COMPLETE EVALUATION OF LANDSLIDE ACTIVITY

Peter Wagner, Peter Pauditš

Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava, Slovakia
(wagner@gssr.sk, paudits@gssr.sk)

Abstract: Slope deformations are the most widespread geological hazard in Slovakia. The present state of landslide stability and prediction of its development can be evaluated based on the long-term monitoring results. Individual measurements analysis is usually very complicated. Therefore, authors describe the method of complete evaluation of landslide activity expressed in the form of special zoning. Using of this method is illustrated on the complete evaluation of Okoličné landslide activity during the period 1996 – 2001.

Key words: monitoring, landslide activity, data processing, special zoning

Introduction

Slope deformations negatively influence the quality of the environment in Slovakia. According to a recent data they cover nearly 3,7 % of the total area of Slovakia but in some geographic units their density is much greater. Understanding of mechanism of the landslide movements and the conditions of their activation are basic pre-condition to design effective use of the environment. This information can be obtained by long-term monitoring of the slope deformation development (Wagner et al., 1997, Klukanová, 1998).

The project entitled „Partial monitoring system of geological factors of the environment in Slovakia“ has been in effect since the 1993. The project is funded by the Ministry of the Environment of the Slovak Republic and is carried out by the Geological Survey of Slovak Republic. The monitoring of landslides and other slope deformations is an important part of this project (Klukanová, Liščák, 1998, Klukanová, 2001).

Methodology of landslides monitoring

The methodology of slope movements monitoring consists of the following stages:

- Selection of the representative localities according to type of slope movement, location of slope failures and economic significance of the locality.
- Creation of a monitoring system, i.e. selection of monitoring methods and frequency of data collection.

- Monitoring data processing, i.e. methods of monitoring results presentation (Wagner et al., 2000).

Sliding is the most widespread type of slope movements. Moreover, this type is usually monitored by a group of various methods, which register individual features of this complicated geodynamic process.

Methods of landslide monitoring, used in our practice can be divided into three basic groups:

1. Surface measurements of landslide activity, which use the following methods:

a/ Geodetic survey of the movement of geodetic net points. To compare the movements over time, the velocity can be calculated in mm/year for each stage.

b/ The surface residual stress measurement in chosen surface points. The values of stresses are given in kPa.

2. Subsurface measurements of landslide activity:

a/ Inclinometric drill logging. The inclinometric measurements are concentrated on the largest movements along the slide surface; the results are expressed in mm/year.

B/ Geophysical method of pulse electromagnetic emissions (PEE). The method identifies zones of higher stress within the body of the slide. The measurements can be taken in the inclinometric boreholes.

3. Total regime measurements record the changes of the main factor of sliding - influence of water. The regime observations consist of measurements of groundwater level in boreholes in 1 or 2-week intervals (or continually by the automatic water stage indicators) and the yield of water, flowing from the subdrainage boreholes. A part of the regime measurements is an evaluation of the observations of precipitation from the nearest ombrometric stations.

According to substance of monitored phenomenon, the measurements can be divided into the group, which measures deformations per certain time period (geodetic and inclinometric measurements) and the group, which measures stress state of certain parts of slide at the moment of measuring (the surface residual stresses measurement and PEE method). The regime measurements help to explain the causes of changes, recorded by the above-mentioned methods.

Monitoring data processing

Results of the monitoring observations can be expressed in various ways. The surface and subsurface movements, recorded by geodetic and inclinometric

measurements are expressed usually by vectors. Values of the residual stresses and PEE are compared with a previous measurement and a development of stress-strain state is indicated by special marks. Though this way of monitored results is complete, its graphical expression is complicated and, for the users, difficult to read (Wagner et al., 2000).

Each of the monitoring methods provides a certain information on the state of landslide body (not seldom various information are controversial). Therefore, there is a possibility to summarise results of all measurements and to express them in a complex way as the state of slope movement activity in the certain period.

The composition of a classificatory evaluating scale for the results of various monitoring measurements is an entry operation. The results of monitoring measurements are divided into three degrees according to criteria, which characterise degree of landslide activity. Though the used scale is partly subjective, its development is based on numerous experiences from various landslide localities. The classificatory scale, used at present is summarised in Table 1.

The next step is weighting of individual monitoring measurements in dependence on their credibility. For example, the exact geodetic and inclinometric measurements are considered as the most relevant (Table 1). This operation cannot avoid a certain degree of subjectivity, as well (Jadroň et al., 1998).

In the case that two or more measurements were carried out at one monitoring object, a less favourable result (from the viewpoint of the stability state) is taken into account.

After the given revaluation of the data from monitoring measurements a set of numbers, characterising the state of landslide activity is obtained. With regard to situation that single measuring objects are spaced over the landslide area irregularly, it is possible to apply to data processing some of interpolation methods.

An interpolation function – regularised spline with tension was used in complete evaluation. The same parameters of interpolation function were used in each case of evaluation. The final evaluation is expressed in the simple way as a five-degree scale for combination of methods with observation weights, without the final reclassification of combined methods into three categories. The selected graphic interpretation (in form of the special zoning map) is based on the principle of gradual pointing up the deepness of hues – ranging from white to black (Jadroň et al., 1998).

The complete evaluation of a landslide activity, based on the results of long-term monitoring is illustrated on the locality of the Okoličné landslide.

Complete evaluation of the Okoličné landslide activity

The Okoličné landslide is situated in the central part of the Liptov Basin near the Liptovský Mikuláš town. The failured slope consists of flyschoid Paleogene strata, in which claystones prevail over sandstones. Sandstone intercalations act as aquifers facilitating deep-water circulation within the slope.

Recent activation of landslide has been caused by a railway cut made in the accumulation zone of a large fossil landslide in 1949. The activated landslide area reaches 750 m length and 230 – 260 m width (area about 0.16 km^2). Since that time the slope creates potentially unstable and permanent threat for an important railway line in spite of several stages of its stabilisation (Fussgänger, Jadroň, 1977, Wagner et al., 1997).

The monitoring net consists of 26 geodetic points, 4 inclinometric boreholes and a set of piezometric and drainage boreholes for regime observations. Geodetic measurements, inclinometric drill logging and measuring of surface residual stresses is realised yearly since 1993. The PEE method was experimentally used in 1995-1997.

Summarised results of all monitoring methods identify the slow, creep character of movement of landslide body and its most active parts (Fig. 1). The movements of upper and lower parts vary in response to hydrogeological conditions in the slope and lead to slow, permanent creep of the landslide. From the practical point of view, the railway line was the most endangered in 1997 (wet year with extremely precipitation in July), when a frontal part of landslide was very active. According to monitoring measurements a critical situation was recorded also in 2000, when the small landslide activated (the movement of geodetic point P-9 was nearly 10 cm per year). Activation of central part of landslide in 2001 can lead to mass movements in frontal part in future.

The method of complete evaluation of monitoring measurements is in evolution yet and has several weak sides (subjective criteria of measurements evaluation, a different substance of individual measurements etc.). Despite of this, the method gives lucid general information about landslide activity and its development in time.

References

Fussgänger, E., Jadroň, D., 1977: Engineering geological investigation of the Okoličné landslide using measurement of stresses existing in soil mass. Bulletin of IAEG, No 16, Krefeld, p. 203-209

Jadroň, D., Wagner, P., Pauditš, P., Vybíral, V.,1998: Evaluation of slope movement activity based on the results of monitoring. Proceedings of 8th Int. Congress of IAEG, Vancouver. Balkema, Rotterdam/Brookfield, Vol. III, p. 1653 - 1659

Klukanová, A., Liščák, P., 1998: Monitoring of geological hazards of the Slovak Republic. Proceedings of 8th Int. Congress of IAEG, Vancouver. Balkema, Rotterdam/Brookfield, Vol. III, p. 1113 - 1120

Klukanová, A., 1998: Mapovanie a monitorovanie geologických faktorov životného prostredia. In zborník referátov Geológia a životné prostredie. GS SR, Vyd. D. Štúra, Bratislava, p.123-126 (in Slovak)

Klukanová, A., 2001: Čiastkový monitorovací systém geologických faktorov ako súčasť monitorovacieho systému životného prostredia Slovenskej republiky. Geologické práce, Správy 106, Vyd. D. Štúra, Bratislava (in Slovak)

Wagner, P., Vybíral, V., Andor, L., Szabo, Š., 1997: Monitoring of landslides in Slovakia. Proceedings of Int. Symposium on Engineering Geology and the Environment, Athens. Balkema, Rotterdam/Brookfield, p. 1131 - 1136

Wagner, P., Iglárová, Ľ., Petro, Ľ., 2000: Methodology and some results of slope movement monitoring in Slovakia. Mineralia Slovaca, 32, p. 359-367

Table 1: Scale of classificatory evaluation of the results of monitoring measurements

Degree of activity	**Monitoring measurements**							
	Geodetic	Weight	**Surface residual stresses**	Weight	**Inclinometric drill logging**	Weight	**PEE**	Weight
	Velocity of movement [mm/year]*		$(\sigma_x / \sigma_{x-1}).\ 100$ -100 [%]**		Velocity of movement [mm/year]++		Activity level+++ [qualitative]	
1	to 20	1	Decrease and changes till 20***	1	to 2	1	WA, IA	1
2	20 to 60	3	Increase 20 to 100****	2	2 to 5	3	RL, MA	3
3	over 60	5	Increase over 100+	4	over 5	5	RH, VH	4

* values of displacements registered since previous measurement and calculated in relation to velocity of movement;

** values of measured stress compared with values obtained in a previous stage of measurement;

*** decrease in compressive and tensile stress generally, or increase of stresses till 20 %;

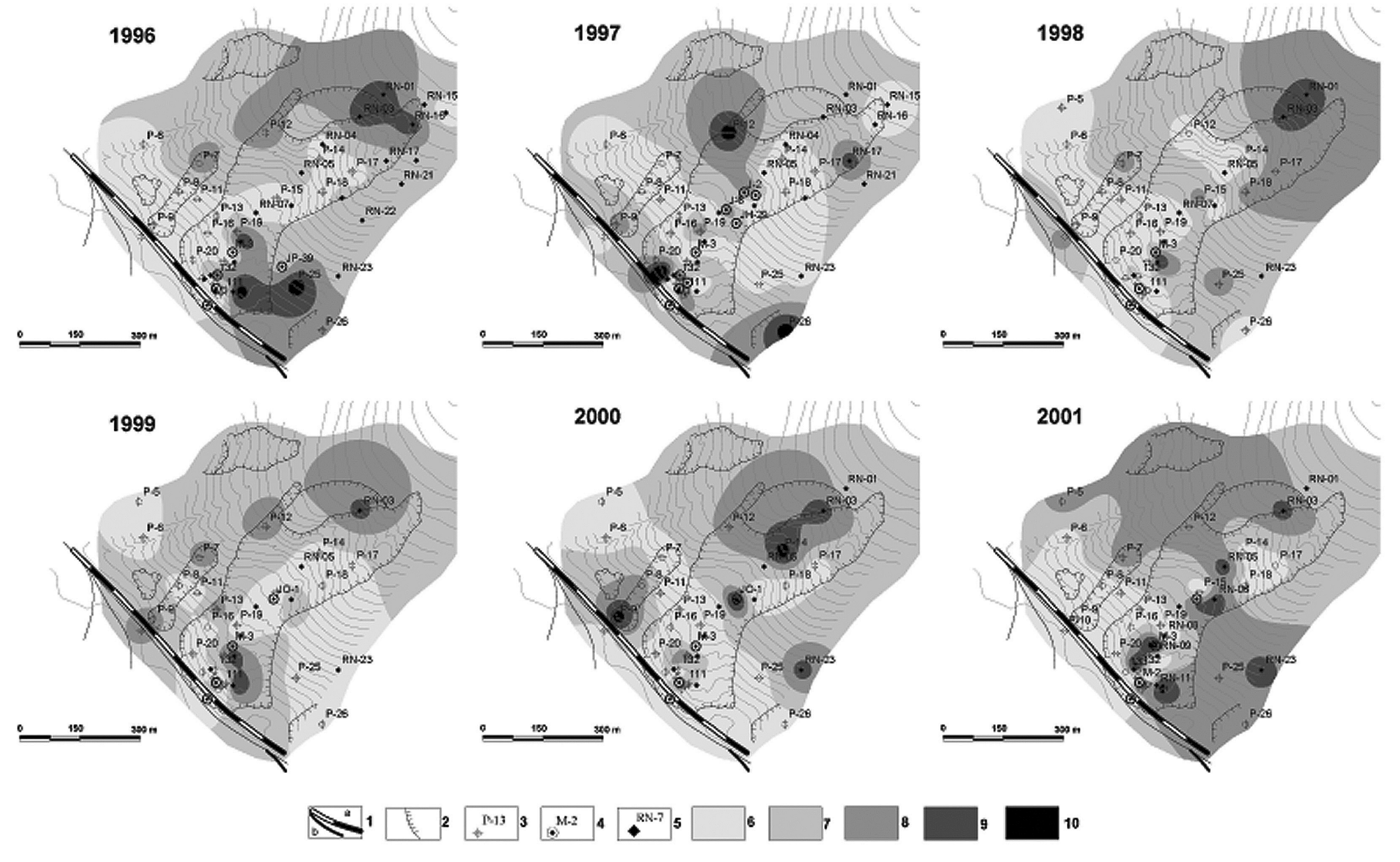
**** increase in compressive and tensile stress and changes of character of stress less than 3 kPa (in absolute values);

\+ expressive increase in compressive and tensile stresses and changes of character of stress more than 3 kPa (in absolute values);

++ values of deformation registered since previous measurement and calculated in relation to velocity of movement;

+++ evaluation is based on semi-quantitative scale: WA-without activity, IA-indication of activity, RL-relatively low, MA-middle activity, RH-relatively high, VH-very high activity.

Fig. 1: Complete evaluation of Okoličné landslide activity in the period 1996 – 2001.
1-railway: a/main line, b/ industry line, 2-morphological border of landslides, 3-geodetic points, 4-boreholes, 5-points of surface residual stress measurements, 6 – stable stage of landslide, 7 –activity indications, 8-slightly active, 9-active, 10-distinctly active


1996
1997
1998
1999
2000
2001
0 150 300 m
1
2
3
4
5
6
7
8
9
10