Demonstration Experiment of Geothermal Reservoir Exploration Techniques: Three-Dimensional Seismic Survey in the Yamagawa Geothermal Field

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An experimental three-dimensional (3-D) seismic survey was conducted in the Yamagawa geothermal field, Kagoshima, Japan for verifying its efficiency for geothermal reservoir exploration. This demonstration experiment was conducted by Japan Oil, Gas and Metals National Corporation. JOGMEC is developing several geothermal exploration methods to locate geothermal reservoirs more accurately by applying recent technologies used in other sectors such as oil, gas, and metal mining. Reflection method is one of the most promising geophysical survey methods which delineate subsurface geology precisely. It is proven in the oil sector that seismic method, especially 3-D seismic, reduces geological risks and increases success rates in drilling. However, many of geothermal fields in Japan exist in mountainous area. Seismic surveys might suffer from a rough topography and complicated geological structure. Since effectiveness and cost of seismic survey in Japanese geothermal area are arguable, the Yamagawa 3-D survey had the following aims. First, high density 3-D data were collected to show proper images of the geothermal reservoir. Second, several subsets with different survey designs were extracted and their images were compared to determine the relative cost-effectiveness. Since the Yamagawa geothermal field has a smooth topography comparatively, it allowed us to collect high density 3-D seismic data. The area of the survey was about 32 sqkm (4.5 km in N-S and 8 km in E-W). Both wireline telemetry system having 3,134 channels and 1,855 wireless nodes were used for the receiver lines. Two types of vibrators (18 tonnes and 7.4 tonnes), a fleet of 4 vehicles for each type, were uses for seismic source. While the larger vibrators were used at 988 shot points, the smaller vibrators were used at 2,274 shot points. Maximum Displacement Sweep technique enriched the low frequency components of the source frequency band. Sweep frequencies of 3-60 Hz and 4-60 Hz were used, respectively. Sweep length was 16 seconds. Number of sweeps is defined shot-by-shot as follows: 3 or 4 sweeps for the standard shot points and 8 or12 sweeps for the high energy shot points. The high energy shot point was distributed at every 200 m or less so that refraction tomography could be analyzed more properly.

Data processing is being conducted at the time of writing this report. The preliminary results have depicted complicated structure in the volcanic region and shown a consistency with geological information from the wells. We plan to conduct several decimation tests that evaluate 3D and 2D geometries. Full Waveform Inversion, attribute analysis, and an integrated study with gravity, magnet-telluric, and well data will also be applied in the next phase.

Keywords: Geothermal, Yamagawa, Fault, Fracture, 3D, Seismic


Survey Map
Yamagawa 3D Seismic
Source Point
Receiver Line
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Estimating of infiltration path using 3D simulation of groundwater flow and resistivity survey

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Resistivity survey is a useful method for noninvasively imaging continuous water flow in soil because water saturation increases electrical conductivity. Several methods have been applied to determine the water flow in soil by monitoring the resistivity change that is associated with variation in water saturation or water salinity. A change in resistivity before and after infiltration provides a 3-D image of the water flow; however, a detail distribution of resistivity sometimes cannot be obtained because of the inherent limitation of the observation data (i.e., number of measurements, time represented, and measuring sensitivity). However, a resistivity change is caused by the water flow in soil, and the water flow is governed by the seepage phenomenon; therefore, a method that uses data from resistivity surveys and seepage analyses would be effective. Thus, a water flow model was developed, which compared the water content converted from resistivity survey data as well as water content simulated from hydraulic models. This method provide both an image of the water flow and the properties of the hydraulic conductivity; however, if the number of measurements is low, the resistivity obtained from inversion remains uncertain because of spatially varying resolution. Comparing water content values obtained from resistivity surveys with those from water flow simulations includes a 3-D inversion uncertainty. However, according to the coupled approach, the observed resistivity data are directly used for determining the hydrological properties. In this method, water content simulated from water flow analysis is converted to a resistivity model, and a resistivity survey is conducted using this model to interpret the results. The simulated resistivity data are compared with the field observations to estimate the water flow hydraulic properties. This method can reduce the spatial uncertainty of the 3-D invasion because the resistivity model is constrained by the seepage analysis data. One dimensional hydraulic properties were inverted from 1-D water flow simulations, whereas, using 2-D hydraulic properties were inverted via Bayesian and multi-criteria inversion and via neural networks. However, few studies investigated 3-D hydraulic properties using 3-D water flow simulation and 3-D resistivity survey data. Inversion of 3-D hydraulic properties is best but it is difficult because reconstructing the 3-D conditions is complex, and there are many unknown parameters. In this study, we propose an easy the method to estimate hydraulic properties of the shallow soil layer, which is responsible for many hydraulic problems in the field. To evaluate this method, numerical and field experiments ware conducted. In the numerical experiment, the resistivity survey provides an image of the preferential flow; however, the infiltration locations are unclear. Assuming that high hydraulic conductivity zones exist somewhere, an analysis of saturated–unsaturated seepage is conducted for several water-flow models with different locations of high hydraulic conductivity. Subsequently, a resistivity survey is implemented based on the water content that was simulated by seepage analysis. The high hydraulic conductivity location of the model that provides the minimum errors corresponds to the high hydraulic conductivity location of the numerical field model. In the field, resistivity is measured during groundwater recharge experiment in a pyroclastic plateau. This resistivity survey provides an image of the preferential flow; moreover the high hydraulic conductivity location of the model that provide the minimum errors corresponds to filling water rage, whereas that of the model that gives the maximum errors

corresponds to no filling water range. These results indicate that estimating high hydraulic conductivity locations using simulations of the groundwater flow and resistivity survey is possible. This work was supported by JSPS KAKENHI Grant Number 25850170.

Keywords: infiltration path, groundwater flow, resistivity survey

Case study on a newly modulus of deformation considering a continuous state of crack in the tunnel ground

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The physical properties concerning the state of the tunnel ground is very important for the accurate re-modification of tunnel ground classification and numerical analysis in the tunnel construction stage. Therefore, the geological properties ahead of tunnel face might be confirmed by the horizontal drilling survey results. And the physical properties, such as P-wave velocity by the velocity logging, the modulus of deformation by the borehole loading test, and the P-wave velocity results, etc., of the laboratory tests of the bore cores were measured for re-evaluation just before the tunnel excavation. Though, P-wave velocity by the velocity logging is different from a P-wave velocity of bore core in method for measurement and a target range, P-wave velocity by the velocity logging was continuously measured value along the all borehole length with influence of the state of the crack in the tunnel ground. Therefore a coefficient of fissures is found from a core and a ratio of P-wave velocity of the tunnel ground, and the item of the ground classification is corrected by this coefficient of fissures. On the other hand, the modulus of deformation is measured at the loading point as a limitation. However, when the modulus of deformation can be grasped as the continuous distribution, we could obtain the more accurate geo physical data.

In this report, we compiled the geological survey results of national highway tunnels which were constructed into the volcanic rock area in Hokkaido. To obtain the modulus of deformation along the borehole, S-wave velocity along the continuously borehole was calculated using the P-wave velocity by velocity logging, the P-wave and S-wave velocity by the bore core test results. Then, the dynamic modulus of elasticity of borehole was calculated using the dynamic shear modulus of elasticity and the dynamic Poisson's ratio based on the P-wave velocity by velocity logging, the S-wave velocity along the continuously borehole and wet density results of the laboratory tests of the bore cores. This determined dynamic modulus of elasticity is correspond to modulus of deformation considering a state of crack in the tunnel ground, due to the S-wave velocity along the continuously borehole is already considered the coefficient of fissures. After that, the dynamic modulus of elasticity along the borehole was compared with the modulus of deformation by the borehole loading test and the dynamic modulus of elasticity by bore core.

As a results, the dynamic modulus of elasticity along the borehole was obtained as 3,000 - 36,000 MPa. These values are lower than the dynamic modulus of elasticity by bore core, 300 - 68,000 MPa, and higher than the modulus of deformation by the borehole loading test, 400 - 10,000 MPa, due to different of the method for measurement and a target range. Moreover, the proportional relation was confirmed between the dynamic modulus of elasticity along the borehole and P-wave velocity by the velocity logging, as a better tendency than the relationship between the modulus of deformation by the borehole loading test and P-wave velocity by the velocity logging. Thus, the P-wave velocity by the velocity logging is thought to be useful for the estimating the modulus of deformation along the continuously borehole and re-design of tunnel.

Keywords: tunnel, ground classification, modulus of deformation

Effects of surface irregularity of embankment on wave propagation

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Phase velocity of surface wave, mainly Rayleigh wave, generated by artificial sources is used in the surface-wave exploration method to estimate a shallow S-wave velocity structure. It has been often used in soil surveys in, for example, river embankment, landfill and residential land. A horizontal layered model with the flat Earth’s surface is assumed in data analysis of the method. However, the appropriateness of the assumption has not been sufficiently discussed for its application for a site which has surface and subsurface complex irregularities.
In this study, we investigate effects of surface irregularity on characteristics of surface-wave propagation through numerical experiments based on a finite-difference method to understand its applicability. First, we conducted 3D simulations of wave propagation in shallow soil models with and without surface irregularity considering realistic cases, such as embankment. Then, we derived frequency-dependent phase velocity from synthetic waves obtained on the surface of the models. we also examined effects of slope of embankment and a velocity contrast between surface layers and basement on the surface-wave phase velocity.
The effects of the 3D shape of surface topography are significantly identified in the surface-wave characters in the models with a high velocity contrast between surface layers and basement, when the model has a steep slope on a side of the embankment. In the embankment models, scattered wave generated in the upper surface and the base of the embankment was observed. The estimated phase velocity for the surface wave differs from those of the horizontally-layered model indicating difficulty to deduce a true velocity model. However, the phase velocity for the model having a low velocity contrast is similar to those in the horizontal model even in the models with steep slopes. It is concluded that effect of surface irregularity on the surface wave propagation is small in sites with a low velocity contrast with regardless of surface irregularity.

Keywords: surface irregularity, phase velocity, surface-wave exploration, S-wave velocity

An interpretation result of the integrated geophysical survey at river levee using interpretation template

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Safety of the river levee is assessed from existing soil profiles of the levee body and foundation based on drilling results as well as a detail investigation conducted at a specific location. Even though the soil type is confirmed at drilling locations, typical distance between the drilling wells is about 1 km long, so the soil profile between the wells is basically estimated by an engineer. On the other hand, geophysical survey provides geophysical property at every 10 m, for instance even though it does not directly reflect soil type. Therefore, the combination of the geophysical survey with the drilling results contributes to build a detailed soil profile, and it helps us to determine the location of the detailed investigation.
For a river levee investigation, cross-plot of S-wave velocity by MASW (Multi channel analysis of surface wave) and resistivity by CCR (Capacitive coupled resistivity survey) is used to evaluate levee body and foundation along a river. Here, the soil type classification by the interpretation template, which is proposed by Konishi et al. (2016), is applied to the cross-plot, and the result is verified by drilling.
Interpretation template can be generated by selecting any physical models, but it is hard to judge the validity of the template from the only geophysical dataset. Thus, in principle, the interpretation template must be checked and adjusted by drilling information. In this study, in order to verify the result of the estimated soil type, we separate several existing drilling wells into interpretation wells and validation wells. The interpretation wells are only used for the check and adjustment of the interpretation template, while validation wells are used to compare the estimated soil type with actual one.
The soil type profile estimated from the integrated geophysical survey suggests that the top of the clayey soil deposit is deep between the interpretation wells. The distribution of the clayey soil is confirmed by the validation wells. This result indicates the validity of the soil type estimation from the geophysical survey, and it means that we can build a detailed soil profile by combining the geophysical survey with drilling results.

Keywords: interpretation template, integrated geophysical survey

Integrated Geophysical surveys in levee excavation sites on the Chitose river, Central Hokkaido

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A levee excavation was conducted to construct a new sluice at two sites along Chitose River, Central Hokkaido. The high-density electrical resistivity survey and the surface wave survey were carried out on the levee at the crown and high-water channel before the excavation. The electrical resistivity and S wave tomography were also carried out across the levee at the excavation sites. After the excavation, the short electrode spacing resistivity mapping and the short spacing surface wave survey were carried out at the excavated slope surface to measure directly on the resistivity and S wave velocity (Vs).
The resistivity and Vs structures obtained by the surface surveys were verified by the resistivity and Vs distribution measured on the excavated slope surface. These surveys delineated imhomogeneity of soils in the levee and the basement. Comparing the resistivity and the grain size evaluated by soil tests, the resistivity structure identified a permeable zone in the levee and showed the extension to the basement.

Keywords: Integrated Geophysical Survey, Levee Survey

