CONTRIBUTION OF ELECTRICAL RESISTIVITY TOMOGRAPHY APPLIED TO THE SLOPE DEFORMATION SURVEY IN LIDEČKO

PŘÍNOS ELEKTRICKÉ REZISTIVITNÍ TOMOGRAFIE PŘI PRŮZKUMU SVAHOVÉ DEFORMACE U OBCE LIDEČKO

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Abstract

In the last years, electrical resistivity tomography (ERT) has been increasingly used to solve various types of problems in engineering geological survey, geotechnical investigations, etc. It gradually replaces a traditional combination of methods of resistivity profiling (RP) and vertical electrical sounding (VES). This paper provides selected results obtained from the survey of a slope deformation in Lidečko. It brings also some new details about its construction and results of monitoring carried out in the year 2011. The largest landslide hazards result from its position over a water pipeline line, where there is a real risk of a massive landslide of the slope ending in the valley of the Senice River. It is an old landslide reactivated during the floods in the years 1997 and 2006.

Abstrakt

Elektrická rezistivitní tomografie (ERT) je v současné době stále více používána k řešení různých problémů v oblasti inženýrsko-geologického průzkumu, geotechnických výzkumech atd. Postupně nahrazuje tradiční kombinaci metod odporového profilování (OP) a vertikálního elektrického sondování (VES) při průzkumu svahových deformací. V tomto příspěvku jsou uvedeny vybrané výsledky získané při průzkumu svahové deformace u obce Lidečko. Přináší některé nové poznatky o jeho stavbě a výsledky monitoringu provedeného v roce 2011. Největší nebezpečí sesuvu vyplývá z jeho polohy nad vodovodním přivaděčem, kde existuje reálné riziko mohutného sesuvu svahu končícího v údolí řeky Senice. Jde o starý sesuv oživený při povodních v roce 1997 a 2006.

Key words: electrical resistivity tomography, slope deformation, engineering geological survey.

1 INTRODUCTION

In the last ten years, we have encountered the presentation of results of using a relatively new method, or measurement methodology, which uses a large number of connected electrodes – 25 and more (Loke 2001), which is most commonly known as resistive tomography or shortly called as “Multi-cable”, etc., however, the most suitable indication is electrical resistivity tomography (ERT). The principle of measurement, as well as the processing of measured data are already well known, e.g. Loke (1996), so the attention is paid to the use of the ERT method in the exploration of a hazardous slope deformation near the town of Lidečko. Currently, the landslide front is located about 17 meters from the main water pipeline, which supplies with water the citizens of Horní Lidečko, Valašské Klobouky, Slavičín and Luhačovice Regions.

Recently initial stages of remediation work have been made on this landslide, (Ryšávka, Skopal 2008), which were based mainly on the results of existing reconnaissance of the slop5e deformation and also the results of geophysical survey carried out by the firm KOLEJ CONSULT & servis spol. s r.o., Brno, in the years 2007 –

Volume LVIII (2012), No.2
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2008. The first stage of redevelopment work includes drainage of surface water from the areas of the greatest subsidies to the landslide body.

2 LOCATION, GEOLOGICAL AND GEOMORPHOLOGICAL CONDITIONS

The massive landslide is located in forest stands east of the spot elevation of the peak called “Kopce” (699 asl), 1 km north-west of the town of Lidečko in the Vsetín Region (Fig. 1). The affected area is located on an old landslide, where the active part of the landslide develops in the space above a fossil landslide. This area is heavily violated. The landslide is classified as a current block slide with a thickness of up to 30 m (KOLEJ CONSULT & servis s.r.o., in Ryšávka, Skopal 2008).

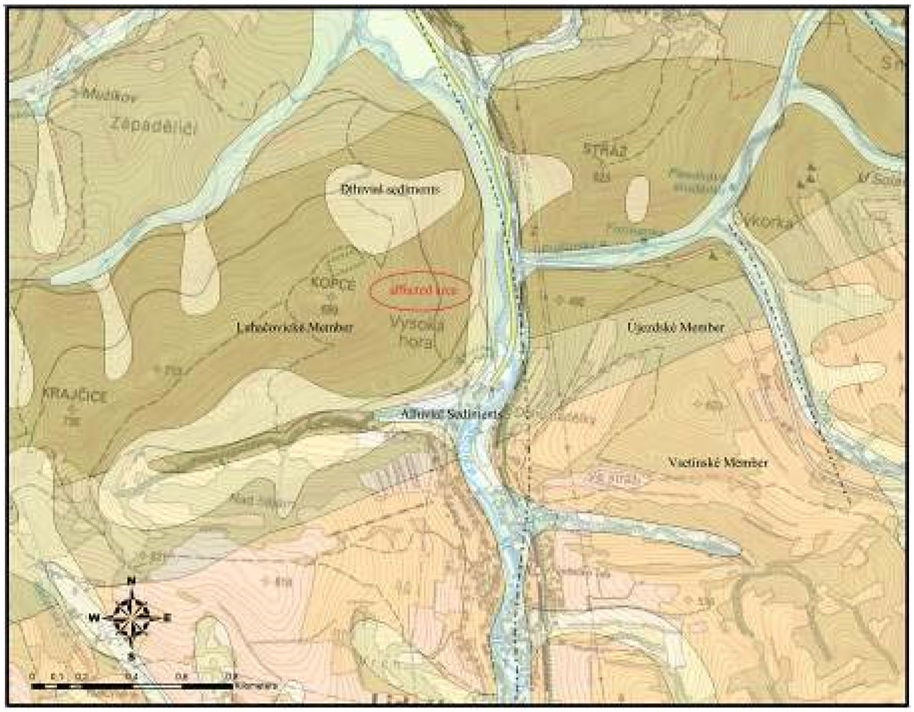

Fig. 1 Situation map of the Lidečko locality and cut of the geological map with description of basic rock complexes.

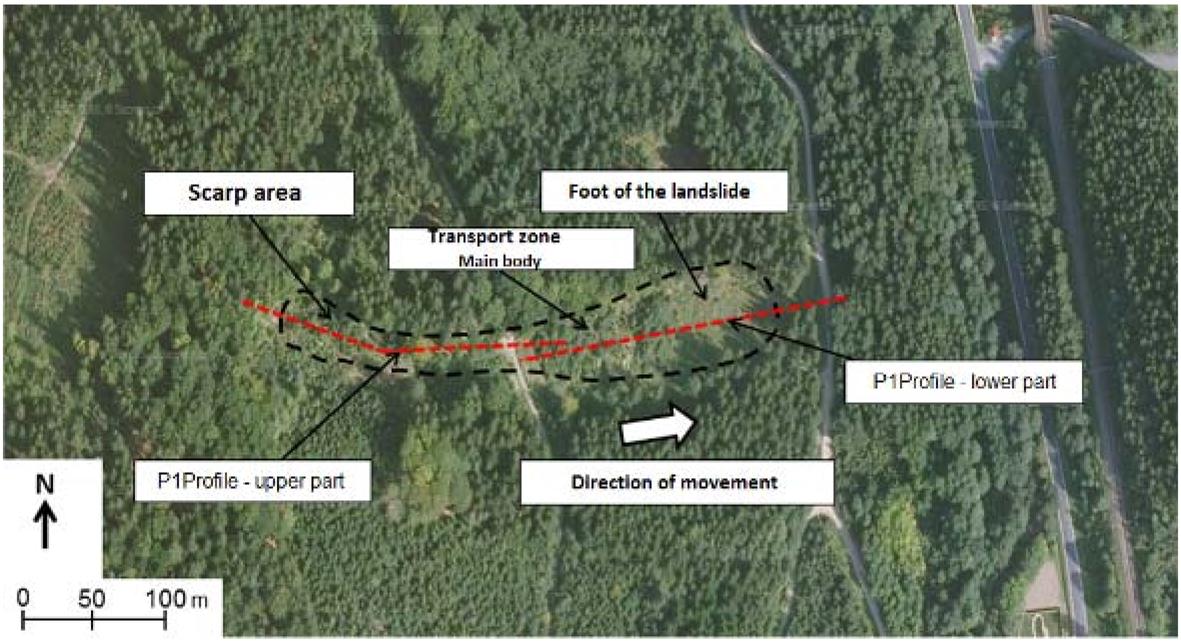

Fig. 2 View of individual parts of the landslide and presentation of profiles along the slide axis - satellite image (www.mapy.cz)

From the geomorphological point of view, the area is located in the subprovince of the Outer Western Carpathians, in the area of the Slovak-Moravian Carpathians, the unit of the Vizovice Highlands, the subunit of Komonec Upland. The landslide terrain is manifested by significant degrees of slope and laterally elongated depressions. Blocks of sandstone are separated along a series of cracks in the ENE-WSW direction, perpendicular to the direction of movement (Baroň 2004). The average slope inclination is between 25 to 30°, locally up to 40°. The presence of relatively thick resistant sandstones and their tectonic disturbance cause a relative difference in elevation up to 260 m along the length of 500 m (Baroň 2004).

From the regional and geological points of view, the locality is situated in the territory belonging to the Rača Unit of Magura Paleogene. Pre-Quaternary bedrock of the locality of interest is built up by Palaeoceneous to Eoceneous Soláň Formation - arkose of a Luhačovice menber. The sandstones are light grey to tan, mostly medium to coarse grained, often slightly conglomeratic with calcareous or clay cement (Baroň 2004). They are thin-to-thick tabular and in different parts of their surface affected by weathering processes. The Quaternary cover is in the area of interest represented by loose diluvial sediments that are highly heterogeneous, somewhere having a character of sands, at the base gravels. Somewhere else it is rocky and boulder deluvium with sandy and loamy sediments. The complex of Quaternary sediments ends close to a special-purpose forest road with a layer of anthropogenic made-up ground of a gravel character (Merta 2006).

From the hydrogeological point of view, fissure permeability is applied in the pre-Quartenary formations, which is predominantly bound to near-surface eroded parts of the Soláň Formation. Underground water is also bound to the quaternary diluvial sediments of a character of clastic sediments (gravel, sand) – collectors with intrinsic permeability. Diluvial cohesive soil (clay) probably behaves in the water-bearing systems as insulators or as semi-insulators (Ryšávka, Skopal 2008).

2.1 Basic characteristics of landslide

The landslide has an elongated shape in the W-E direction with a length of about 350 and an average width of 50 m. In the accumulation area of the landslide (foot of the landslide), the width exceeds 70 m and in the upper half, it is about 30 m. In height the landslide is bordered with the spot elevations – 465 m asl and 615 m asl. The landslide can be divided into three parts: scarp area (main scarp and minor scarp), transport zone (main body) and foot of landslide (Fig. 2). The scarp area is bordered by a distinct scarp line with a spot elevation of 615 m asl (Fig. 3) and the lower part by a forest path with a spot elevation of 545 m asl. This is the longest part of the landslide with a length of approximately 160 m. This scarp area has a concave shape. Earth and rock material is moved into the transport zone and foot of landslide. In the scarp area, a large sandstone sheet can be seen, on which the rock material rolled off. This area represents a part of the left side border of the landslide scarp area. The transport zone is located below the forest road level at 542 m asl. In this part, the slope terrain is chaotically covered with rock blocks together with the remains after uprooted trees. The transport zone passes to the foot of the landslide at a level of spot elevation of 525 m asl. The surface of the foot area is similar to that in the transport zone. The foot area is made up of accumulated rock sandstone blocks, to a lesser extent conglomerates and uprooted trees (Fig. 4). Rock blocks in the foot area reach sizes up to several meters. The massive sandstone blocks show a grossly low to moderate level of weathering.

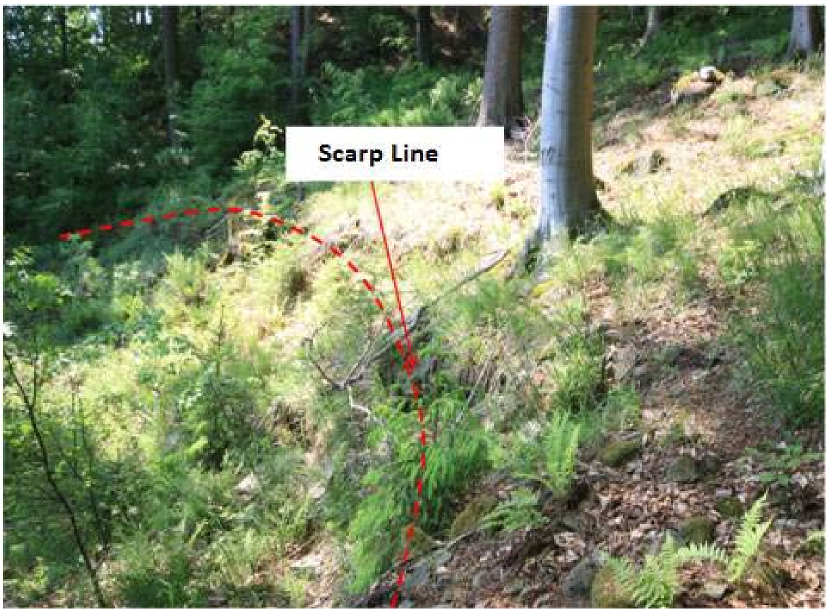

Fig. 3 Illustration of the scarp line of the landslide (photo: A. Poláček, 2011)

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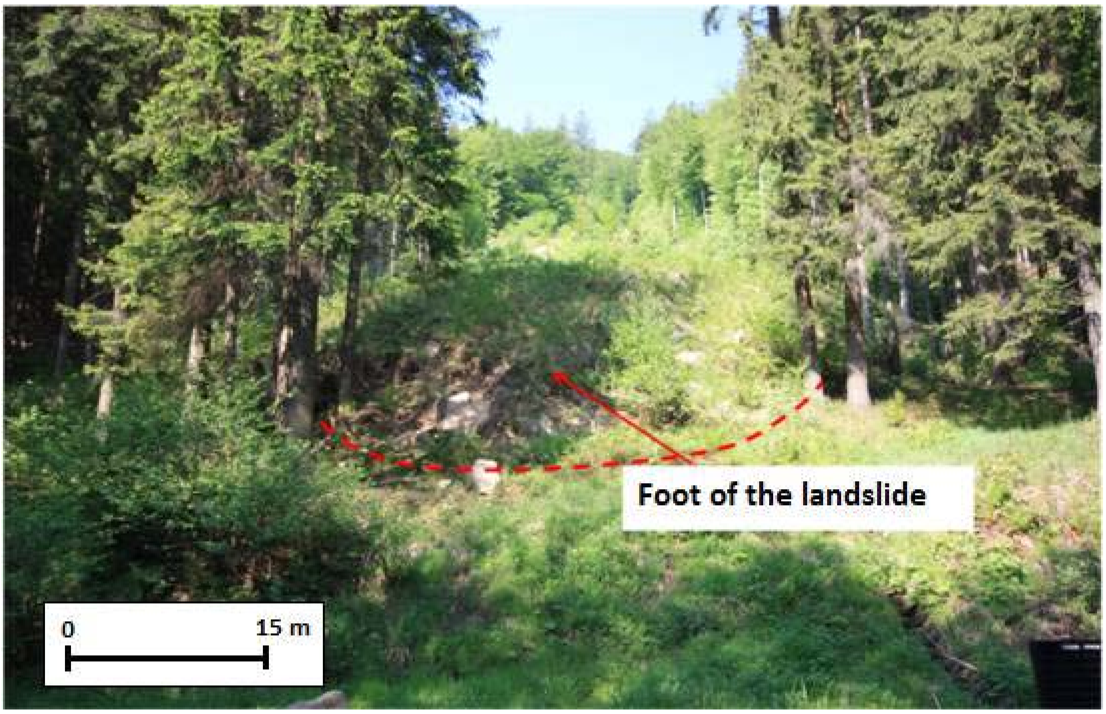


Fig. 4 The accumulation area and the foot of the landslide (photo: A. Poláček, 2011)

According to the determined structure of the landslide, geological, hydrogeological conditions and geotechnical parameters (Mack 2008) it can be assumed that the triggering mechanism of landslide activation was extreme precipitation in July 1997. In this period, the maximum saturation of permeable sandstones and near-surface layers occurred. Deposit layers and their tectonic fracturing (Merta 2006) cause the creation of slickensides (discontinuities and jointing) along which landslide movements take place.

4 FIELD WORK AND MEASUREMENT METHODOLOGY

Geophysical works were carried out using the method of electrical resistivity tomography (hereinafter referred to as ERT) which followed previous geophysical measurements, where the methods of ground penetrating radar (hereinafter referred to as GPR), refraction seismic and the VES method (in two cases) were applied. A detailed assessment is provided in a report (KOLEJ CONSULT & servis s.r.o., in Ryšávka, Skopal 2008).

Geoelectric measurements in the area of interest took place in the period March – November 2011. The measurements were performed at a total of eight profile lines along the axis of the landslide body and transverses to it (Fig. 5). In the axis of the landslide, the main profile was carried out marked as P 1, which consists of two parts with lengths of 254 m and 258 m. Further measurements took place at six cross sections Pp0 - Pp5. The cross sections Pp0 and Pp5 are outside the landslide body itself. The cross sections were 156 m long. The behaviour of all profiles is indicated in Fig. 5. The total length of the geoelectric profiles was 1448 m.

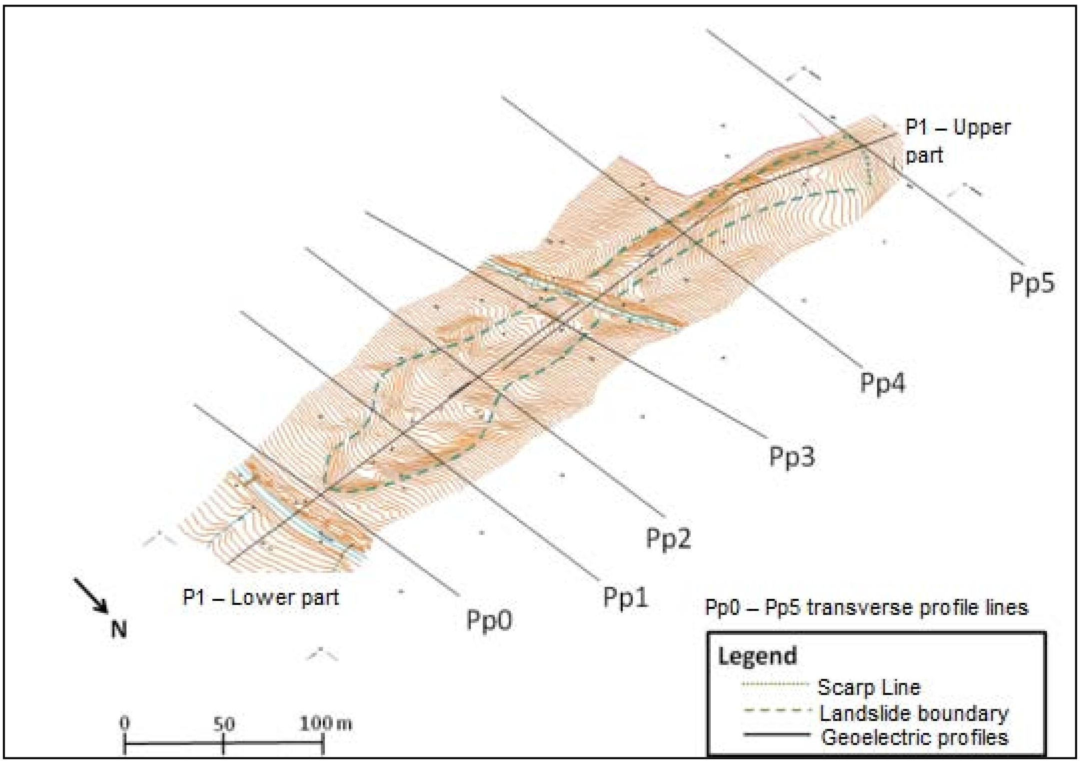


Fig. 5 Schematic representation of all geoelectric profiles

In these measurements, a Wenner-Schlumberger array was used. Under this arrangement, it was possible to detect horizontal and quasi-horizontal structures of larger sizes, different shapes and orientations, to a lesser extent tectonic zones or faults, contacts of layers with high different specific resistivity, etc. The real depth measurement range reached about 1/5 of the maximum distance between the first and the last electrode at the profile (Cervantes, Poláček 2011).

The output data was processed using the algorithm of inverse task by means of the RES2DINV software. This computer program automatically determines two-dimensional models (2D) of the base resistance for the data obtained by the ERT method. The program uses an inverse model, which consists of a series of rectangular pseudo-blocks (Loke 2001). Using this program, basic ideas of physical inhomogeneity of investigated environment using appropriate measurement methodology can be obtained faster than ever before.

5 ASSESSMENT OF GEOELECTRIC MEASUREMENT RESULTS

5.1 P 1 Profile

The results of geophysical measurement at the main – longitudinal profile P 1 consisting of two parts, are shown in Fig. 6. The division of the profile into two parts is performed mainly due to its large total length. It was not possible to perform measurements within one day with regard to quite difficult conditions for movement on the landslide surface as it was covered with dense vegetation of self-seeding trees. Considering the purpose of measurements, the attention is given in the next text especially to the transport and accumulation parts of the P 1 profile, not to the scar one; thus to that landslide part where it was possible to assume changes in the internal construction of landslide and a possible increase of the risk of further movement. The complete graphical illustration of the interpreted vertical resistivity cut at the main profile is shown in the work by Ryšávka, Poláček, Cervantes (2011). In Fig. 6, next to the slickensides, the points are indicated through which cross sections were led. It should be noted that the choice of their direction and position in relation to the results obtained at the longitudinal profile was largely influenced by the terrain possibility and viability even outside, thus in peripheral parts of the landslide.

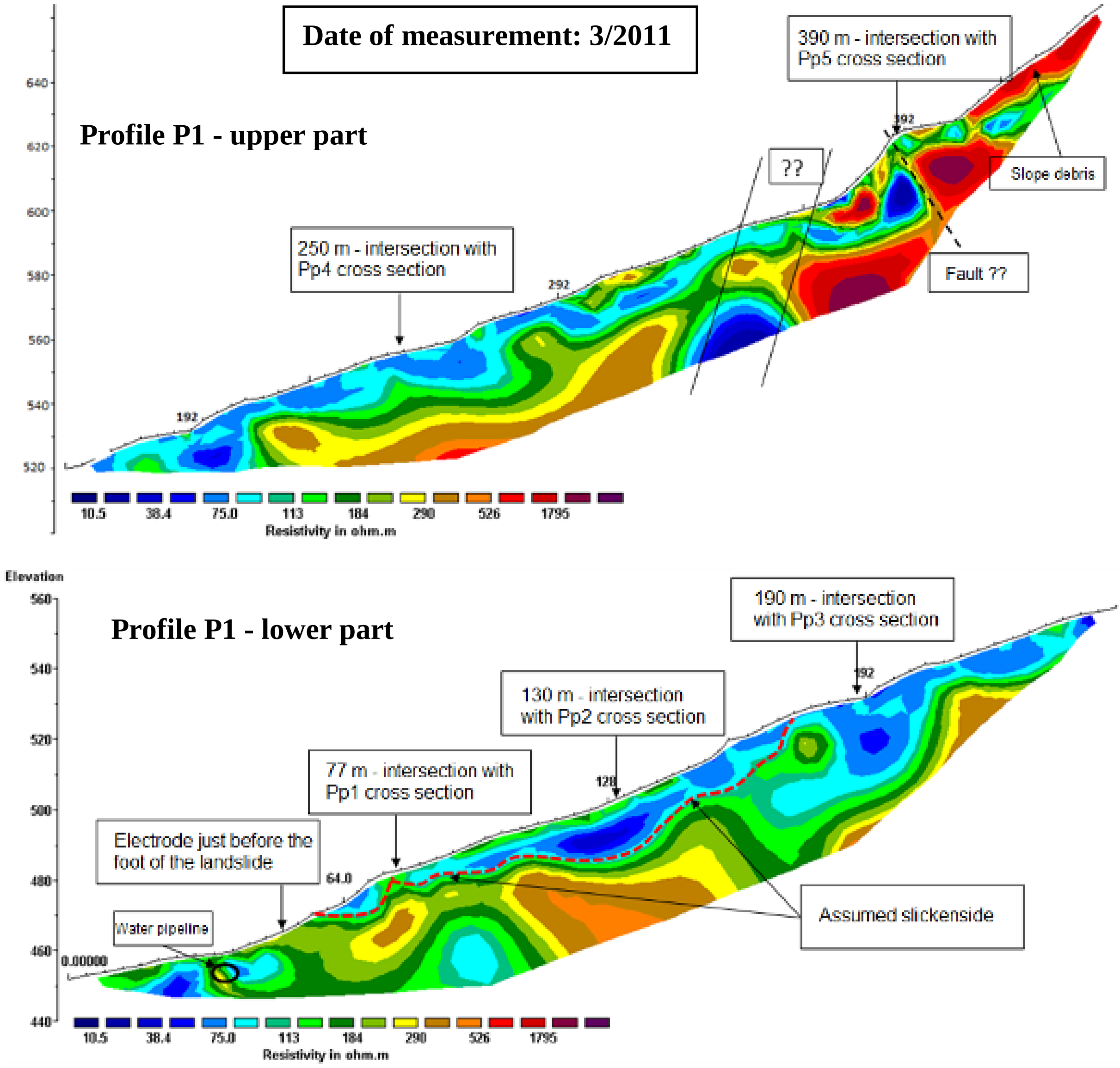
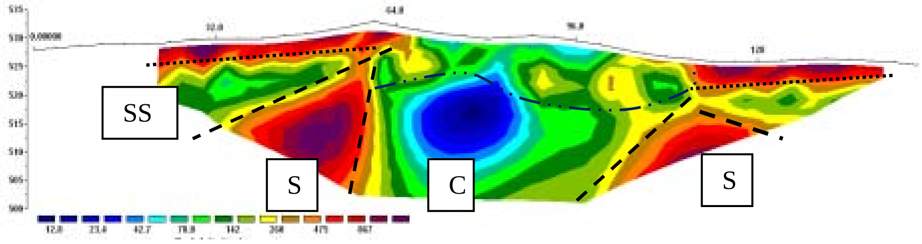


Fig 6: Longitudinal resistive cut P1 and basic representation of slickensides.

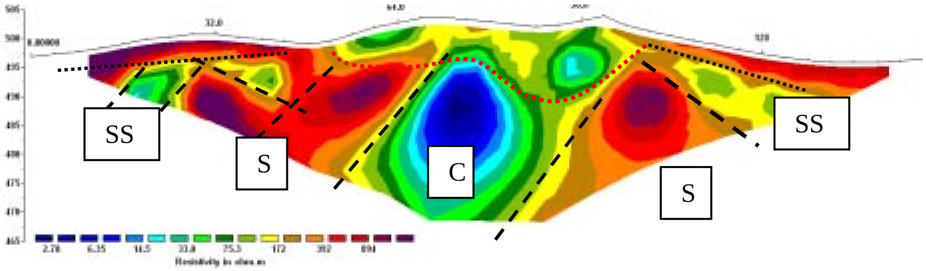
5.2 Pp1, Pp2 and Pp3 cross sections

Fig. 7 shows the interpreted vertical resistivity cuts at the Pp1 to Pp3 (cross sections led through the accumulation (bottom) part of the slope deformation and for comparison then the Pp0 cross section led outside the landslide in the bottom forest path. From the comparison of the resistivity images at the profiles led through the landslide body with the behaviour of the resistivity at the profile Pp0 it is evident that the values of the specific resistivity at the cross sections are similar to each other. On the basis of the results, the Pp1 to Pp3 cross sections differ from the Pp0 cross section by both resistivity values and its overall image. Taking into account the work (Baroň 2004), there is then indicated the lithological interpretation of main petrographic types of rocks, resolution of sandstone and claystone positions as well as slope debris, including the indication of their borders.

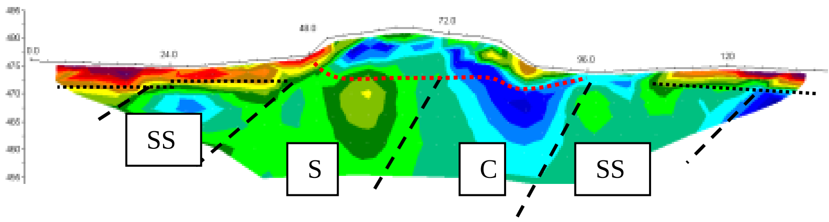
Pp3 Cross section



Pp2 Cross section



Pp1 Cross section



Pp0 Cross section

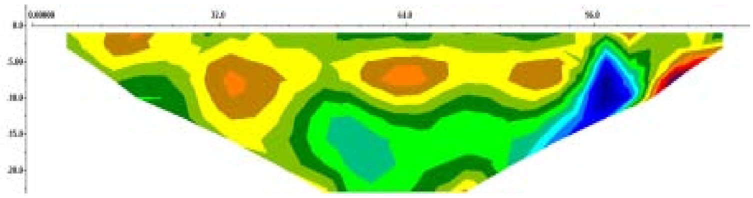


Fig. 7 Interpreted vertical resistivity cuts at the Pp1, Pp2 and Pp3 cross sections at the bottom of the P 1 main profile (the Pp0 cross section was led outside the landslide body).

Legend:

S – sandstone positions
C – claystone positions
SS – saturated sandstones
– – – – – interface between rock types
— · · — · · · – old slope accumulations with a possibility of partial reactivation
.... – slope debris
– – – – (red) – active part of landslide

5.3 Comparison of measurement results at the bottom of the P 1 profile in March and November 2011

With regard to the fact that based on visual reconnaissance a movement of the slope deformation was found out, when the foot of the landslide shifted by about 1 m towards the forest path and thus also towards the water pipeline, repeated geophysical measurements were carried out in this part. The results obtained are shown in Fig. 8. Comparing the obtained resistivity cuts from measurements made at an interval of six months it was found out that adverse development of the slope deformation occurred in this period. A significant completion of the slickenside at a depth of about 8 to 15 m occurred. A loosen, partially consolidated part of the landslide moved slightly across the slickenside. The estimated initiation of this movement is related to the rainfall in this period.

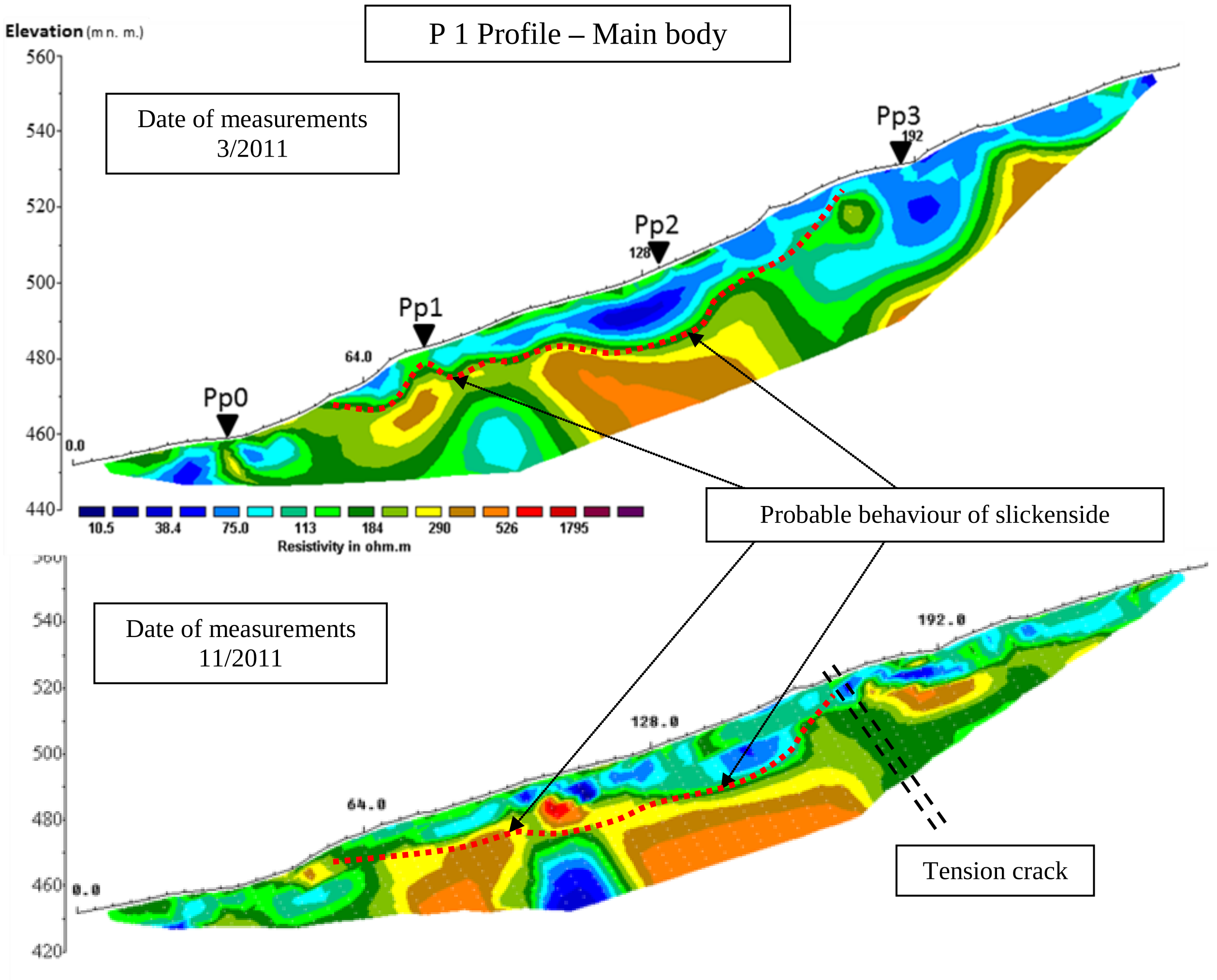


Fig. 8 Interpreted vertical resistivity cuts in the accumulation area of the slope deformation of the P 1 profile. (▼– intersections with cross profiles)

6 CONCLUSIONS

- The ERT measurement results allow a more precise definition of structural, lithological and tectonic interfaces, identification of quasi-homogeneous blocks depending on the landslide construction. On the basis of the performed geophysical monitoring of the slope deformation in Lidečko, it was managed to define and by repeated measurements to confirm the existence of a significant slickenside, which occurs in the depth range of 8 to 15 m. The mentioned slickenside may be the main factor that allows designing optimal prevention and phase-to-phase remediation works that are often very expensive.
- By comparing the results obtained by the application of the ERT method with the methods of GPR and shallow refraction seismic (Ryšávka, Skopal 2008), it was showed that the ERT method is at least fully comparable with these methods, has lower economic exigency and allows more detailed division of measured environment into physically different blocks (a notable difference in resistivity particularly for distinguishing sandstone blocks and claystone positions).

- Optimal utilization of the ERT method is subjected to such a ground surface, which enables high-quality grounding of electrodes, in particular to sandy-clayey environment. The implementation of the measurement itself in the locality of Lidečko, see Figs 3 and 4, was considerably complicated by the nature of the landslide surface. Still it was managed to get the results comparable with the geological conditions of the area.

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RESUMÉ

V článku jsou uvedeny výsledky získané metodou elektrické rezistivitní tomografie na svahové deformaci Lidečko v roce 2011. Zejména jsou diskutovány výsledky zjištěné ve svahové deformaci dlouhé 250 m, která z hlediska stavby sesuvu představuje část transportní, ale zejména část akumulační. Čelo sesuvu se v současné době nachází cca 17 m před vodovodním přivaděčem. Sesuv tak představuje značné riziko ohrožení jeho funkce.

Výsledky získané metodou ERT doplňují a upřesňují geofyzikální měření prováděné cca před třemi lety, které jsou součásti zprávy (Ryšávka, Skopal 2008). Jedná se zejména o vymezení smykové plochy, která byla interpretována v březnu 2011 a po té ověřena po pohybu sesuvu o 1 m blíže k vodovodnímu přivaděči. Geofyzikální měření bylo do značné míry limitováno nevhodným stavem povrchu terénu. Povrch sesuvu se vyznačoval v důsledku samotného horninového složení a sesouváním nesourodých hmot značnými nerovnostmi a hustým náletovým porostem, který znesnadňoval samotné měření, uzemňování elektrod a do určité míry i optimální volbu geofyzikálních profilů.

Publikace je součástí řešení grantového projektu SGS SP2011/113 “ Metoda ERT (elektrická rezistivitní tomografie) jako prostředek k významnému zlepšení informace o fyzikální nehomogenitě sesuvu včetně vymezení smykových ploch“.