The displays of unsaturated zone moisture changes in the results of surface geo-electrical measurements

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Abstract: The Archie law relating the specific resistivity of rock ρ [Ωm], the specific resistivity of underground water ρ_w [Ωm], the porosity φ [%] and lithology has in the case of the 100 % water saturated environment (saturated zone) a formula (Mareš et al., 1983)

$$\rho = \rho_w \, a \, \varphi^{-m},$$

where the lithology is defined by the structure coefficient a with values from 0.6 to 2 (a < 1 for rocks with the intergranular porosity and a > 1 for rocks with the fracture porosity) and by the cementation exponent m describing the pore shape and the compaction degree with values from 1.3 for unconsolidated sands to 2.2 for cemented limestones.

However, the changes of the specific resistivity of rock caused by the changes of moisture and water saturation are minimal in the case of the saturated zone. Totally different situation is inside the aerated unsaturated zone above the underground water level where the space and time changes of moisture and water saturation could be considerably variable and the interpretation of results of mainly shallow geo-electrical measurements for engineering geological and environmental (contamination spreading) purposes could be misrepresented and inaccurate. Then, the Archie formula for the unsaturated zone built by clean sands is (Schlumberger, 1991)

$$\rho = \rho_W \, a \, \varphi^{-m} \, S_W^{-n},$$

where S_w is the water saturation [%] and n is the saturation exponent (n=2 for most of loose soils).

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An important factor in this situation is the presence of clays in the unsaturated zone and their influence on resistivity characteristics of soils. There are several formulas relating the specific resistivity and the water saturation in this case. Mostly the formulas are in the shape (Schlumberger, 1991)

$$\frac{1}{\rho} = \frac{S_w^2\,(1-V_x)}{a\,\varphi^{-m}\,\rho_w} + \frac{C\,V_x}{\rho_x},$$

where V_x is an expression applying to the volume or a specific volume characteristic of the shale or clay material; ρ_x is an expression applying to the specific resistivity of the shale or clay material and C is expression applying to the water saturation S_w.

Five monthly repeated measurements with three surface geo-electrical methods (the method of electric resistivity tomography ERT, the method of induced polarization IP and the method of spontaneous polarization SP) were carried out in the area of water fill dam slope base from June to October 2010. The measured area (approx. 100 x 100 m) covered both the dam slope and the flood plain. Two monitor hydro-geological wells situated exactly inside the measured area were utilized for repeated underground water level measurements as well as for repeated measurements of moisture/porosity of the unsaturated zone above the underground water level by the method of neutron-neutron logging (NNL). The changes of pore water content in unsaturated zone could be attributed to the water filtration and ingress through the dam body as well as to the rain precipitation. Therefore, the measured results of the specific resistivity, the induced and spontaneous polarization fields were correlated with the rain precipitation data from the closest station of the Slovak Hydrometeorological Institute monitor net.

The measurements investigate how a time variation of actual resistivity at shallow depth can influence time-lapse ERT results. The repeated measurement data acquired during dry and wet conditions of the 2010 period provide for an investigation of the time-lapse change of the electrical conductivity and its relation to hydrologic conditions. However, we note that the repeatability of the data sets acquired during wet conditions is better than those acquired during dry conditions and this is likely due to higher contact resistance during the dry season.

The results of the neutron-neutron logging in the central well situated in the centre of the study area on flood plain (Fig. 1) show variable character of the

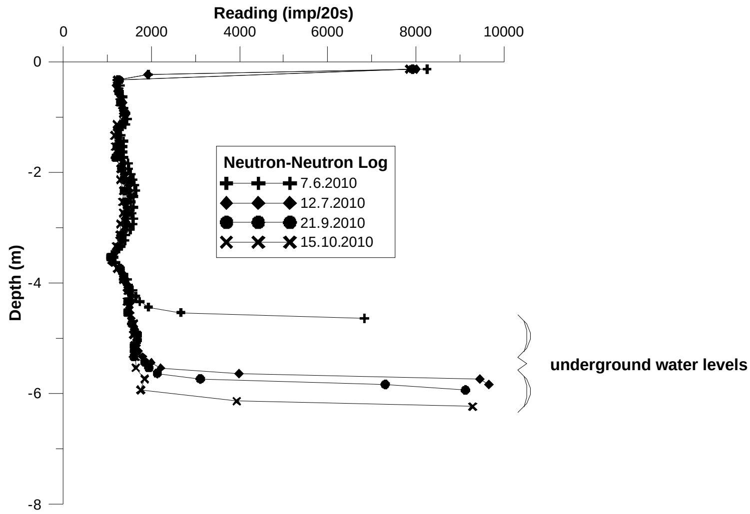

Fig. 1. Results of neutron-neutron logging in the central well.

unsaturated zone volume in time. The decrease of the underground water level in the range of approx. 1.5 m during study time period presents an intensive influence of rain precipitation and good transportation properties of the unsaturated zone material.

Key words: unsaturated zone, underground water level, Archie law, specific resistivity, polarization, moisture, precipitation, fill dam

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