Joint acquisition, inversion, and interpretation of electric resistivity and seismic data

Dikun Yang, Daopu Wang, Southern University of Science and Technology; Yong Zhu, SmartSolo Inc.*

Abstract

Integration of electric and seismic data has been proven to be able to suppress the non-uniqueness in single data-type interpretation (Garofalo et al., 2015), because most of the geological objects can be characterized by distinct mechanical and electric properties. Previous studies mostly integrated the two methods by seeking joint data processing and modeling approaches after the seismic and electric/electromagnetic datasets have been acquired separately using dedicated instruments. Recent development of geophysical nodal systems has made it possible to integrate different methods as early as at the stage of data acquisition. Such a paradigm shift of how multi-physical survey should be implemented does not only reduce the cost of field survey, but also brings us new insights about data fusion at the algorithm level.

We take the near-surface application as the showcasing scenario, because the dc electric resistivity and the passive source ambient noise tomography are the two most commonly used methods for the top tens of meters below the surface. We develop a multi-physical nodal acquisition unit by modifying a single-channel nodal seismometer. The acquisition units receive operator instructions through Bluetooth connections and can switch between the seismic mode and electric mode in a few seconds. The spike (steel rod) at the bottom of the unit is used to maintain mechanical and electrical coupling with the ground.

In our field experiment, we chose a test line near a river on SUSTech campus. The test line was on the bank of the river and perpendicular to the direction of river water flow. Sixteen nodal instruments were deployed at a constant spacing of 2.5 m. The instruments first collected ambient noise seismic data for 40 minutes, then recorded full waveform electric potential difference data during the transmission of electric current at these 16 stations with a pre-programmed pole-pole configuration. The raw time series exported from the instruments contain both seismic and electric data, and they can be separated using the satellite-synchronized time stamps. We also employed another commercial ERT system at exactly the same electrode stations as an instrumental validation.

With the new instrument, we are able to export the full time series and then extract the potential difference data; in contrast, the conventional ERT instruments only deliver stacked and averaged data to users. The recording of the transmitter current waveform is crucial for our nodal acquisition mode, because it can be used to normalize the electric data and provide a precise time reference of the extraction of the active source electric data. The electric datasets from the commercial ERT system and from our new system are inverted to recover resistivity models with the same inversion parameters. The two models are mostly consistent, except for some details. The ambient moise seismic data are processed to generate dispersion curves and consequently a cross section of shear wave velocity after inversions. The velocity model presents a layered structure similar to the one in the resistivity model. We note that the top interface of the bedrock dipping towards the river can also be found in the seismic and electric model. The cross validation of seismic and electric data at exactly the same position is crucial in many field applications.

As the first step of utilizing the coincident seismic and electric data, we experimented a seismic-guided electric resistivity inversion by assuming the ambient noise tomography is more accurate in finding the depth of interfaces. Our preliminary approach uses the gradient in the seismic velocity model to construct the model weighting matrix so that the resistivity inversion tries to duplicate the same patterns of variation in the velocity model. The seismic-guided inversion model still shows three layers, but the layers are flatter in comparison with the unconstrained inversion. The new inversion evidently incorporated some seismic model features to the resistivity model, while still fitting the field data equally well. The freedom of electric resistivity inversion has been restricted by the layering information.

We interpret the inversion results to contain three strata. The top layer is made of sand and dirt, so it has a very low velocity and a moderate resistivity as a result of sprinkled water. The second layer is believed to be saturated by groundwater with a higher velocity and a low resistivity. The bottom layer, with a high velocity and high resistivity, is considered to be the bedrock that is both try and solid. The dipping interface between the second and third layer is consistent with the thickening of water-saturated overburden towards the river.

Our preliminary results of the newly developed nodal system have proven the feasibility of joint seismic-electric acquisition, inversion and interpretation. Our next step is to scale up the survey in 3D, so the efficiency of joint acquisition can be better demonstrated. Additional approaches of fusing seismic and electric/electromagnetic data will also be explored by taking the advantage of coincident acquisition.