QUANTITATIVE ANALYSIS OF ELECTRICAL RESISTIVITY DATA FOR THE SAFETY OF SEA DIKE

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ABSTRACT

Electrical resistivity (ER) survey was used for delineating seawater inflow through sea dike and diagnosing the safety of sea dike. To identify the part of anomalous seawater inflow through the sea dike, we carried out ER survey including ER monitoring along the dike including anomalous regions. However, ER survey results can be affected by the drastic change of groundwater level affected directly by tidal fluctuation even though ER survey has been widely used to image the electrical properties of the subsurface because of the convenience of data acquisition and interpretation. To overcome the limitation, quantitative analysis approach using the relationship between pore pressure and ER data obtained from piezometers and automatic ER monitoring systems was applied. From the results of analysis, relationship between two components was appeared to be high so that ER survey without drilling for obtaining pore pressure data turned out to be applicable for estimating the anomalous region. Therefore, time-series data from monitoring system would be effective to determine the cause of subtle changes in ER of the dike.

Keywords: Sea dike, electrical resistivity, quantitative analysis, pore pressure, leakage.

1. INTRODUCTION

Sea dike has played an effective role in the field of the agriculture and fisheries in South Korea after the big reclamation projects were started along the coastline to ensure a large farmland. However, several problems are appearing in terms of stability of dike because of continuous load on it, changing the structure with time and the surrounding environment. Furthermore, more than 90% of the sea dikes are more than 35 years old.

According to the previous researches related to the stability of sea dike, various approaches including geophysical methods have appeared to be useful for diagnosis of dike condition. Among them, electrical resistivity (ER) survey associated to small-loop electromagnetic (EM) method was applied for the detection of leakage pathways through sea dike in South Korea and turned out to be delineated them successfully (Song et al., 2000; Song et al., 2007). There are other examples of analysis using ER monitoring data for leakage and internal erosion in embankment dams of Sweden and Norway (Sjodahl et al., 2009; 2010).

However, there were many difficulties of quantitative evaluation due to the site specific conditions although geophysical methods were often applied to solve the problem of leaks in sea dike. Therefore, in this study, new applicable techniques that improved the existing inversion methods for quantitative evaluation using ER data are applied.

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2. METHODOLOGY

Conventional electrode array methods in two-dimensional electrical resistivity survey are pole-pole, pole-dipole, dipole-dipole, Wenner and Schlumberger. Among these, the dipole-dipole array method is commonly used in Korea since the resistivity of bedrock is relatively high ranging over several thousands of ohm-m.

In general, the measured potential in field indicates the summation of electrical responses and noises. The signal-to-noise ratio of measured data is decreased as the measured potential is decreased because electrical noises are relatively increased assuming the constant of electrical noises. Therefore, the signal-to-noise ratio of measured data can be smaller as both conductivity of ground and separation index increase due to decreasing measured potential. Because the conventional electrode array method can distort the measured potential in case of pole-pole and pole-dipole using remote electrodes, Kim et al. (2001) proposed a modified electrode array method in which remote electrodes were located at both ends of survey line. Figure 1 shows the schematic view of the conventional and modified electrode array for pole-pole array.

![Figure 1. Schematic comparison diagram of surface electrical resistivity survey between conventional and modified pole-pole array.](image)

3. FIELD APPLICATION

The Saemangeum sea dike in this study was completed in 2006 for water blockage and for constructing the final section in 2008. Length of the dike is 33.9 km, the longest in the world, and average floor width is 290 m having maximum 535 m with 36 m height. The dike was constructed by dredged sea sand after setting up riprap with inside filter to prevent tidal force.

According Song et al. (2009), the ER of dredged sand saturated with seawater (0.25 ohm-m) was measured to 0.97 ohm-m. Figure 2 shows the measured ER results for the sea dike in 2010 and 2012, respectively. Dark red lines indicate area below 1 ohm-m estimated to be saturated with seawater. In general, ER may be affected by electrical conductivity of pore water as well as the particle size. Therefore, ER of material completely depends on the particle size in case of pore water with very low electrical resistivity. Consequently, there are two possibilities the charge state of the medium caused by the failure or water recharge state in empty space in case of below 1 ohm-m as in Figure 2.

However, these results indicate the calculated value at measured time regardless the change of ER conditions including tide and saturation state on medium. Therefore, two-dimensional (2D) ER ratio using inverted resistivity data was calculated to monitor anomalous regions and lowered regions indicate the decrease of ER (Figure 3). From the results, the variation of ER ratio turned out to be depended on the amount of leakage. However, it is very difficult to estimate the accurate amount of leakage due to the drastic change of groundwater level affected directly by tidal fluctuation of about 7 m.
Figure 2. Comparison of two inverted sections (December 8, 2010 and July 3, 2012) for each section: (a) No.26+00-27+80 and (b) No.30+80-32+40

Figure 3. Section of ER ratio for 2013 to 2011.

To identify the effect of tide for ER survey, sea level and reservoir water level at two different time (September 17, 2011 and September 12, 2013) (Figure 4). Sealevel was 0.49 m falling at 2013 while reservoir water level was constant. Therefore, inverted ER section would be more affected by seawater inflow during high tide in 2011 compared to in 2013.

Figure 4. Difference between sea level and reservoir water level at the time of ER survey.

Nevertheless, it is difficult to delineate the leakage areas from the inverted ER section due to the continuous sea level fluctuation and accompanying groundwater level.
change through sea dike. To overcome this problem, inverted ER values are compared to pore pressure obtained from piezometers, installed at the same point with automatic ER monitoring systems. The positions of the piezometers are at 8.6 m, 13.6 m under No.60+25, depth 10 m, 15 m under No.65+00 and depth 11.7 m, 16.3 m under No.69+80.

The results of correlation analysis indicate that pore pressure is decreased while electrical resistivity is increased (Figure 5). In particular, correlation between two data in 2013 was close to 95% higher. As a result of this correlation, the pore pressure can be estimated indirectly in certain points. In addition, the reliability of ER data will be high.

![Figure 5. Relationship between ER and pore pressure](image)

(a)

(b)

Figure 5. Relationship between ER and pore pressure (a) in 2011, (b) in 2013.

However, ER data for sea dike can be affected significantly in surrounding environment such as tide, reservoir water level and weather condition. However, it takes a lot of time in the preparation process such as electrode state, contact resistance test and connecting cable check.
Therefore, automatic ER monitoring system was installed. This system can be remotely controlled to the desired time, as well as may be used semi-permanently by burying electrical cables and electrodes. Monitoring system is composed of three parts: main device part, line part and communication unit. Main device part is separated as an input device flowing a micro current and an output device displaying the potential difference. Line part was buried in 0.5 m depth and waterproof.

Measurement period was set at three stage units considering resistivity changes by tide. After installation, ER section from background data was obtained corresponding to stabilized time (Figure 6).

![Figure 6. Background data acquired from automatic ER monitoring system.](image)

Figure 6 shows tide, reservoir water level, temperature and rainfall data extracted for No.16+60 point from August 7, 2013 to September 23, 2013. ER changes in depth 20 m appeared to have little impact during rainfall, while those in depth 1.25 m showed a high impact. Therefore, time-series analysis results using the ER monitoring system can indicate more useful information than in conventional survey.

![Figure 7. Change of ER values in accordance with the surrounding environment for No.16+60 (a) Depth 1.25 m, (b) Depth 20 m.](image)
4. CONCLUSION

To identify the part of anomalous seawater inflow through the sea dike quantitatively, we carried out ER survey and ER monitoring along the dike including anomalous regions. To enhance signal-to-noise ratio, a modified electrode array method in which remote electrodes were located at both ends of survey line was applied. 2D ER ratio using inverted resistivity data was calculated to monitor anomalous regions and lowered regions indicate the decrease of ER. These results indicate the variation of ER ratio turned out to be depended on the amount of leakage.

To overcome the effect of continuous sea level fluctuation and accompanying groundwater level change through sea dike, inverted ER values are compared to pore pressure obtained from piezometers. As a result of this correlation, the pore pressure can be estimated indirectly in certain points. In addition, the reliability of ER data will be high.

Automatic ER monitoring system was installed and measurement period was set at three stage units considering resistivity changes by tide. After installation, ER section from background data was obtained corresponding to stabilized time. ER monitoring data was obtained by automatic measurement system to improve the reliability for interpreting data. As a result, it was confirmed that the influence of tide, reservoir water level, and weather condition. From the monitoring results, time-series analysis results using the ER monitoring system can indicate more useful information than in conventional survey.

REFERENCES


