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# Analysis of chosen factors influencing stability of slide Okolicne

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## Abstract

The paper deals with chosen factors influencing stability of slide Okolicne in North Slovakia. Slide area is about 0.16 $km^2$ with slide length about 750m. In the lower part of the slide there is a main railway line between Kosice and Zilina which is in operation from 1869. In 1949, the second track was built by making cut with volume about 3800 $m^3$ of soil which activated old slides and endangers the traffic from that time. The landslide area consists of flyschoid Palaeogene strata, where claystones prevail over sandstone. The Quaternary cover is formed of eluvio-coluvial sediments, in which slope loams prevail over debris. Influences of shear strength parameters (values of residual angle of internal friction of soil are in a range from 14.1$^o$ to 17.7$^o$) and piezometric level of underground water (changing from 0.3m to 5.9m above shear surface) on stability of slide were analysed. Stability of slide was characterized by factor of safety (by Petterson´s and Bishop´s method) or by over-design factor ODF (by Eurocode 7). It was found that small increase in residual angle of internal friction of soil increases factor of safety (over-design factor ODF) by a significant amount. By contrast, increase of piezometric level from minimal to maximal value decreases factor of safety (over-design factor) by a significant amount.

**Keywords**: slide, stability of slide, residual angle of internal friction, piezometric level, Petterson´s method, Bishop´s method, Eurocode 7, Okolicne

## Streszczenie

Analiza wybranych czynników wpływających na stateczność osuwiska Okolicne

Artykuł dotyczy wybranych czynników wpływających na stateczność osuwiska Okolicne w północnej Słowacji. Powierzchnia osuwiska wynosi około 0,16 $km^2$, a jego długość to około 750m. W dolnej części osuwiska znajduje się główna linia kolejowa łącząca miejscowości Koszyce i Żylina, która eksploatowana jest od 1869 roku. W roku 1949, zbudowany został drugi tor poprzez wykonanie wykopu o objętości około 3800 $m^3$, który aktywował stare osuwiska i od tego czasu stanowi to zagrożenie dla ruchu. Strefa osuwiska składa się z paleogeńskich warstw fliszowych, w których iłowce przeważają nad piaskowcami. Czwartorzędowa pokrywa utworzona jest z eluwialno-koluwialnych osadów, w których zboczowe gliny przeważają nad gruzami. Wpływy parametrów wytrzymałości gruntu na ścinanie (wartości resztkowego kąta tarcia wewnętrznego są w zakresie od 14.1$^o$ do 17.7$^o$) i poziomu piezometrycznego wód gruntowych (zmienia się od 0,3m do 5,9m powyżej powierzchni poślizgu) na stateczność osuwiska były przedmiotem analiz. Stateczność osuwiska scharakteryzowano współczynnikiem bezpieczeństwa (wg metody Pettersona i Bishopa) lub współczynnikiem pomocniczym ODF (wg Eurokodu 7). Stwierdzono, że niewielki wzrost resztkowego kąta tarcia wewnętrznego gruntu znacznie zwiększa współczynnik bezpieczeństwa (ODF). Natomiast wzrost poziomu piezometrycznego od minimum do maksimum znacznie go zmniejsza.

**Słowa kluczowe:** osuwisko, stateczność osuwiska, resztkowy kąt tarcia wewnętrznego, poziom piezometryczny, metoda Pettersona, metoda Bishopa, Eurokod 7, Okolicne

## 1. Introduction

The landslide area "Okoličné" belongs to the city part of the town Liptovský Mikuláš, Slovakia (see Fig. 1.1). By Fussgänger and Jadroň [1], the landslide area is situated in the central part of the Liptov basin on the south-western slope of a morphological elevation. The top of the elevation is the hill "Háj" (746.4 m a. s. l.).

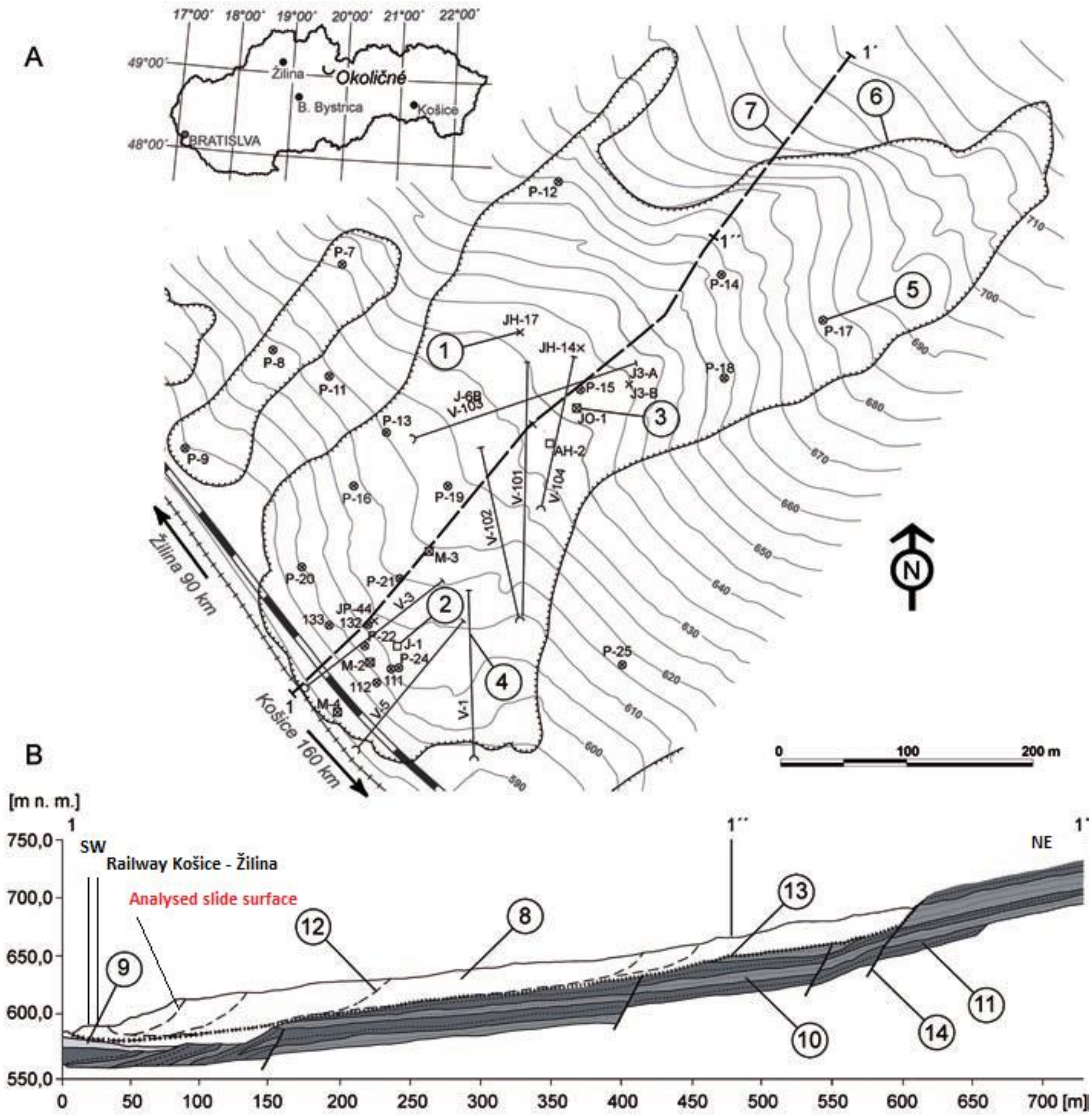


Fig. 1.1 Landslide area Okoličné near town Liptovský Mikuláš. A – the landslide area with location of the net of monitoring objects; B – schematic geological profile 1 – 1´ (according to Fussgänger et al. [2]). 1 – hydrogeological boreholes; 2 – hydrogeological boreholes with automatic water level indicator; 3 – inclinometric boreholes; 4 – horizontal drainage boreholes; 5 – the points of the geodetic net; 6 – border of the landslide; 7 – line of schematic (1 - 1´´ - 1´) profile; 8 – landslide deluvial deposits and weathered bedrock claystones;9– Váh river terrace fluvial deposits;10– Paleogene sandstones; 11 – Paleogene claystones; 12 – partial slip surfaces; 13 – basal slip surface; 14 – Neogene faults ([3], customized).

Recent slope deformation constitutes a relatively extensive sliding complex, which is of earthflow type in the main area. Its surface is about 0.16 $km^2$, the height of the landslide is 130m and the whole length is about 750m. Within the landslide area there are different kinds of failures including block type. The accumulation part of the slide has covered deposits of flood plain of the river Váh to a distance of 70m from the toe of the slope.

In 1869 the main railway line between the towns Košice and Žilina was situated in the lower part of the failure slope. During the works connected with construction of the second track in 1949, a cut was made by an excavation of the length 125m and volume 3800m$^3$ just at the tip of the former accumulation part of the landslide. Due to this interference the whole lower part of the failure slope had come into active state. Landslide pushes the railway lines aside and endangers their traffic in spite of the fact that in the years 1952-1967 partial protecting measures (construction of the drainage system) were performed. That is why in the years 1971-1975 an integrated engineering geological and hydrogeological investigation was carried out, while the previous investigation had involved the lower part of the failure slope only [1].

## 2. Slide engineering-geological conditions and monitoring

By Fussgänger and Jadroň [1], geological conditions of the affected area are given by its position in the Liptov basin, which is built by a thick complex of flysch rocks of the Central Carpatial Paleogene. The landslide area itself consists of flyschoid Paleogene strata in the so-called Zakopané facies, where claystones prevails over sandstones. The crest of Háj elevation and its steeper northern and north-eastern slopes oriented towards the Smrečianka valley built by Chocholov Beds with a predominance of sandstones over claystones. The Quaternary cover is formed of eluvio-coluvial sediments, in which slope loams prevail over debris. The ground waters in the area in question are confined owing to the predominant presence of pelitic soils and rocks. The occurrence of aquifers is connected with the clastic and sandy seams in the Quaternary overburden, the sliding colluvium and often with the upper weathered zone of underlying Paleogene sediments. Deeper groundwater circulation in bedrock is provided by the existence of tectonic fractures and of the Chocholov Beds (fractured sandstones). This formation has caused that the infiltration area extends beyond the Háj ridge to the Smrečianka valley.

The origin and development of sliding and slope failure have been since the Pliocene related to the erosion-denudation processes under favourable geological-tectonic, hydrogeological and climatic conditions. The erosion activity of the river Váh and its right-side tributaries Smrečianka and Jalovčanka had main influence in the formation of the present relief. Their activity after the Pliocene era was controlled by the tectonically predisposed zones of longitudinal and lateral directions.

Slope failure and their development stages were determined on the basis of mapping and exploration holes as well as by using some special methods (geophysical-geoelectrical and geoacoustical) and field measurements (pressuremeter test, penetration test, surface and subsurface stress measurements). It was found, that the first two stage were caused by river erosion at the toe of the slope when the deepest landslides have originated, stretching retrogressively to the middle part of the slope. Within the third stage the retrogressive progress of slope deformations reached the upper parts of the slope. Owing to tectonic predisposition the large blocks of underlying rocks were disturbed and they started to creep and separate, resulting in block fields and disintegration. The fourth youngest stage is characterized by the occurrence of earthflows, which have developed progressively on the dissected relief of the previous slope failure. At present they are either potential or slightly active slides. Their shear plane or zones are mostly planar and relatively shallowest (Fig. 1.1).

There is one up two levels of underground water level in the slide area. The first is shallower, encountered during drilling work at the depth about 4.5 up to 5.0 m under surface (borehole JH-29: 4.8m; J-3B: 4,3m) but also deeper (J-26A: 9.5m, J-1A: 10.8m). The second encountered level corresponds with the basal slide surface, eventually under it (J-3A: 10.6m, J-6B: 13.5m). Artesian water can be found at the central part of the slide (level lines 635.0m – 650.0m) from boreholes J-2, JH-14 and JH-17.

Permeability of slide soils can be divided into three groups: claystones have low permeability with the values of coefficient of permeability from $1.10^{-7} – 1.10^{-11}$ m.s$^{-1}$. In the case of disturbed claystones with the layers of sandstones the values of coefficient of permeability vary from $5.5.10^{-6} – 4.8.10^{-7}$ m.s$^{-1}$. The slide deluvial deposits have coefficient of permeability from $1.19.10^{-4} – 1.16.10^{-7}$ m.s$^{-1}$. River Váh terrace fluvial deposits have coefficient of permeability from $2.4\text{-}3.5.10^{-6}$.

The values of residual angle of internal friction of soil vary from 14.1$^o$ to 17.7$^o$ [2], which will be used later in the analysis.

To restrict the influence of slide on the railway, various measures had been carried out such as: surface and subsurface drainage (in years 1952-1954), afforestation of slide surface in 1956 up to 1962, thermal burning in 1963/1964, rock ribs in 1967 etc. Mentioned measures had low effect on increasing factor of safety of the slide. In 1973, the drainages D-1, D-2 and D-3 (see Fig. 2.1) had been carried out which increased the factor of safety more than 21.1% [4].

In 1967, 5 horizontal drainage boreholes (V-1 up to V-5) with total length 645m had been carried out. Their diameter was 133mm and boreholes had been cased by perforated casing of diameter 89mm. The lengths of boreholes vary from 122.5m to 136m. Boreholes inclinations vary from $6.5^0$ to $8.5^0$. Exceptions to the V-1, all other boreholes were situated under railway lines. At the present time, only three boreholes of this group work (see Fig. 2.1).

In 1974, further 4 horizontal boreholes (V-101 up to V-104) with total length 648m had been carried out, this time in the central part of the slide. The lengths of boreholes vary from 120m to 210m. Boreholes inclinations vary from $1.5^0$ to $2.5^0$ (see Fig. 2.1).

Taking into account the importance of Slovak main railway line between Košice and Žilina, the slide was classified as very high important and monitored in various stages. From 1993 the slide is systematically monitored by the workers of the State Geological Institute of Dionýz Štúr, which issues the report in every year. The list of monitoring activities for the slide Okoličné in the report from 2012 can be seen in the Tab. 2.1

Table 2.1 The list of monitoring activities for the slide Okoličné in 2011 and 2012 [5]

| Monitoring methods | Monitoring objects | | Amount of measurements (measurement data) | |
|---|---|---|---|---|
| | Amount | Identification | 2011 | 2012 |
| Geodetic | 19 measured,<br>1 referenced | P5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 22, 24, 111, 112, 132, 133<br>Referenced point in Liptovský Mikuláš | 1<br>(14.05.2011) | 1<br>(31.05.2012) |
| Inclinometric | 4 | M-2, M-3, M-4, JO-1A | 1<br>(28.11.2011) | 1<br>(17.07.2012) |
| Measurement of underground water level | 8 | J-3A, J-3B, J-6B, JP-44, JO-1, M-2, M-3, M-4 | 51<br>(1 per week) | 48<br>(1 per week) |
| | 2 | J-1, AH-2<br>Automatic underground water level indicator | Continuously<br>(every hour) | |
| Measurement of drainage objects capacity | 12 | D-1, D-2, D-3, V-1, V-3, V-5, V-101, V-102, V-103, V-104, JH-14, JH-17 | 51<br>(1 per week) | 48<br>(1 per week) |
| Annual rainfall | 2 | The Slovak Hydrometeorological Institute stations Liptovský Mikuláš and Liptovský Mikuláš - Ondrášová | Daily rainfall<br>Stations Liptovský Mikuláš – Ondrášová does not work from December 2011 | |

The results of regime monitoring of underground water level and capacity of drainage for years 2011 and 2012 can be seen in the Fig. 2.1 and results of geodetic and inclinometric measurement for years 2011 and 2012 can be seen in the Fig. 2.2

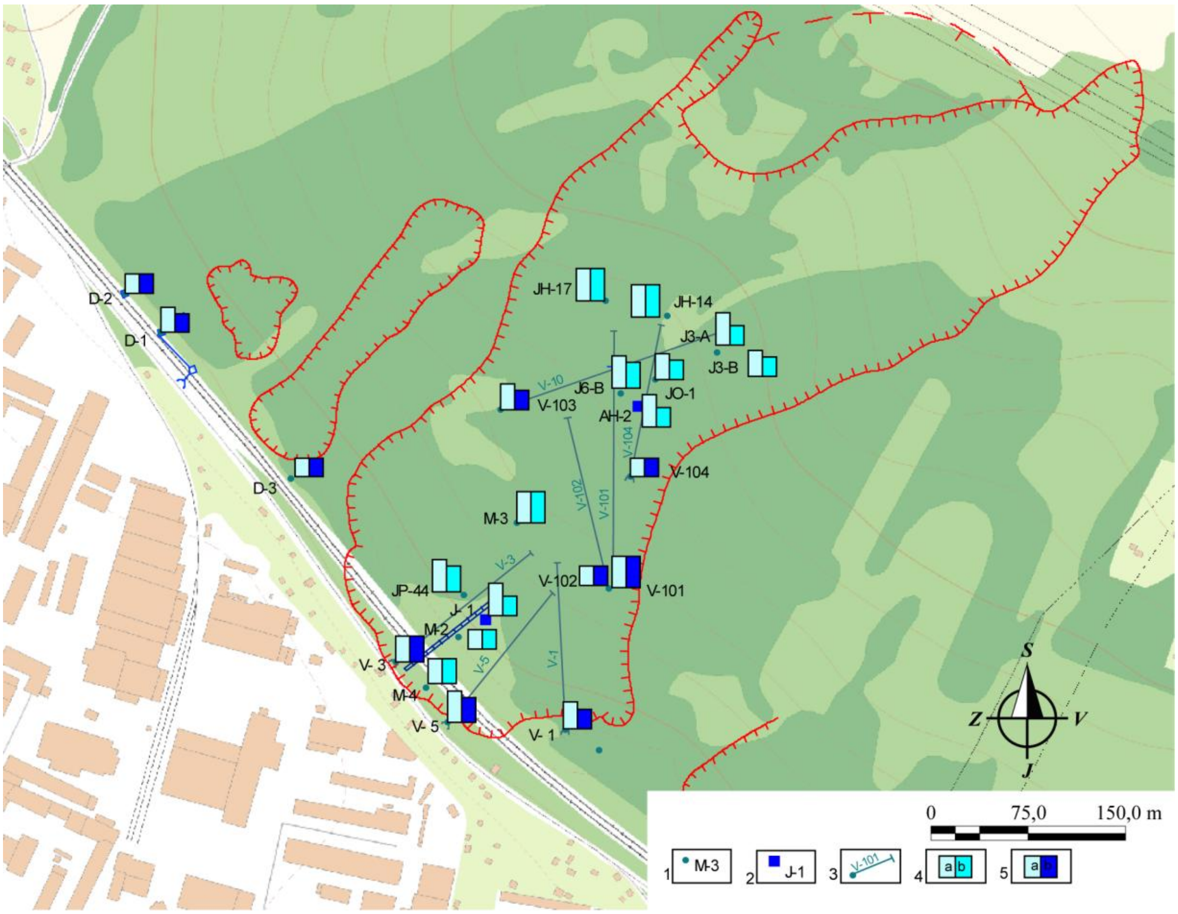


Fig. 2.1 The results of regime monitoring of underground water level and capacity of drainage for years 2011 and 2012. 1 – vertical boreholes; 2 – boreholes with automatic underground water level indicator; 3 – horizontal drainage boreholes; 4 – regime monitoring of underground water level changes in year: a – 2011, b – 2012; 5 – regime monitoring of drainage capacity change in year : a – 2011, b – 2012; map base: *ZBGIS*® ([5]; customized).

More details on the results of monitoring can be found in [5]. Taking into account the purpose of this paper, only conclusions of the report will be cited here. By the report, in 2012 the decrease of the underground water level was recorded, therefore it is better for slope stability. Similar as the previous years, water outflows from vertical boreholes JH-14 and JH-17. In Fig. 2.3 one can see water flowing from the vertical borehole JH-14. Water from the borehole inflows again into slope, by this way it worsens the slope stability.

From long-term geodetic and inclinometric measurements, one can states that there is a decrease of kinematics of slide movement. The recorded movements of monitored geodetic points reached usually the values under 7mm with the exception of point P24, where this value exceeded 8mm. The measured movement values are the lowest in whole monitored period. Inclinometric measurements give the similar values. This is caused by the favourable climatic conditions (lower rainfalls recorded in 2011 and 2012) which naturally made lower levels of underground water and also lower capacity of drainage.

In spite of the favourable development of the monitored parameters of movements, one can see continuing deformation in the accumulation part of the slide, along unpaved sidewalk next to the railway. Taking into account very high importance of the locality where the main railway, connecting several regional cities, is endangered, it is necessary in year 2013 to continue monitoring with the same frequency as in 2012 [5].

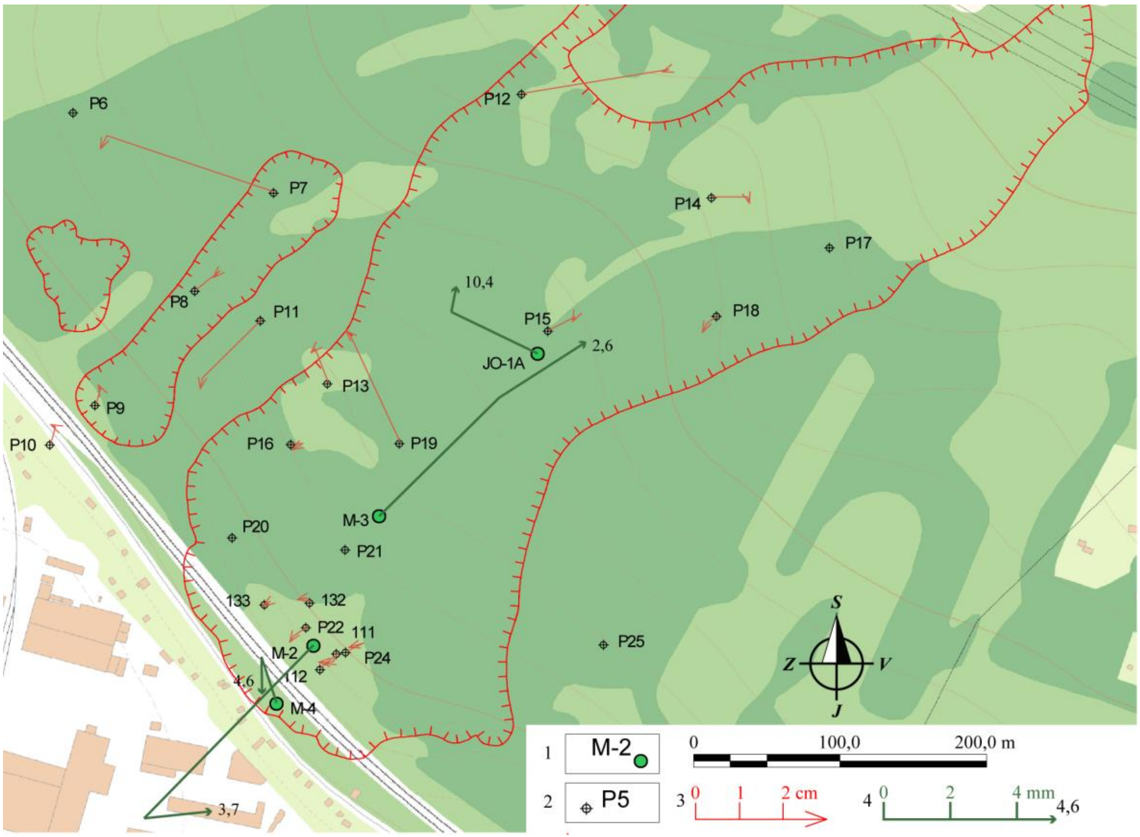


Fig. 2.2 The results of geodetic and inclinometric measurement for years 2011 and 2012. 1 – inclinometric borehole; 2 – geodetic points; 3 – scale of movement vector of geodetic points for period IV. 10 – V. 11 – V. 12; 4 – scale of vector of inclinometric casing deformations for period IV. 10 – XI. 11 – VII. 12 (the number indicates depth of recorded deformation from terrain surface in m); red line – border of active slide; map base: *ZBGIS®* [5].

Fig. 2.3 Water flowing from the vertical borehole JH-14 (state 19.09.2014, photo by the author)

## 3. Factor of safety of the slide

In the following we will analyse two main factors influencing the stability of the slide Okoličné: shear strength of soils and underground water level. The analysis is carried out for the slide surface next to the railway which all the time directly endangers the railway (see Fig. 1.1). The slide massive has the length 51.2m, height 7.6m and divided into 6 slices.

By Fussgänger et al. [2], values of residual angle of internal friction of soil are in a range from 14.1$^o$ to 17.7$^o$. The monitoring system enables to measure level of underground water under terrain, in this case the maximum (5.9m) and minimum (0.3m*)* piezometric level about shear surface is determined.

Stability of slide is characterized by factor of safety (in this paper calculated by Petterson´s and Bishop´s method) or by over-design factor (in this paper calculated by Eurocode 7). Taking into account well-known procedure of the stability calculation of the slide by Petterson´s and Bishop´s method, they will not be introduced in this paper.

In Slovakia, stability of slope should be calculated by the design approach No. 3 in Eurocode 7, part 1 [6]. By the Eurocode 7, slope analysis should verify the overall moment and vertical stability of the sliding mass. If horizontal equilibrium is not checked, inter-slice forces should be assumed to be horizontal. Therefore the factor of safety of the slide is calculated by the formula:

$$F_S = \frac{1}{\sum G_i.\sin\alpha_i}.\sum\frac{c_i'.b_i + (G_i - u_i.b_i).tg\varphi_i'}{\cos\alpha_i + \frac{\sin\alpha_i.tg\varphi_i'}{F_s}} \tag{3.1}$$

Where: $G_i$ is the weight of slice i [kN]; $\alpha_i$ is the angle of bottom of slice i from the horizontal direction [$^0$]; $c_i'$ is the effective cohesion of soil of slice i [kPa]; $b_i$ is the width of slice i [m]; $u_i$ is the pore water pressure at the central point of the base of slice i [kPa]; $\varphi_i'$ is the angle of internal friction of soil of slice i [$^0$].

In accordance with the Eurocode 7, design values of effective cohesion and angle of internal friction are calculated using their characteristic values and partial factors 1.25 (in case of angle of internal friction, partial factor 1.25 is applied for tanφ).

The minimum (14.1$^o$), medium (15.9$^o$) and maximum (17.7$^o$) value of residual angle of internal friction had been used in calculations of factor of safety (over-design factor). Similar, minimum and maximum piezometric level of underground water had been used in calculations. The obtained results can be seen in the Tab. 3.1.

As can be seen in the Tab 3.1, residual angle of internal friction of soil has big influence on the stability of the slide. Small increase in residual angle of internal friction of soil increases factor of safety (over-design factor) by a significant amount. By contrast, increase of piezometric level from minimal to maximal value decreases factor of safety (over-design factor) by a significant amount.

Table 3.1 Values of factor of safety (over-design factor) for various values of residual angle of internal friction of soil and piezometric level

| Angle of internal friction [$^o$] | Piezometric level | Factor of safety by various calculation method | | |
|---|---|---|---|---|
| | | Petterson´s | Bishop´s | Eurocode 7 |
| 14.1 | Without water | 1.26 | 1.33 | 1.07 |
| | Minimal piezometric level | 1.15 | 1.22 | 0.97 |
| | Maximal piezometric level | 0.88 | 0.93 | 0.70 |
| 15.9 | Without water | 1.43 | 1.51 | 1.21 |
| | Minimal piezometric level | 1.30 | 1.38 | 1.10 |
| | Maximal piezometric level | 1.00 | 1.06 | 0.80 |
| 17.7 | Without water | 1.60 | 1.70 | 1.36 |
| | Minimal piezometric level | 1.46 | 1.55 | 1.23 |
| | Maximal piezometric level | 1.12 | 1.19 | 0.89 |

It is confirmed, that factors of safety calculated by Petterson´s method is smaller than those ones calculated by Bishop´s method. The factors of safety calculated by Eurocode 7 are smallest. The possible first reason why whole analysed slide is not active in full range when values of factor of safety are under 1.0 is that proposed maximal piezometric is not reached at once in whole slide. The possible second reason why whole analysed slide is not active in full range when values of factor of safety are under 1.0 is that proposed minimal angle of internal friction is not applied at once in whole slide but from nonhomogeneous character of slide deluvial deposits, when there is minimal angle of internal friction at some sections of slide surface, in other sections of slide surface, angle of internal friction can reach intermediate values or even maximal values.

## 4. Conclusions

Results show that internal friction of soil and underground water level have big impact on the slide stability. Even small changes in their values considerably change values of factor of safety; therefore their accurate determination is necessary. In case of underground water level, using automatic indicator of underground water level can be helpful. Accurate determination of soil shear strength parameter requires more time and financing. Taking into account random character of slide movement, occasional geodetic and inclinometric measurements cannot provide sufficient information on slide behaviour so automatic indicator of slide movement will be welcome.

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Európska únia

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