New methods of investigation and controlling of landslides

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Introduction

The prerequisite of optimal investigation and controlling of landslides is the knowledge of its kinematics. 5 types of mass movement can be distinguished by their different kinematic behaviour:

- Falling
- Toppling
- Sliding
- Spreading
- Flowing

New methods of landslide research and monitoring are presented:

- Natural electromagnetic pulse radiation
- GPS-based online control and alarm system

A new feature of the second method is the wireless transmission of data. Case studies show the successful application in landslide areas. At least a rock fall simulation program for risk assessment and dimensioning of rock fall barriers is presented.

Electromagnetic Pulse Radiation:

Recently, a geophysical method for detecting landslide areas of the types sliding, spreading and flowing has been developed. It is based on the registration of natural electromagnetic emissions. The accuracy of this method was checked by comparing it with common investigation techniques at well known landslide areas in Germany. All these areas were investigated thoroughly in the past by visually recognizing and mapping displacement phenomena, air-photo analysis, geodetic surveys and other investigation methods in the subsoil environment such as applying inclinometers or extensometers.

The new method can be used on the surface and in boreholes to identify not only landslide areas but also volcanic and earthquake prone zones.

The instrument, the so-called Cereskop, can be operated by just one person.
The measured data are stored in the instrument and can be downloaded to a PC.

The electromagnetic emission originates in microscopic scale. The relaxation of the molecular lattice of minerals leads to the emission of electromagnetic radiation. When a deformation is setting in the electrical output will increase rapidly.

Tests have shown that this method is capable of recognizing and distinguishing landslide areas as good as usual investigation techniques. This can be demonstrated by case studies (fig. 2-5). A second result is that the stress conditions can be different in landslides. Sliding planes can be monitored in boreholes and the landslide body can be defined in the depth. Mapping of slope failures in Flysch rocks of the Carpathian mountains proved that different types of landslides were registered by characteristic curves of stress rates (VYBIRAL et al. 1995). Four of the typical indications are illustrated in fig. 1. Narrow zones of anomalous stress rates represent a sliding surface (shear planes), broad zones indicate deformations of a flow regime.

![Graphs of stress vs depth](image)

**Fig.1:** Different types of slope movements in flysch rocks, Slovakia (VYBIRAL et al. 1995 in OBERMEYER et al.)

Under natural conditions the electromagnetic field is a picture of the mechanical field of tensions.
Case Study:

Landslide at a slope at Mosel valley, near of Traben-Trarbach

An old landslide area on a steep slope is located in a loop of river Mosel near of Traben-Trarbach. Because of permanent slope movements it has come to a bulging out of the shore line. This is a very typical phenomenon for landslides at the Mosel valley. The bulging out could be easily recognized at topographic maps or air-photos. The subsoil consists of Devonian slates.

Corresponding to that it was difficult to build the road section of B 53 at the foot of this landslide. Many investigations (air-photo analysis, landslide mapping, geodetic survey) were conducted to build this road section. A velocity rate of slope movements up to 0,06 mm/d was proved.

Profiling by Cereskop along this road section should show, where the highest rate of stress can be find. In graphical analysis of this profile in fig. 2 it can be seen that the course of energy level is very anomalous along a distance of 480 m. There are definite zones with high energy rate between 60 m and 540 m (LAUTERBACH 2000).

The maximum rates of energy (260-360 m) correspond highly to geodetic survey. The delimitation of the landslide area by Cereskop investigation is wider than monitored with former investigations (fig. 3).

The concentration of stress is situated in the middle of the landslide body.

Case study:

Landslide at a motorway embankment, near of Quirnbach/Palatinate

In a section of an embankment of the motorway A 62 Landstuhl-Trier immediately north of Quirnbach/Palatinate extensive deformation has been appearing repeatedly in cruising radius
of the line of construction at top of the embankment and in the area of the cemetery below foot of the embankment. Also the country road L 352 is affected by deformation. The damages are explained by landslides of type sliding. Thereby the embankment, which is raised on a slope, and the uppermost beds of subsoil have been moving downhill. The subsoil consists of variable-solid alternations of mud-, silt- and sandstone (Quirnbach beds, Lower Permian), which dip subparallel to the slope. These rocks are well-known to be susceptible for landslides in the Lower Permian of the Saar-Nahe-Basin.

It was shown by geodetic survey, that the movements have been their maximum rates in a section which is crossed by a side-valley (fig. 4). With that the maximum rates of displacement (1.6 cm/a) were detected in the section of largest thickness of the embankment. Also measurements with spies at a retaining wall have showed large displacement vectors.

The investigation by Cereskop at the foot of the embankment shows a 110 m wide section with very high stress rates in this area (fig. 5). This zone is located exactly below the section of motorway with highest thickness and largest displacement velocity (Lauterbach 2000).

Case study:

Pünderich at the river Mosel

The electromagnetic investigation method was carried out and a new controlling method is installed. The emplacement of the riverbank, again, indicates the movements within the slope. An important railway runs at the base of the slope. Under construction of the railway the landslide was already known and the deformations of the slope were minimized by draining measures. During the last decade the movements where reactivated and even accelerated. The average rate of movement is about 3 to 8 cm per year. The tracks were displaced and lifted
allowing some deformation but no rupture. The depth of the landslide was evaluated by geodetic investigations, which was afterwards confirmed by drilling.

The measurements with the Ceresop have lead to the results that the sliding area is larger than expected which is similar to Trarbach. The sliding plane is situated 30-35 m below the surface. With the extensometers installed in the boreholes a permanent control of the mass movement could be ensured. The new method is the digital data transmission. Data can be transmitted by telephone into the PC. The alarm is applied when a certain value of danger is overstepped and is carried out by telephone call.

**GOCA-System**

Another new method of controlling all types of deformations at slopes is the GOCA-System (GPS-based).

The GOCA-system (GPS-based Online Control and Alarm System) can be used to on-line monitor geological and geophysical processes. This system uses GPS (Global Positioning System) sensors that measure horizontal and vertical displacement. From that data the GOCA-system derives, the 3 dimensional displacement, the 3 dimensional velocity and the 3 dimensional acceleration of the monitored site.

This method will be used to monitor the movement of a road dam construction of highway A62 near Quirnbach (Germany).

The GOCA-system consists of GPS-receivers, data modems, the GOCA-central unit and the software that is necessary to operate all hardware and retrieve all measured data.

In the GOCA-central unit all measured data are combined and stored. The GOCA-central can be an ordinary PC (personal computer) with the hardware control software MONITOR, the GOCA-deformation analysis software, a wireless modem unit for the registration of GPS-information on local GPS-receivers and the warning software PCAnywhere. The hardware on survey and reference points consists of a GPS-receiver and a GOCA/NMEA-box. The system needs at least 2 fixed reference points outside the slide area. The sensors can be placed at any desirable location within the slide area. Therefore it is possible to monitor any kind of slope or industrial structure for movement. The central unit can be placed either inside or outside the survey area.

The retrieval of horizontal and vertical displacement data is done electronical by the GOCA-central. These data can then be accessed from another location by means of a modem connection on a normal telephone line.

This way it is possible to constantly monitor the deformation of slopes. The deformation is measured by software, which makes use of critical values to analyse if there has been a certain movement of the sensors. These critical values have dynamic character and will only trigger
an alarm if there is a sudden change in the movement parameters. This way no unwanted alarms are triggered.

Initially the critical values can be set to measured movement rates from similar slide areas or to corresponding geodetically measured movement rates. After a test measurement period of several weeks the values can be adjusted to the actual movement rate of the particular slide.

In case of an alarm the following can happen:

- A telephone or cellphone call stating a pre-recorded message
- A SMS-message
- A fax message

It is also possible, if wanted, to sound a sirene or activate a flashing-light.

**Rockfall simulation program**

Last but not least a new rockfall simulation program for risk assessment and dimensioning of rockfall barriers will be presented. This simulation program for PC can not only support the design of rockfall barriers, but is also a valuable tool in evaluating the risks of rockfalls. The rockfall paths are calculated in two dimensional sections. All relevant surface and rock block data are considered. Up to 10,000 rocks can be simulated by a single run. The results can be analyzed by a wide range of different statistics. Barriers can be installed at any location (SPANG 1988).

Compared to the historical and the empirical approach, as described by SPANG 1987 rockfall simulation has considerable advantages. The historical approach assumes no rockfall risks at locations, where rockfall never had been observed. Thus neither deterioration of stability conditions nor new slopes can be assessed. The empirical approach relies on rockfall tests, which might endanger the structures to be protected or require the interruption of traffic lines. It can be combined with the historical approach and can evaluate rockfall tests on a sound scientific base.

In a first step the existing structures had to be finally assessed and if required, the location, height and energy consumption of additional rockfall mitigation measures had to be determined. This assessment was done by ROCKFALL. Input data are shown by table 1. The variation considers the degree of uncertainty in the determination of the specific parameter.
Table 1: Input data; surface types: 1 rock surface, uneven; 2 debris cone, scarcely wooded (SPANG & KRAUTER 2001)

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Dimension</th>
<th>Surface type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>mean</td>
</tr>
<tr>
<td>1</td>
<td>Static friction</td>
<td>°</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>Dynamic friction</td>
<td>°</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Normal damping</td>
<td>/</td>
<td>0,03</td>
</tr>
<tr>
<td>4</td>
<td>Tangential damping</td>
<td>/</td>
<td>0,9</td>
</tr>
<tr>
<td>5</td>
<td>Rolling Resistance</td>
<td>/</td>
<td>0,08</td>
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<tr>
<td>6</td>
<td>Roughness-amplitude</td>
<td>m</td>
<td>0,1</td>
</tr>
<tr>
<td>7</td>
<td>Roughness-frequency</td>
<td>m</td>
<td>1,0</td>
</tr>
<tr>
<td>8</td>
<td>Mass</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Geometry</td>
<td>/</td>
<td></td>
</tr>
</tbody>
</table>

The most important numerical results are summarized in table 2, whereas table 3 shows their statistical analysis and graphical representation.

Table 2: Numerical results of ROCKFALL 6.0 (Spang & Krauter 2001)

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Dimension</th>
<th>min.</th>
<th>max.</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Required barrier height</td>
<td>m</td>
<td>0,83</td>
<td>5,77</td>
<td>0,98</td>
<td>0,22</td>
</tr>
<tr>
<td>2</td>
<td>Total energy</td>
<td>kJ</td>
<td>31</td>
<td>2.512</td>
<td>253</td>
<td>356</td>
</tr>
<tr>
<td>3</td>
<td>Translational kinetic energy</td>
<td>kJ</td>
<td>22</td>
<td>1.958</td>
<td>184</td>
<td>260</td>
</tr>
<tr>
<td>4</td>
<td>Rotational kinetic energy</td>
<td>kJ</td>
<td>9</td>
<td>646</td>
<td>69</td>
<td>99</td>
</tr>
<tr>
<td>5</td>
<td>Translational velocity</td>
<td>m/s</td>
<td>3</td>
<td>25</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Rotational velocity</td>
<td>i/s</td>
<td>3</td>
<td>27</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Momentum</td>
<td>t m/s</td>
<td>17</td>
<td>158</td>
<td>41</td>
<td>26</td>
</tr>
<tr>
<td>8</td>
<td>Angular momentum</td>
<td>t m²/s</td>
<td>6</td>
<td>48</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Angle against barrier</td>
<td>°</td>
<td>-123</td>
<td>-72</td>
<td>-87</td>
<td>17</td>
</tr>
</tbody>
</table>
The diagrams 1 and 2 represent the distribution of the kinetic energy and the bounce height along the profile. The following diagrams show the distribution of the indicated parameters at the moment of impact in the axis of the new barrier.

Table 3: Graphical presentation of ROCKFALL 6.0 results

The results of the rockfall simulation correspond with one-to-one in situ tests.
References:


