Scientific Research and Essays Vol. 6(23), pp. 4936-4945, 16 October, 2011
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2011 Academic Journals

*Full Length Research Paper*

# Case study of landslide in the Karviná region using resistivity tomography measurements

**Marian MARSCHALKO[1], Işik YILMAZ[2]*, Karel KUBEČKA[3], Martin BEDNÁRIK[4], Barbara STALMACHOVÁ[5], Tomáš BOUCHAL[5] and Orlando ARENCIBIA[6]**

[1]VŠB-Technical University of Ostrava, Faculty of Mining and Geology, Institute of Geological Engineering, 17 listopadu 15, 708 33, Ostrava, Czech Republic.
[2]Cumhuriyet University, Faculty of Engineering, Department of Geological Engineering, Sivas, Turkey.
[3]VŠB-Technical University of Ostrava, Faculty of Civil Engineering, Department of Building Structures, 17 listopadu 15, 708 33, Ostrava, Czech Republic.
[4]Comenius University, Faculty of Natural Sciences, Department of Engineering Geology, Mlynská dolina, 842 15, Bratislava, Slovak Republic.
[5]VŠB-Technical University of Ostrava, Faculty of Mining and Geology, Institute of Environmental Engineering, 17 listopadu 15, 708 33, Ostrava, Czech Republic.
[6]VŠB-Technical University of Ostrava, Faculty of Economics, Department of Mathematical Methods in Economics, Sokolská třída 33, 701 21 Ostrava, Czech Republic.

Accepted 8 September, 2011

**The paper deals with the slide of Doubrava Vrchovec that occurs in district of Karviná in Doubrava Village. The slope deformation in this area was reactivated by mining effects and by precipitation. The studied area is the Ostrava-Karviná coalfield, situated in the Northeast of the Czech Republic. Objective area is situated in efficient distance of mining activity of both mining fields. Great movements temporally correlate with mining of most thick seams of Mine Doubrava and Mine CSA. Archive materials, basic data, aerial photographs of slope deformation were studied and evaluated at the beginning of the research. Moreover, engineering-geological mapping were performed, on the basis of which all landslide manifestations, such as starting scar, transport zone, accumulation area, cracks, sliding blocks, side banks, layer outcrops, hydrogeological structures (for example, wells, wetlands, springs, line of springs). Resistivity tomography measurements (geophysical method of multielectrode resistivity measurement) were taken. On the basis of the carried out exploration work, it can be said that the manifestation of sliding activities have been clearly proved. The stability can be considerably affected by heavy rainfall due to their degradation effects on the mechanical properties of soils. More intense effects of rainfall are also caused by the existence of tension cracks that occur in the slide. These discontinuities substantially weaken the slope, facilitate the seepage of rainfall and can possibly lead to the formation of other partial slides.**

**Key words:** Landslide, geophysics, engineering geology, Ostrava-Karviná coalfield, undermining, resistivity tomography measurements.

## INTRODUCTION

Slope deformations of Doubrava Vrchovec occur in the district of Karviná the in village of Doubrava, the slope deformations were reactivated by mining effects and by precipitation and they were approximately 400 m long and 200 m wide with a dominant teat edge under the hilltop.

There are a lot of phenomena and factors that influence slope deformation in mining areas (Cala, 2007; Kalisz, 2009; Marschalko et al., 2008a, b, c; Marschalko and Treslin, 2009). The sinking of the land surface, changes

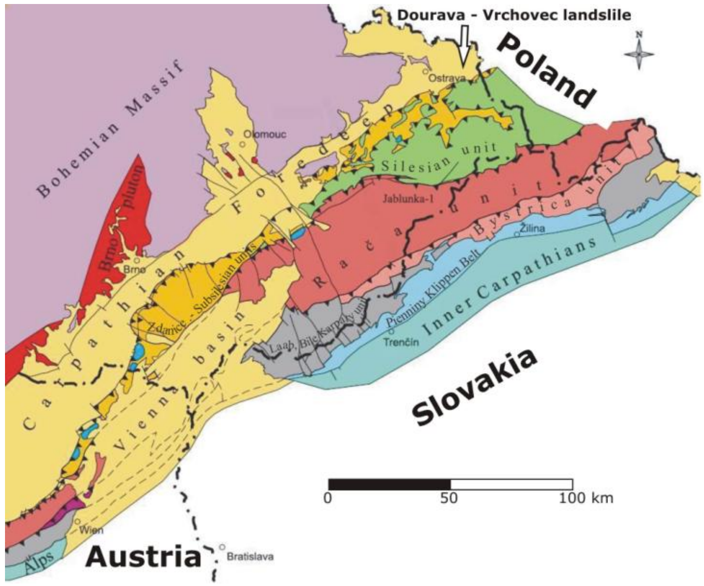


**Figure 1.** Situation of Doubrava Vrchovec landslide in schematic geological map.

in slope gradient, changes in height differences between the affected ground surface and the surrounding ground are the crucial ones. The existence of increased tensile load in the affected areas and its influences are very often underestimated, because even in places with minimum subsidence, it may be decisive of the activation of slope deformation. For this reason, the loosening of the inner structure or an increase in the void content or a decrease in rock cohesion can occurred. In some cases, above all makes a change in hydrogeological conditions and gives a great influence on slope stability.

The character of undermining and processes associated are mainly affected by the thickness of the worked-out layer, the geological structure of the roof, the depth of mining, the rate of advance, the method of mining, the dip of seams, terrain morphology, tectonic structure, changes in the regime of groundwater, changes in physical-mechanical properties related to soil bulking, drying, or saturation should be taken into consideration. This study used and applied experiences from previous studies and articles about engineering geology conditions, land use, planning, hazard, susceptibility (Dopita, 1997; Yilmaz and Yavuzer, 2005; Yilmaz and Bagcı, 2006; Yilmaz and Yıldırım, 2006; Yilmaz, 2009a, b; Marschalko and Duraj, 2009; Marschalko and Juris, 2009; Marschalko et al., 2008a, b; Marschalko et al., 2009; Bednarik et al., 2010; Yilmaz, 2010; Yilmaz et al., 2011).

## Natural conditions

According to geomorphological classification, the monitored area falls in the province of the Western Carpathians, subprovince of the Inner-Carpathian depressions (VIII), areas Northern Inner-Carpathian depressions (VIIIB), unit Ostrava basin (VIIIB – 1), district Orlovská plateau (VIIIB-1-g). Inner-Carpathian depressions form a strip of lower terrain in the surroundings of Ostrava. The Ostrava basin is a flat hilly area and flatland. Various thick groups of Tertiary marine and quaternary glacial, fluvial and eolian sediments lie on consolidated carboniferous sediments which contain coal seams.

Orlovská plateau is a flat hilly area (282 m-Doubrava), which is situated in the middle part of the Ostrava Basin. As for lithology, it is formed by variously thick strata of glacigenous gravels, sands, loams covered by loess-loam in the Miocene overburden and carboniferous carbon. This plateau is of an erosively accumulation glacigenous and eolian origin, divided by the processes of periglacial and humid breakdown with the remains of accumulation plains and mounds of impact moraines. There are asymmetrical valleys, slides, ravines, anthropogenic heaps, embankments, depressions, etc. It is medium-afforested mainly by spruce growth and by pines and oaks in places.

The locality (Figure 1) is situated in the Northeast part of the platform, Orlovská plošina. The topography is

*Corresponding author. E-mail: iyilmaz@cumhuriyet.edu.tr or isik.yilmaz@gmail.com.

**Abbreviations: RMS,** Root-mean-square error.

uneven and has a form of a peneplain at the altitude ranging from about 232 to 270 m above sea level.

The original topography given by the accumulation and modulation activity of the Saalian continental ice-sheet and subsequent erosion and deluvial, or deluvio-fluvial sedimentation is influenced markedly by long-term sliding activity due to stream erosion, and lately by anthropogenic influences, especially impacts produced by undermining and ground shaping performed in the framework of former securing the landslide.

In the given locality, the pre-quaternary bedrock is composed of Miocene sediments of the character of calcareous claystones and clays, locally with silty-sandy laminae, with typical disintegration, or conchoidal fracture with conspicuous polishing in places. In the surface part, the Miocene sediments have the nature of clays of variable consistency (both solid and soft).

The quaternary cover consists of a broad scale of sediments. However, particular types are preserved in their original positions merely sporadically; slope movements disturb mostly their positions. Glacigenous sediments are primarily sandy, in a lesser degree clay-sandy, or gravel with the grains of quartz and erratics. The alluvium of the stream, Kotlínský potok, and sediments of small water reservoirs form the deluvio-fluvial sediments. They are represented prevailingly by clays with a content of organic matters and plant remains. Sediments formed due to sliding activity are very variable; their character depending upon the original type of soils. They are characterised by various grain size distribution, variable calcareous contents, and often by the presence of plant remains and wood substance.

From the hydrogeological point of view, it is the case of a complex of insulators that is, as a result of landslide movements, redeposited and intercalated with layers of glacigenous sediments that fulfil here the function of a collector. The level of underground water is unconfined; in the zone of sliding it is a slightly pressure level. The flowing of underground water follows the northeast and east directions in accord with a hydraulic gradient.

## Engineering geological conditions

On the basis of previously carried out borehole work, the following engineering-geological types of soils were defined within the geological structure of the slope deformation. Miocene sediments have the character of calciferous, finely silty claystone of green-grey colour. They are characteristic for fragmental disintegration by a conchoidal fracture and in places by fine sandy lamination on the bedding planes. The plasticity is medium to high – $W_L$ 50.3% on average, and the consistency firm to stiff–$I_C$ 0.80 on average. The surface of Miocene sediments is mouldered, it has a reddish to reddish-brown colour (according to the advanced state of weathering), and the form of claystone is degraded to clay with the signs of fragmental disintegration. These sediments have a high plasticity–$W_L$ 54.8% on average, and the consistency is predominantly firm–$I_C$ 0.66 on average.

Rotten Miocene sediments–"eluvium" is formed on the top of the Miocene claystone and it has the appearance of green-grey to brown-grey, reddish-streaked clay, decalcified to calciferous, with the signs of fragmental disintegration in isolated cases. The plasticity is medium to high–$W_L$ 49.9 % on average, and the consistency is firm to soft in places–$I_C$ 0.62 on average.

Deluvial-fluvial sediments are mainly represented by alluvium sediments of the Kotlinský Stream and the sediments of small water bodies. They are predominantly represented by blue-grey and brown-grey clays with frequent fragments of wood and isolated boulders of glacigenous origin. It is the case of very plastic clays–$W_L$ 59.0% on average, and of firm consistency–$I_C$ 0.77 on average.

Glacigenous sediments of the salic glacial age formerly probably covered the surface by a continuous layer. Currently, their original placement is disrupted by slope movements. Mostly it is the case of badly-graded, course-grained sands of grey-yellow colour, formed mainly by Nordic materials and the grains of $SiO_2$. In a smaller extent there are sandy clays and fine gravels of grey, reddish or blue-grey colour. The plasticity of clays is low–$W_L$ 35.4% on average, and the consistency is firm–$I_C$ 0.67 on average. The sands and gravels are medium-compact to compact. The sediments of Halštrov glacial have the appearance of green-grey silty, non-calciferous clay with mean-grained to course-grained clayey sands with tiny pebbles of $SiO_2$ and Nordic materials.

Sliding-combined types of sediments were formed by sliding activities. These new types of loams, on the composition of which participate all the above mentioned genetic types, are characteristic for their variety, irregular calciferous character, frequent occurrence of blackened plant and wooden remains and a very low value of specific dry bulk density - $\rho_d$ 1370 kg.m$^{-3}$ on average. They are highly plastic loams–$W_L$ 59.2% on average, and of a predominantly firm consistency–$I_C$ 0.74 on average.

Humic soils form the top soil on the majority of the interest area (they close the succession of Quarternary sediments). Made-up ground is quite common in the locality, but its thickness is not significant. It is due to the fact that a part of this locality was built up in the past (building waste, ash) and because of partial improvements of damage caused by sliding movements (coarse waste rock, slag).

On the basis of older samples and laboratory analyses, the individual types of soil identified by geological survey can be characterized as follows (Table 1):

## Realized investigations

Engineering-geological mapping was performed, on the

**Table 1.** Overview of characteristic values of physical–mechanical properties.

| Genetic soil type | Bulk density $\gamma_n$ ( $kg.m^{-3}$) | Shear strength | | Shear strength | | Classification according to ČSN 73 1001 | Symbol according to ČSN 73 1001 |
|---|---|---|---|---|---|---|---|
| | | $\phi_{ef}$ (°) | $c_{ef}$ (MPa) | $\phi_{rez}$ (°) | $c_{rez}$ (MPa) | | |
| Miocene sediments | | | | | | | |
| Sound | 1920 | 23.1 | 0.034 | 17.4 | 0.026 | F 6 | CI |
| Weathering | 1850 | 14.8 | 0.025 | 10.3 | 0.025 | F 8 | CH |
| Eluvium | 1870 | 15.0 | 0.049 | 16.6 | 0.035 | F 8 | CH |
| Glacigenous sediments | | | | | | | |
| Sands | 1850 | 32.0 | 0.000 | | | S 2 | SP |
| Sandy clay | 1910 | 22.0 | 0.010 | | | F 4 | CS |
| Deluvial-fluvial sediments | 1860 | 19.0 | 0.042 | | | F 8 | CH |
| Sliding-combined types of sediments | 1850 | 19.9 | 0.035 | 14.2 | 0.026 | F 8 | CH |

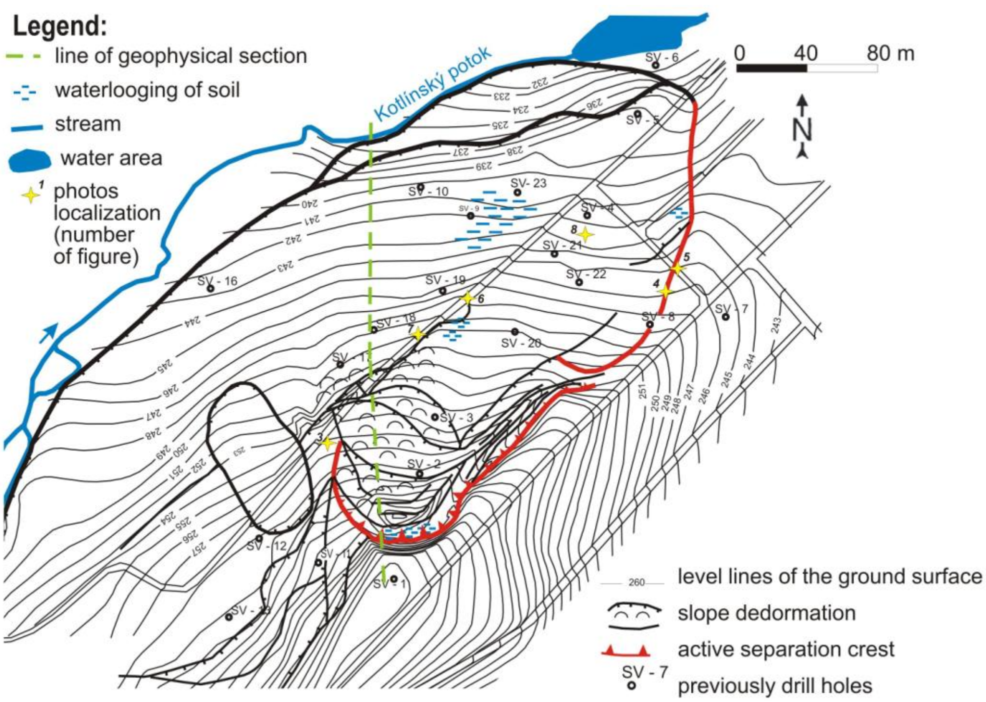


**Figure 2.** General situation of the slope deformation.

basis of all sliding manifestations, such as starting scar, transport zone, accumulation area, steep non-overgrown slopes of the scar, open cracks, subsidence, inclined trees, and deformation of the ground surface, sliding blocks, side banks, layer outcrops, hydrogeological structures (for example, wells, wetlands, springs, line of springs).

It is important to discover and map the tension cracks above the main scarp. Presence of these cracks indicate the possibility of the movement extension upwards the slope. The tension cracks near the scarp are open and perpendicular to movement direction. Lower part of the landslide has cracks that are tight compressed or deformed by compression.

The results of field mapping are in Figure 2. The tear edge of the slide is pronounced, it reaches as high as 8 m (Figure 3) and spreads in the direction southwest-northeast. Due to heavy rainfall towards the end of the

**Figure 3.** Top tear edge.

**Figure 4.** Recent movements on the side tear edge and a tilted tree.

winter and probably in concurrence with undermining impact, there was a significant movement in the central part of the slide. On the tear edge, two new movements appeared up to 0.5 m long (Figure 4). The road connect the southeastern and northwestern part of the slide, runs almost perpendicular to the side tear edge. It was disrupted by those movements to such an extent repair by means of panels to maintain its capacity (Figure 5).

**Figure 5.** Disrupted road.

**Figure 6.** New cracks up to 10 cm wide and 90 cm deep.

The second road runs through the slide section and connects the local part of Kotlina to Šimíčkova Colony and it is not open to motor vehicles any longer. The slide was pushed itself under the road and therefore lifted it and broke it. New cracks with a width of up to 10 cm in a depth of 90 cm occurred across the whole road (Figure 6).

The top soil slumped directly down the road and made it narrower, such that, it was only 1.5 m in wide in contrast to the original 3 m (Figure 7). In the central part of the slide there was a noticeable system of cracks running along the tear edge. In the southwestern part of

**Figure 7.** Narrowing of the local road due to sliding of the topsoil.

**Figure 8.** Executed ground shaping.

the slide, the manifestation of sliding gradually lost and became unclear. In the northeastern part of the slide, ground shaping was carried out as a result of reconstruction of water pipeline (Figure 8). In the whole slide there were several areas that are heavily saturated, which also contributes to a decrease in stability.

## METHODS

It is very important to use geophysical measurements in the evaluation of landslides (Bruckl et al., 2006; Godio et al., 2006; Hildenbrand et al., 2006; Jongmans and Garambois, 2007; Tingey et al., 2007; Eichkitz et al., 2009; Pennington et al., 2009; Suski et al., 2010; Travelletti et al., 2010). A method of resistivity

**Figure 9.** ResiStar device.

tomography was applied at Doubrava Vrchovec landslide. This method combines an advantage of either resistivity profiling or sounding and allows obtaining 2D conception of resistivity condition at measured rock environment.

Resistivity tomography measuring was performed by the usage of electrode system. Electrodes were earthed into the rock environment. They were subsequently switched on either current (A, B) or potential (M, N) electrode during the measurement controlled by the computer. Current electrodes conduit an electric current into the rock environment; potential difference is measured between potential electrodes. ResiStar device (Figure 9) allows an electrode connecting as symmetrical four-electrode Wenner and Schlumberger configuration. Apparent resistivity of rock environment is established from measured intensity of current I (mA), voltage potential difference U (mV) measured between two electrodes; and configuration constant that depend on electrode spacing:

$$\rho_Z = k.\frac{U}{I} \qquad (\Omega\text{m})$$

Apparent resistivity is determined to the deep; the depth range depends on A, B electrodes spacing.

Configuration constant for symmetrical configuration *k* is established after the equation:

$k = 2.\pi.\overline{AM}$ for Wenner electrode configuration,

$k = \pi.\frac{\overline{AM}.\overline{AN}}{\overline{MN}}$ for Schlumberger electrode configuration,

where $\overline{AM}$, $\overline{AN}$, $\overline{MN}$ are the electrode spacing. Depth range is conventionally specified and varies from 1/3 to 1/6 of $\overline{AB}$ in case of Wenner configuration and form ½ to ¼ of $\overline{AB}$ in case of Schlumberger configuration. It means that apparent resistivity (ρZ) depends on applied electrodes configuration. Basic electrode spacing was 2, 0 m.

Apparent resistivity (ρZ) are interpreted and resistivity model of measured rock environment is made up by using of Res2Dinv computer program from Geomoto Software Company.

Computer program choose a resistivity model of rock environment upon an obtained set of apparent resistivity values. The resistivity model is in the form of rectangular cells that have constant resistivity. A number of cells do not exceed number of measured data. Final depth range of resistivity model corresponds to an equivalent depth range of measurement. Depth cell size increases together with depth by 10 or 25%.

Computer program calculates a course of apparent resistivity corresponding to the used electrodes configuration. The computation proceeds to the chosen general resistivity model by means of finite difference or finite element method and non-linear optimization techniques-least square method. A several model variant could be chosen; in case of Skalice landslide, the optimizing of depth step was chosen. Visualization on computer monitor allows a comparison calculated apparent resistivity field with original measured field. Correspondency rate is expressed also by the root-mean-square error (RMS). However, the minimum value of error does not mean the optimal result of interpretation. The result can by unreal, can not correspond to a specific geological condition. Resistivity model autocorrecting is usually finished after five iterative steps, or till the value of RMS do not vary (5% difference). Number of iterative steps could be increased (for 5) or RMS percentage change could be limited. Computer gives a notice in case of wide interval, sudden change of measured resistivity or instability of iterative process.

## RESULTS

In the locality, a 286 m geophysical section V1 was measured (144 electrodes, pace survey 2 m). The first part was 110 m southnorth and of 340° azimuth. After 110 m (on an impassable road) the section broke more to the north with azimuth 352°. The beginning of the section is situated 14 m above the main tear edge and the end was 10 m behind the Kotlinský Stream. The position of the section is marked on a purpose situation (Figure 2). Figure 10 shows results of resistivity interpretation

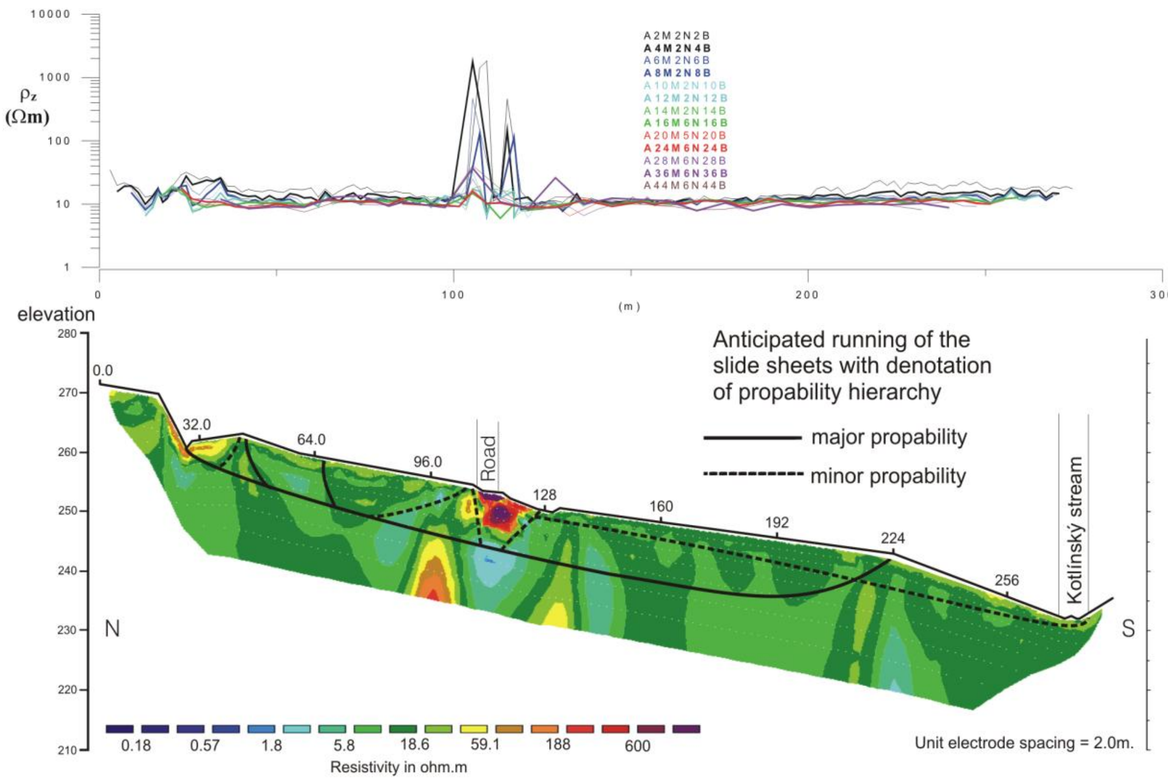


**Figure 10.** Interpretation of resistivity measurement results–profile V1.

(including topography data) of geophysical profile. Course of interpreted sliding surfaces is also drawn in.

In this locality inclinometric bores were not made, thus the interpretation is grounded in the results of resistive tomography and the course of section curves of impedance in the relation to petrography of archive bores.

The V1 section interpretation is characterized by 2 levels of slip surfaces. The more shallow slip surface with maximum depth of 2.5 to 5 m starts under the disturbed road on the stationing 126 m and continues to the Kotlinský Stream as far as 176 m from the beginning of the section. This slip surface is situated in the positions of local maximums and minimums. In terms of lithology, in the initial part it is the case of a boundary plane between sliding material and Miocene clays or claystone. The end of this slip surface is already found in fine sliding sediments.

The deeper slip surface connects to the tear edge, which is 8 m high in the place of the section and it continues in the depth of 8 to 10 m after the stationing 224 m, where it rises to the surface. It is the case of a slip surface which is again placed on positions with lower or higher values of impedance. Due to the impact of material shifts on this slip surface there are frequent cross and longitudinal cracks and the local road is often broken and lifted. These elements were localized based on significant minimums in the resistive model and section curves.

## Conclusions

Geophysical survey localized the position of probable sliding surfaces after correlation with previous lithological bore-hole results. The manifestations of sliding activities have been clearly proved. The stability can be considerably affected by heavier rainfall due to their degradation effects on the mechanical properties of soils. Primarily, it is the angle of internal friction that can be significantly reduced. More intense effects of rainfall are also caused by the existence of tension cracks that occur in the body of the slide. These discontinuities substantially weaken the slope, facilitate the seepage of rainfall and can possibly lead to the formation of other partial slides.

The slide has been improved only partially and ineffectively so far. The further development in the locality can be forecast as resumed manifestations of slides in dependence on the occurrence of extreme rainfall, impact of undermining and erosion of the Kotlinský Stream in the slope foot.

The extent of the potential risk is high. Apart from the own swerve of the course of the Kotlinský Stream, by sliding, another damage will be faced by the mains of high voltage, local road, residential and weekend houses and underground services could be caused.

Based on the information from the applied resistive tomography for the survey of the slope deformations, this indirect research method can be recommended as complementary for the identification of slipping planes or as an interpolating method for the identification of geological structure between the direct technical works, especially bores, if changes in lithology are manifested by changes in resistivity.

## ACKNOWLEDGEMENT

The Authors would like to thank the European Union (CENTRAL EUROPE Programme co-financed by the ERDF) for their support (COBRAMAN – 1CE014P4), which is the base of this article.

### REFERENCES

Bednarik M, Magulova B, Matys M, Marschalko M (2010). Landslide susceptibility assessment of the Kralovany-Liptovsky Mikulas railway case study. Phys. Chem. Earth, 35(3-5): 162-171.

Bruckl E, Brunner FK, Kraus K (2006). Kinematics of a deep-seated landslide derived from photogrammetric, GPS and geophysical data. Eng. Geol., 88(3-4): 149-159.

Cala M (2007). Convex and concave slope stability analyses with numerical methods. Arch. Min. Sci., 52(1): 75-89.

Dopita M (1997). Geology of Czech part of the Upper Silesian Basin. Ministry of Environment, Prague, (in Czech)

Eichkitz CG, Schreilechner MG, Amtmann J, Schmidt C (2009). Shallow Seismic Reflection Study Of The Gschliefgraben Landslide Deposition Area - Interpretation And Three Dimensional Modeling. Aust. J. Earth. Sci., 102(2): 52-60.

Godio A, Strobbia C, De Bacco G (2006). Geophysical characterisation of a rockslide in an alpine region. Eng. Geol. 83(1-3): 273-286.

Hildenbrand A, Gillot PY, Bonneville A (2006). Offshore evidence for a huge landslide of the northern flank of Tahiti-Nui (French Polynesia). Geochem. Geophy. Geosy. 7: Art. Num. Q03006.

Jongmans D, Garambois S (2007). Geophysical investigation of landslides: a review. B. Soc. Geol. Fr., 178(2): 101-112.

Kalisz P (2009). Impact of mining-induced surface deformations on reinforcement of structural embankments. Arch. Min. Sci., 54(4): 657-670.

Marschalko M, Duraj M (2009). Knowledge of engineering-geological conditions as decisive factor for good-quality and functional foundation of potential structures. Conference proceeding - SGEM 2009: 9th International Multidisciplinary Scientific GeoConference, Modern management of mine producing, geology and environmental protection, Jun 14-19, Albena, Bulgaria, I: 261-269.

Marschalko M, Fuka M, Treslin L (2008). Influence of mining activity on selected landslide in the Ostrava-Karvina coalfield. Acta. Montan. Slovaca., 13(1): 58-65.

Marschalko M, Fuka M, Treslin L (2008). Measurements by the method of precise inclinometry on locality affected by mining activity. Arch. Min. Sci., 53(3): 397-414.

Marschalko M, Hofrichterova L, Lahuta H (2008). Utilization of geophysical method of multielectrode resistivity measurements on a slope deformation in the mining district. SGEM 2008: 8th International Scientific Conference, Conference Proceedings - Modern Management of Mine Producing Geology and Environmental Protection, Varna, Bulgaria, I: 315-324.

Marschalko M, Juris P (2009). Task of engineering geology in land-use planning on the example of four selected geofactors. Acta. Montan. Slovaca., 14(4): 275-283.

Marschalko M, Juris P, Tomas P (2008). Selected geofactors of floodland, radon risk, slope deformations and undermining as significant limiting conditions in land-use planning. Conference proceeding - SGEM 2008: 8th International Scientific Conference on Modern Management of Mine Producing, Geology and Environmental Protection, JUN 16-20, 2008 Varna, Bulgaria, I: 201-210.

Marschalko M, Lahuta H, Juris P (2008). Analysis of workability of rocks and type of prequarternary bedrock in the selected part of the Ostrava conurbation by means of geographic information systems. Acta. Montan. Slovaca., 13(2): 195-203.

Marschalko M, Tomas P, Juris P (2009). Evaluation of four selected geobarriers flood lands, radon hazard, undermining and slope movements by means of geographic information systems. Conference proceeding - SGEM 2009: 9th International Multidisciplinary Scientific GeoConference, Modern management of mine producing, geology and environmental protection, Jun 14-19, Albena, Bulgaria, I: 221-228.

Marschalko M, Treslin L (2009). Impact of underground mining to slope deformation genesis at Doubrava Ujala. Acta. Montan. Slovaca., 14(3): 232-240.

Pennington C, Foster C, Chambers J, Jenkins G (2009). Landslide Research at the British Geological Survey: Capture, Storage and Interpretation on a National and Site-Specific Scale. Acta. Geol. Sin.-Engl., 83(5): 991-999.

Suski B, Brocard G, Authemayou C, Muralles BC, Teyssier C, Holliger K (2010). Localization and characterization of an active fault in an urbanized area in central Guatemala by means of geoelectrical imaging. Tectonophysics, 480(1-4): 88-98.

Tingey BE, McBride JH, Thompson TJ, Stephenson WJ, South JV, Bushman M (2007). Study of a prehistoric landslide using seismic reflection methods integrated with geological data in the Wasatch Mountains, Utah, USA. Eng. Geol., 95(1-2): 1-29.

Travelletti J, Demand J, Jaboyedoff M, Marillier F (2010). Mass movement characterization using a reflexion and refraction seismic survey with the sloping local base level concept. Geomorphology, 116(1-2): 1-10.

Yilmaz I (2009a). Landslide susceptibility mapping using frequency ratio, logistic regression, artificial neural networks and their comparison: a case study from Kat landslides (Tokat-Turkey). Comput. Geosci., 35(6): 1125-1138.

Yilmaz I, Marschalko M, Bednarik M, Kaynar O, Fojtova L (2011). Neural computing models for prediction of permeability coefficient of coarse-grained soils. Neural. Comput. Appl. DOI: 10.1007/s00521-011-0535-4

Yilmaz I, Yavuzer D (2005). Liquefaction potentials and susceptibility mapping in the city of Yalova, Turkey. Env. Geol. 47(2): 175-184.

Yilmaz I, Bagcı A (2006). Soil liquefaction susceptibility and hazard mapping in the residential area of Kütahya (Turkey). Env. Geol., 49(5): 708-719.

Yilmaz I, Yıldırım M (2006). Structural and geomorphological aspects of the Kat landslides (Tokat-Turkey), and susceptibility mapping by means of GIS. Env. Geol., 50(4): 461-472.

Yilmaz I (2009b). A case study from Koyulhisar (Sivas-Turkey) for landslide susceptibility mapping by Artificial Neural Networks. B. Eng. Geol. Environ., 68(3): 297-306.

Yilmaz I (2010). Comparison of landslide susceptibility mapping methodologies for Koyulhisar, Turkey: Conditional Probability, Logistic Regression, Artificial Neural Networks, and Support Vector Machine. Environ. Earth. Sci., 61(4): 821-836.