A Laboratory Experiment on the Resistivity Tomography Applicable to TBM

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ABSTRACT: It is important to predict the ground condition ahead of tunnel face during tunnel excavation in order to prevent serious problems. In mechanized tunnelling job sites, it is hard to observe the condition of tunnel face with naked eye, but prediction of anomalies and mixed ground is very important. In this study, laboratory tests are performed to predict anomaly/mixed ground ahead of tunnel TBM tunnel face utilizing resistivity tomography. Results from the resistivity tomography were consistent with the actual ground condition reasonably well.

1 INTRODUCTION

Various kinds of geological surveys, such as drillings, geological mapping, and geophysical surveys, are generally conducted to clarify the ground condition of the proposed tunnel route and/or the existence of anomalies to allow proper design of the tunnel. The geological survey performed in the design step mostly focuses on estimating the overall ground condition or underground geological structures over a broad region, and thus it is not easy to accurately predict the condition of the ground adjoining a tunnel route. As a result, there are many cases where unpredicted anomalies are found during tunnel construction. These anomalies may degrade the stability of the tunnel and cause temporal and economic losses, such as construction delays and higher costs.

In mechanized tunnelling job sites, it is not easy to observe the tunnel face with the naked eye, and thus there are cases in which these methods cannot well cope with sudden changes in ground condition or groundwater. Although there is a large demand for methods to predict the ground conditions ahead of the tunnel face, very few have been developed for TBMs. In mechanized tunnelling job sites, various kinds of equipment, including the chamber, pressure cell, conveyer, and cylinder, are placed behind the cutter head depending on equipment characteristics, so that there are spatial limitations on the survey equipment that should be installed to predict the ground conditions ahead of the tunnel face. It has been proposed to predict the ground condition ahead of the tunnel face using elastic waves, electromagnetic waves, and electricity (Kneib et al., 2000; Dowden and Robinson, 2001; Kaus and Boening, 2008; Richter, 2011).

Generally, it is possible to drill a borehole using probe-drilling equipment installed on the upper side of the main body of the TBM. Therefore, we propose to install multiple electrode arrays to the probe-drilled hole to perform resistivity tomography tests. These tests can analyze the profile of the characteristics of the ground in front of the TBM face. Laboratory experiments of multiple electrode arrays installed to the probe-drilled hole were performed in this study to assess applicability of electrical resistivity tomography in mechanized tunnelling job sites.

2 BACKGROUND THEORY

Electrical resistivity is a constant representing the electrical property of a material regardless of its shape and size, and its unit is the ohm-meter (Ωm). Whereas electrical resistance represents the difficulty of passing an electric current through a particular structure, electrical resistivity means the electrical resistance of a given material. In an arbitrary conducting wire, the relationship between electrical resistivity (ρ) and electrical resistance (R) is written as:

$$R = \rho F_s \tag{1}$$

Here, F_s is a shape factor that changes according to the shape of the object through which the current is flowing. For a cylindrical conducting wire, F_s is calculated by dividing the object's length by its cross section.

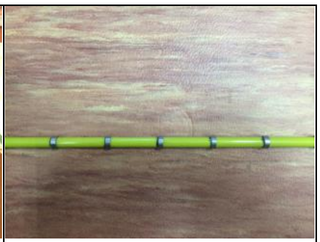
Electrical resistivity in rock is affected by porosity, saturation, the electrical conductivity of groundwater, and clay content. To evaluate the ground condition using electrical resistivity, various surveys are conducted. Generally, in geophysical electrical resistivity surveys to evaluate a wide range of ground conditions, electrical resistivity logging to investigate the ground condition around boreholes and electrical resistivity tomography to evaluate the ground condition between boreholes are performed.

Electrical resistivity tomography is a kind of electrical resistivity surveys that involves measurement and analysis using the same principles as electrical resistivity surveys. Boreholes are drilled, multiple electrodes are installed in each borehole, and potential differences are measured. Therefore, compared with an electrical resistivity survey, electrical resistivity tomography can explore a narrower area and produce higher-resolution output. For surveys, electrical resistivity tomography mainly reveals the heterogeneity of the ground and the characteristics of the fluids in the ground. Ground heterogeneity is attributable to low-resistivity anomalies including alteration, and cracking of rock, and to high-resistivity anomalies including cavities and intrusive rock. Electrical resistivity tomography is aimed at surveying such heterogeneous factors, and is applied to alternation zones, fault zones, and cavities, or the assessment of ground improvement effects.

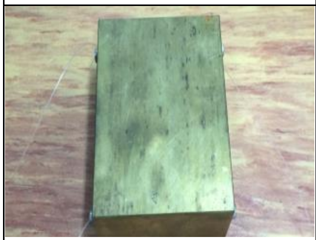
3 LABORATORY EXPERIMENT

In scale model tests through the use of a water tank, it is possible to set the location and form of the ground model. Therefore, there is no uncertainty by the surrounding geographic features and circumstance. Therefore, Cutter-head and anomaly/mixed ground were simulated considering an environment of mechanized tunnelling job-sites. Laboratory experiments were performed to assess applicability of electrical resistivity tomography in mechanized tunnelling job sites. Fig. 1 shows materials for laboratory experiment and Fig. 2 shows the schematic diagram of laboratory experiment setup: ground with anomalies.

(a) Water tank



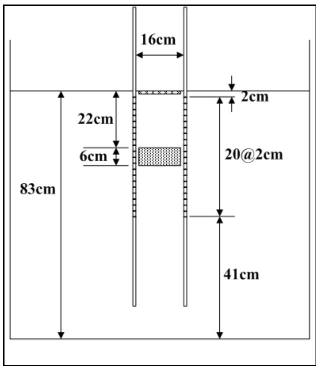
(b) Electrode



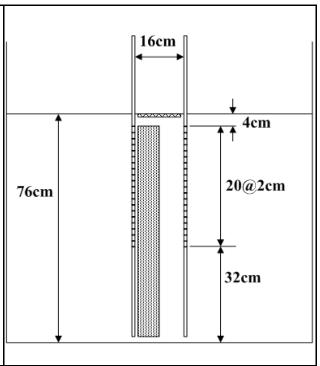
(c) Brass block for anomaly

(d) Aluminum disk for cutter head

Figure 1. Materials for Laboratory experiment setup



(a) Ground condition with anomaly

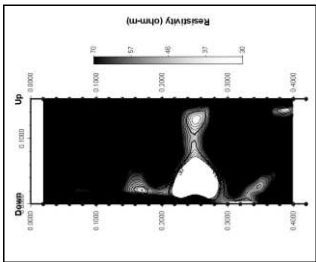


(b) Ground condition with mixed ground

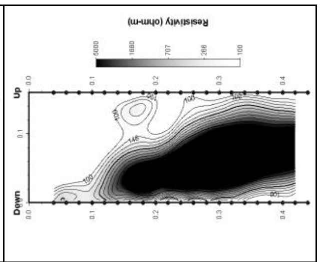
Figure 2. Schematic Diagram of Laboratory Experiment Setup

In the anomaly/mixed ground modelling laboratory experiment, a cross-hole survey, reverse cross-hole survey and inline survey were performed utilizing modified dipole-dipole electrode array. The equipment for measuring the electrical resistivity for this study is Supersting R8/IP/SP, survey instrument sold by the American AGI. Also, we used Tomo DC ver. 1.2 to analyze measured data of laboratory experiment.

Fig. 3 shows the results of laboratory experiments. The results show that electrical resistivity tomography survey predicts the location and form of the anomalies. However, the right side of analysis zone has low resolution because the number of measurement data is small. The mixed ground was not well predicted.



(a) Ground condition with anomaly



(b) Ground condition with mixed ground

Figure 3. Laboratory experiment result

4 CONCLUSION

In this paper, laboratory experiments were performed to predict anomaly/mixed ground ahead of tunnel TBM tunnel face utilizing resistivity tomography. The electrical resistivity tomography survey utilizing modified dipole-dipole array was found to be able to predict the location and form of an anomaly/mixed ground reasonably well. In other words, results from the resistivity tomography were consistent with the actual ground condition reasonably well.

The parts of this article is based on a study first report in Ph. D dissertation "Prediction of ground conditions ahead of tunnel face applicable to TBM"(Lee, 2014).

5 ACKNOWLEDGEMENTS

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