

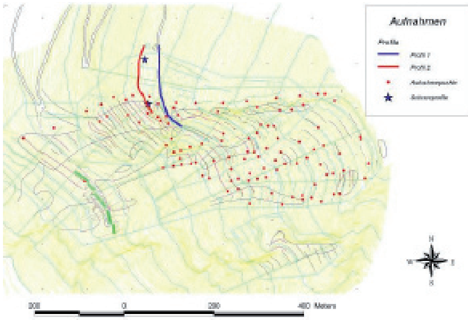

Fig. 4: Locations of snow height measurements (red points). The solid lines are indicating the paths were wind speed measurements have been done with a mobile wind sensor and snow pits have been dug for detailed analyses of the snow cover.

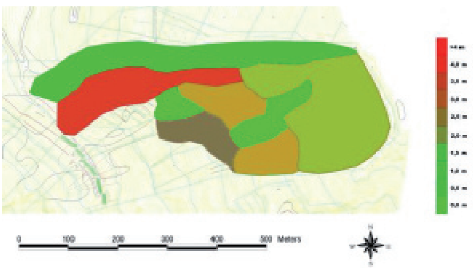

Fig. 5: A main classification of areas affected to snow deposit and –erosion.

Extreme events: To estimate extreme events in the project area meteorological data (snow heights) from surrounding weather stations have been used.

For further data analyses, time series of surrounding weather stations have been used as well as recent data from meteorological stations close to the release area of the Feuersang.
Long lasting time series have been extrapolated to a 150-year Event using a Type-1 Gumbel distribution function of the form

$$F_x = \exp\left(-\exp\left(-\frac{x-\alpha}{\beta}\right)\right) \quad \textbf{(Equ. 1)}$$

Numerical simulation models: to estimate the run-out distance of an avalanche from the Feuersang and to calculate the impact on the infrastructure we used several types of avalanche simulation models. The 1D model AVAL-1D (Christen et al., 2002), the 2D-models ELBA+ (Volk, 2005) and SAMOS (Sampl and Zwinger, 2004) and for the simulation of the three-dimensional powder part of the avalanche we also used SAMOS. For all models a DEM is necessary as a primary input parameter. Release areas and the related snow height have been defined according to the in situ observations. Additionally entrainment sections and resistant areas have been chosen according to the needs of each model (HÜBL et al. 2006 [2]).

Technical measures: state-of-the-art solutions of permanent avalanche protection measures are on-site in the release area of the Feuersang slope but do not cover the whole range of potential starting zones. Therefore permanent and temporary actions are compared according to their protective means.

HAZARD ANALYSES

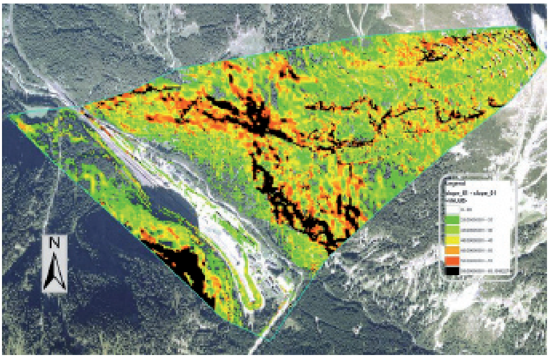

Fig. 6: Inclination of the project area. Only potential release areas with inclinations more than 28° got a related colour.

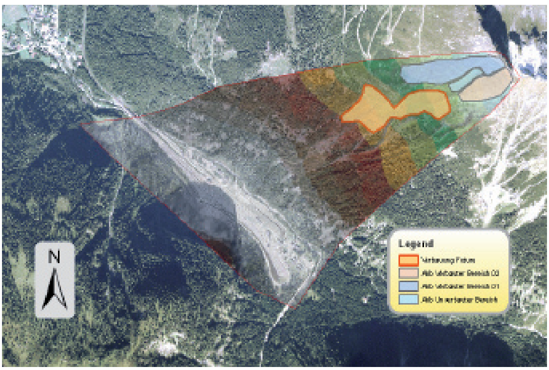

Fig. 7: Release areas after detailed investigation taking into account, snow deposit and erosion by wind and technical measures. For final calculations we used the area with the orange border where actually no technical counter measures are installed.

In a first step of our analyses we focused on the characteristic of possible release areas taking into account the observations and measurements in the upper part of the Feuersang slope as well as the morphology. Existing technical measures have also been considered for the definition of release areas.

Release areas: the overall potential release area has first been defined according to the topology (see Fig. 6) and the snow deposit (see Fig. 5).

A more detailed definition of potential release areas was made by taking into account the influence of technical measures combined with the overall wind influence. These areas have been outlined as seen in Fig. 7.

Snow height: The snow height in the relevant release area was calculated as stated above (see chapter **METHODS**). Additionally the wind influence, the altitude and the inclination was taken into account according to the Swiss guidelines (BUWAL 1990).

Thus we got an average snow height for our release area of 110cm for a 150-year event. Using the models mentioned above we started numerical simulations with the elaborated parameters and plotted the result on an orthophoto as shown in Fig. 8.

The simulation model ELBA+ shows the influence of the deflection dam which is still under construction. The avalanching snow masses are not reaching the critical areas in the railway station.
The avalanche simulation with the SAMOS model (Fig. 9) shows that in the case of a 150-year event the avalanching snow masses will come to rest along the railway tracks of the railway station Böckstein. The average width of snow deposits on the rail tracks where the dynamic pressure of avalanching snow masses is bigger than 10kPa is about 125m (see also Tab. 2).

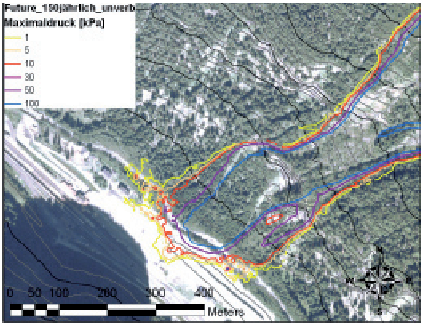

Fig. 8: Result of a 150-year event (pressure) with the avalanche simulation model ELBA+. One can identify the avalanche catching dam at the bottom of the valley in the lower right corner of the picture. Part of the deposition reaches the area of the railway station.

EXPOSURE ANALYSES

Austrian Federal Railways are running a car shuttle train crossing through the 'Hohe Tauern' Alpine range between Böckstein and Mallnitz. So the railway station is frequented by people who want to pass through the tunnel either with or without a car. To get on the train by car people have to wait for the incoming train in the avalanche-prone deposit area. Additionally international trains and rail cargo are passing through the Böckstein railway station without stopping. See for details of rail-traffic through the tunnel Tab. 1 (HÜBL et al. 2006 [2]).

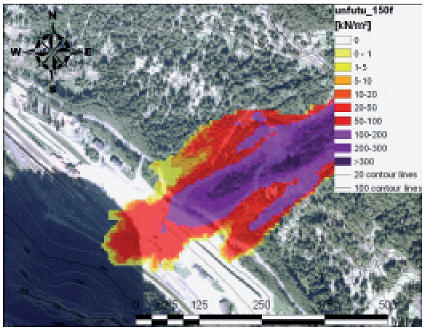

Fig. 9: Result of a 150-year event (pressure) for a dense snow avalanche of SAMOS. Some parts of the dense snow avalanche are estimated to reach the area of the railway station including rail tracks (HÜBL et al. 2006 [3]).

Tab. 1: Rail traffic between Bad Gastein and Mallnitz / Obervellach

	Length of train [m]	Number/day	Number/h	Interval [min]	%
Intercity rail traffic	200,00	20,00	0,83	72,00	12,70
Short-distance traffic	100,00	23,00	0,96	64,20	14,29
Car-transport	100,00	33,00	1,37	43,80	20,95
Transportation of cargo	500,00	73,00	3,04	19,80	46,35
Maintenance traffic	20,00	9,00	0,37	160,20	5,71
Sum	**-**	**158,00**	**6,57**	**9,13**	**100,00**

There are three rail tracks in the railway station whereas track 1 is used for the car transportation through the tunnel. Intercity and short-distance traffic are using track 1 and track 2 in equal shares according to the direction of travel. Track 3 is used by maintenance work only. Track number 1 is the closest regarding the avalanche track and track number 3 is the furthest rail track. Deposit lengths and deposit heights over the rail tracks are taken from numerical simulations.

Tab. 2: Total length of snow deposit on rail track 1 for different return periods (T) and varying snow heights in the release area.

T	3d-snow height [cm]	Deposit length [m]
<30	h < 143	86,70
30-75	143 < h < 162	111,97
75-125	162 < h < 174	144,78
>125	h > 174	143,20

TECHNICAL MEASURES

To avoid an event with significant deposit in the area of the railway station, technical measures either in the release area or in the deposit zone have to be installed.
Since 2002 a catching dam is constructed in the deposit zone of the avalanche. The dam is about 250 m long and about 30 m high. Due to the huge amount of building material the construction of the dam will be finished in 2008.
The most efficient technical measures are supporting structures in the starting zone of the avalanche. Different types are used in this area. The most common type is the steel snow bridge. But also snow nets and stone walls are used. Against snow drift special drift fences are constructed.

These types of permanent technical measures are already on-site but do not cover all potential release areas. Therefore selected temporary actions are analyzed and compared to permanent measures according to their financial and safety input.

Tab. 3: Existing technical measures in the starting zone with the overall construction length.

Technical measure type	Length [m]
Steel snow bridges	4.500
Snow nets	500
Stone walls	1.200
Drift fences	80
Sum	**6.280**

Tab. 4: Comparison between permanent and technical measures based on a price level 08/2007. No maintenance work has been considered.

Technical measure	permanent	temporary	Comments	Price (one-time installation plus explosive)	ranking	Quantity	Total price (one-time)	Price per year
Supporting structures	+	-	+ permanent support even with bad weather - not working, if snow height overcomes constructive height - expensive	about 1000 €/m	4/5	about 400m/ha	2.820.000 €	
Avalanche Guard	-	+	+ can be installed outside the starting zone. + can reach several points in the starting zone - limited number of shots - shots can be deviated by strong winds - danger from avalanches of the upper part	about 75.000 € plus about 40 € / shot	3/5	1	75.000 €	400 €
Gaz.Ex	-	+	+ highly efficient due to explosion above the snow cover - have to be installed directly in the starting zone - efficiency decreases with lower inclination (< 35°)	about 70.000 € plus about 2-4 € / shot	3/5	1	70.000 €	40 €
Hand triggered	-	+	+ explosive can be placed exactly where it is needed - helicopter and good weather needed for triggering	about 900 € a flight including the explosive	2/5	-	-	10.800 €

The potential avalanche starting zone where actually no technical measures have been built covers an area of about 7.05 ha. This area has been considered to calculate the costs of future permanent measures in the above table.

AVALANCHE WARNING COMMISSION

Conferring to the high security level of Austrian railway tracks a multifunctional avalanche control system is used. Together with the above described technical measures an avalanche warning commission is installed. The members of the commission are special trained employees of the railway company. They must have experience and knowledge about the local avalanche situation. The executive work of the commission is described in the "Avalanche warning system for the avalanche warning commission". The duty of the commissioners is to watch the weather forecasts, the local meteorological data, and official avalanche bulletins. The members of the commission also make snow pits to analyze the snow stratigraphy and observation flights per helicopter.
The warning scale is conferring to the European avalanche warning system. So the warning levels can be compared to all official warning levels of the governmental avalanche warning system.

Tab. 5: Avalanche danger levels and the local actions regarding the railway station Böckstein.

Avalanche danger level	Action
1	No actions
2	No actions
3	The warning commission is on duty
4	According to the actions decided at level 3 the car shuttle train is closed
5	The total track is closed

Due to the special wind situation and the snow drift distribution in the starting zone of "Feuersang" avalanche different meteorological criteria measured by automatic stations in the release area are now combined as decision support for the avalanche warning commission. During a snow fall period snow can be transported into well protected areas by wind (see areas of erosion and deposit in Fig. 5). More critical are situations if there is heavy snow fall and no wind: snow is than deposited mainly in unprotected areas where no supporting structures are able to stabilize the snow pack.

Tab. 6: Decision support for critical meteorological situations according to the snow height, wind speed and air-temperature for danger levels 4 and 5

3-d-snow height [m]	Presence of Wind / Temperature	Existing snow height at the observation station [m]	Danger level
0,75 m	Temp < 0°C / wind	2,0 – 2,50	**4**
	No wind	-	
> 0,75 m	Temp < 0°C / wind	>2,5	**5**
	No wind	-	

CONCLUSION

Some of the most important European North-south transversing railway tracks are running through the Austrian Alps. These tracks play a very important role in the Austrian railway system. According to law the Austrian Federal Railway Company is responsible at the one hand for the safety and on the other hand for the high availability of these transnational corridors.

To fulfill the high demands the investigated railway station Böckstein is protected by using a multifunctional avalanche control system.
The influence of wind and of snow drift is the most important avalanche building factor in the investigated area. The direction of wind and the wind speed are main inputs for the decision support system. Heavy snow fall in times with no or less wind leads to a deposit of snow in unprotected areas. This observation was verified by the snow distribution model. These areas are now under special observation. In the next winter it is planned to use Laser-Scanning images to get more detailed information about the snow distribution conferring to wind speed and wind direction.
Nearly 75% of the starting zone is protected by supporting constructions like steel snow bridges, snow nets or stone walls with a total length of about 6.280 m. These technical measures are planned according to the Swiss guidelines (BUWAL, 1990) and constructed for a 150-year event. The constructions are controlled and maintained by the railway authority and the avalanche warning commission.
The deflection dam which is built in the deposit zone of the avalanche is under construction and will be finished in 2009. This control measure will protect the railway station against dense snow avalanches.
The avalanche safety concept for the investigated area contains technical and organizational countermeasures. About 7 hectares of the avalanche release zone are currently not controlled by supporting structures. Different temporary and permanent measures are described and compared to each other (Tab. 4). Referring to the high security level for railway tracks a permanent solution should be aimed.
In addition to the technical counter measures the importance of organizational tasks is discussed in the present paper. The members of the Avalanche warning commissions will be supported in their decisions about danger levels. Regarding the massive influence of wind on the danger level the data of the meteorological stations is correlated with the snow distribution model. So the existing snow height at the observation point, the wind situation and the snow fall intensity leads to a helpful support for the avalanche warning commission.

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