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THE MYSTIQUE OF ERT

TAJE ERT

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Abstract

Electrical resistivity tomography (ERT) is, nowadays, the most used geoelectrical method. A development of measurement devices and computer data processing make geophysical measurements available not only to a geophysical groups, but to a wide range of geoscience disciplines, including civil engineering and archaeology. However, it brought not only an expansion in using of geophysical methods but also problems with final interpretation of ERT results. Non-specialist geophysicists are not aware of complexity of parameters hidden behind the final picture given by interpretative program for ERT. They take the final output of the computer processing as the only possible solution and they completely neglect boundary conditions of the solution and, in fact, of whole processing. Within this paper, we would like to point out on some aspect of this problem.

Abstrakt

Metoda elektrické odporové tomografie (ERT) je v současnosti nejpoužívanější geoelektrickou metodou. Rozvoj přístrojové techniky a počítačového zpracování umožnil pořízení přístrojového i počítačového vybavení nejen geofyzikálním „skupinám", ale i širokému okruhu všech geovědních disciplin včetně stavařských a archeologických pracovišť. To ovšem přineslo nejen rozšíření používání geofyzikálních metod, ale i problémy se závěrečnou interpretací výsledků ERT. Nespecialisté geofyzici si neuvědomují, co vše je za výsledným obrázkem na výstupu interpretačního programu ERT. Berou výsledný výstup počítačového zpracování jako jediné možné řešení a zcela jim unikají okrajové podmínky řešení a celého zpracování. Chtěli bychom v tomto článku upozornit na některé aspekty tohoto problému.

Keywords

electrical resistivity tomography, models, RES2DINV, RES2DMOD

Klíčová slova

Elektrická odporová tomografie, modely, RES2DINV, RES2DMOD

1 Introduction

A distribution of resistivity, as well as distribution of other physical properties of the rock massif, represents a reality, which we try to describe by geophysical methods as good as possible. During the time, we have been getting better and better tools which allow us to recognize a condition of the rock massif. However, even such tools are not perfect and, without knowledge of the basic theory of the method, wrong conclusions might be determined. It applies also for method of electrical resistivity tomography. Its depiction of the rock massif structure and rock properties are affected by mere possibilities of measurement with this method, including displaying the results, and objective conditions for its application and interpretation. Measurement itself is trouble-free. The ERT apparatuses are equipped by sufficient control mechanisms which exclude gross measurement errors. If some of the values are yet measured with error higher than with other values, it is possible to exclude them from further processing within the first processing step. Despite of this fact, the depicted results are influenced by the processing procedure, including a setting of parameters of calculation and of parameters of displaying.

2 Differences in ERT processing

Details of using the RES2DINV program will not be described here; however, some differences in measured data processing will be highlighted. The outputs of the RES2DINV software can be affected by different setting of the inversion process. Surprisingly, even the result gained from the same data set but interpreted in different version of the program can vary.

Fig.1 shows the examples of the outputs from program versions 3.54, 3.58 and 4.04. A comparison of all three pictures (results) shows us five differences. The biggest variations are with high resistivity anomalies at the stationing of 48 and 88 meters. The first distinction is represented by low resistivity anomaly located from the beginning of the profile to the stationing of 32 meters. This anomaly is the most distinct in the version 4.04, whilst in the version 3.58 is the least significant. Nevertheless, the lowest resistivity values are in the version 3.54. Second differing anomaly is represented by the resistivity maximum on 88 m which appears to have the biggest anomaly in 3.58 versions and the smallest one in version 4.04. The third difference is a low resistivity anomaly at stationing 74 m at the bottom of the space interpreted. This anomaly has the lowest resistivity values in the version 3.58 with the “smallest minimum”. The highest values can be found in version 4.04 when the centre of the minimum is shifted of five meters to the lower stationing. The fourth distinction is the course of the middle resistivity values in the centre of the profile. In the version 4.04 the anomaly has the smallest “thickness”. The last difference is the high resistivity anomaly with centre on 48 m. The anomaly has the highest values in version 4.04 and the lowest ones in version 3.58. The geological evaluation of the results of all three program versions would not be completely different provided on condition that all tiny anomalies would not be explained in terms of geology and the geological boundaries would not be drawn strictly along the isoohms of certain value.

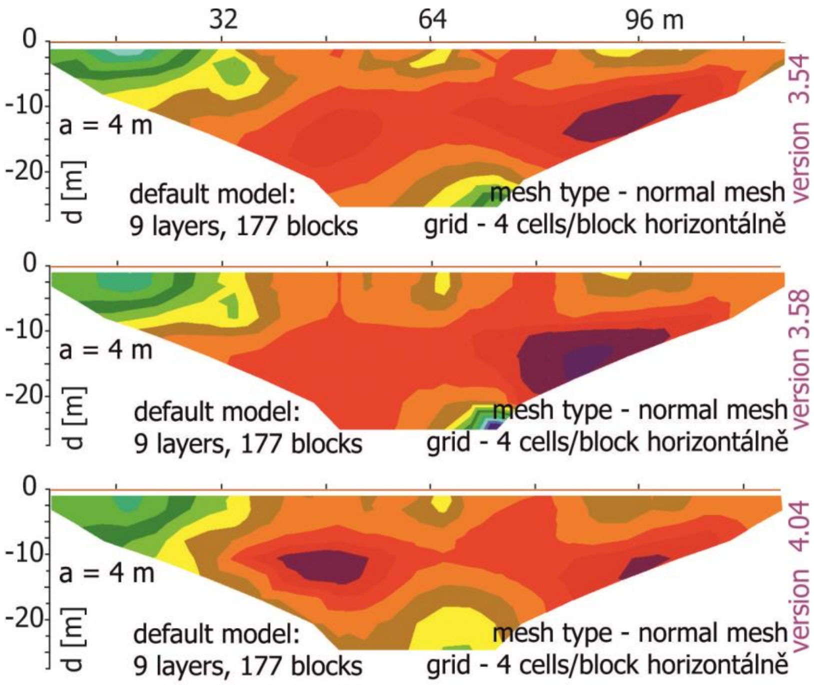

Fig. 1 Differences in interpretations among versions of the RES2DINV program

It is not surprising that slightly different results from the original measured data sets are given by “robust inversion” compared to the results of standard method of the least squares; fig. 2. Comparing both pictures, we can see that depiction of the resistivity distribution in the massif does not fundamentally differ, however, compared to the robust method, the picture obtained from standard inversion by the least square method shows generally smaller maxima and minima of particular anomalies, i.e. it gives lower range of resistivity. The character of the field distribution practically remains the same, but two significant variations can be found in the shape of anomalies. The most significant distinction is within the robust method at the maximum of the anomaly at stationing ca. 40 m and depth of approximately 14 meters. Within the robust method, the maximum value is higher by approximately 25 percent. Similarly, the anomaly on 72 meters and in depth of 24 meters is more pronounced in the robust method.

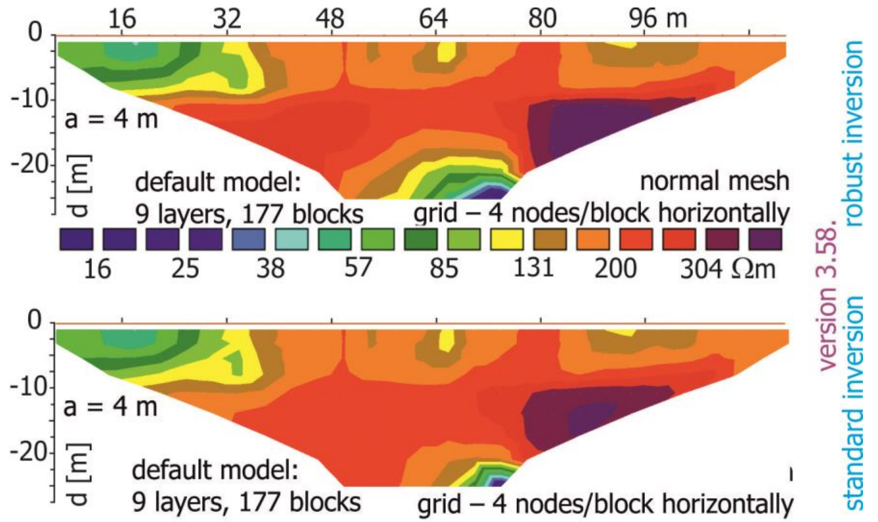

Fig. 2 Comparison of robust and standard inversion

In fig. 3, we can observe how the final picture is changing with use of 2 or 4 cells on the block. In case that we choose processing with use of 2 or 4 cells on the block (compare upper and middle image) within the least square method (standard inversion), we will obtain practically identical results, or only slightly different respectively. The only difference, that needs to be described, is the change in a distribution of resistivity values > 200 Ωm, when the anomaly is continuous across the whole profile with gridding of 4 cells on block, while with gridding of 2 cells on block it is not. If we will not consider detailed changes during a geological interpretation, then no wrong conclusions should be determined. In case that we will compare “normal mesh” and “the finest mesh” type used in isoline drawing, we will come to the conclusion that differences are very small and they can be neglected within the geological interpretation.

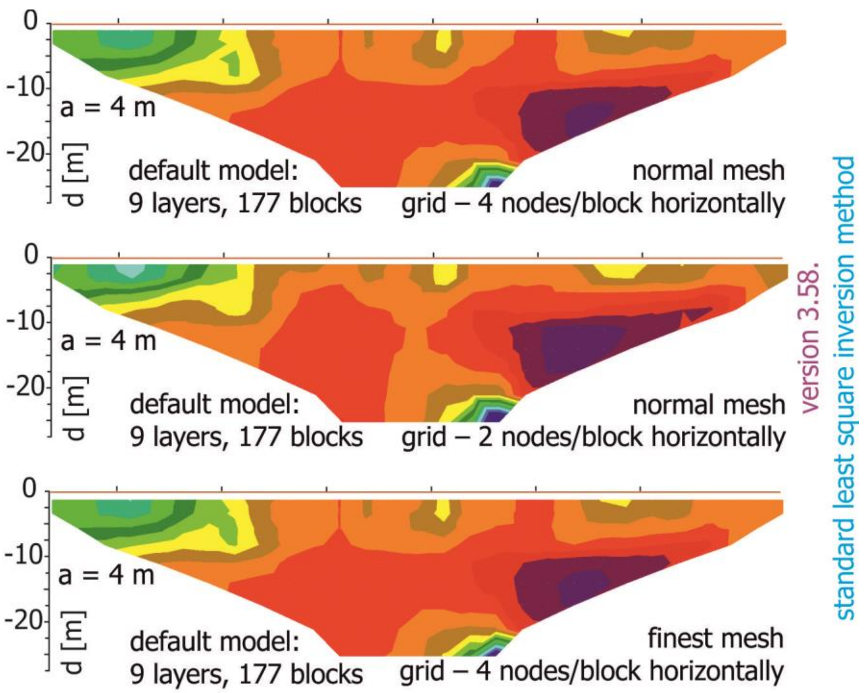

Fig. 3 Division into 2 or 4 cells per block

In case that we will use the computation of half spacing of electrodes, then the ascertained differences are more significant; see fig.4 – upper image compared to middle and bottom one. The low resistivity anomaly on 72 m in depth of 24 m practically disappeared. The maximum of the high resistivity anomaly in the right portion of the profile decreased and the anomaly shifted into the lower stationing. If we will observe an effect of number of layers and number of blocks (middle and bottom model) we will find that the shape of the high resistivity anomaly, with centre in depth of 15 m and at stationing of 82 m, slightly changes.

If we will evaluate the results of interpretations of the resistivity field in RES2DINV program, then the most identical results will be obtained with standard setting with 2 or 4 cells on block. Any significant influence of the grid mesh cannot be further observed. In research papers, there is quite often that results from RES2DINV program are presented as isolines of resistivity in the professional graphic software; fig. 5. A short testing brought unequivocal recommendation how to work in this case. It shows that isolines are roughly distorted if we will use double value of electrode spacing during setting of gridding in SURFER software. It can be proveded by evidence on comparison of isolines in fig.5 „**B**“ with images „**BS$_4$**, **BS$_8$** a **BS$_{16}$**“. It is obvious that isolines **BS$_{16}$** are significantly different than isolines **BS$_4$**. That is why we should use in Surfer grid with maximum value equal or even smaller than electrode spacing used.

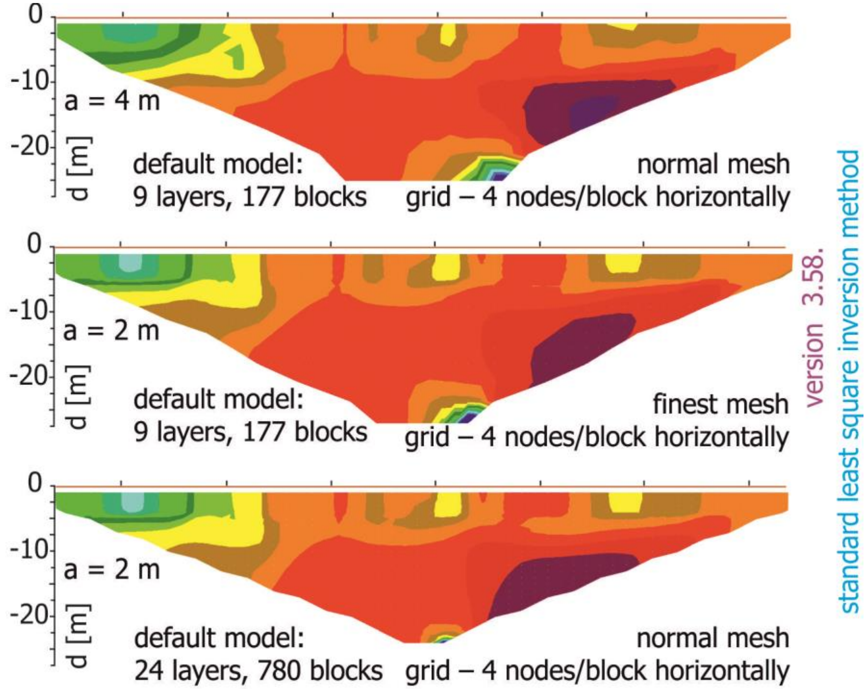

Fig. 4 Changes when decrease the electrode spacing

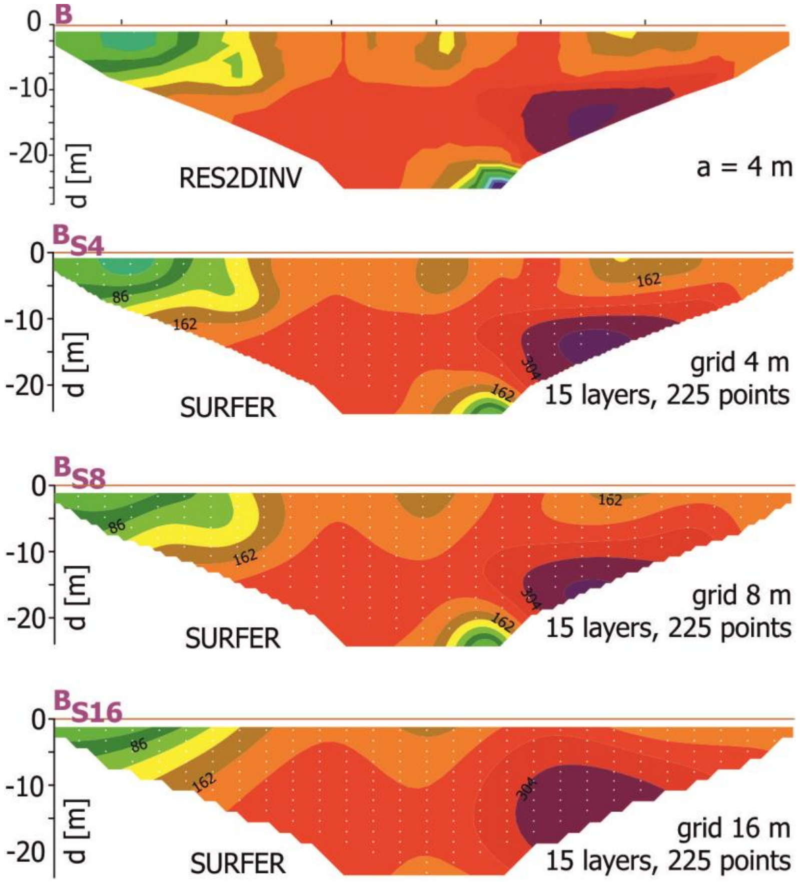

Fig. 5 Drawing of isoohms in program Surfer

Certain variations in the way of the interpretation of electrical resistivity tomography in are described in RES2DINV software user manual. Examples of differences between the standard least square method and robust method as well as using of various electrode spacing are mentioned. Described differences are smaller than in the examples presented in the text above.

Another parameter, which affects final resistivity field very significantly, is the damping factor. It can be understood as a parameter affecting the “amplitude of the value range (amplitude of the scatter). It can be achieved higher or lower intensity of smoothing of the final inversion model by adjustment of the damping factor (DF). We have possibility to change „Initial damping factor“ or „Minimum damping factor“. The testing of various settings of DF proved that more significant smoothing of final resistivity field is given by the „Minimum damping factor“ parameter. With its application, a fragmentation of interpreted resistivity field is supressed.

An increase in the minimum DF value causes the decrease in number of the depicted partial structures and it lead to its merging to larger units. The model is thus becoming simpler. It is clearly visible e.g. on conductive zone in the left part of the profile, fig.6, which is more or less discontinuous, formed of individual rather separated anomalies. Although the series of individual anomalies would probably be interpreted as a single geological structure, we can find examples in scientific and technical texts when it does not apply. With the adjustment of the DF we can achieve the situation when the particular anomalies unify into the one unit what is simpler for geological interpretation and, moreover, it is more illustrative. The change of the DF brings a smoothing of data and, thus, a suppression of extreme values, both lower and higher ones. We can state that this procedure prevent the development of “bead-type” anomalies. If the value of both parameters is set higher, then the smoothing is quite significant. It is indisputable advantage for an essential cognition of the geological structure. A selection of the very high DF can even cause a complete change of resistivity field, fig.7. It is a question how much we deprive of possibility of detailed interpretation by this procedure.

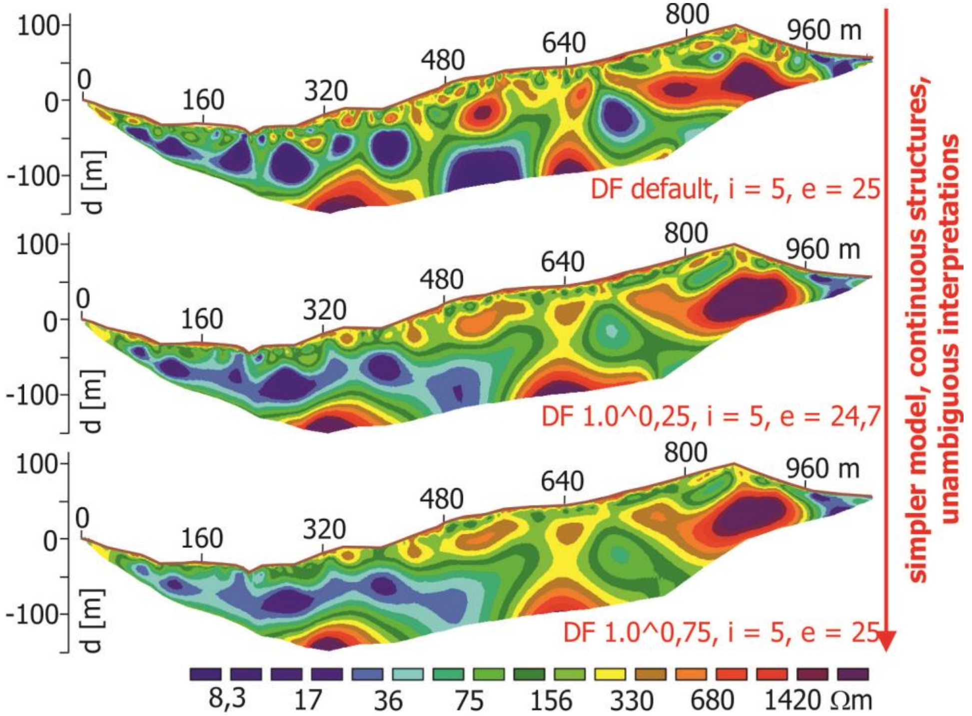

Fig. 6 Example of effect of damping factor

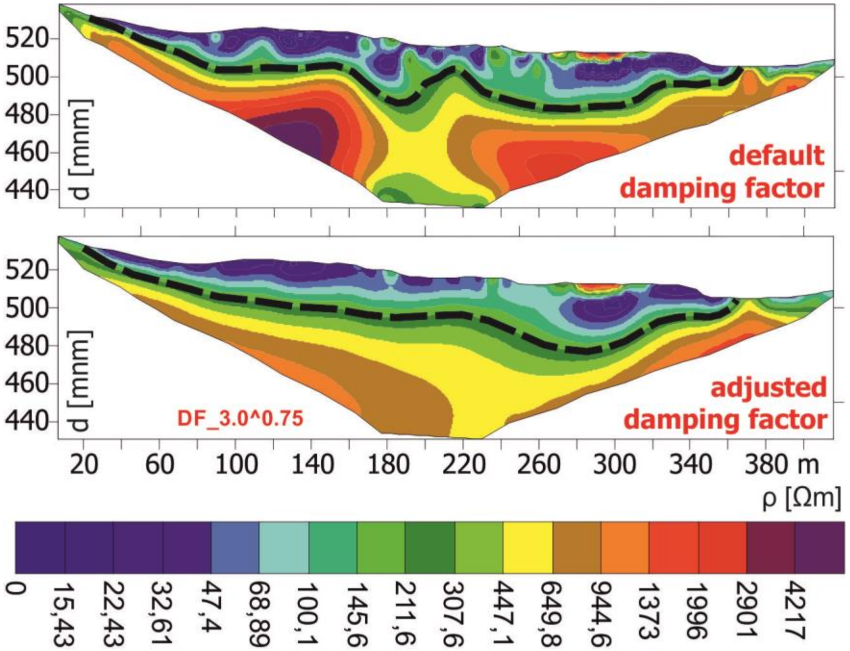

Fig. 7 Effect of damping factor on resistivity field and an interpretation of the slip plane

Another option is a forward modelling in RES2DMOD software, i.e. to create apparent resistivity field “above” specific geological structure. The first step of the rock environment model creation is a determination of geometric characteristics of the whole model and selection of relevant parameters. It is possible to define following types of electrode arrays: Wenner, Wenner-Schlumberger, pole-pole, pole-dipole etc., however, we focused only on modelling using Wenner-Schlumberger configuration. After creation and debugging of the model according to the input parameters, a computation process of resistivity manifestations of the model environment follows, in the manners how it would look during areal measurement. The output of forward modelling is possible to be exported into the format applicable for RES2DINV program where the interpretative algorithms can be set in order to get the inverse result matching the considered model as much as possible.

In the selection of models we focused on a modelling of landslides only. An interesting example of use of electrical resistivity tomography is given by French authors, JOMARD, H. et al. (2010), during the research of La Clapière landslide in the southeast France; fig.8. The rock massif is affected by a large landslide with width of 800 m and length of ca. 1000 m.

The thickness of the slope deformation was described in a range of 100 to 150 m by several authors. Bedrock is formed of metamorphic complex which was affected by the Variscian and Alpine orogenic processes. The landslide is characterized by resistivity significantly exceeding the resistivity of the bedrock. In the model, the resistivity value of 5000 Ωm is assigned to the landslide, while the bedrock has 5 Ωm. Vertical strips (weakened zones) are characterised by resistivity of 250 Ωm.

The authors initially modelled a two-layer task when the thickness of a sliding material was determined as 80 m. The result of modelling gave a system of parallel isolines without any side effect. The authors state the error in determination of the non-conductive layer as negligible. In this case, we have to put the question what isoline of resistivity should be marked as a boundary line. Without a direct survey it is very difficult task. The second model also resulted from two-layer structure; however, four zones of rock disruptions were defined in rock massif; fig.8. It is obvious from the figure, that the final resistivity image is immediately strongly complicated. The horizontal course of isolines is distorted and the course of vertical disruption is practically invisible. According to the authors, the depth is still depicted correctly but it is intensively undulated. The question, what isoline should be considered as the boundary, remains.

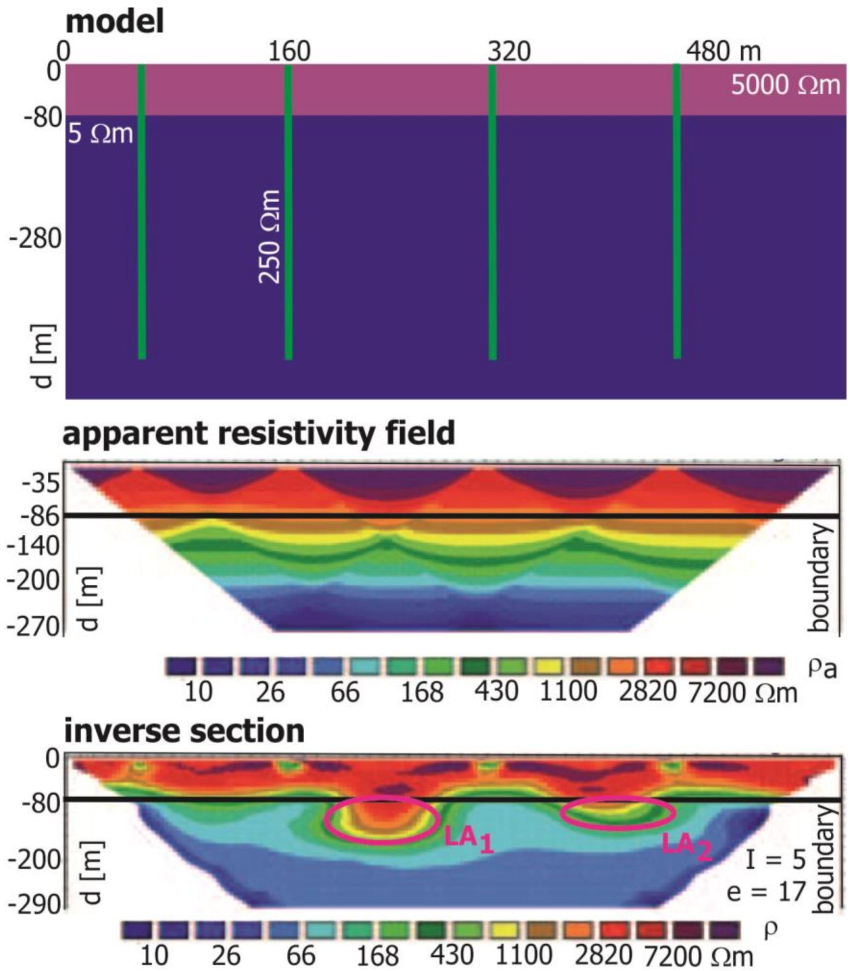

Fig. 8 ERT modelling of the slip zone, after: Jomard H. a kol., 2010

Nevertheless, another circumstance is fundamental. Beneath the slip plane there are two, alternatively three, elliptic anomalies within the isolines, that have no origin in geological structure. Two more distinctive are marked as LA_1 a LA_2 in fig.8. Its horizontal dimension corresponds to the distance among ca. nine electrodes (80 m). In many cases, these anomalies are interpreted as geological features. This example shows very illustratively that we have to be very vigilant during a geological interpretation of the ERT method, namely in explanation of such anomalies.

Another model contributes to the knowledge how to identify a shear zone by the ERT method. The answer is ambiguous; however, it brings many interesting findings; fig.9. Also in this example an environment with two parts differing in resistivity is, in fact, modelled. The first part represents a slope deformation which was not significantly disrupted during movement. That is why the environment above and also below the shear zone has assigned the resistivity of 300 Ωm. The slip plane itself then has resistivity by an order lower, i.e. 20 Ωm. The final resistivity section obtained after five iterations is much more complicated then original model. Again, it shows that we cannot put any boundary, neither slip plane or slip zone, to the position of the specific resistivity, or to the centre of low-resistivity anomaly. The model shows that low resistivity anomaly has bigger thickness than the real thickness of the shear zone. The whole task documents that the sliding surface lays at the upper limit of the low resistivity anomaly and it cannot be put neither at the upper limitation of the low values of resistivity nor to the centre of low-resistivity anomaly.

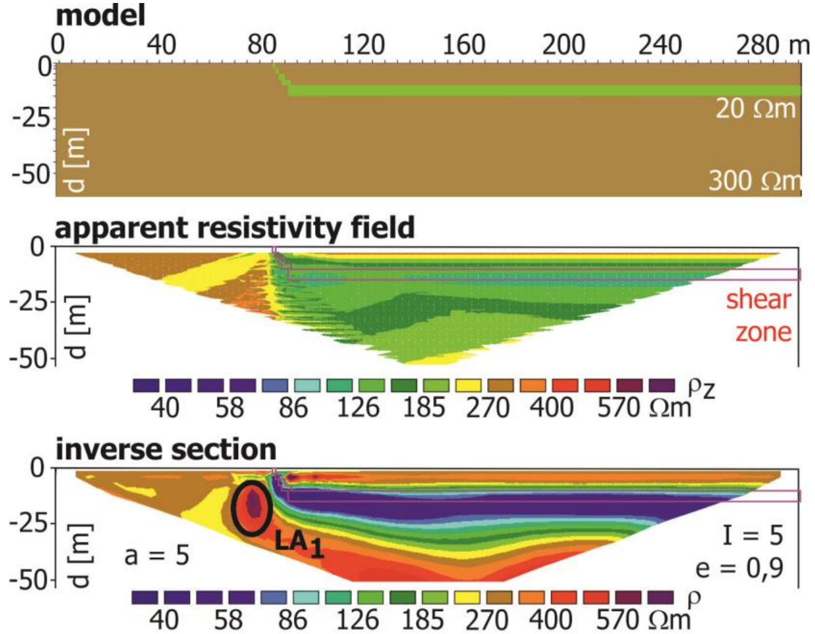

Fig. 9 ERT modelling of the shear zone

The modelled measurements indicate that a resistivity contrast of the investigated geological environment has a considerable effect on reality of the results. On the presented examples, the resistivity contrast between intact and disrupted massif was always more than one order higher. The Slovakian colleagues also modelled slip plane and they used relatively small changes in resistivity; DOSTÁL, I. et al. (2014). The result of such measurement is in the fig.10. The authors did not use for the landslide model its real shape, but they redraw the model in graphic software. That is why the geological boundaries are not tortuous as on the previous figures, but they are smooth. According to the own figure, it is evident that the image of the slip plane is, in such case, much more closer to the reality than with the use of models with high resistivity contrast. During practical measurements, we usually experience bigger differences of resistivity of particular environment than it is stated in this case. Even in this case, a single value of resistivity cannot be considered as the

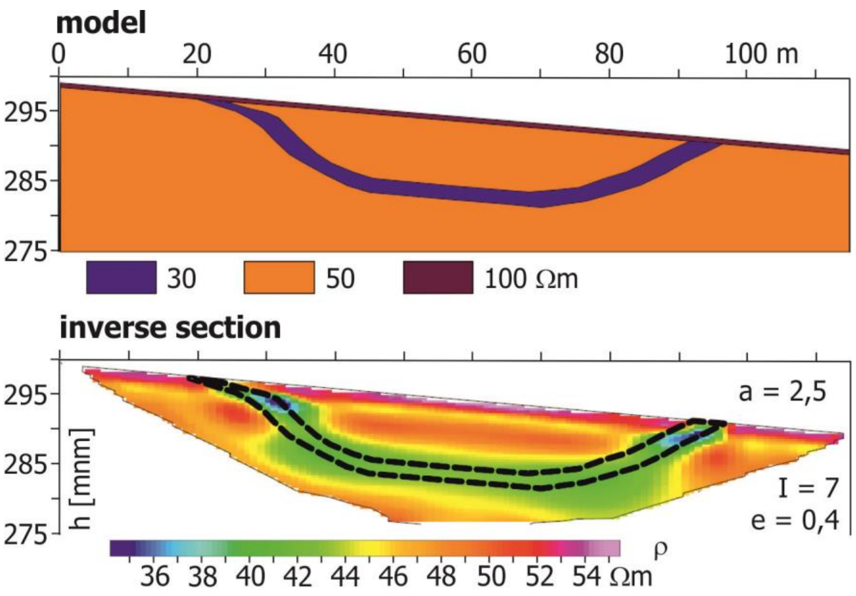

Fig. 10 ERT model of the shear zone, after: Dostál I. et al., 2014

boundary of the slip plane but we have to follow geological rules and the real abilities of the method used. It is matter of course that the interpreted “thickness of the slip plane” can be influenced by a selection of the isoohm step.

Namely with use of special graphic programs, we would be able to get to the entered thickness of shear zone within the modelling calculations and, in real terrain conditions, to the thickness of the shear zone determined from direct survey. In that case the position of the selected isoline would not be in the exact location of the slip plane Another unfavourable fact is that “false” anomalies” with the high resistivity are generated in such cases. It appears that not all high resistivity anomalies detected within slope deformations, namely using the resistivity profiling, mean an indication of the tensile stress of the rock massif. Thus, it is necessary to be cautious when we interpret the tensile stress in the cases of simple high resistivity anomalies behind the outcrop of slip plane. If the anomaly is fluctuating and it incorporates also low resistivity values, its interpretation as the spot of increased tensile stress will be correct. A very helpful tool for the assessment, whether the anomaly has real geological cause or it is a “false anomaly”, represents undoubtedly the observation of P-waves velocities and its distribution in the rock massif.

The ERT method has gained its widespread utilization in the survey of slope deformations during last two decades. The method is very popular among geomorphologists, namely for its unequivocally non-complicated field measurements and, for people with a computer literacy, also for quite easy primary interpretation. Many of the authors state the results of the ERT applications only as a graphic, typicaly a picture., without deeper analysis of the obtained results; e.g. ERENOGLU, R.C. et al. (2013), HEINCKE, B. et al. (2010); CHAMBERS, J.R. et al. (2011); MERIC, O. et al. (2005); PIEGARI, E. et al. (2009) and SHERROD, L. et al. (2016). Another group of authors proceed to a geological interpretation of the ERT results, however, only with variable results; BARI, C. et al. (2011); CERVANTES, B. (2016); CRAWFORD, M. M. et al. (2015); DRAHOR, M. G. et al. (2006); FRIEDEL, S. et al. (2006); JOMARD, H. et al. (2010) and LAPENNA, V. et al. (2005).

3 Conclusions

Geoelectrical methods bring immensely valuable findings in survey and research of slope deformations and, generally, for observation of geological structure. Within the common engineering geological survey the direct current methods (DC methods) are mostly utilized. Nowadays, electrical resistivity tomography prevails over other resistivity methods.

The asset of the electrical resistivity tomography is its system of result depiction (imaging), i.e. a 2-D distribution of resistivity, emphasized by its coloured drawing. This advantage, nevertheless, hides also a danger of enormous confidence in depicted results. It applies namely for non-specialist geophysicists, geomorphologists, geologist and, generally, also archaeologists. During inversion of data, they totally use default settings and subsequently interprets minor anomalies if these satisfy their idea of result. They completely omit a possibility to use different settings of input parameters during inversion and, particularly to utilize the ERT modelling. Experienced geophysicists do not have a real chance to change this fact. The automatization of the measurements and data processing leads to the situation when it is not a problem to acquire the measurement equipment to an unqualified companies and then yet measure and make interpretations. Unfortunately, the geophysical community does not make a sufficient effort to introduce possible difficulties of the use of ERT to public.

Despite that the electrical resistivity tomography proved its applicability in geological surveying. As documented by the above-mentioned examples, we can gain interesting results by its applications. Similarly to all other geophysical methods, its interpretation should be based on results of direct surveying or, at least, on results of cross-VES (vertical electrical sounding). The appropriate options of further data processing (e.g. statistical tools) should be applied within ERT interpretation.

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