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Application of Resistivity Technique for Identifying Cavities Near Surface in Karst Area, Muan-gun, South of Korea

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무안군 카르스트 지역의 지하공동 탐지를 위한 전기비저항 탐사 기술 적용

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Abstract: This study evaluates the usefulness and capability of surface electrical resistivity technique for identifying the weak zones or subsurface cavities in karst area with limestone formation. Weak zones or cavities near surface can be potentially dangerous and several problems are associated with collapse of roads or buildings accompanied by subsidence phenomena. In this paper, both two and three dimensional resistivity investigation were conducted to investigate subsidence along a road in Yongweol-ri, Muan-gun, South Korea. The results of the resistivity survey using dipole-dipole array provide a clear view of the weathered regolith, the distribution of weak zones or cavities and bedrock. Several low resistivity areas were identified and subsequent drilling led to the discovery of several weak zone or clay-filled underground cavities. The drilling results show excellent correlation with the resistivity images. It is illustrated, the ability of electrical technique to produce high resolution images of subsurface, which are useful for subsidence assessment. Also the results of this study have demonstrated that two and three dimensional electrical resistivity surveys are useful for delineating the subsidence area. Based on resistivity imaging, the map of hazardous zone has been developed.

Keywords: two and three dimensional electrical resistivity survey, karst area, limestone cavities, ground subsidence

요 약: 이 연구는 카르스트 지역에서 발생하는 연약층 또는 지하 석회암 공동의 영상화를 위한 지표 전기비저항 탐사의 유용성을 파악하고자 수행되었다. 연약층 또는 공동은 잠재적인 위험성을 가지고 있으며, 이들은 도로 및 건축물의 붕괴를 야기한다. 따라서 이 연구에서는 이미 지반침하가 있었음이 보고된 바 있는 전남 무안군 영월리에 있는 한 도로를 따라 2-3차원 전기비저항 탐사를 수행하여 지반 침하 현상을 조사하였다. 이 지역의 쌍극자배열 전기비저항 탐사 결과, 풍화된 표토층과 연약층 또는 공동 그리고 기반암이 뚜렷이 구분되어 나타났으며, 또한 여러 곳의 저비저항 이상대가 나타났는데 이는 점토로 충전된 공동으로 시추결과 확인되었다. 아울러 시추 결과와 전기비저항 탐사 결과는 매우 일치함을 알 수 있었다. 따라서 지반 침하를 평가하는 데 있어 전기비저항 탐사를 통한 지하영상화 작업이 매우 높은 분해능을 가짐을 알 수 있었으며 또한 지반 침하 지역을 조사하고 이를 평가함에 있어 2 ~ 3차원 전기비저항탐사가 매우 유용함을 확인할 수 있었다. 이러한 탐사 결과를 바탕으로 연구지역 주변의 재해 취약정도를 작성하였다.

주요어: 2 ~ 3차원 전기비저항탐사, 카르스트 지역, 석회암 공동, 지반침하

Introduction

Sinkholes and subsurface cavities are often a major risk in the areas lying underneath by carbonate rocks. There are several problems associated with sinkholes such as collapse of building foundation, road subsidence, and et cetera (Kim *et al*., 2006). The presence of subsurface cavities can cause great public safety hazards in civil engineering works. Civil engineering problems include underestimation of foundation dimensions and catastrophic subsidence of building and roads created by the occurrence of sinkholes (Park *et al*., 2006). Therefore, the detailed subsurface mapping leading to the identification of sinkhole areas is need. Non-destructive geophysical techniques are inexpensive and effective methods to obtain subsurface information, and hence non-destruc-

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tive geophysical methods have been used widely in karst region. Cavities may be dry, air filled, soft sediment filled and full or partial filled with water, which affect the geophysical response in density, resistivity and other measurable contrasts. GPR, gravity, seismic and electrical resistivity methods are found to be the most effective tools to detect voids. Each geophysical technique requires sufficient contrast in measurable physical properties. An electrical resistivity survey has been recorded as a well-known geophysical method to detect subsurface cavities in karst regions where the cavity can be detected based on resistivity anomaly from background (Zhou *et al*., 2002).

The purpose of this study is to delineate the presence of underground cavities with the electrical resistivity technique and drilling results. To evaluate these methods, we have carried out two and three dimensional electrical resistivity surveys and have analyzed 15 drilled data.

Site of investigation

The test site is located at Yongweol-ri, Muan-gun on the southwestern of Korean peninsula. About 3 km north of Muan city, a busy road is passing through karst region leading toward small town Yongweol-ri. The subsidence in the test site is commonly affected by the decline of groundwater level by excessively pumping for agricultural irrigation. Muan city, southwestern Korea, provides several examples of ground subsidence related to dissolution of carbonate rock (Kim *et al*., 2003). Roads and buildings in this area have already been damaged, and the risk of subsidence damages with future development is considered to be high (Park *et al*., 2006). Karst conditions in the test site are characterized by variable suite of subsurface features due to the dissolution of soluble limestone. Karst features in this area include sinkholes and subsurface cavities. The limestone is broadly distributed in the Muan-gun including the study area. The subsurface cavities widely present within the limestone formation. The main geological feature of the area is, so called, the Kwangju fault, which is one of the major faults in the study area, is passing through the NNE-SSW of the survey area (Kim *et al*., 2003). At this site, borehole investigations confirmed the existence of subsurface cavities at various depths and complicated networks of subsurface cavities have developed as a result of limestone dissolution. Most cavities are located in the upper part of the bedrock which is right beneath the regolith layer (Park *et al*., 2006).

The mechanism of the sinkhole collapses at the study area

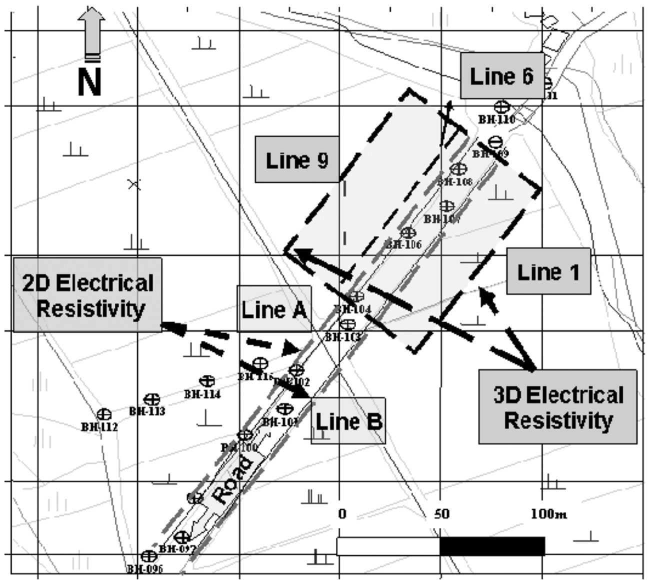

Fig. 1. Location of the survey area.

is that during the agriculture off season, the water table lies above the regolith limestone. On the other hand, the water table drops into or below the cavities due to a large volume of groundwater pumping for irrigation during the farming season (Park *et al*., 2006). This causes the regolith arches, spanning the opening in the bedrock. Finally, the collapse occurs due to the loss of buoyant support for the regolith arches, attributed to the downward moving groundwater (Park *et al*., 2006).

Data acquisition and processing

Electrical resistivity surveys were carried out in two phases. In Phase I, two profiling lines were measured using dipole-dipole array on the both side of the road, as shown in (Fig. 1) represented by Line 'A' and 'B'. The electrode spacing was 5 m and length of traverse was 300 m. Based on two dimensional electrical resistivity imaging, borehole was drilled. In Phase II, a portion of road was selected for three dimensional electrical resistivity measurement. In three dimensional electrical resistivity survey, 12 multi electrode resistivity profiling lines were measured with the aid of R8/IP SuperSting meter using the dipole-dipole array. To ensure a good coverage of the study area, 9 of the traverses were oriented SW-NE, where other 3 lines were oriented SE-NW. The electrode spacing was 5 m. The total length of the each traverse was 100 m. Fig. 1 shows the survey plan view of the study area with the locations of the traverses. The traverses 1, 2, 3 and 4 were located on SE side of the road and other traverses 5, 6, 7, 8, and 9 on NW side of the road.

The data acquisition process was completely controlled by software, which checked that all electrodes were connected and properly ground before actual measurement started.

Measured data were calculated by two dimensional inversion method 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). Data from 9 lines were combined into one single data and three dimensional inversion algorithm was used to generate fence images.

Results and Discussion

Two dimensional resistivity survey

Surface electrical resistivity survey was used to identify possible subsurface cavities and less competent rock. The resistivity imaging profiles provide two dimensional images of the subsurface within the site and show distinct electrical resistivity conditions and contrasts. The regions with low resistivity within profiles are consistent with conductive materials, while those with higher resistivity materials are consistent with less conductive materials. Within this type of geological setting, conductive material is attributed by increasing clay content from weathering of limestone which is filled with water or silt/clay. These types of conditions are generally corresponding to less competent rock such as subsurface cavities. High resistivity material within this geological setting can be attributed to more competent rock such as fresh limestone. Fig. 2(a) shows the results of resistivity traverse of Line ‘A’ and Line ‘B’ in the Yongweol-ri road side and indicates that two traverses have low resistivity zone that could be due to weak zone and cavities filled with clay. NE side profile shows much lower resistivity. The acquired resistivity images of Line ‘A’ and Line ‘B’ indicate the presence of a low resistivity zone at ranging 150 m ~ 250 m and 200 m ~ 270 m, respectively, in horizontal direction. On the whole the resistivity distribution is ranging from 20 ~ 1000 ohm-m. The low resistivity values of subsurface indicate the presence of cavities filled with clay, while the higher resistivity values of subsurface indicate the presence of bedrock. Resistivity images indicated that the overburden soil thickness is ranging from 3 to 7 m.

Drilling data

Based on geophysical results, 15 boreholes were drilled along Line ‘A’ and Line ‘B’. The drilling results obtained

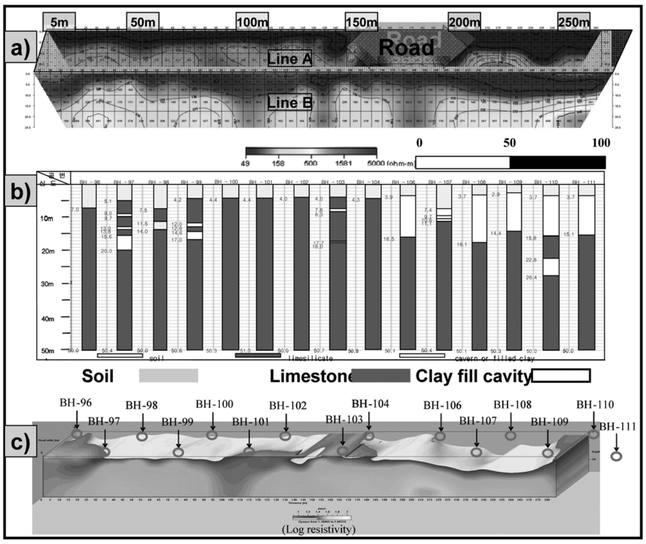

Fig. 2. (a) Inverted resistivity section along the road site “Line A and B”. (b) Boreholes drilling results (c) Resistivity map generated from surface measurements (Park *et al.*, 2006).

from BH-97 to BH-99 indicates subsurface cavities or weak zone at the various depths, ranging from 9 to 20 m (Fig. 2(b)) and that the overburden soil thickness is highly variable, ranging from 3 to 7 m thick across the site. Coring results obtained from BH-106 to BH-111 indicate a complex subsurface cavities network and most cavities are located near the upper part of the bedrock (Fig. 2(b)). Clay filled cavities were identified at core samples collected at BH-106 to BH-111. The results of drilling activities indicate that this area is undergoing aggressive karst development.

Comparison of the two dimensional resistivity and drilling results

Comparison of the two dimensional electrical resistivity survey results with coring information allowed calibration of the geophysical data interpretation. Drilling results were compared to the resistivity traverse. Fig. 2(b) and Fig. 2(c) show boring results and resistivity images respectively. The boring results demonstrated that the weak rock or clay filled cavity existed and the corresponding resistivity images identified low resistivity at this depth.

Three dimensional electrical resistivity survey

In order to obtain a more reliable and realistic representation of subsurface cavities images, two dimensional electrical resistivity survey was designed to acquire data in grid form. Nine parallel resistivity profiles were acquired on the both sides of the road (Fig. (1)) and two dimensional resistivity

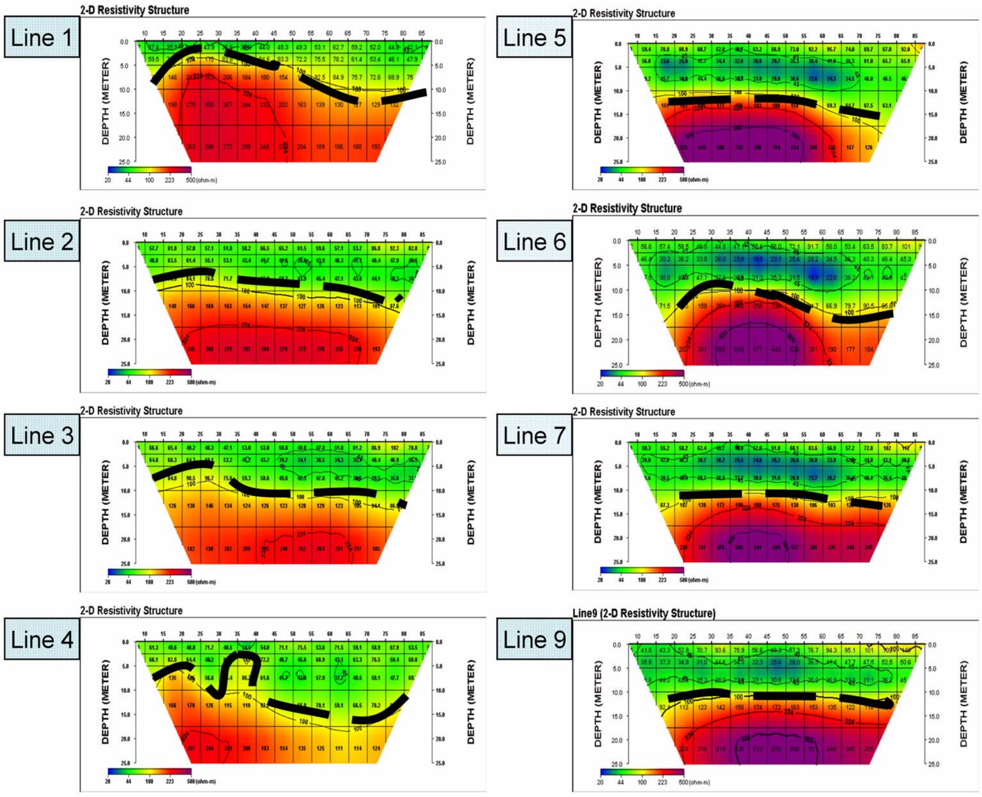

Fig. 3. All electrical resistivity profiles resulting from three dimensional area. Blue colors correspond to low resistivity values and dashed lines indicate the depth of bed rock.

measurements were processed with three dimensional algorithm (Yi *et al*., 2003).

Fig. 3 shows that results of the electrical resistivity acquired in most risky area, where blue colors represent low resistivity values are depicted. As it is shown, resistivities values greater than 200 ohm-m are mapped as limestone while resistivities less than 50 ohm-m is mapped as clay filled cavities or weak zone. The resistivities greater than 50 ohm-m, but less than 200 ohm-m is interpreted as weathered soils. The resistivity imagings are in great agreement with the information gained from the boreholes drilling. Fig. 3 shows that the limestone in the region (line 1, 2, 3 and 4) is covered by weathered soils and there are no known karstic features such as subsurface cavities or weak zone. The resistivity images of line (5, 6, 7, 8 and 9) show low resistivity region and indicate that karst development such as weak zone or subsurface cavities is going through in this region.

Results of three dimensional inversion, shows that the main karstic bodies are started from line 5 to 9. The anomalies at the depths of 5 to 10 m clearly indicate the location of a weak zone or subsurface cavities. Alternately, in order to display the three dimensional extent of a low resistivity zone, an iso-resistivity surface was also produced (Fig. 4), which corresponds to resistivity lower than 50 ohm-m. According to Fig. 4, the low resistivity anomalies are located between lines 5 to 9, which clearly indicate the subsurface cavities zone. From the three dimensional results, the area has been divided into two region, stable zone and cavities or weak zone and karst development is going through (Fig. 5).

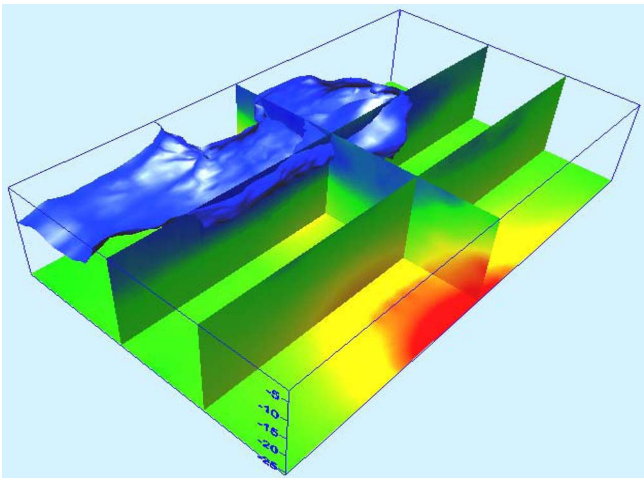

Fig. 4. Three dimensional resistivity distribution for depicting the position of subsurface cavities or weak zones.

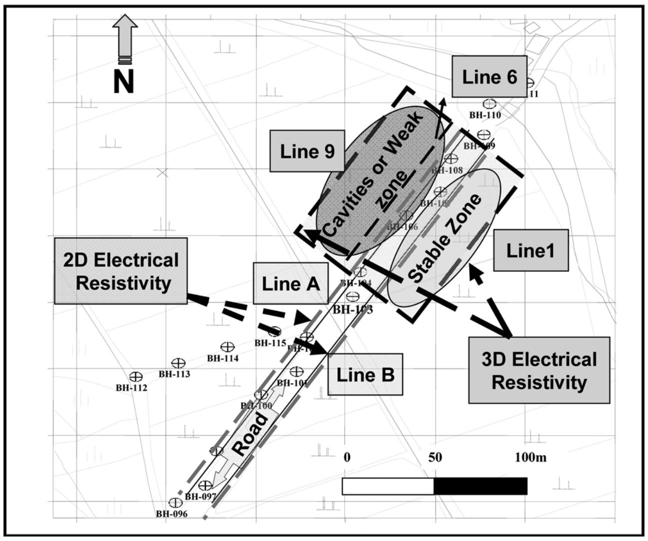

Fig. 5. Conceptual view of interpreted cross sections from resistivity survey.

Conclusions

The case studies demonstrate that electrical resistivity profiling can be successfully used to image the subsurface in karst terrain because this method is ideally suited to differentiating weathered soil, clay filled cavities and bedrock. The objective was to apply resistivity method for locating weak zones or subsurface cavities in karst regions. Clays in Yongweol-ri are normally characterized by low resistivities (typically 20 to 30 ohm-m). The electrical resistivity traverses and boreholes drilling technique effectively created the subsurface imaging at the study site. The geophysical and drilling results showed the occurrence of soil layers ranging from 3 to 7 m thoughtout the site. According to the results obtained from two and three dimensional electrical resistivity method and borehole drilling, it is concluded that electrical resistivity has proved to be effective tools for imaging subsurface cavities. Finally, it is recommended to inject cement based grout into subsurface cavities in order to improve strength and reduce permeability.

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