Analysis of a large deep-seated creeping mass movement using GIS and DEM

M. Weißflog
Geoconsult, Salzburg, Austria

K. Thuro
Technische Universität München, Engineering Geology, Munich, Germany

Ch. Zangerl
alpS Centre for Natural Hazard and Risk Management, Innsbruck, Austria

ABSTRACT: In the European Alps, several deep-seated creeping mass movements are known, nevertheless most of them are largely unexplored. In this paper, a deep-seated mass movement in the Kauner valley in Austria is described and an analysis with conventional methods is shown to set up a basis for further research.

This paper represents results of a geological mapping exercise focusing on geomorphologic structures. The basement rock consists of paragneisses of the Oetztal crystalline complex. Based on morphological structures and measurements of joints and schistosity planes a suggestion for a mechanical slide model has been submitted.

A computer-assisted evaluation of the structural data collected in the field indicates that no obvious single discontinuity plane is available on which the landslide is able to move. Hence, the intersection of a joint set and the schistosity plane that can work as sliding basis, guides to the conclusion that the Stupfarri landslide type is a very slow rock slide. Finally, some considerations for alternative solutions and recommendations for further exploration have been made.

1 INTRODUCTION

In 1939 Ampferer described slow but very large mass movements, which he found all over the Eastern Alps. Stini (1941) extended this topic under the name “Talzuschub” (so called valley close-up) and turned it into an engineering challenge by drawing attention to the constructive consequences despite the hardly measurable slope deformations. Since terminology varies to a large extent in international scientific literature, the terms “compound sagging” (according to Hutchinson 1988) or “rock flow” (according to Varnes 1978) will be applied for complex large deep-seated, creeping mass movements like the one presented here.

Several such saggings or rock flows are known in the European Alps; nevertheless most of them are largely unexplored. In the following a “Talzuschub”, a deep seated mass movement, is described and an analysis with conventional methods is shown to set up a basis for further research.

Due to the behaviour and observed features, the Stupfarri landslide is referred to here as a very slow rock slide.

2 STUDY SITE

The area is situated in the entrance of the Kauner Valley, Tyrol, Austria (Figures 1 and 2). The Stupfarri rock slide covers an area of 7.2 km² and the height of the slope reaches about
1,760 m (from 1,040 to 2,800 m a.s.l.). Geometrically the mass movement has a width of 1,950 m and a length of 3,700 m, respectively and a preliminary estimation of the volume, based on an equation by Beyer (1987), yields about 0.8 km³.

The area is characterized by a typical Alpine climate zone with long periods of freezing in winter and spring and changeable summers. It receives approximately 820 mm/m² of rainfall
per annum, with maximum snow heights of about 2–4 m. The area is drained by several small creeks, which can dry up in summer. All creeks drain into the main river of the “Kaunertal” Valley named “Fagge”, which is a tributary to the river Inn.

3 GEOLOGICAL AND STRUCTURAL SETTING

The study site area is situated within the poly-metamorphic Oetztal-Stubai crystalline complex of the Austroalpine units. In the study area the crystalline complex is composed mainly of layers of paragneisses, surrounded and interstratified mica schists, orthogneisses and amphibolites (Figure 3). After deglaciation several slope instabilities occurred in this region as a result of stress redistribution by valley steepening and deepening within the low strength paragneisses and schists. The Stupfarri rockslide system is located within an extensive paragneiss complex which is framed by amphibolitic rock masses. Generally, the paragneissic series are characterized by a variable content of plagioclase, biotite and quartz. A detailed map of the region can be found in Weissflog (2008).

The foliation is folded and the dip direction ranged from NW to N with a dip around 30°. Based on individual outcrops and systematic scanline measurements, three major joint sets were distinguished of which one joint set (K1 096/51) is dominant (Figure 4). Some of these

Figure 3. Geological map of the study area with underlying digital elevation model as hillshade. The Stupfarri rock slide is framed in red; the surface rock is drawn in lighter colors.
prominent joint sets were also found by Zangerl and Prager (2008) on the Kreuzkopf rockslide system located in the higher Kauner valley. Several brittle fault zones were measured near the “Kaunergrat” ridge. One more distinctive fault zone strikes NE-SW and dips with a mean angle of 50° towards SE.

4 GEOMORPHOLOGICAL OBSERVATIONS

Generally, this study focused on the mapping of geomorphological and lithological features of the rockslide system. A major part of the area has previously been mapped lithologically by Zangerl (1997). Therefore, a primary aim of the current field work was related to the study of geomorphological key-features of the landslide i.e. the boundaries of the rockslide mass, different parts of the sliding mass, uphill facing scarps, extensional cracks and other features (Figure 5).

The digital elevation model (hillshade) in Figure 7 impressively shows the main but also secondary scarps which point to several individual sliding masses. A major brittle fault zone defines the upper part of the rockslide boundary, as detailed above. At the main scarp area a double ridge formation can be observed (Figure 6). Considering all facts the rockslide has slid at least more than 200 m downhill in the main scarp region. At the toe of the slope a large bulge formed and it seems that the valley was closed in the past. This hypothesis is confirmed by the accumulation of backwater sediments upstream of the valley restriction and the meander-like behaviour of the river “Fagge”. Moreover, as shown in Figure 7 there are several linear structures in the upper part of the slope transverse to the slope line. These extensional cracks have uphill facing scarps with aperture widths up to 10 m and depths up to 8 m (Figure 7).

Within the mass movement the gneisses are highly fractured and disaggregated, there are only a few small areas with relatively intact rock mass. Most of the surface is covered with talus and glacial till deposits. Typically there is a lack of surface water within the moving area. In the village of Kaltenbrunn streets and buildings, especially the little church, have been damaged by at least several tens of centimetres of slope deformations over the last few decades.

5 GEOLOGICAL AND KINEMATIC MODEL

All considerations concerning the underground geometry of the deeper slope are based on surface investigations, since no boreholes were made and up to now no geophysical investigation
were performed within or close to this area. Furthermore due to the slow deformation velocities no deformation measurements were available. Therefore the geometric and kinematic model presented herein is only assumptive and still possesses a high degree of uncertainty.

Given the lack of deformation measurements, the activity is still unknown. Because of damage to roads and some buildings in the lower part of the rockslide, it is suspected that movements are still proceeding at least in this area. The degree of internal deformation may result from dissimilar movement rates by individual sliding masses as described above. Based on observations at the scarps, the large slope displacement and for geometrical reasons, the depth of the mass movement may reach 200–300 m. Another consideration is the possibility that the movements fade away at depth and that no discrete sliding zone exists.
Due to the adduced arguments above, this mass movement can be characterized as very slow rock slide or rock flow (UNESCO 1993) depending on the constitution of the surface of rupture. Figure 8 gives a schematic longitudinal section of the Stupfarri rock slide and shows the overall dimensions given in Table 1. The characteristic of the surface of rupture is presumed.

Of course this is a first estimation and has to be verified by subsurface investigations. The results of the structural analysis showed three distinct joint sets. The schistosity of the

Figure 7. Airborne laser scanning based digital elevation model (hillshade) showing geomorphologic features of the Stupfarri rock slide (e.g. different parts of the sliding mass, boundaries, uphill facing scarps, extension cracks). Reference: LIDAR height model, Tyrol government, geoinformation.
Figure 8. Schematic longitudinal section through the Stupfarri rock flow. Domain of spreading shaded in light grey, domain of bulging shaded in dark grey color. Abbreviations see Table 1.

Table 1. Dimensions of the Stupfarri landslide.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Height of the landslide H</td>
<td>1700 m</td>
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<tr>
<td>Total length L</td>
<td>3700 m</td>
</tr>
<tr>
<td>Length of displaced mass L_d</td>
<td>3500 m</td>
</tr>
<tr>
<td>Length of surface of rupture L_r</td>
<td>3450 m</td>
</tr>
<tr>
<td>Travel angle</td>
<td>28°</td>
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<tr>
<td>Depth of displaced mass D_d</td>
<td>220 m</td>
</tr>
<tr>
<td>Depth of surface of rupture D_r</td>
<td>250 m</td>
</tr>
<tr>
<td>Width of displaced mass W_d</td>
<td>1950 m</td>
</tr>
<tr>
<td>Width of surface of rupture W_r</td>
<td>1950 m</td>
</tr>
</tbody>
</table>

Figure 9. Left: Block model of joints sets with generalized surface. Schistosity plane in grey lines, slope plane in green. No single discontinuity is able to form the plane of rupture. Right: Schematic sketch showing the possibility of sliding on the intersection of K1 and the schistosity plane.
paragneisses is predominately dipping moderately to NW or N. Thus the joint sets and the foliation are orientated transversal to the slope and therefore unfavorably in order to promote slope failure due to in-plane shear (Figure 9, left). Nevertheless it would be possible, that the intersection of of K1 and the schistosity plane is used for sliding (Figure 9, right).

6 CONCLUSION

In this field study it was possible to obtain a first impression of the character of the Stupfarri landslide. Field investigations and data analysis could confirm the hypothesis of a large-scaled deep seated mass movement (also referred to as compound sagging or rock flow). Intensive field mapping helped to outline the mass movement on the surface and to make presumptions about subsurface structures and geometries. GIS-based analysis of the field data provides an initial geological–kinematic model of the rock slide system. It is not clear to what extent the rock mass structures determine or influence the mass movement. A relationship between the structural inventory and the failure mechanisms of the rockslide was found (Figure 9), since the intersection of discontinuities could work as a basis of sliding.

By processing the data within a geographic information system, a basis for further investigations was created. The next step may focus on a survey of the underground (by seismic survey and drilling) to reassess the suggested assumptions linked to the sliding process and to quantify them if possible. A long-term geodetic monitoring of the slope’s surface could also shed light on its activity. Such data could be interesting for the design of constructions sensible to deformation on the one hand and for scientists to gain important information on this common type of mass movement in Alpine regions on the other hand.

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