Multidisciplinary Monitoring Demonstrated in the Case Study of the Eiblschrofen Rockfall

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On July 10, 1999 a first series of rockfalls of initially several thousand cubic metres occurred at the Eiblschrofen massif near the town of Schwaz (Figure 1). Settlement and industrial areas were situated directly in the hazard zone. 56 homes as well as eight commercial and industrial enterprises with about 270 inhabitants were evacuated. On the following day the government of the Tyrol and the Federal Service for Torrent and Avalanche Control arranged for the following measures to be taken in co-ordination with the municipality of Schwaz:

- planning and installation of a measurement system monitoring the detachment zone at the Eiblschrofen and the hillside slopes
- immediate implementation of geodetic measuring profiles at the Eiblschrofen plateau, which were already monitored and measured from July 11/12, 1999 onwards
- feasibility study and detail design for construction measures for the protection of settlement areas and infrastructure (see article by Bayer et al., this journal).

The aims of the monitoring programme which was commissioned and run by the Federal Service for Torrent and Avalanche Control as a result of the rockfall event of 10 July are as follows (Figure 2):

- Regular and continuous acquisition of measurement data for the evaluation of the current hazard situation which from the beginning was backed up by geodetic measuring systems, seismic measuring instruments for the recording of vibrations and observations of the terrain;
- Process analysis of the rockfall event in connection with the structural geological results for the elaboration of possible rockfall and landslide scenarios for the evaluation of the evacuation area and planning of protective measures;
- Approval of working field on account of the daily synoptic evaluation of the measurement results during the erection of the protective structures in accordance with safety at work and as defined by the construction co-ordination law (1).

Heavy and continuous rockfall activities were observed during July 1999. The most severe subsequent rockfall event to date occurred on 20 August 1999. The intensity of rockfall events until October 1999 has decreased but there are still continuous measurable deformations in the observation area (Figures 2 and 3).

The evaluation of results and implementation of measures were initially done daily by

Multidisziplinäre Überwachung am Beispiel Felssturz Eiblschrofen, Schwaz / Tirol

Das Felssturzereignis vom Eiblschrofen vom 10. Juli 1999 zog großräumige Evakuierungen und Betriebsschließungen nach sich. Zur Evaluierung der Evakuierungsmaßnahmen und der geplanten Schutzbauten sowie zur Beurteilung der aktuellen Gefährdungssituation wurde ein Beobachtungs- und Meßprogramm installiert, das sowohl dauerregistrierende und alarmfähige Systeme als auch kontinuierliche Meß- und Beobachtungsprogramme umfaßt. Die Gesamtheit der Systeme wurde von einer zentralen Datenerfassungsgruppe betreut, die der Projektleitung unterstellt wurde.

Die Meßergebnisse stehen den Fachgutachtern, die seitens des Forsttechnischen Dienstes für Wildbach- und Lawinenverbauung im Rahmen der Maßnahmenplanung bestellt wurden, zur Verfügung. Die Beurteilung hinsichtlich der Baustellensicherheit oblag während der Bauphase der Schutzdämme der Datenerfassungsgruppe. Organisation und Systemausstattung ermöglichten eine synoptische Erfassung ereignisrelevanter Parameter und deren kurzfristige Umsetzung hinsichtlich Prozeßanalyse und Baustellensicherheit. Im Schutz dieses Monitorings konnten die Ausführungsarbeiten an den Schutzdämmen, die innerhalb der Risikobereiche erfolgten, gesetzeskonform, sicher und erfolgreich abgewickelt werden.

The rockfall event at the Eiblschrofen on July 10, 1999 resulted in extensive evacuations and closures of enterprises. In order to evaluate the evacuation measures and the planned protective structures, as well as to assess the current hazard situation, a monitoring programme was installed which comprises permanent registration and alarm signalling systems and constant measuring and observation programmes. A central data acquisition team, which has to report to the Project Team, was in charge of these systems.

The measurement results are available to the technical experts who were appointed by the Federal Service for Torrent and Avalanche Control. It was the data acquisition team's responsibility to evaluate daily the construction site safety during the construction phase of the restraining dams. This monitoring allowed the restraining dams to be constructed within the risk areas in accordance with legal provisions, safely and successfully.

Fig. 1 General photo of Eiblschrofen detachment front.

Bild 1 *Übersichtsbild der Abbruchfront des Eiblschrofen.*

the Project Team and the Civil Emergency Board. With the start of the construction phase of the restraining dams and with the availability of all measuring and observation systems, the entire monitoring on site was handed over to a data acquisition team which permanently comprised a geologist, a geotechnical engineer, a computer specialist and a measuring engineer.

The daily evaluation of the situation on the basis of the current measurement results and observations (site inspections and survey flights) was the responsibility of this team which had to report to the Project Team on a weekly basis.

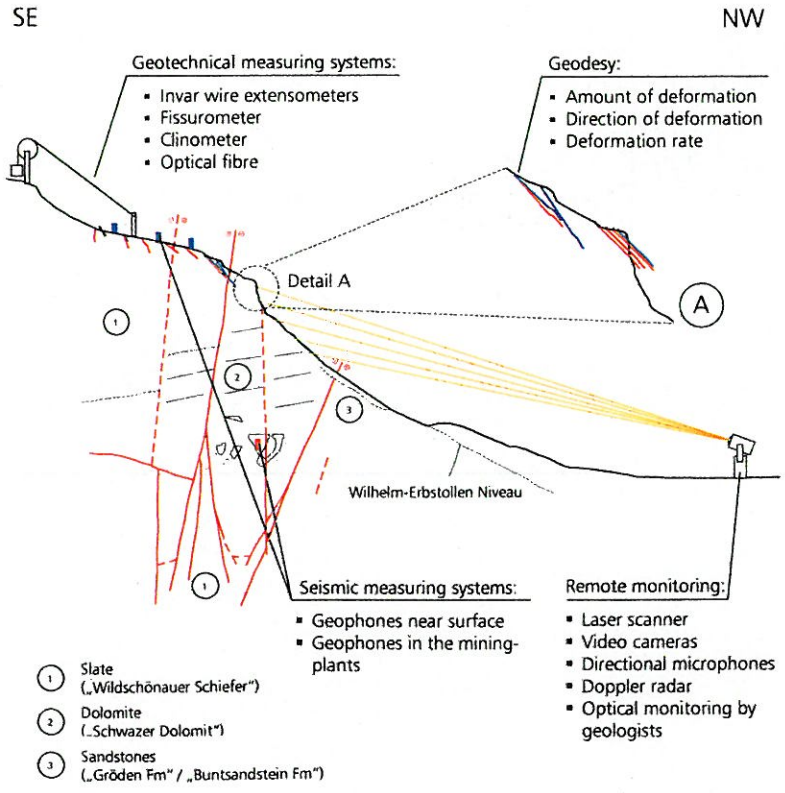

Fig. 2 General profile with depiction of monitoring and deformation vectors in profile section plane.

Bild 2 *Übersichtsprofil mit schematischer Darstellung der Überwachungs- und Meßsysteme sowie der Deformationsvektoren.*

Geological background and chronology of events

The Eiblschrofen massif consists of rock of the Palaeozoic "graywacke zone" and its sedimentary Permo-Triassic cover (see Figure 2). It is a steeply dipping segment of Palaeozoic carbonates, with Permo-Skythian sediments (Bunter Sandstone) at the foot of the detachment wall. On the mountain side, the carbonate massif of the Eiblschrofen plateau is delimited by Palaeozoic slate which also occurs at lateral displacement zones within the carbonate massif. The fabric of tectonic joints in the carbonates of the wall areas is characterised by desk-like planes dipping both towards the mountainside and the valleyside striking parallel to the Inn valley as well as by orthogonal joints. A detailed structural geological survey of the slope was initially done in 1995. Besides the prehistoric and medieval mines in the Eiblschrofen massif there is active mining for Palaeozoic carbonates. The collapse of an underground cavern in 1993 led to a discussion about the influence of the underground mining activities on the stability of the Eiblschrofen. A study had been conducted on the risk of rockfalls in 1995, showing that the Eiblschrofen is at the limit of equilibrium in various sections. The study also showed indications of numerous historical rockfalls. The rockfall of July 10, 1999 was preceded by a local rockfall in the autumn of 1998.

The event of July 10, 1999 lay at the zenith of local seismic activities which were measured by the underground measuring instruments.

Measuring systems and data acquisition

General

Observation and documentation takes place on three levels:

- ➤ Continuous registration systems and continuous observation
  - ⇨ Extensometer, clinometer and fissurometer
  - ⇨ Geophones above ground and underground
  - ⇨ Monitoring of temperature and precipitation
  - ⇨ Video monitoring (fixed system, controllable system)
  - ⇨ Directional microphones for recording rockfall events when there is no visibility
- ➤ Regular monitoring at defined intervals
  - ⇨ Geodetic survey in the area of the plateau behind the detachment front and at mountainside slope areas including GPS survey of selected points
  - ⇨ Thermographic image registration of the detachment walls by means of a thermographic camera for the evaluation of thermal anomalies with reference to the opening of selected joints
  - ⇨ Hydrometric and hydrochemical observation of springs and groundwater occurrences at the portals of mines
  - ⇨ Mapping of joints opening since July 1999 and additional mapping of hillside slopes as well as control flights
  - ⇨ Measurement of deformations at the inaccessible detachment front by means of a laserscanner
- ➤ Investigations and instrumentations with large observation intervals

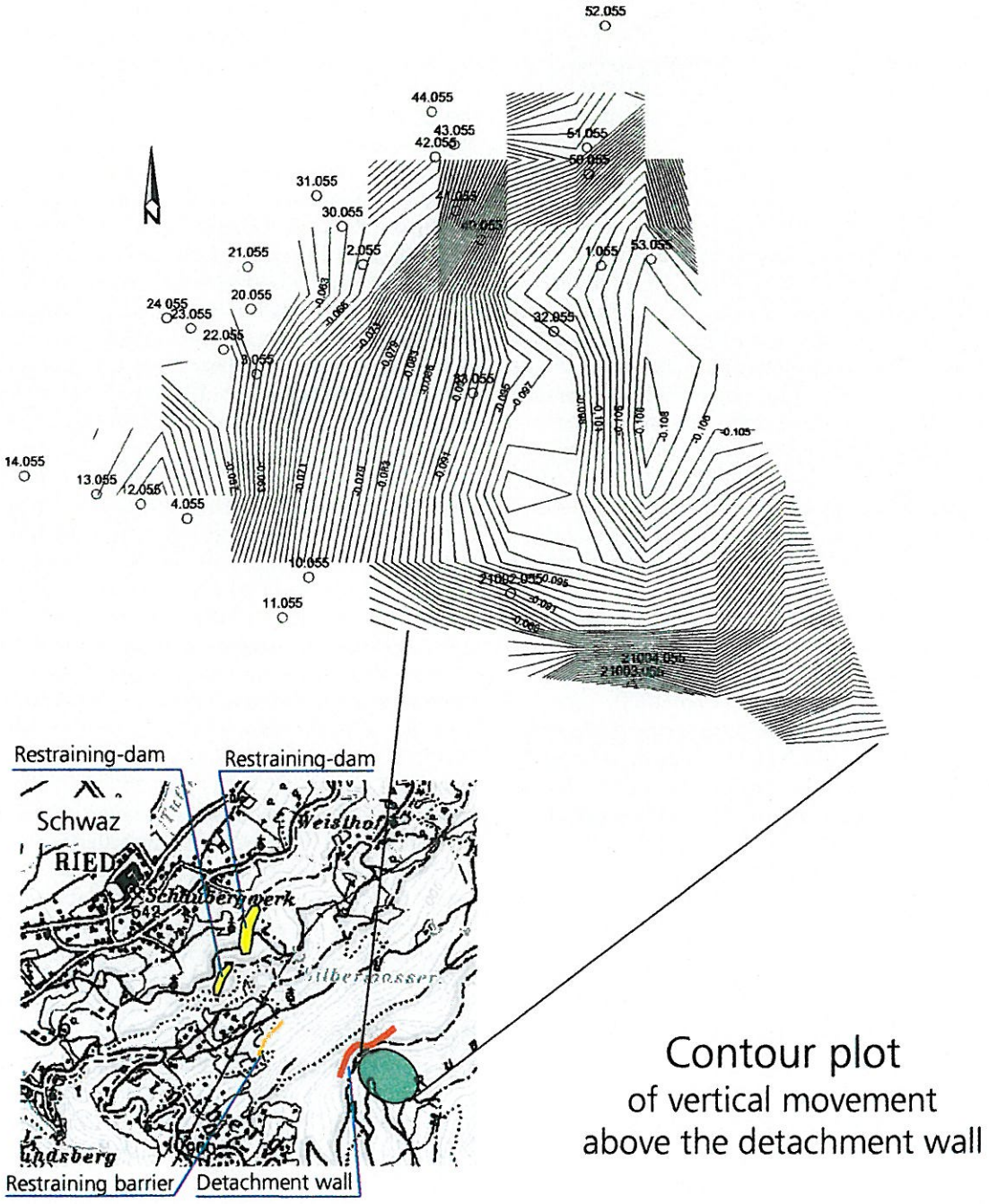

Fig. 3 Contour lines of settlement above the detachment front with sketch map of location.

Bild 3 *Isolinienauswertung der Setzungen am Eiblschrofen-Plateau über der Abbruchfront.*

Table Seismic measuring systems.
Tabelle *Seismische Meßsysteme.*

	VPM	ZAMG	MUL
System Geophone	VIBRAS 5005 or 3004 eleven 3-component geophones above ground	two 3-component geophones (since 9 Oct. 95) mounted at the invert; six vertical geophones (since Oct. 97) at the side walls of the mine	portable seismic system five 3-component geophones in 3 m bore holes
Maximum vibration velocity	currently 5 mm/s		10 mm/s
Scanning rate Trigger type and trigger threshold	1 kHz event triggered 0.02 mm/s	250 Hz	16 kHz three trigger channels
Maximum duration of registration per event	2 s	60 s	0.25 s
Energy supply	mains supply (lightning protection fuse, emergency supply via no-break power supply)	mains supply and/or internal supply for 3 days	mains supply
Control and evaluation	online via monitoring system	daily manually	daily by mining company, manually by MUL

- Structural geological and geotechnical mapping to complement the survey of 1995
- Uncovering the rock surface for observation of cracks in fault zones
- Placing of glass feelers in (pre)historic mine workings.

Seismic measuring systems

In the area of the active mining plant as well as behind the detachment front, three independent seismic measuring systems have been installed (Table). The three systems have different specifications and measuring ranges and complement each other (see Figure 2). The measurements above ground are carried out by the Verbundplan Prüf- und Meßtechnik GmbH (VPM). Underground seismic measuring systems are operated by the Central Institute of Meteorology and Geodynamics (ZAMG) and the Leoben University of Mining (MUL – see table, page 28).

When the data from the three systems are compared, a high correlation is found between the events measured underground and above ground. On the basis of the amplitudes the coordinates of the seismic focus are calculated in the central data office and the seismic events are assigned to the following five categories for the time being on account of the findings gained so far:

- "deep-seated, strong" events (registered by all three systems),
- "deep-seated, weak" events (registered only by the underground systems),
- rockfalls (registered mainly by the above ground system),
- precursors of rockfalls,
- other shallow events.

Geotechnical measuring system

The installation of geotechnical measuring systems aims at recording, in quasi-real time, relative movements in an area which is directly affected by the mass movement. The entire measuring system is depicted schematically in Figure 2.

The measured values are transmitted to a measuring container which also supplies the measuring instruments with power. From the container they are transmitted to the central data office via a fixed connection. The system allows the measured values to be constantly controlled and the alarm to be triggered automatically by establishing tolerance limits. Currently it delivers a series of readings every 300 seconds, but it can be changed to any desired measuring interval in order to meet the corresponding movement tendencies.

Invar wire extensometer

In the area of the Eiblschrofen plateau six invar wire extensometers were installed. The measuring instruments have been prestressed depending on the respective length and equipped with inductive distance sensors with probe tips (Hottinger W20TK). Relative movements are registered with a resolution of <0.01 mm. The measuring range is ±20 mm.

Optical fibre

In the area directly behind the detachment front two optical fibres (SOFO) were installed with an active measuring length of 10 m each. The system is based on the principle of interferometry. The resolution of the measuring system is 2 mm, the measuring range 10 cm in the extension and 5 cm in the shortening.

Fissurometer

To evaluate the effect of the geodetically registered movements on the rock, test trenches were made, equipped with a total of ten fissurometers, with inductive distance sensors (Hottinger W20TK), registering joint openings with a resolution of <0.01 mm.

Clinometer
For the observation of rotation of the individual blocks seven servo-inclinometers (four dual-axis, three mono-axis; Althen) have been installed. The necessary resolution is guaranteed by using high-precision inclinometers with a resolution of 0.1 arc sec. The measuring range lies between ±3° and ±14.5°.

Acoustic-visual monitoring of the detachment front
In the area of the detachment front three directional microphones were installed and coupled to an alarm system which triggers an acoustic alarm in the central data office and at the construction site in case of rockfall events. The visual monitoring of the wall by sentries is supported by video cameras which can be controlled from the central data office.

Data transmission and recording

The continuous observation of the area which is relevant for the short- and long-term development produces measurement data simultaneously and constantly (24 h). These data are collected in the central data office, for processing and graphical representation.

Data are mainly transmitted via online connections which were established through Telecom's own lines. The transport of the data from the self-recording measuring instruments to the central data office is done via data buffer and transmission units. The pertinent receivers which are connected to the server (4 x 16 GB HD) via a central distributor are located in the central data office. The adequately dimensioned buffers guarantee redundant data acquisition. Those measured values which are relevant for the advance warning at short notice are routed via an interface which enables threshold values to be defined. When a threshold value is exceeded an alarm is triggered which leads to the evacuation of the hazard zone at once.

The central data office is used to record online data as well as to collect and process data from periodic measurements (geodesy, thermography). All data gathered are visualised in time-related or space-related graphics.

Conclusion

The monitoring system at the Eiblschrofen guarantees constant monitoring of the events in the rockfall area and in the hinterland through the automatic registration of geophysical/ geotechnical measuring data and the continuous transmission to the central data office in quasi-real time. The data are collected in the central data office together with other, analogous data and events (hydrology, thermography, rockfalls) and are available in synoptically processed form and in a daily update for further evaluation by and as the decision-making basis for the experts, the Project Team and the Civil Emergency Board. Under these boundary conditions is was possible to erect the restraining dams within the hazard area successfully and within a short period, while maintaining a high safety standard and complying with legal provisions.

The data gathered through observation, mapping and monitoring furthermore constitute the basis of the geomechanical modelling of the possible failure mechanisms which are to be used for the evaluation of the relevant models of scenarios.

References

1. Council Directive 92/57/EEC of June 24, 1992 on the implementation of minimum safety and health requirements at temporary or mobile construction sites. Bauarbeitenkoordinationsgesetz, 1999.

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