Development of 3D Soil Profiling System for A Damaged River Levee

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Abstract. A 3D soil profiling system for effective design of countermeasures for a damaged or potentially damaged river levee is developed. This system consists of a 3D integrated seismic and electric measurement tool and a 3D visualization system of its soil properties such as hydraulic and mechanical properties estimated from the geophysical data. For a quick survey, the 3D measurement tool is a sensor belt with both geophones and electrodes to be able to measure seismic and electric data simultaneously. S-wave velocity and resistivity data acquired by this tool are converted to soil properties such as hydraulic and mechanical properties and support a countermeasure design of levee. In this study, we introduce the experimental result of the 3D soil profiling by using the integrated seismic and electric measurement tool in the field.

1. Introduction

In Japan, recent localized torrential rainfalls have often caused serious damages to river levee as seen in the water floods in the Kinugawa River, 2015 in Ibaraki Pref. and in the Yabe River, 2012 in Fukuoka Pref. They have brought much public attention to the present state of river levee and to their investigation for safety evaluation and strengthening. In such investigations the internal structure of the earthen levee must be delineated for further analysis and design for countermeasures.

Geophysical methods can be one of the most effective tools for that purpose because of their quick and non-destructive subsurface profiling capability. Especially the seismic and electric methods with land streamer-type measurement systems have been aggressively employed for profiling the dike body and subsoil in the longitudinal direction along the levee.

On the other hand, geophysical methods have not been employed so often for profiling the cross-section of the levee, where mechanical and hydraulic analyses are performed for safety evaluation. The reason is said that the accuracy of the geophysical profile is not so enough for further analyses and geotechnical parameters such as permeability necessary for numerical simulations cannot be directly given. However recently 3D geophysical survey which is more accurate than conventional 2D survey is attempted to be applied to river levee and new interpretation techniques of multiple geophysical properties based on rock physics have been proposed to estimate geotechnical parameters from geophysical ones [1].

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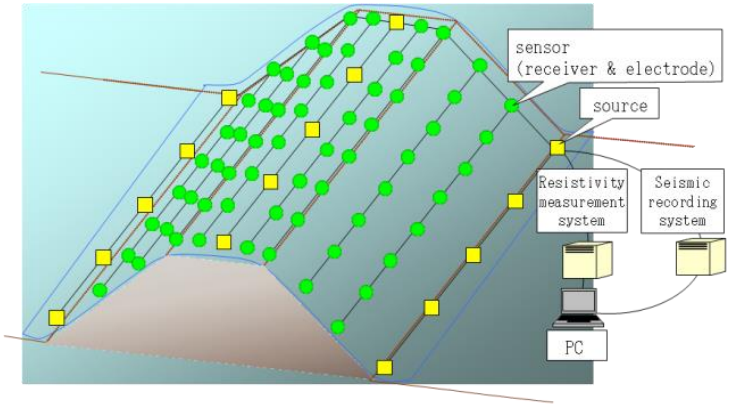


Figure 1. The schematic diagram of the 3D integrated seismic and electric measurement tool

In this study, therefore, we have started to develop a 3D geophysical soil profiling system consisting of a 3D integrated seismic and electric measurement tool and a 3D visualization system of soil profiles estimated from geophysical parameters. So far a prototype of the measurement system was manufactured and tested in a river levee and an interpretation technique of seismic velocity and resistivity was developed for estimating a soil type of a levee body. Figure 1 is the schematic diagram of the 3D integrated seismic and electric measurement tool.

2. 3D Integrated Seismic and Electric Measurement Tool

For safety evaluation of river levee, we have to know soil properties, permeability, strength of soil of river levee. These parameters can be estimated from seismic velocity, especially S-wave velocity, and resistivity because S-wave velocity strongly relates to strength of the soil and resistivity correlates with grain size for unsaturated soil. The measurement system we are developing, therefore, is designed for measuring S-wave and resistivity.

The prototype of the measurement tool is shown in Figure 2. The specification of the sensor belt is also shown Table 1. In the investigation of damaged and potentially damaged levee, the geophysical survey should be conducted as quickly and economically as possible. For that reason, the sensor belt of our measurement tool equips multiple geophones with a specially designed steel spikes which is used also as electrodes (Figure 2).



Figure 2. The prototype of the measurement tool

Table 1. specification of the sensor belt

Name of the part	Specification
Fabric belt	Width:70mm, Length:50m
Sensor interval	4m in basic
Geophone	28Hz, 12 string/belt
Spike electrode	Stainless steel with a base plate

This measurement tool is designed for measuring S-wave as well as P-wave by changing the geophone orientation to the ground surface. The fabric belt is very flexible so as to easily change the geophone interval. The steel spike electrode is designed and manufactured so as to be moved easily location by location.

An experiment for evaluation of the prototype of the measurement tool was carried out on a river levee. River front side of the levee body mainly consists of sand, and river back side mainly consists of cray. Its height and width are 5m and 30m, respectively. Eight sensor belts (96 channels) were set

up on the ground surface. The geophone interval was 2m, meaning that the fabric belt was folded for adjusting the geophone interval to 2m from its original interval of 4m. S-wave seismic data acquisition was conducted by using a plank hammering as a seismic source. At the same time an electric survey with the pole-pole array (2m electrode interval) deploying the spike electrode of the sensor belt was carried out. The survey was completed within 90 min. for preparation, 90min. for the electric survey and 60 min. for the seismic survey. Our goal of this development is 180min. (3 hours) for all data acquisition procedures for a survey. In our final measurement system simultaneous seismic and electric data acquisition is designed so that the targeted goal is accomplished.

The result of S-wave velocity and resistivity are shown in Figure 3. River front side of the levee body (mainly sand) is relatively imaged in higher velocity and higher resistivity. And river back side (mainly clay) is relatively imaged in lower velocity and lower resistivity.

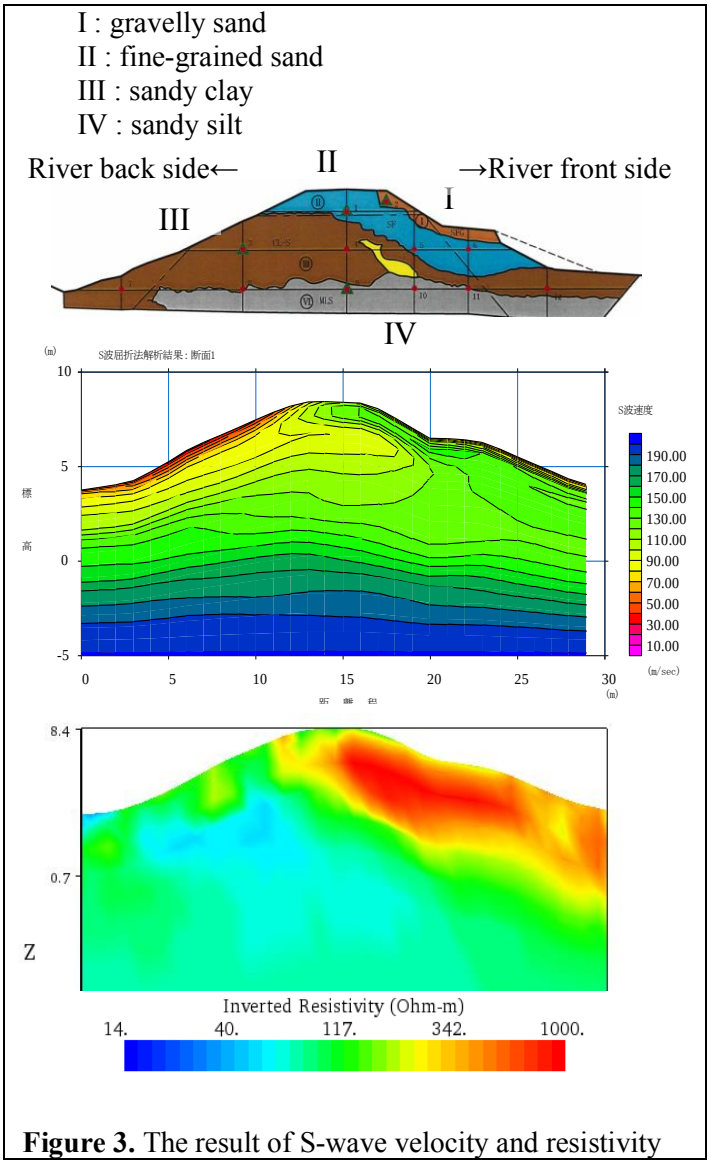


Figure 3. The result of S-wave velocity and resistivity

3. 3D Visualization System of Soil Properties

The system targeted in this project first builds a 3D geotechnical parameter model from a 3D geophysical model as output of the 3D geophysical measurement system. This model is of course built by interpreting the geophysical data in conjunction with the geotechnical data obtained in the boreholes and other investigations. The 3D visualization system helps the engineer to build the final model for the numerical analysis by visualizing the damaged interior of the levee in three dimensions.

Estimation of geotechnical parameters from geophysical parameters is conventionally performed by using a cross-plot and/or the empirical relation of both parameters. In this project to make estimation more accurate and reliable, rock (soil) physics is utilized. Figure 4 shows an example of prediction of S-wave velocity - porosity relation based on a rock physics model called as the unconsolidated sand model [2]. In this diagram actual data are also plotted, which is composed of clayey gravel, sand and clayey sand. This figure shows that the model predicted curves for different

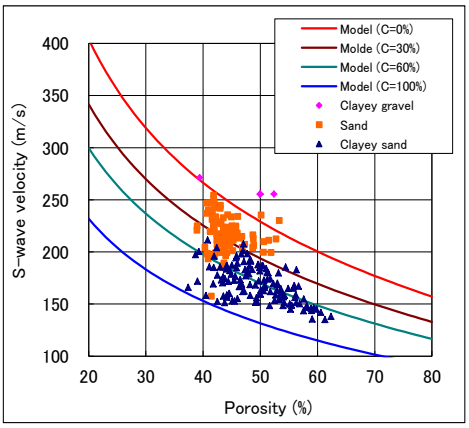


Figure 4. The prototype of the measurement tool

clay contents (0, 30, 60 and 100%) represent actual soil types very well.

We also estimate permeability by using kozeny-carman equation [3]. The equation is shown as follows.

$$k = \frac{1}{72\tau^2}\frac{\phi^3}{(1-\phi)^2}d^2$$

k: permeability

ϕ : porosity

d : particle size

Porosity can be estimated from S-wave velocity, and average particle size can be estimated from soil type. Therefore, permeability can be calculated from the two parameters. Soil type and permeability are shown in Figure 5. This figure shows good consistency between open-cut of the levee and the estimated soil profile. The estimated soil profile verified by the real data obtained in the open-cut of the levee body as shown in this figure proves that geophysical soil profiling can be feasible.

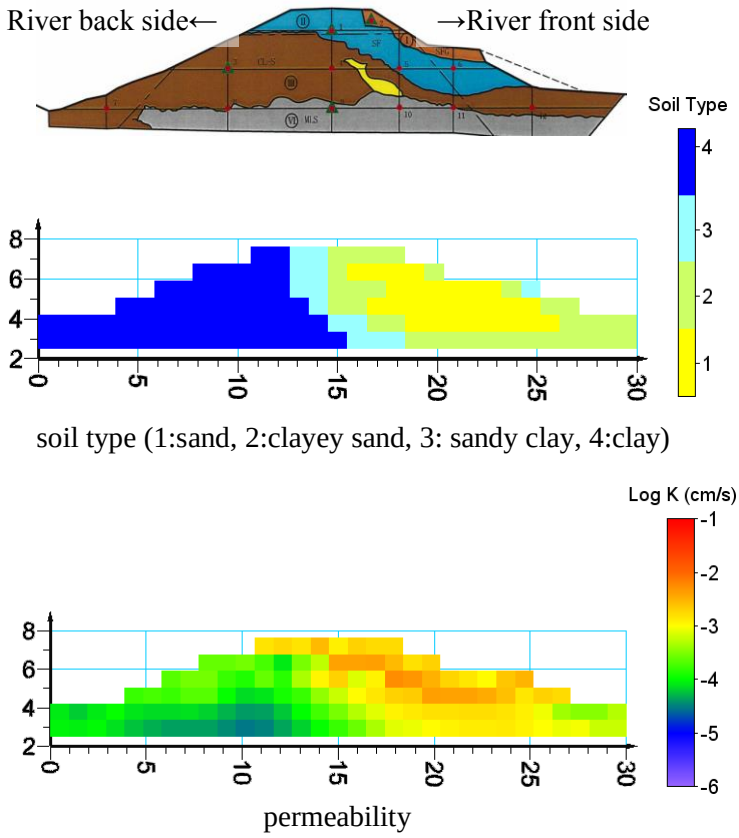


Figure 5. Soil type and coefficient of permeability estimated from geophysical data

4. Conclusion

For effective design of countermeasures for a damaged or potentially damaged river levee, we are developing a 3D geophysical soil profiling system, consisting of a 3D measurement tool for seismic and electric properties of the levee and a 3D visualization system of its soil properties such as hydraulic and mechanical properties estimated from the geophysical data. A prototype of the measurement system has been manufactures and tested on a real river levee to evaluate its performance. An estimation technique of geotechnical parameters from geophysical ones has been developed and verified through an application to real datasets of S-wave velocity and resistivity obtained seismic and electric surveys on a river levee.

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