An analysis of changes in resistivity of general reservoir dams based on 4D inversion of time-lapse resistivity data

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SUMMARY

There are many reservoir dams in the South Korea for the purpose of agriculture. It is necessary to monitor these agricultural facilities to prevent accidents such as water leakage in the deteriorating equipment in advance. Resistivity surveys are commonly applied to determining leakage of water under the dams. Resistivity monitoring had been conducted every six hours during September, 2015 at the Cheongcheon reservoir on the Chungcheongnam-do in the south-west of the South Korea. Prior to analysing this monitoring data, it is needed to pick specific section of the data having meaningful changes of resistivity structure. Forward modelling was performed to determine variations of resistivity based on the variations of characteristics under the dams, consequently selecting proper dataset and doing inversion well. To reflect various underground feature like distorted dam structure and determine exactly, I developed three-dimensional (3D) electrical-resistivity modelling algorithm, using finite element method (FEM) based on tetrahedron element. Also, I examined rate of resistivity variation on the crest of the dam according to the changes of properties of reservoir. On the basis of this rate, valuable monitoring data were chosen and used to do time-lapse resistivity inversion. We also improved three-dimensional inversion algorithm to 4D algorithm, adding time constraint section, considering the rate of changes as time passes by. From this method, we could evaluate conditions of reservoir dam and avoid damage of human life or property by dam collapse.

Key words: water leakage, resistivity monitoring, FEM, time-lapse resistivity inversion

INTRODUCTION

South Korea has many reservoir dams for agriculture purpose (Kim et al., 2013; Cho et al., 2010). Most of the facilities are old being about 60 years old. For the prevention of dam collapse, it is necessary to explore and monitor the reservoir dams in order to detect water leakage in dam (Ikard et al., 2014). Between various geophysical-exploration investigation methods that can be employed for examining the seepage, resistivity surveys are the most widely used one since the method can investigate the structure of electrical resistivity of dam, which are function of water distribution. Employing dipole-dipole array, we had been conducting resistivity surveys on the crest of Cheongcheon reservoir dam every six hours (00:00, 06:00, 12:00, 18:00) for a month of September.

The dam is located on the Chungcheongnam-do, South Korea. The Cheongcheon dam built in 1962, is 23 meters high and the length of the dam is 286 meters. Including geophysical exploration, geological surveys had been also made. Water permeability test and standard penetration test during the course of the drilling investigation were performed. As a result of those tests, we could know the vertical layered structure and judge shielding property of dam has no problem, but there is sandy soil partially in the solum and there are concerns about piping by low plasticity. So an additional examination is necessary.

First of all, rates of changes of resistivity at the crest of dam have been carefully analysed to evaluate data quality, while distinguish data containing information on the variation in the resistivity from those with no information. For the analysis, we conducted three-dimensional (3D) forwarding modelling for various models of characteristics that reflect general conditions of usual reservoir dams: how much changes in resistivity are roughly observed during water leakage, water level change in the reservoir, and so on. When each of different models having different conditions is analysed, we could get various rates from that analysis. And then we could use this information about rates to choose proper field resistivity data set. To numerically conduct the forward modelling, we used an algorithm employing finite element method with tetrahedron elements being able to describe more realistic geometry to consider complex topography such as tilted dam.

After the analysis on the data, we make time-lapse (TL) resistivity inversion of several data sets, which are evaluated to contain meaningful information on the changes in resistivity of the dam to interpret the possibility of water leakage of the dam.

ANALYSIS ON MODELLING OF ELECTRICAL-RESISTIVITY DATA

First of all, we should analyse the monitoring data of Cheongcheon reservoir dam for TL inversion of the resistivity. From the field data, we calculated the rates between resistivity of the continuous times and found that the rates of specific section have higher values sequentially. And we modified an existing 3D finite element method (FEM) modelling algorithm using linear tetrahedral elements to consider irregular tetrahedral cells. FEM using tetrahedron elements helps to make possible to consider irregular geometry complicated models like dam.

Using the algorithm, we make forward modelling of various dam models with different reservoir water level, different resistivity distribution of dam, and so on. We tried several changing rates of resistivity of the dam to determine proper models showing water leakage in the dam. By analysing the forward modelling results and comparing the field data sets, we determine meaningful data sets containing information on the variation of electrical resistivity with the dam, possibly explaining water leakage.

TIME-LAPSE RESISTIVITY INVERSION OF FIELD MONITORING DATA

In TL inversion of chosen data sets, we employed active time constraint method (Karaoulis *et al.*, 2011).

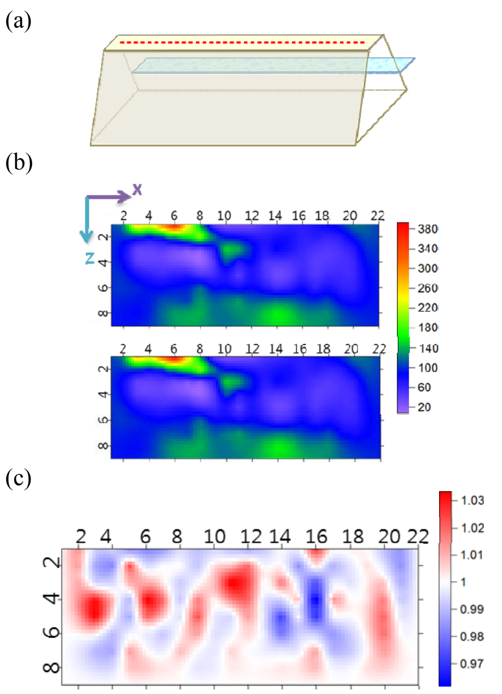

Figure 1: Time-lapse resistivity inversion about Cheongcheon reservoir dam (a) dam model (block: 22 × 15 × 9), resistivity survey is done at the crest drawn red dotted line, (b) time-lapse inversion of resistivity about 2 times (1st,Sep. 00:00 and 1st,Sep. 06:00) (c) resistivity ratio between two times shown in b).

We first make TL inversion of randomly-chosen two-different-vintage field data sets of the Cheongcheon dam for a preliminary inversion analysis. The preliminary inversion assumed that the crest of dam is wide enough not to consider the dam (Figure 1(a)) as a box-like one. The two inverted resistivity models look generally similar to each other (Figure 1(b)). However, their ratio (Figure 1(c)) shows difference in resistivity at least, even though does not clearly locate clear leakage section.

For a more precise inversion, we proceed with several steps. First, we make TL inversion of the carefully chosen data sets from field-data analysis based on modelling experiments. Further, we consider the real geometry of 3D dam structures in inversion, and the changes in the water level. We will interpret inversion results with consulting existing geological information in order to properly investigate regions of water leakage.

CONCLUSIONS

The point of this study is to investigate the old facility of dam to secure from the water leakage through the time-lapse resistivity inversion of measured TL field data over Cheongcheon reservoir dam. For the analysis of field data sets of different time-vintages, we made forward modelling experiments of resistivity surveys for the dam and analyse simulated data sets. For the simulation experiments, we improved an existing FEM modelling code using linear tetrahedral elements to be able to reflect complicated and irregular geometry of the dam. Using the developed algorithm, we can properly describe irregular geometries of dam models and obtain more realistic results of electrical resistivity survey. Through forward modelling analysis, we choose several meaningful data sets from the whole TL data sets.

For the TL inversion of the selected TL data, we applied active time constraint method to the inversion. Utilizing this inversion code, we could obtain better results to analyse monitoring data. Also we can estimate from the results that some weak places are more dangerous to generate water leakage.

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