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Risk Evaluation of the Landslide Lärchberg – Galgenwald (Austria)

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1. Introduction

The Lärchberg – Galgenwald landslide is part of the south-western slope of the Rantenbach valley about 2 km upstream of the city of Murau. The main scarp at 1060 m above sea level of some 70 m length and up to 10 m width has repeatedly given reason for investigations (Pohl 1983, Becker 2001). In April 2001 some rock blocks the size of some cubic meters hit the 50 to 70 m broad zone next to the main road to Murau. Consequently this zone was declared prohibited by the local authorities allowing only residents of the farm "Fritz" to pass on special terms.

As a first step of monitoring 10 wire extensometers and a precipitation measuring device were installed in the early summer of 2001. Additionally, following a coordination meeting between the provincial authorities and the service for torrent, erosion and avalanche control, the federal road administration had a dam of the length of 300m and the height of 5 m constructed for the protection of the main road against rock falls. Due to the results brought forth by the wire extensometers a monitoring and investigation project was initiated by the administration of the Land Styria, department 19B.

2. Geological conditions, morphological characteristics and geomechanical interpretation

Parts of the Rantenbach valley including the slopes of Mount Lärchberg indicate an area prone to landslides due to erosion and melting down of a Quaternary glacier.

The slope is built up by a 300 m thick formation of mylonitic and strongly foliated marbles. These marbles rest on phyllites interlayered by graphitic schists. The border between phyllites and marbles generally dips with 10˚ to 15˚ out of the slope. On top of Mount Lärchberg quarzitic schists of assumed late paleocoic age are found. The whole sequence belongs to the Upper Austroalpine nappe complex (Hermann 2004).

At Mount Lärchberg, three areas of different landslide morphology were mapped (Hermann 2004). These landslides are arranged concentrically and indicate both, different landslide mechanics as well as different landslide activities:

1. A rotational rockslide (activity zone 1), cutting the lower section of the marbles and the basal phyllites, is more likely to show high landslide activity. There, a rockmass of about 900,000 m^3 moves down 0.30 m per year. The main scarp does not follow pre-existing joints and shows features of high activity. Rotation of this zone is indicated by the dipping of the phyllite - marble border into the slope with some 30˚.

2. Low landslide activity corresponds to undulated morphology that is characterized by open cracks and gashes, a tearing trench parallel to the slope dip, uphills and major cut-off structures (activity zone 2). The volume of this zone is estimated up to 10,000,000 m^3.

3. A creeping mass hardly if at all moving at present encloses activity zones 1 and 2. This creeping mass covers the entire north – east facing slope of Mount Lärchberg and extends up to 2.5 sqkm.

These observations indicate that the slope is a system of hard rock lying on a soft base. The competent part of the system consists of a 300 m thick formation of mylonitic and strongly foliated marbles. This block rests on a soft, ductile 140 m high base of phyllites interlayered by graphitic schists. Due to the squeezing out and yielding of the incompetent base material the competent block is subjected to tensile stresses, is therefore fractured intensively and thus shows various zones of mountain tearing and a disintegration into huge blocks (Poisel & Eppensteiner, 1988). Generally these blocks may

1. slide downhill translatoric and upright,

2. form a rotational slide together with the moving base material (internal rotation) or

3. topple downhill (external rotation; most dangerous case leading to sudden rock avalanches).

Murau and its environs adjoin to the seismic active Mur-Mürz fault zone (Lenhardt 1995). There, several earthquakes with intensities up to Io = 6 according the European Macroseismic Scale 1998 (EMS-98) were reported during the last century. The largest earthquake at that fault was reported 1201 with the intensity Io = 9 (evaluated). Thus landslides may be triggered by seismic events.

3. Monitoring Results and their interpretation

Since the early summer of 2001 the changes in width of the main scarp (wire extensometers) of activity zone 1 as well as amounts of precipitation, spring deliveries and air temperature have been monitored. In spring 2002 wire extensometers also in the upper part of activitiy zone 2, an autotheodolit on the opposite slope of the Rantenbach valley and signals (reflectors) in all three activitiy zones were installed. The positions of the signals are determined and saved every six hours and passed on by mobile phone (Gillarduzzi 2003).

3.1 Results and interpretation of wire extensometers measurements

The results of the wire extensometer measurements show that the main scarp of actvity zone 1 is opening up by 30 cm per year mainly between July and December. Statistical investigations by means of multivariate analyses yielded that the displacements heavily depended on the amounts of precipitation. These results can be interpreted as a descending and reascending of the hydrostatic head in the various, partly wide open, joints in the first half of the year. When a certain level of the hydrostatic head is reached, there is an immediate reaction of displacements after each individual rain fall in the second half of the year.

The wire extensometers in the upper part of activitiy zone 2 show decisively lower opening velocities of the fractures than those in activity zone 1. This corresponds to the observations of morphological features in activity zones 1 and 2: activity zone 1 is more active than activity zone 2.

3.2 Results and interpretation of autotheodolit measurements

The observations by means of the autotheodolit (Gillarduzzi 2004) revealed an area of maximum displacements identical with activity zone 1. The distribution of displacements over time is identical with that determined by the wire extensometers. It is highly essential for the assessment of the developments of the various displacements that the signals with the largest displacements have displacement vectors parallel to the slope at the moment, i.e. they have no displacement component normal to the slope.

The uppermost signals show steep vectors, the lowest signals of the base show only small, low-angle dipping vectors. Thus the observations by means of the autotheodolit also indicate that activity zone 1 is a rotational rockslide.

4. Results and interpretation of numerical models

4.1 FLAC and FLAC^{3D}

Analyses by means of the programmes FLAC und FLAC^{3D} (Fast Lagrangian Analysis of Continua) of the ITASCA Consulting Group have shown that at the beginning of the movements only activity zone 1 is moving (Lang 2002). Subsequently the displacements expand, finally affecting all of activity zone 2, which results in a reduced opening of the main scarp of activity zone 1. The positions of the main scarps of activity zones 1 and 2 resulting from the numerical analyses coincide with the positions in reality.

The failure mechanism is determined by tension fractures in the marble and shear zones in the phyllites. That means that a marble block with a volume of up to 6.10^6 m^3 moves downwards on a creeping phyllite block. Finally the complete activity zone 2 (up to 10.10^6 m^3) is affected by this kind of movement.

According to the analyses by FLAC^{3D} the movements of the base at the Rantenbach valley bottom extend to an area of 250 m Northwest and Southeast of the farm “Fritz” in the final state. This corresponds with the results of the geological investigations (activity zone 2). The FLAC^{3D} analyses have also shown that tensile stresses develop not only in slope dip direction, but also in horizontal direction, which might offer an explanation for the tearing trench in slope dip direction in activity zone 2.

4.2 PFC^{2D} and PFC^{3D}

The Particle Flow Code (PFC) of the ITASCA Consulting Group is modelling the displacements and interactions of loaded assemblies of sphere shaped particles being in or getting into contact with wall elements. The particles may be bonded together at their contact points to represent a solid that may fracture due to progressive bond breakage. Every particle is checked on contacts with every other particle in every time step. Thus PFC can simulate not only failure mechanisms of rock slopes (Preh 2004) but also the run out of a detached and fractured rock mass (Roth 2003; Poisel & Roth 2004).

4.2.1 Failure mechanisms

The results of the numerical simulations by means of PFC^{2D} und PFC^{3D} showed agreement with the results of the numerical simulations by means of FLAC und FLAC^{3D} concerning failure mechanisms (Poisel & Preh 2004) and detachment scenarios. According to the results of the numerical simulations by means of PFC as well the failure mechanism is determined by tension fractures in the marble and shear zones in the phyllites originating in the valley bottom. At the beginning only activity zone 1 is in motion followed by the extension of movements to the border of activity zone 2 (Pouzar 2003). Digital extensometers in the numerical models monitoring the main scarps of activity zones 1 and 2 showed decreasing widths of the main scarp of activity zone 1 and increasing widths of the main scarp of activity zone 2. There could not be found any indications for a toppling downhill of huge marble blocks (volume some 10^6 m^3) and consequently for rock avalanches. These results again correspond well with the results of the geological and morphological investigations, which revealed that activity zone 1 can be interpreted as a rotational rockslide.

4.2.2 Run out and closing up of the valley

The PFC models have also shown that there will be no sudden rock avalanches of marble of a volume larger than 50,000 m^3. The slope failure causing a danger for the valley occurs by a continuously sagging downwards of marble blocks on creeping phyllite shear zones with an overall volume up to 10 x 10^6 m^3 (activity zone 2). Thus a damming up of the river Rantenbach by mainly fine grained phyllite masses is possible. The height of the run out cone forming after a sudden shearing through of the activity zone 2 phyllite base is difficult to prognosticate. The PFC^{2D} – analyses yielded a height of some 15 m.

5. Danger scenarios

At the moment there are various indications brought forth by the geological and morphological investigations, as well as by the monitoring results so far and by the numerical models that the Lärchberg – Galgenwald landslide is in an early stage and that there is time to set measures for risk reduction. These conclusions, however, are based on a relatively short time of observation, which means that long term tendencies might be completely different. Thus a long term monitoring is essential.

Both the geological – morphological investigations and the numerical modelling indicate that the essential failure mechanism is to be expected as a sagging downwards of marble blocks on creeping phyllite shear zones. At the time being there are no indications for the toppling of huge marble masses. Sudden rock avalanches of marble of a volume smaller than 50,000 m^3 are, however, considered as possible.

The following danger scenarios have been derived from the considerations described above:

1. rock block falls

2. rock avalanches up to 50,000 m^3
3. run out of activity zone 1 (volume some 900,000 m^3), destruction of the road probably
4. run out of activity zone 2 (volume up to 10 x 10^6 m^3), closing up of the valley, damming up of the river Rantenbach, erosion of the dam, flood wave and/or debris flow catastrophe.

Scenarios 1 and 2 can take place without warning by monitoring results. Warnings by increased block falls and by monitoring results deviating from the general trend are expected for scenarios 3 and 4 (e.g. significant elongation of wire extensometers in activity zone 2).

Numerical investigations showed that single rock blocks are not able to cross the dam. However, the unprotected farm „Fritz“ and the road as well are endangered by single blocks in case of rock block falls as well as rock avalanches up to 50,000 m^3.

Investigations by Lenhardt (2004) showed that an earthquake with an Intensity I=7 has an occurrence probability of 1/174 years and may trigger danger scenario 3. Danger scenario 4 may be triggered by an earthquake with an Intensity I=8 which has an occurrence probability of 1/1,000 years. An estimation of the time till the landslides are triggered by large displacements proved similar results.

6. Measures for Risk Reduction

Economically justifiable measures for risk reduction are:

1. sealing of the roadways surfaces, drainage and diversion of precipitation
   (estimated costs: EUR 150,000.- , estimated durability 10 years),
2. realization of a watershed management project (improvements of the forest situation)
   (estimated costs: EUR 270,000.- , estimated durability 30 years),
3. excavation of a drainage gallery in the phyllite base (estimated costs: EUR 1.5 Mio),
4. excavation of a by-pass tunnel for the Rantenbach river in the opposite slope
   (estimated costs: EUR 10 Mio, estimated durability 100 years),
5. toe weight at the bottom of the slope in connection with a covered tunnel for the Rantenbach river (estimated costs: EUR 25 Mio, estimated durability 100 years).

Measures 1 and 2 reduce the infiltration of water and consequently normally the displacement velocity by half up to one tenth. In the present case a reduction by half is more likely due to the high degree of rock fracturing.

The effectivity of a drainage gallery in the phyllite base is expected to be very low due to the high degree of fracturing of the rock mass. Furthermore the excavation of a drainage gallery in the phyllite base may weaken the toe area of the moving mass and thus may accelerate the slope movements and may trigger a slope failure.

The excavation of a by-pass tunnel for the Rantenbach river in the opposite slope (measure 4) and a possible diversion of the road are merely security measures in case a larger rock mass comes down. They do not influence the slope movements.

A toe weight at the bottom of the slope in connection with a covered tunnel for the Rantenbach river (measure 5), however, may stabilize the slope movements and thus minimize the risk.

7. Risk assessment and conclusions

All numbers given above are rough estimations. Thus an exact risk assessment is not possible at the time being. However, costs for the estimated damage of scenario 4 amount to approximately EUR 80 Mio. Therefore the risk of scenario 4 (damage costs times occurrence probability, which is the reciprocal value of the period of time till the run out takes place) is some EUR 80,000,- per year. The risks of scenarios 1 to 3 could be estimated in a similar way.

Furthermore the risk of scenario 4 can be determined in a relative value. If the displacement velocity can be reduced by half on account of the reduction in water infiltration, the occurrence probability is divided by two as well. The risk without any measures for the reduction in water infiltration is: the costs of damage / number of years till the run out of activity zone 2. If measures are taken to reduce the water infiltration, then the risk is: the costs of damage + costs of measures / twice the number of years till the run out of activity zone 2. Since the costs for measures 1 and 2 are rather low in comparison to the costs of damage, the risk is divided by two due to the measures reducing the water infiltration. These measures are therefore highly economical.

Due to the low effectivity and the potential weakening of the base of the moving mass the excavation of a drainage gallery in the phyllite base is not recommended.

The comparison of the risks of the scenarios with the costs of measures for risk reduction divided by their durability will provide an assessment of the profitability of these measures. All numbers given above are rough estimations and the risks on the one hand and the investment costs on the other hand do not provide a solid basis for the responsible authorities to take decisions about the measures now. Thus occurrence probability, damages, investment costs and durability of the measures have to be determined on more accurate bases (e.g. a long term monitoring programme).

Consequently the following measures are paramount:

- the continuation of the monitoring programme to provide a basis for the assessment of the future development of the slope movements and of occurrence probabilities,
- determination of critical displacement velocities, development of alarm plans,
- realization of a watershed management project (sealing of the roadways surfaces, improvements of the woods) in order to reduce the displacement velocities,
- determination of occurrence probabilities, damages, investment costs and durability of the measures for risk reduction on more accurate bases.

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