Utilization of integrated geophysical investigation for near surface surveying

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Integrated geophysical investigation has been playing an important role in the near-surface surveying because only it can provide high-resolution, quantitative, and reliable information to the near surface as continuous 2D or 3D profiles. Near-surfaces, mainly composed of man-made strata, weathered layers, and Holocene soft sediments, inherently imply small-scaled irregular or various structures. It means conventional geotechnical boring is inadequate to reconstruct surface 2D geology of the region of interest because of its sparseness. Recently, identification and engineering characterization of local heterogeneity in the near surface has become more important in the viewpoint of sustainable and cost-effective utilization of existing infrastructures. Enhancement of resiliency against natural disasters is also one of the current issues in Japan. Development and utilization of field measurement techniques have been required to deal with the above issues.
The integrated geophysical investigation, we proposed first for the safety assessment of levee systems, is not merely a combined field application of several geophysical methods, but a geotechnical characterization method for the near surfaces. Making use of measured S-wave velocity and resistivity, we assess the safety condition of a levee system on underseepage. Soil types, permeability, and seismic resistance are evaluated.
Case histories of the integrated geophysical investigations successfully applied to levee systems, road embankments, and pavements are presented in association with brief introduction of newly developed field measurement techniques.

Keywords: Near-surface, Integrated geophysics , S-wave velocity, Resistivity , Geotechnical characterization

Geophysical Survey in Engineering Geology and Integrated Geophysical Survey

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In The Integrated Geophysical Survey proposed by Inazaki and Levee Consortium, the process of safety assessment of levees based on geophysical surveys from the planning to the evaluations have been organized. It also have presented the semi-qualitative interpretations by means of the combination of S-wave velocity and resistivity. The idea of integrated geophysical survey is expected to improve the applications of geophysical surveys in engineering geology.

Various geophysical surveys have been applied to many engineering geology projects. However, reliability of geophysical surveys is questionable in some cases, and this situation have brought the feelings of mistrust to many geologic engineers although geophysical surveys have been expected as a powerful method. The Society of Exploration Geophysicist of Japan has worked toward standardization of the method of geophysical surveys to improve the reliability of surveys. However, it could be considered that viewpoint of using survey results to geotechnical interpretation was weak. From this background, The Integrated Geophysical Survey Committee has been organized.

The Integrated Geophysical Survey Committee has established 3 working groups, and the following activities have been carried out. In the working group 1, the documentary searches and case studies have been made to investigate applications and development of the integrated geophysical survey. According to the documentary searches, the combination of S-wave velocity and resistivity is utilized for evaluation of ground condition in the field of levees survey, and integrated geophysical survey are conducted. However, in the field of tunnel survey, ground conditions are evaluated by seismic refraction survey in many cases. The electric or electromagnetic survey, together with seismic refraction survey, have been usually adopted for detecting weak zone, where these results have been interpreted qualitatively. In the field of landslide and slope survey, the combination of P-wave velocity and resistivity have been also used for the evaluation of ground conditions. However, its usage also have been a qualitative manner in many cases.

In the working group 2, the research on the interpreting methods have been made to improve performance of the evaluation of ground conditions. According to the case studies on combined interpretation using plural geophysical surveys data, interpretation methods are divided to 3 categories, which are the cross plot method, the method based on empirical relationship and the method based on Rock Physics. The cross plot method are simple and effective when a large amount of surveys data and physical property testing results on the site is available. The method based on empirical relationship, which is the extension of the cross plot method, is more general, and many relational expressions have been proposed. However, these empirical relationship could not apply to the interpretation beyond based geological conditions, limitations of the relationship, and so on. The method based on Rock Physics is sophisticated and is expected to apply to various geological conditions. However, a large amount of surveys data and physical property testing results is demanded to construct constitutive law, and a lot of work is also demanded to validate the constitutive model. A selection of the interpreting methods is depended on quality and quantity of the available data.

The working group 3 have dealt with the digital standard formats and electronic delivery of geophysical survey results. The purpose of the working group is to improve performance of geophysical surveys, and it is considered that the improvement contribute to the growth of the

geophysical survey utilization in engineering geology.
In this report, the present situation of geophysical surveys and applications of integrated geophysical surveys will present.

Keywords: geophysical survey, integrated geophysical survey, engineering geology

Interpretation template for the integrated geophysical investigation

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Theoretical background or physical based models for an interpretation of geophysical survey results is necessary for converting velocity and resistivity to other geotechnical properties or soil type classification. If the physical theory was completely developed to simulate geophysical properties from others, any required parameters could be obtained by solving an inverse problem. However, subsurface is heterogeneous and too complicated to formulate perfectly, and the geophysical property is affected many factors; therefore, it is not easy to solve the inverse problem. In contrast, preparing an interpretation template by a forward modeling based on simple physics based models and obtaining the parameters by comparing the interpretation template and observation seems to be practical solution. This approach is called rock physics template analysis in the reservoir characterization, and it has been used for facies and fluid discrimination (Avseth et al., 2005). In this method, only few specific properties are target parameters and others are regarded as constant values. Nonetheless, it will be a useful and practical solution by selecting dataset before applying it. Especially, this method will be valuable when the data set has limited numbers of observations because inversion and statistical approach is more beneficial for a dataset that consist of many kinds of properties.

A cross-plot analysis is a basic tool for the integrated geophysical survey. Particularly, S-wave velocity and resistivity cross-plot is accepted for a river levee survey. Thus, we created the interpretation template for the cross-plot of S-wave velocity and resistivity to estimate clay content and porosity. The clay content ranging from 0 to 1 represents volume fraction of clay in a sand and clay mixture. It can be regarded as a soil type. Porosity is a fundamental property of soil to indicate volume fraction of each phase (solid, water, and air). Additionally, the porosity can be regarded as an index of looseness for the same soil type.

We adopt unconsolidated sand model (Avseth et al., 2005) for velocity model. The model is based on Hashin-Shtrikman lower bound that calculates the effective elastic property of a mixture of two phases: one is solid and the other is an aggregate of grains. The elastic property of the grain aggregate is calculated by Hertz-Mindlin theory, but it sometimes overestimate for a sediment of shallow subsurface. Thus, Walton model is also available for it. The clay content is a parameter of the solid phase; therefore, S-wave velocity is associated with clay content.

In general, parallel circuit model is accepted to represent resistivity. Resistivity is not affected by soil type below water table, while soil type can be a dominant factor for unsaturated shallow subsurface soils. In the resistivity model, clay content and porosity are included in the conductivity of excess conductivity; therefore both parameters relate to the resistivity.

By calculating S-wave velocity and resistivity for any combinations of the clay content and porosity, we can create the interpretation templates for estimating clay content and porosity. Using the interpretation templates, we obtain soil type classification map and porosity distribution along a river levee.

S-wave velocity and resistivity are presently computed by considering only soil type and volume fraction of each phase. But, it is possible to calculate new template to estimate saturation by treating soil type is constant. In addition, using a range of uncertain input parameter, probabilistic interpretation template is also possible to be computed. Although it is difficult to implement whole theory in the model; instead, making interpretation templates from a simplified model will be effective for the interpretation of geophysical surveys.

Keywords: interpretation template, cross-plot

An attempt at model-based quantitative rock mass classification using integrated geophysical data

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Rock mass classification has been widely used for designing and constructing engineering structures such as tunnels and dams. There are several classification methods proposed such as RMR and Q-value. As these methods, however, are somewhat qualitative and subjective, it has been long recognized that the rock mass classification thus obtained strongly depends on the engineers who make classification. We have, therefore, studied a classification method which can more quantitatively and objectively classify the rock mass grade with multiple geophysical data based on rock physics.
This proposed method applies rock physics models to multiple geophysical data measured in the rock mass for relating them to the rock mass grade. In this study, seismic P-wave velocity and resistivity measured in a few boreholes on a planned tunnel route are modeled with the shaly sand model as an effective medium model for seismic velocity and Glover’s equation for resistivity to estimate the relationship between these geophysical properties. Then RMR measurements with rock core samples obtained in the same boreholes as geophysical logs are compared to the geophysical data through the estimated relationship in order to have a rock mass classification map with geophysical data. Using the map, a rock mass classification of the rock mass along the tunnel formation is obtained and evaluated through comparison with the conventional classification. This comparison clearly proves feasibility of the proposed method in practical use.

Keywords: rock mass classification, integrated geophysical data, rock physics model

Investigation of the depth of steel pile embedment by the integrated geophysical exploration

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In this report, we applied plural geophysical exploration and investigated the cause that a tunneling machine collided in other structure during construction.
A flood gets up in the urban area and becomes the social problem by localized torrential rain in late years. A reservoir to save rainwater is built underground temporarily to prevent a flood. However, a neighboring construction is forced for the underground facilities because the urban area underground is crowded.
We often understand the depth of embedment of the established structure from drawings in the construction under the established structure. However the drawings may be missing with the old structure. When there is a drawing, a trouble may occur while we construct the underground structure because of the difference of the real structure or the depth of embedment.
The depth of embedment of the steel pile is investigated by magnetic survey. However we cannot usually be informed the direction from the borehole using by the conventional magnetic survey. We were developed the borehole vector magnetometer (BVM) to solve this problem (Oshida et al., 2006). BVM is arranged the three component magnetic sensor and measure the three dimensional magnetic fields by the residual and induced magnetization of the steel pile. BVM data estimate a three dimensional position of the tip of pile by analyzed wavelengths and the amplitudes of the three measurement waves.
It was estimated that a tunneling machine had already collide a steel pile by the construction status. It presents the existing abutment pier basement of steel and the complicated structure including the soil retaining piles as well as the steel pile when we confirm the existing drawings. Therefore we planed the BVM and the seismic velocity logging to estimate the depth of embedment of the steel pile. The seismic velocity logging is technique using the transmitted P wave velocity of the steel pile which is larger than that of the soil. We impact the structure itself to produce P wave. Then we can measure the P wave velocity only for steel pile to intend for because P wave does not propagate to other structures. We can estimate that it is an object surely even if the large P wave velocity and BVM anomaly is detected.
As a result of investigation, the following information was provided.
(1) A point of inflection of the travel time curve is accepted in GL-15.5m by seismic velocity logging. This depth is estimated the embedment of the steel pile.
(2) The calculated P wave velocity is the 4.3km/s of the depth zone assumed to be the steel pile by the seismic velocity logging that is clearly larger than the velocity of the soil.
(3) We interpreted difficult to estimate the depth of embedment until GL-14m because the BVM waves of the magnetic fields complicated by the borehole neighborhood construction for example the abutment pier or the soil retaining piles.
(4) However we could estimate the depth of embedment by the independent BVM wave of GL-15.6m, and the depth almost agrees with point of inflection depth of the seismic velocity logging.
(5) We concluded the depth of embedment of the steel pile in consideration both survey results.
(6) We could consider that the tunneling machine is collided the existing steel pile from depth of GL-15.6m because the upper edge of the tunneling machine is GL-14.5m
Even in the case of complicated structure, this report was able to raise its certain result by the integrated geophysical exploration that combined the seismic velocity logging with BVM. The cause

that the depth of embedment deeper than the construction completion drawing is unclear for the moment, but it will be investigated that an underpinning construction and the change of the route are considered based on this result in future.

Keywords: Neighboring construction, Steel Pile, Depth of embedment, Magnetic survey, ,Seismic velocity logging

Study on the prediction of the large shallow landslides areas using Airborne Electromagnetic Survey, hydrological investigation and water quality investigation

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In recent years, the investigations of deep-seated catastrophic landslides and volcano using airborne electromagnetic survey have been carried out. And, the study on prediction of sediment disasters occurrence areas gradually progresses. On the other hand, recently, many shallow landslides disasters including Hiroshima in 2014, Izu-Oshima island in 2013 and Nachi river basin in 2011 were occurred. If we can predict the collapse occurrence slopes by using airborne electromagnetic survey, we can easily decide the priority of the constructions of sabo dams and make the evacuation systems. In this study, we nominated Nachi river basin where large shallow landslides were occurred in 2011 for an example and examined the difference of the resistivity characteristics of collapse and non-collapse slopes from the result of the airborne electromagnetic survey.First, we arranged the relationships between geological features and resistivity distribution. Because Nachi river basin is parted in the area of Kumano Acidic Rocks (granite porphyry) and the area of Kumano Group (sandstone mudstone alternative rock), we considered whether these were distinguishable by the resistivity distribution. Next, we put the collapse slopes on the map of the resistivity distribution and examined the resistivity of the collapse slopes. Final, we paid our attention to the pattern of resistivity contour lines and the rate of change in the resistivity. We examined the difference of them about collapse and non-collapse slopes of Nachi river basin.Kumano Acidic Rocks (granite porphyry) had high resistivity and Kumano Group (alternated sandstone and mudstone layers) had low resistivity. As a result, we can express geological borders very well by airborne electromagnetic survey. In addition, we understood that the most of the collapse slopes were distributed near the geological border. From this, it is thought that collapses were occurred by the difference in geological properties of the plumb direction. About the difference of the collapse and non-collapse slopes, we found that the collapse slopes have vertical pattern of resistivity contour lines against the slope directions. And we found that the areas of the large rate of change in resistivity are disappeared at the upper parts of the collapse slopes about the collapse slopes. On the other hand, about the non-collapse slopes, we found that the resistivity contour lines were parallel with the slope directions and the areas of the large rate of change in resistivity are continued at the upper parts of the slopes. The resistivity contour line shows the structure of geological features. Because the resistivity contour lines of the collapse slopes are vertical, the geological structures of the collapse slopes are vertical and it is thought that Kumano Acidic Rocks (granite porphyry) penetrates Kumano Group (alternated sandstone and mudstone layers) vertically. In addition, when geological structure is vertical, infiltrated water is hard to flow to the slope lower part, and it is thought that water level under the ground is easy to rise and the slope is easy to be collapsed. It is thought that the areas of the large rate of change in resistivity expresses water level under the ground. Because the areas of the large rate of change in resistivity are disappeared in the collapse slopes, it is thought that drainage abilities were low. Above all, in the risk evaluation of the shallow landslides, it is thought that we can evaluate the water levels under the ground and the drainage abilities of the groundwater by using the airborne electromagnetic survey.

Keywords: Airborne electromagnetic survey, Hydrology, Ion concentration, Shallow landslide

