Time-lapse Resistivity Investigations for Imaging Subsurface Grout during Ground Stabilization

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Abstract: Cement-grouts are injected into limestone cavities beneath the road in the project area, in order to improve strength and reduce permeability; the extent to which grout has penetrated in cavities need to be monitored in order to determined effectiveness of cement-grout. Geophysical approaches, offer great potential for monitoring the grout injection process in a fast and cost-effective way as well as showing whether the grout has successfully achieved the target.
This paper presents the ability of surface electrical resistivity to investigate the verification of the grout placement. In order to image the cement-grout, time-lapse surface electrical resistivity surveys were conducted to compare electrical resistivity images before and after injection. Cement-grout was imaged as anomalies exhibiting low resistivity than the surrounding rocks. In accordance with field monitoring, laboratory study was also designed to monitor the resistivity changes of cement-grout specimens with time-lapse. Time-lapse laboratory measurements indicated that electrical methods are good tool to identify the grouted zone.
Pre-and post grouting electrical images showed significant changes in subsurface resistivity at grouted zone. The study showed that electrical resistivity imaging technology can be a useful tool for detecting and evaluating changes in subsurface resistivity due to the injection of the grout.

Keywords: resistivity, cement mortar, subsurface cavities, monitoring, laboratory observation

1. Introduction

Infrastructure in karst terrains are influenced not only by the character of the bedrock but also by the nature and thickness of the soil cover. Voids and cavities in both the bedrock and the soil are significant as potential sites for collapse. A large number of limestone cavities that develops in the karst region beneath a road at Yongweol-ri, South Korea, these cavities are widely present within limeslicate bedrock, and filled with groundwater and clay, further drilling job, confirmed the actual depth of subsurface cavities (Park, et al., 2005). These buried cavities may lead to property damage and is thus serious threat to human safety (Kim et al., 2003). Grouting is a kind of ground treatment techniques used quite often in underground stabilization works.

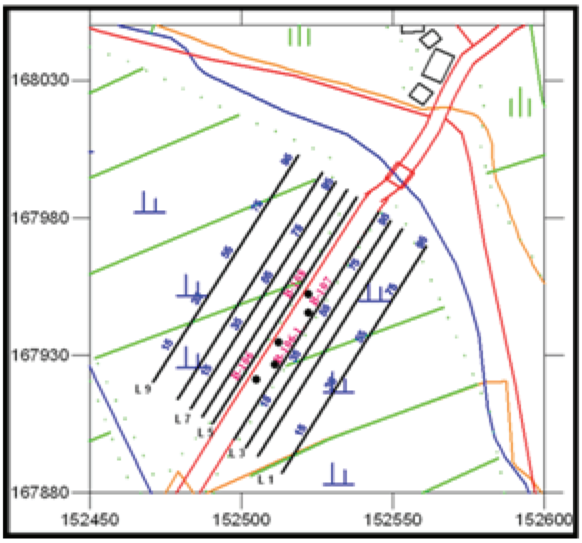

Figure 1. field layout of electrical survey profiles

Monitoring of the grouting effect during ground stabilization will be meaningful to control the actual grouting operation for better performance. The geophysical approaches, offer great potential for monitoring the grout injection process in a fast and cost effective way. An electrical resistivity investigation was used to assess the success of cement-grout modification work. Electrical resistivity surveys were carried out in two phases, pre and post grouting injection. In accordance with the field monitoring survey, laboratory study was designed to monitor the resistivity change of cement mortar specimens. We tried to examine the applicability of electrical method to the evaluation of the cement-grout during ground stabilization.

2. Field survey

To monitor the changes in ground resistivity pre-grouting and post-grouting, surface resistivity survey has been conducted. Resistivity data were acquired along the survey lines parallel to the road (Figure 1). Electrodes were installed with 5 m spacing and length of each line was about 95 m. Lines 4, 5 and 6 has been permanently installed in the monitoring area, to which a data acquisition system has been hooked up each time. At the first stage of monitoring, electrodes were buried at 10 cm depth to improve the electrode contact. Resistivity survey data were measured using SuperSting R8/IP™ systems made by Advanced Geosciences Inc. The data acquisition process was completely controlled by software, which checked that all electrodes were connected and properly ground before actual measurement started. Two kinds of electrode array were deployed dipole-dipole array and modified pole-pole array (Kim et al., 2001).

DIPROfWin, two dimensional resistivity interpretation software developed by KIGAM, coded based on the 2.5 dimensional finite element modeling and the smoothness constrained least- squares inversion adopting Active Constraint Balancing (ACB) method (Yi et al., 2003) has been used for data processing. Monitoring system is categorized into two different phases. Nine lines data have been acquired.

Table: Monitoring of resistivity data

Acquisition date	Measurement method	Condition
February 2006	Surface electrical resistivity method	Pre-grout
May 2007	Surface electrical resistivity method	Post-grout

3. Laboratory experiment

Laboratory measurements were conducted to investigate the time-lapse electrical changes that occur as the grout specimens undergo two different conditions (in air and in water). Four identical specimens were made, having 20 cm in length and 10 cm in diameter. Four electrodes were embedded within specimen to measure the electrical resistivity of the specimen. The outer two electrodes (C1 and C2) were used to apply current to the specimen. Two inner electrodes (P1 and P2) were used to measure the potential difference. Resistivity of specimens was measured by Mini OHM™ (OYO, Co, Japan). Four specimens were exposed two different environmental conditions. Specimen (1) and Specimen (2) were exposed to air, while Specimen (3) and Specimen (4) were placed inside water container. Grout specimens resistivity is measured at

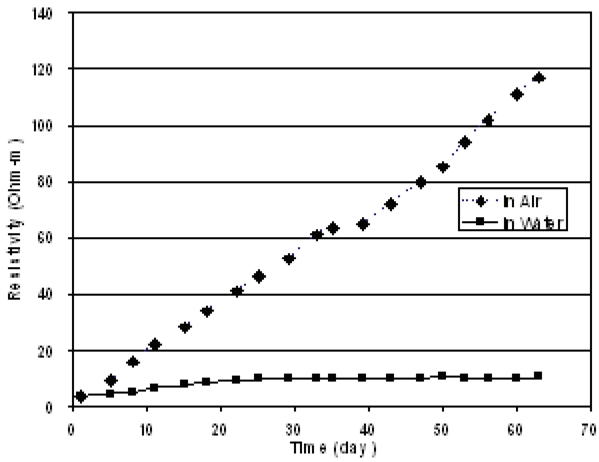

Figure 2. time-lapse resistivity monitoring of cement mortar specimens

different ages, for about 8 weeks.
In general, electrical resistivity of grout specimen will increase with time. Increase will be greater for air curing than for moist curing.
In our study, it is observed that electrical resistivity vary over a wide range, mainly influenced by the moisture content. It is observed that electrical resistivity of exposed specimens is mainly depending on the moisture content and temperature. The resistivity of specimens is increased with time when the specimen is drying out. It is shown in Fig1. On the other hand, the specimens within water environment absorbed water and gradually started cementation, showing the steady increase in resistivity. The resistivity of the specimens within water condition, increased so slowly that we could hardly identify the amount of resistivity increases with time-lapse. After two month monitoring, the resistivity of saturated specimen remained less than 20 ohm-m (Figure 2). The laboratory result indicated that electrical method is good tool to identify the grouted zone.

4. Discussion

One the basis of pre-grouting survey, the project area is divided into two parts, “A” (from Line 1 to 3) and “B” (from Line 4 to 9) as shown in the figure 6a. Line 1 to 3 images show stable condition at the “A” region, while images from line 4 to 9 indicate low resistivity zone at the “B” region corresponding to subsurface cavities. To monitor the changes in ground resistivity, two kind of electrode array were deployed, dipole-dipole and modify pole-pole. In this paper, Dipole-dipole data were used to construct inverted section because this method provided the highest resolution. Here we are trying to discriminate the location where the grout had been injected into the subsurface cavities beneath the road. Pre grout data set was obtained prior to grouting provide the baseline electrical resistivity values as shown in Figure 3. The electrical resistivity survey was repeated after post-grout as shown in Figure 4. Total nine lines data has been acquired. Figure 5 shows the phase difference result of line 6. As discussed earlier, greater difference between the grout electrical properties and the surrounding rock, thus grout would be imaged as anomalous body. Many boreholes were drilled along both side of the road (between line 4 and 5) as shown in figure 1.Two major grout injections were carried out along the line 5 at 20 and 60 m. the phase difference record, low resistivity appear near the location at 20 and 60 m. these were the position where grout was injected. In the project area very complex subsurface cavities system exist. Significant changes in ground resistivity is detected at 60 m, other hand small change in resistivity near 20m, it might be possible that grout material migrated to other location. Figure 6b shows the phase difference results of electrical survey for line (1 to 9). Grout material was injected in few boreholes along line 4. It was found that holes along line 4 accepted much less grout than line 5 other side of the road. In figure 6b, line 4 show shallow subsurface changes in resistivity due to grout injection. In figure 6b no significant change in resistivity along the line 1, 2 and 3 was observed which might be an indication that the grout material could not infiltrated in this direction. On other hand, grout material injected along line 5 infiltrated toward line 6, it might be indicated that, developed subsurface cavities are well interconnected.

5. Conclusions

In this study surface electrical method was used because it is a non-destructive technology and the technology also provide good level of resolution to detect grouted zone due to big contrast between grout material and surrounding rock. A comparison of the pre and post grouting results showed a significant change in subsurface resistivity at the grouted zone. Good correlation was obtained between the location where grout was injected and inverted resistivity sections. The post grout results show low resistivity value because grout may have infiltrated and displaced water that was contained in the subsurface cavities. The result of this study can be summarized that electrical method is an effective method to monitor grout injection.

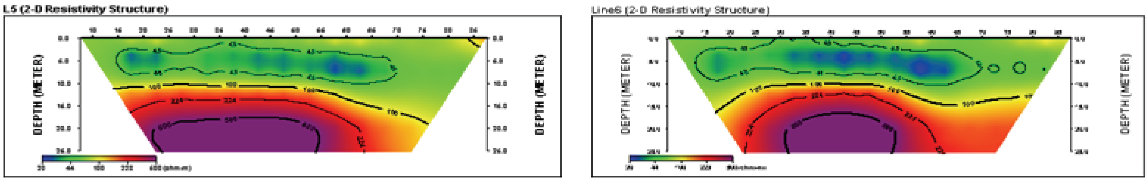

Figure 3 Inverted resistivity images of pre-grouting injection (Line 5 and 6)

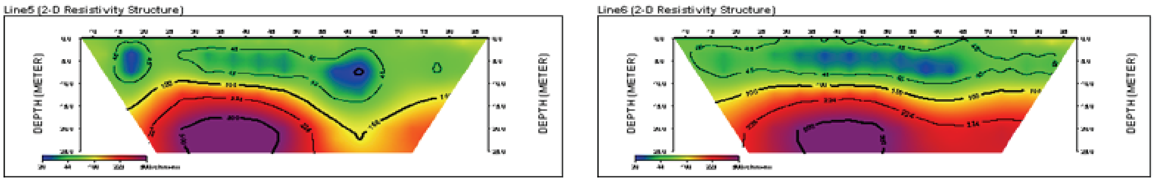

Figure 4 Inverted resistivity images of post-grouting injection (Line 5 and 6)

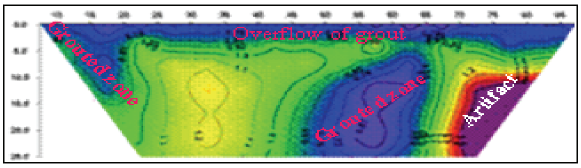

Figure 5 Phase difference resistivity image of line 6

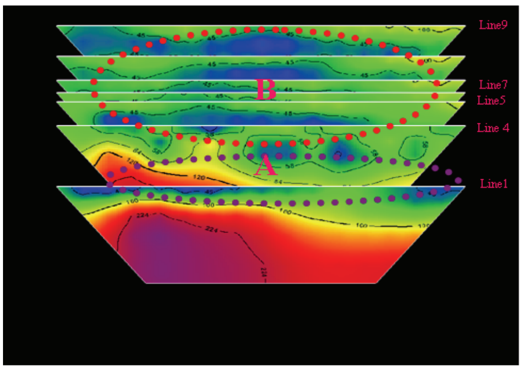

Figure 6a Pre-grouting fence diagram (Line 1 to 9)

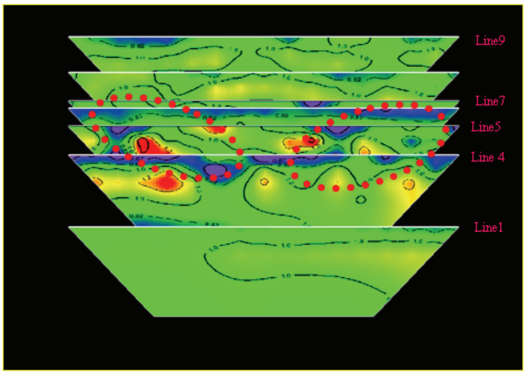

Figure 6b Phase difference fence diagram (Line 1 to 9)

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