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Choice of effective electrode array for 3D electrical resistivity monitoring during rainfalls

N. Denchik, L. Marescot and D. Chapellier

Institute of Geophysics, University of Lausanne, Collège Propédeutique, 1015 Lausanne, Switzerland

The aim of this study is to select an appropriate array type for 3D resistivity monitoring using a permanent electrode device (Denchik et al., 2004). Such surveys would allow a precise characterization of vertical and lateral preferential flow during rainfall. The collected information will permit to increase the understanding of the flood generating mechanism. Due to technical limitations, the number of current and potential electrodes is limited in the field. Therefore, the choice of the appropriate array for the survey is crucial. To help identifying the most suitable configuration, 3D sequences of measurements for three different resistivity monitoring arrays (Pole-Pole, Pole-Dipole and Wenner-Schlumberger) have been simulated, using a finite element code, and the most appropriated array has been selected to detect the vertical and lateral variation of the electrical resistivity in the framework of a permanent surveying installation system.

The study site is localised in the Swiss Plateau, 20 km north of Lausanne (Switzerland). It includes a square zone (8x8 m) in a spruce forest along the slope of the Ruzillon river (Haute-Mentue catchment). On the Haute-Mentue, the soil properties are a factor that influences flood generating hydrological processes. We are in presence of two lithological formations represented by the altered Tertiary « Burdigalien » OMM Molasse (Obere Meeres Molasse) which is composed of massive interlocked sandstone, with resistivity of 100-200 Ohm.m. The molassic bedrock is covered with the Quaternary Moraine (30-100 Ohm.m), which is less permeable. Soils are sandy loams and loamy sands.

In this paper, a modified version of the CESAR-LCPC finite element code is used for the forward modelling of 3D resistivity data (Marescot et al., 2004). This forward modelling code uses an electrode-independent mesh that allows to place the electrodes at their exact locations and not obligatory on a node, thus making the modelling task easier. To calculate apparent resistivity values, a normalisation approach is used that gives significantly better results than the use of the geometrical factor and allows the modelling of any kind of complex 3D structure.

The mesh we used is composed of hexahedral elements (10x10x7 meters) with 8 nodes. The centre of the mesh represents the study site where 49 potential electrodes and 8 current electrodes are located. Zero-value potentials are imposed at the vertical and bottom bounding planes of the finite element domain. The vertical bounding planes are 30 meters away from the centre of the mesh where the measurements were simulated.

As water propagation can have both a vertical and a horizontal component, two different situations are envisaged. A vertical descending displacement of a 1-meter thickness layer and a lateral displacement of a 2-meter side cube are simulated. The modellings have been done using two resistivity contrasts in view of the geology of the area of interest. In the first situation, the layer and the cube have a resistivity of 100 Ohm.m, whereas their resistivity is increased to 200 Ohm.m for the second situation. The background resistivity is set to 200 Ohm.m for the first situations and 100 Ohm.m for the second situation.

Three cases were tested for vertical displacement when the layer is located 1, 2, and 4 meters underneath the surface. We also simulated three cases of lateral displacement of the cube, which is 1 meter underneath the surface, along the study site. After simulation of sequences of measurements (apparent resistivities), the resistivity variations between two different displacements for the cube and the layer are calculated for each array and the resulting resistivity variations are analysed according to the length of the array.

In case of a vertical displacement, we notice a general diminution of the resistivity variation with the augmentation of the array's length for Pole-Pole and Pole-Dipole arrays. For Pole-Pole array, the resistivity variation is significant (10 %) for 1 to 3 m array's length. Nevertheless, due to the large investigation depth of the Pole-Pole array, the sensitivity to vertical displacement strongly decreases to 1-3 % for array length larger than 6m. The Pole-Dipole array seems more appropriated for the detection of vertical variation of electrical resistivity. For this array, the maximum resistivity variation (15 to 20 %) corresponds to variation between the case when the layer is 1 meter and the case when the layer is 4 meters underneath the surface. This variation can be observed for all Pole-Dipole array lengths less than 6 m. Nevertheless, with the augmentation of the investigation depth of the Pole-Dipole array, the sensitivity to vertical displacement decreases to less than 7 % for array length larger than 8 m. For Wenner-Schlumberger array the resistivity variation remains 10 to 15 % on average for all array's length. However, Wenner-Schlumberger array is not commonly used for the 3D surveys because of the small number of possible measurements in comparison with other arrays. In case of lateral displacement of the cube, the resistivity variation is insignificant (less than 2 %). This might be related to the small dimensions of the cube. The lateral displacement could be simulated using more important dimensions for the cube.

Simulation of the sequences of measurement for three different monitoring arrays using a finite element code showed that Pole-Dipole array is the most appropriated to follow vertical resistivity variation for the electrode configuration imposed in the field. However, according to simulation, it is not possible to distinguish small lateral resistivity variation with the three investigated arrays. These simulations will be confirmed by 3D monitoring of the electrical resistivity during rainfalls at the Ruzillon test site.

References

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