MONITORING OF A LANDSLIDE IN VORARLBERG/AUSTRIA

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Abstract

Landslides and rock falls are disastrous processes of mass movements in alpine regions. Monitoring slowly creeping movements and their velocity variations enables the prediction of future risks. An interdisciplinary research-project located at Ebnit (Vorarlberg/Austria) deals with the combination of geologic, hydrologic and geodetic examinations. The project-partners need the topical kinematic behaviour of the slope to refine or to adjust the mechanical model within an interactive procedure. In summer 1995 a combined deformation network based on GPS and terrestrial measurements was installed and observed nearly quarterly. Until the end of the project in December 2001 fifteen epochs had been measured. The analysis results show a significant behaviour of the movements towards the valley. Another interesting result is the seasonal dependence of the movement direction in the wooded area of the slope.

1. Introduction

The Alps are a region where very often disastrous processes of mass movements take place such as landslides or rock falls. Particularly the fast movements mostly cause considerable damage to persons or objects. Slowly creeping movements are not so interesting for the general public, but often they are the preliminary stage of such disasters. An example for such a slow movement is the village Ebnit in Vorarlberg/Austria. Ebnit is situated about 10 km south of Dornbirn in a height of approximately 1100 m. Slopes with various geological characteristics and a different hazard surround this place.
In the framework of an interdisciplinary research-project a lot of geologic, hydrologic and geodetic examinations were realised. The aim of the geodetic project was to get the best possible information about the actual kinematic behaviour of the slope. Our project-partners use this three-dimensional geometric information to refine or to adjust the mechanical model within an interactive procedure. The examinations on this slope might also be used as a model for other creeping slopes in the alpine regions.
In summer 1995 the observations started with a combined deformation network in the form of GPS measurements and terrestrial measurements in the wooded area. After the implementation of the network by permanent point marks, the network was measured in time intervals of three months in summer and six months in winter. Until the end of the project in December 2001 fifteen epochs had been measured. The examination field has been divided into 5 different areas (Fig. 1). The "Heumöser Hang" as the largest hazard area is the object of this paper.

2. Characteristics of the "Heumöser Hang"

The west-east orientated "Heumöser Hang" has an extension of about 1800 m in east-west direction, 500 m in north-south direction and an altitude difference of about 400 m. Two buildings and a small holiday village as well as a skiing lift are situated on the slope. The surrounding bedrock and also the top area of the "Heumöser Hang" consist of upper cretaceous sediments, mainly marls and limy marls (Fig. 2). These layers belong to the Amden, Wang and

Leimern groups and have a low to very low hydraulic conductivity (Zehe et al., 2003). The bottom of the slope in the east has been eroded by the Ebnit River down to the bedrock. The "Heumöser Hang" itself is built up of glacial till, which is overlaid by scree and weathered scree. Inclinometer measurements show a weak but clear deformation zone between 7.5 m to 8 m depth. Geoelectrical investigations reveal a total depth of glacial till and scree material on top of the marls of more than 60 m in the central part (Van den Ham and Czurda, 2002). The soil distribution and the vegetation properties are crucial for understanding the infiltration behaviour of the slope. The "Heumöser Hang" is divided into a gentle to steep upper part, a flat area in the middle and a steep lower part. It is drained by three deeply cut creeks that contribute to the Ebnit River.

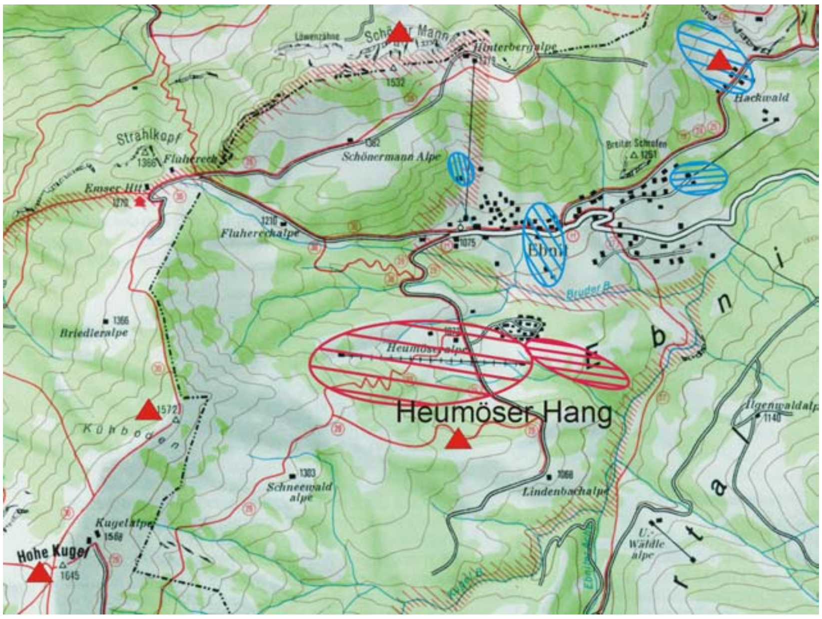

Fig. 1 Deformation network Ebnit with the reference points (triangle) and the 5 examination areas ("Heumöser Hang" red)

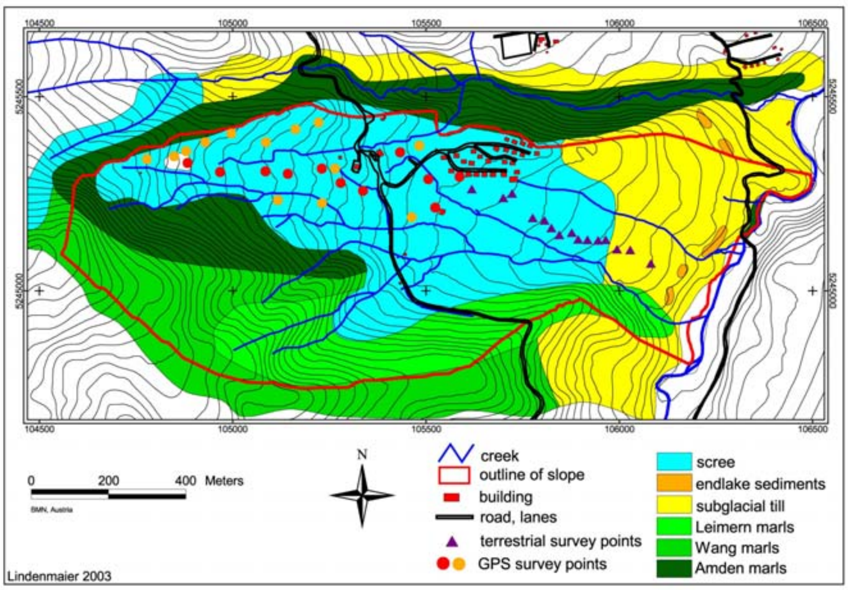

Fig. 2 Geology of the „Heumöser Hang", GPS and terrestrial measurement points

3. Geodetic network

In the beginning, the GPS deformation network consisted of 5 reference points which had been placed on the surrounding mountains (Fig. 1) and 11 object points on the "Heumöser Hang". In 1996 the network was completed by a traverse with 16 points in the wooded area and in 1998 by 13 GPS points (Fig. 3). The traverse was observed by classical geodetic survey techniques. The GPS points were marked by suitable rocks or concrete blocks with special centering devices. The traverse points were marked by tubes. The reference network was observed in the static mode and the object points in stop and go mode in at least 3 sessions (Howind and Schmitt, 2001). Between 1998 and 2001 the network was measured at regular intervals in May, August and November.

The point coordinates were calculated for different epochs by least-squares adjustments (Mierlo and Illner, 1998). In all epochs the achieved accuracies for the GPS coordinates are approximately 6 mm in the plane component and 10 mm in the height component. The achieved accuracies for the traverse coordinates range from 8 mm to 30 mm for both components. These differences had been caused by the bad soil conditions as the wooded area around the traverse is very humid most time of the year.

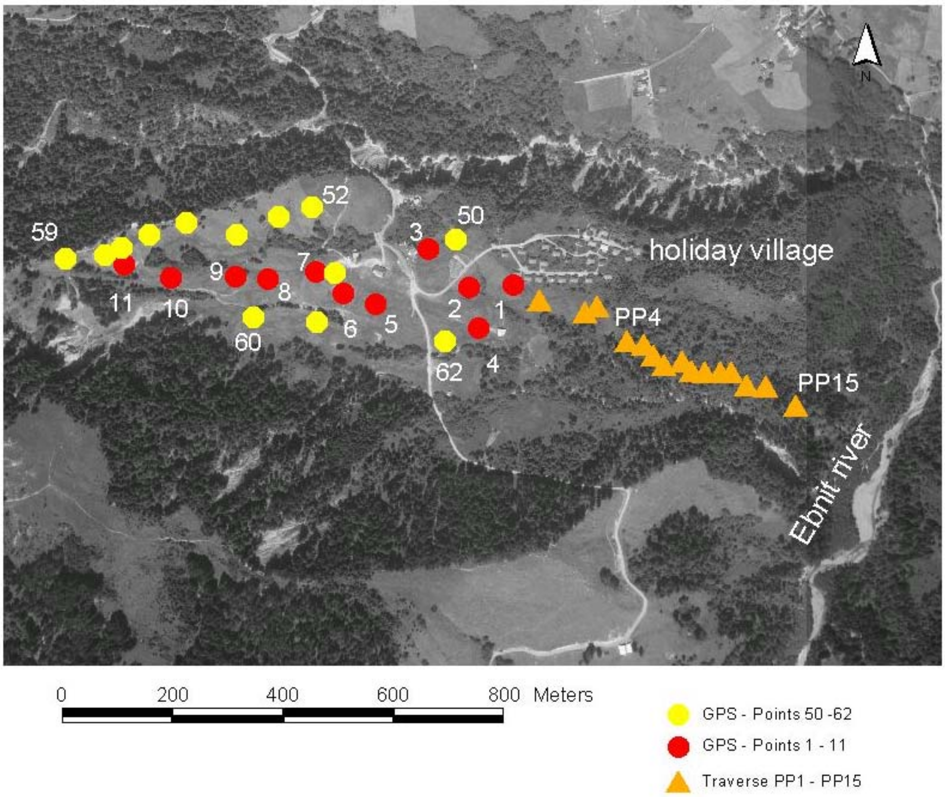

Fig. 3 "Heumöser Hang" with GPS and traverse points (source: Orthophoto, Bundesamt für Eich- und Vermessungswesen, 1990)

4. Results of the deformation analysis

The deformation analysis has been carried out separately for plane coordinates and heights. For the deformation analysis between the epochs the institute's coordinate-related software packages CODEKA1D resp. CODEKA2D had been used (Nkuite, G. and Jäger, R.). Within the deformation analysis the so-called object points in the moving area had to be distinguished from the points in the surrounding area which could be considered as being stable.

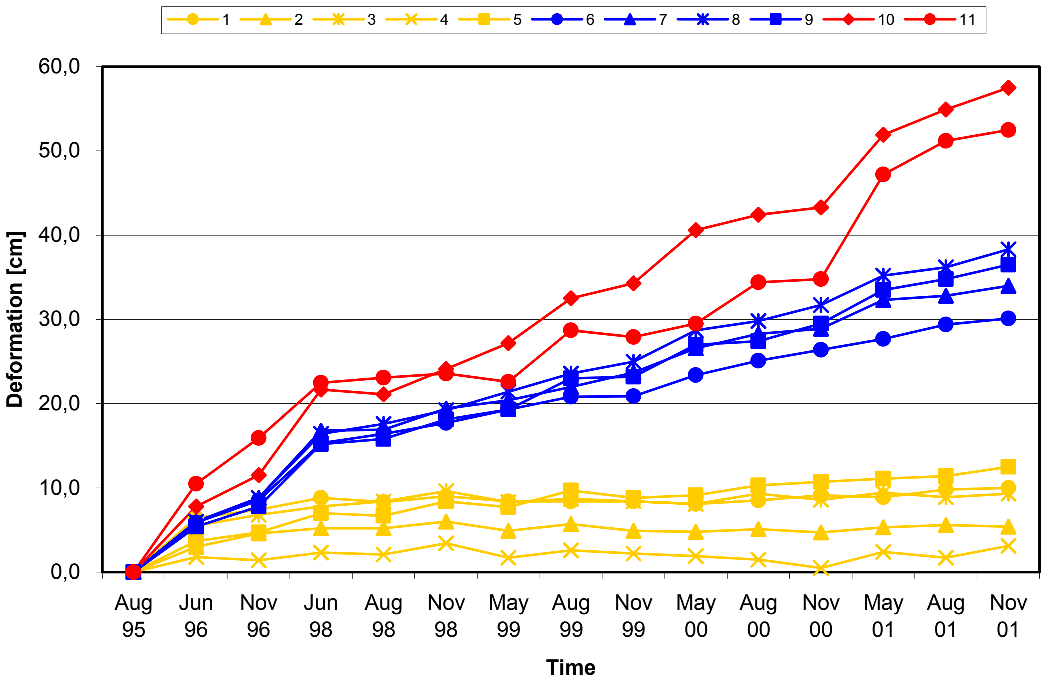

Fig. 4 Deformation analysis “Heumöser Hang” points 1-11, all epochs, horizontal displacements

4.1 GPS measurements

Between August 1995 and November 2001 fifteen epochs of measurements were taken. So the points 1–11 were observed about a total period of 75 months. These points represent the movement behaviour of the slope from the top to the holiday village (Fig. 3). The deformation analysis lead to a classification in 3 groups of horizontal motions (Fig. 4). The points 1–5 were located in the flat area of the slope between the road and the holiday village and they do not show any significant movement. This becomes evident by an average velocity of 1.5 cm/year. A constant increasing of 5.5 cm/year could be observed for the points 5–9. These points correlate with the topography of the western part of the slope which is gentle to steep. An irregular point movement can be seen at points 10 and 11 (Fig. 4) which are situated in the upper steep part of the slope (Fig. 3). However, it is not easy to find out a reason for this different behaviour as a result of rainfall events and soil distribution. In May, 1999, the highest rainfall event has been noticed since the beginning of recording (Zehe et al., 2003). This event may explain the increasing displacement within the measurement of August 1999 (Fig. 4). But there has not been an explanation for the increasing displacement in winter period of November 2000 to May 2001 until yet.

The results of the vertical movements showed considerably smaller displacements than the respective horizontal movements. The points 4 and 1 do not show any significant displacements whereas point 11 represents the maximal value with 18 cm.

To get more extensive information about the movement in April 1998 the points 50-62 were added to the object points (Fig. 3). Figure 5 displays the results of the deformation analysis between the fourth and the last epoch. The horizontal displacements are represented by difference vectors with confidence ellipses at their ends. The horizontal motions correlate again with the direction of the largest slope gradient. On the northern part of the “Heumöser Hang” the points 52-55 do not show a significant displacement. This seems to be in context with a very high stableness of the steep north exposed slopes (Schneider, 1999). Another conspicuous behaviour was recognized at point 58, which also had no significant displacement in horizontal and vertical movements although this point was placed in the steep area. In this connection a possible reason may be the low thickness of scree in this part of the slope. In the flat area the points do not show any movements except of point 50 which moved about 7 cm in the last two epochs. It could be observed that the area around this point was getting more and more wet.

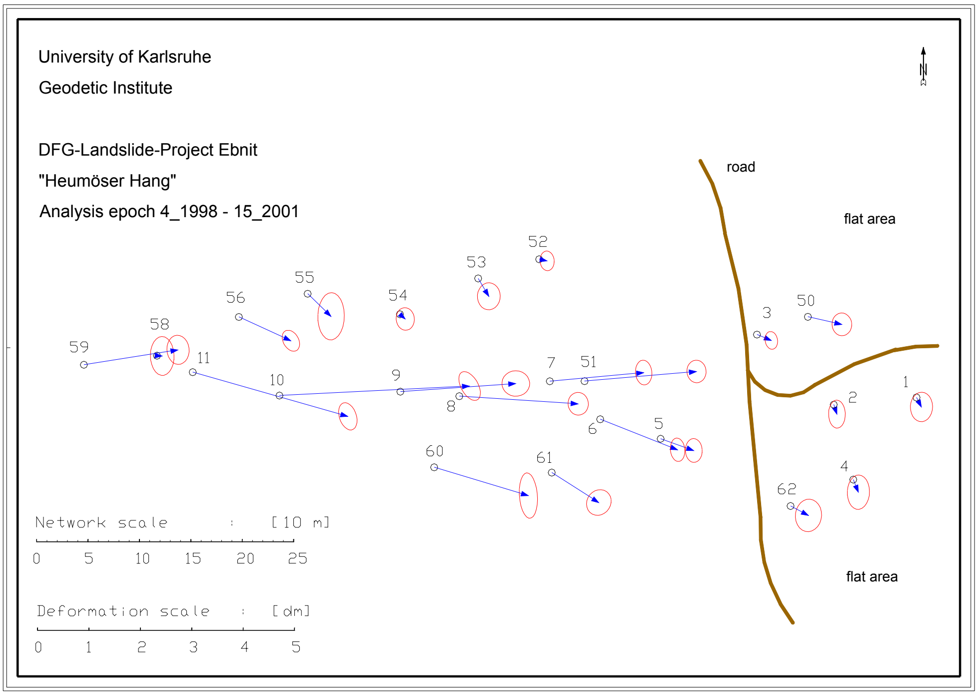

Fig. 5 Deformation analysis "Heumöser Hang" 4th and 15th epoch, points 1-11 and 50-62, horizontal displacement vectors with their confidence ellipses

4.2 Terrestrial measurements

The eastern GPS point 1 was at the same time the starting point for the traverse consisting in the primary form (June 1996) of 16 points (Fig. 3). After 29 months the closing point PP16 showed a displacement of more than 6 m in direction of the Ebnit River. In spring 1999 it got into a slide movement and was lost. The deformation analysis over the time of 65 months lead again to definite results. The points PP1-PP3 which are situated in the same flat area as the GPS points (1-4) do not show a significant behaviour. All further points show a clear horizontal displacement with a maximal value of 123 cm (PP12) and a velocity with a maximal value of 23 cm/year. The vertical movements correlate with the horizontal movements.

Another interesting aspect of the examination's results is the season-related behaviour of the traverse. Figure 6 displays a vector diagram of the points PP4-PP15. Since May, 1998, the object points were measured in equal epoch distances, so there are summer-, autumn- and winter epochs. Figure 6 shows the deformation vectors pointing nearly to the same direction. In the summer epochs (green) the direction of the deformation vectors points preferably to the south, in the autumn epochs (red) to the north-east and in the winter epochs (blue) to the south-east in the direction of the largest gradient. But this regularity could not be validated by the last two epochs as the direction changed. The vectors of the summer epoch 2001 do not point as expected to the south but to the north-east as those of the autumn epoch. The last autumn epoch displays the same behaviour. Instead to the north-east the motions point to the south. A correlation for this season-related behaviour with hydrological and climatological events could not be found, what must probably be ascribed to the different timescales.

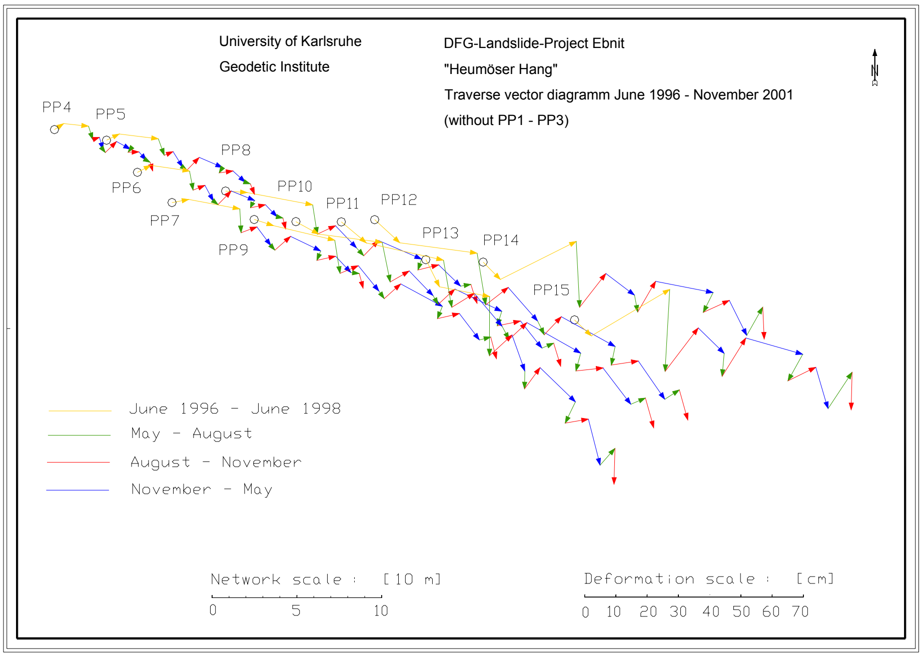

Fig. 6 Deformation analysis traverse (PP4-PP15), 14 epochs, horizontal displacements, vector diagram

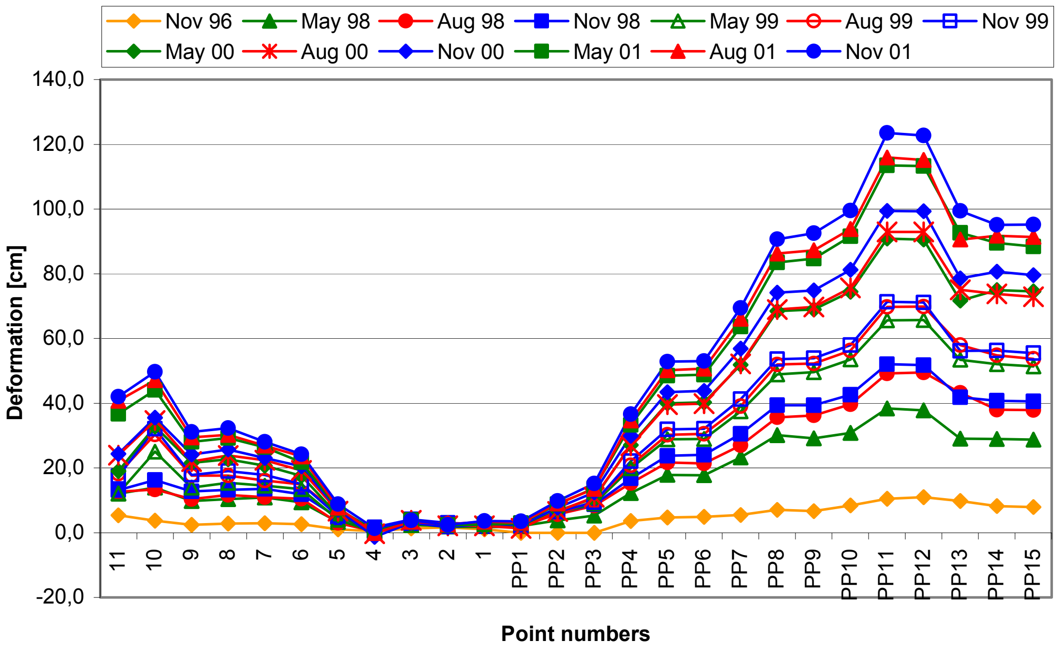

Fig. 7 Horizontal deformation characteristics of "Heumöser Hang", 14 epochs, GPS points (1-11) and the traverse

5. Conclusion

It could be shown that the aim of the geodetic monitoring system, to identify accelerations in landslide movements, could be reached. The achievable accuracies were sufficient to verify the point movements. With the available data a confident and significant result could also be

obtained. The deformation analysis has shown that the "Heumöser Hang" is separated in 3 kinds of movements. Figure 7 displays an overview of the horizontal movements of all epochs from the top to the bottom of the slope. The structure of the slope can be clearly seen. The movements in the upper area show mean values while the flat area around the holiday village can be seen as relatively stable. In the eastern part the movements accumulate to nearly a triple value of the upper slope points. It could also be demonstrated that there is a constant behaviour during all epochs.
Even though the flat area around the holiday village can be seen as stable, a possible hazard should not be neglected. This might be indicated by the already existing building damages in terms of cracks and broken water pipes, for example. Due to the erosive effect of the Ebnit River the edge of avulsion could move to the west and - combined with sliding mass movement from the western slope - hazard the holiday village.
It has become evident that it is not sufficient only to collect and analyze movement rates, but that a cooperation of different disciplines can help to provide a disaster prevention.

Acknowledgement

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