Anthropogenic Caused Mass Movements and their Impact on Railway Lines in Austria

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Abstract

Mass movements like land slides, rock falls or debris flows can cause heavy damage to infrastructure such as settlements, roads or railway lines. These phenomena are not always initiated by natural processes. More often they are caused by anthropogenic influences — the impact can be indirect through climate change but also immediate, for example caused by mining sites. The present paper gives on the one hand an overview of state-of-the-art in the protection of railway lines. On the other hand a specific way of generating basic data, for risk analyses and decision support for countermeasures is demonstrated by means of a case study. An abandoned marble quarry in the "Wachau", an area in the Danube river valley, poses a potential risk to a railway line and a national road. In the year 2002 the central part of the quarry collapsed and 60000 to 85000 m^3 of rock material were deposited in a dump in the immediate vicinity of these "life lines" of this valley. To calculate the risk of potential rock fall geotechnical analyses were made. A 3D terrain model was prepared as basic source of data using laser scanners. The outcome of this was two kinds of countermeasures which were compiled to protect the infrastructure against impacts of rock fall in this area.

Keywords: Risk Management, Infrastructures, Mass Movements, Design of Countermeasures

Introduction

In Austria, the railway system plays a major role in the transport of passengers and goods over short and middle range distances. 11,000 kilometres of tracks, of which 7,900 km are electrified, are connecting regions and cities. About 7,500 trains per day run on these tracks. Due to the growth in urbanization and tourism the train frequency is steadily increasing (Rachoy, 2004). Since Austria is situated in the centre of the Alps, 30 % of the total track length is situated in mountainous regions. They are important European north-south traffic corridors that connect ports on the North Sea (e.g. Hamburg) with harbours on the Adriatic Sea (e.g. Trieste, Koper).

Due to a high relief energy and large amounts of precipitation railway tracks and other infrastructure lines (e.g. roads, energy, and water) are often exposed to natural risk zones. Mass movements like land slides, rock falls or debris flows can cause heavy damages to infrastructure. In an "ordinary" year the Austrian Federal Railway Company spends about 20.0 million EUR for damage compensation, for the construction of control measures and warning systems against natural hazards. Due to extreme situations in the recent years, like the flood events in August 2005 and March 2006, costs raised up to 50.0 million EUR.

With respect to the causes of mass movement events we basically distinguish between 3 types of initialisation: weather related (e.g. precipitation, freeze and thaw), geophysical (e.g. earthquakes) and anthropogenic influences. A combination of the different types is most common. The present paper will focus especially on the anthropogenic influences, their impact on railway lines and countermeasures.

Types of anthropogenically influenced hazards

- **Artificial slopes**
  Most Austrian railway tracks were planned and constructed more than 150 years ago. In order to reach alpine passes the tracks had to be traced out on steep slopes wherefore rock had to be removed which was carried out with steam engine powered sledge hammers or by means of blasting with black powder. The slopes were constructed having steep angles, no berms and are very close to the tracks without safety distance. Due to heavy precipitation events and weathering the rock slopes became now instable and have to be accurately controlled, which means about 27.0 million square metres of steep natural and artificial rock slopes to be monitored along Austrian railway tracks.

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- **Quarries**
  Austrian quarries are subordinated to the control of a special authority. If a quarry puts a railway line at risk the railway authority is asked for a security statement. When a quarry is closed-down safe conditions must be established by the operator. A special circumstance will be described in a case study.
- **Other anthropogenic interventions**
  In some cases forest roads near the railway tracks are in poor condition and can lead to slope instabilities and slope failures. Also deforestation through storms, snow or fire can cause instability of slopes.

Methods

The Austrian Federal Railway Company is fully liable for the security of the transported passengers and goods. Austrian railway engineers have experience in planning and protecting railway infrastructure in mountainous areas over 150 years. The following railway specific characteristics are to be considered when planning protection measures:

Braking distance: Freight trains carry goods with a weight of more than 1,000 tons. While the braking distance of a car is about 45 metres and of a truck about 120 metres, a train needs about 700 to 1,000 meters to stop.

Signal distance: If a green signal indicates a clear line to the engine driver, he must trust that the following distance section is free of obstacles (e.g. rocks, mud, and trees).

Bypasses: Even short term bypasses of railway tracks are connected with a high logistic and personnel expenditure (Rachoy, 2004).

Different state-of-the-art countermeasures are taken by the railway company to reduce the possible impact of mass movements. In the first place technical (e.g. geology, remote sensing, hydrology) and economic (e.g. risk analyses, cost-benefit calculations) analyses are performed. Then temporary, permanent or combined countermeasures are planned and put into action.

Examples for temporary countermeasures

- Track lock and bypass
  In case of acute danger tracks have to be locked and bypasses for trains to be managed.
- Monitoring and alert systems
  Surveillance cameras, geophones, laser scanning, extensometers, rock anchor stress surveillance, different warning systems come into operation. The likelihood of an impact is registered. Referring to the railway specific characteristics, the pre-warning time for trains is much longer than for road traffic.
- Visual control of slopes by roping
  Specially trained staff of the railway company visually controls the stability by roping down the rock slopes. These ropes can have a length up to 200 metres.

Examples for permanent countermeasures

- **Tunnels and galleries**
  These cost intensive measures are only employed on main tracks or in case of very high event frequency.
- **Earth dams**
  The building of dams and safety areas is one of the most effective countermeasure provided that there is enough space between the slope and the track.
- **Slope protection with high-tensile wire mesh**
  This measure is used for large slope areas. There exist different types of meshes.
- **Rock anchors**
  Different types of anchors are used for selective safety measures.
- **Various types of barriers**
  Dynamic and static types of barriers are constructed for special energy levels.
- **Rock removal**
  The complete rebuilding of a rock slope with hydraulic engines and by blasting is a very cost intensive but long term method. The target of this measure is to stabilize the slope in order to construct berms and a safety area between the slope and the railway track.

Table 1. Rock fall events in the mining site (Scheikl, 2005)

Date	Type	Section	Volume
March, 1961	Rock fall	Upper	~70000 m^3
May, 1982	Cracking fissuration	Upper	?
October, 1984	Rock gliding	Upper and central	~10000 m^3
April, 1996	Rock gliding	Upper	?
November, 2002	Rock fall	central	~60000 – 85000 m^3

Fig. 1. Collapsed quarry site, May 2005

Case study — Marble mining site Spitz / Danube river valley

Situation

The following case study deals with the instability of an abandoned marble quarry and its consequences for a railway track in the eastern part of Austria, situated in the "Wachau"-valley, an area that had been declared World Cultural Heritage. This sensitive area is overrun by tourism, and the particular railway line in our case study is used only for touristic purposes. Furthermore a national road, which is the main traffic line in the area, parallels the tracks with a highly frequented bicycle path in-between.

The first mining activities in the area started off already in the beginning of the 19th century. From 1970 to 1991 a commercial quarry enterprise ran the mining site. In 1991 the company went bankrupt and the quarry was closed-down. After that the required safeguarding works were never done.

After the heavy flood event in 2002, during which the central part of the quarry site collapsed, 60000 to 85000 m^3 of rock came down and left a large dump very close to the railway line, the bicycle path and the national road.

All registered rock fall events are shown in table 1.

Immediately after the 2002 event the construction of an earth dam was ordered by the authority which then collapsed in the beginning of 2005. The natural hazards experts of the Austrian Railway Company detected again acute danger of rock fall and started with detailed analyses.

At first the whole mining site was surveyed by means of terrestrial laser scanning. A 3D terrain model was calculated and compared to older aerial photographs. For the first time it was possible to reconstruct all rock fall and rock gliding events since 1961.

The terrain model was a worthwhile basis for the geological and geotechnical survey of the mining site because due to the instability of the area it was dangerous for geologists to make on-site investigations.

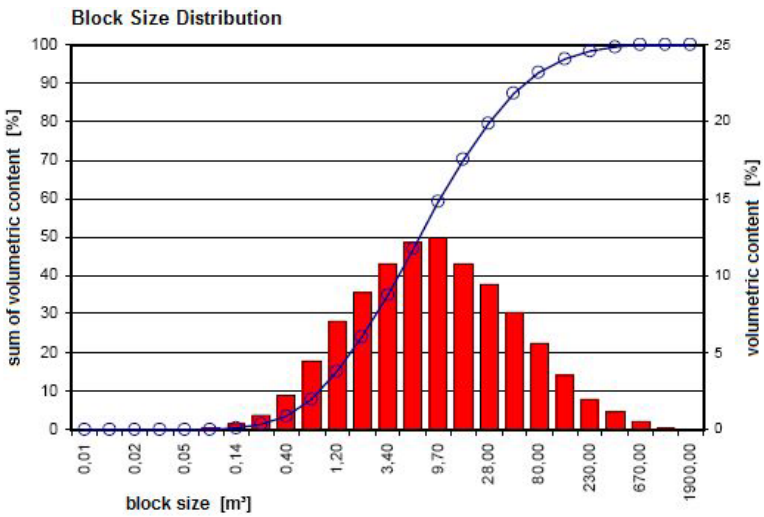

Fig. 2. Block size distribution in the dump (Scheikl, 2005)

Geotechnical investigations

Thanks to the terrain model and aerial photographs made before 2002 it was possible to reconstruct the actual collapse. The results of a parameter study, referring to the friction angle, the cohesion, the density of the rock and the mountain water level, demonstrated a massive influence of the mountain water pressure on a possible collapse of the artificial rock slope.

In the next step the danger of future events was calculated for the railway line and the national road.

Based on the geotechnical data described above as well as a detailed characterization of the rock fall path, considering all parameters required for rock fall-simulations, like slope-roughness, slope-angles as well as tangential and rotational friction-factors, the rock fall-dynamic calculations were performed. The result of these calculations, like the translational and rotational energies, the bounce-heights or the number of passing rocks at a certain section, were calculated for 5,000 rocks in each simulation-run.

The block size distribution in the dump proofed a good indicator for estimated rock fall events.

Risk analyses

Regarding the past events an event frequency of 1/T = 1/40 = 0.025 for large scale events was calculated.

Furthermore a connection between large scale precipitation events and a resulting increase of the mountain water level seems plausible.

For small scale rock fall events the event frequency was calculated with 1/T = 1/2 = 0.5.

Exposition of the railway line: 16 trains per day with an average length of 352 metres.

Probability of damage for a train:

- Whole length	5.38 Km
- Time of presence of a train in the dangerous area per day	0.54 hours
- Probability of presence	2.24 %
- Annuality	40.0
- Probability of an event per day	0.00685
- Damage probability for the railway line	0.01535

Degree of damage for the railway company (referring to the following scenario):

- large scale event
- 2 fatalities
- 5 injuries
- 3 coaches
- 1 engine

The monetary valuation of large scale damage is estimated with about **9.0 to 10.0 million EUR**.

Concept for countermeasures

The main conclusion of the geotechnical investigation was that due to the instability of the slope and the influence of the mountain water level a large scale event is possible at any time, especially after longer periods of rainfall.

The following immediate combined countermeasures were decided:

- Construction of a new rock fall protection dam
  The existing earth dam is about to collapse, therefore a new massive and higher dam was planned to anticipate dynamic stress.
- Clearing of the dump
  About 65000 m^3 rock material must be moved out of the dump to provide space for further events.
- Wire alert system
  According to the rock fall simulation it seems possible in particular cases that rocks will pass over the dump area and the dam. In this case an impact on the railway line and the road is probable. A wire alert system will consequently be installed on the top of the dam comparable to a rock fall barrier. The alarm should then be connected directly to a traffic light and to the railway operator.

Conclusions

The Austrian Railway Company is on the one hand fully liable for the safety of the transported passengers and goods. On the other hand the protection of railway infrastructure has to be achieved in an economic and comprehensible way. As the present case study demonstrates, accurate basic data are necessary for the calculation of risk probabilities and consequently for the planning of countermeasures. In a multitude of cases it is highly dangerous to enter rock fall areas. With new laser scanning methods it is possible to survey the area from safe spots. The highly accurate terrain model serves as an essential data basis for further geotechnical investigations.

The risk analyses help us estimate the risk of an event and the magnitude of the potential damage. This approach is a good way to make the risk of natural hazards calculable. The protection measures need to be dimensioned accordingly and in a comprehensive way. In the majority of cases different types of countermeasures — permanent and temporary as well as constructional and biological — are combined.

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