Abstract

Background/Objectives: This study was to understand non-destructively the underground characteristics on the lower structure of the Sungnyemun Gate (Korea National Treasure No. 1) using geophysical investigation methods of refraction and electrical surveys, and to make an inter-comparison between the excavation surveys. Methods/Statistical Analysis: As the result of geophysical investigation, the ground in the north of the Sungnyemun Gate (hereafter the Gate) showed a relatively fast seismic velocity GL(-) 15.0m at the point of 12.0m and 40m. Findings: Through the excavation survey, it was confirmed that the spot was the border between the main body construction of the Gate, and the core pebbles came out about 1.0 to 1.8m higher than the main body construction section. Applications/Improvement: From this, it can be concluded that by way of the distribution of refraction and excavation survey of geophysical investigation, the locations of the core pebbles at the lower part of the Gate did concur.

Keywords: Electrical Survey, Refraction Survey, Sungnyemun Gate, Underground Characteristics

1. Introduction

Conservation activities of the national cultural heritage have been actively conducted by damage types, physical, chemical and biological deterioration. While the accumulated research materials play an important role in continuously maintaining the original form of cultural heritage, still man-made damages to the property, such as paint scribbles and arson and a total destruction by fire from forest fire have created irreversible situations. For the past few years, the cultural heritages have suffered from both damages, man-made and natural.

The Sungnyemun Gate, the representative architecture of Joseon Dynasty (1392 to 1910 AD) and Korea’s Natural Treasure No. 1, in particular, was damaged by an arson attack in February, 2008, in the first and second floor of its gatehouse. The incident provided a momentum to fortify overall preservation and maintenance of the cultural heritage in Korea. The main stone body construction represents the dignity and formality of the gate with a gatehouse built on top. The gate is consisted of two stone masonry walls built at regular intervals on left and right with the Hongyemun Gate in the center, above which rests the gatehouse. Other four large gates and four small gates along the Seoul fortress are all made in this form.

According to the Law of Cultural Properties Protection, the cultural heritage and its neighboring ground cannot be directly excavated without a permit. But, in case of the Gate, its restoration work on the fire damage allowed a non-destructive geophysical investigation. The investigation helped understand the structure of the main body construction, the foundation ground and more about the Gate. In order to understand the ground characteristics of the lower structure of the Gate, it is appropriate to understand all elements including geological conditions of the area surrounding the Gate, situations in the past and other changes of urban environment before making an investigative approach.

A non-destructive geophysical investigation to restore the gate burned by fire was conducted in 2008. The restoration project, directly conducted by the Administration of Cultural Heritage in Korea, took three years from 2008 to 2010. For the geophysical investigation, non-destructive
seismic and electrical survey were conducted before the excavation, in the east-west direction from the southern and northern surface near the main body construction of the Gate and the south-north direction of the center of the Gate. The cross section of the soil stratum confirmed during a direct excavation survey played an important role in analyzing date obtained from the non-destructive investigation.

This study has an objective to better understand the ground of stone cultural heritage and to preserve and inherit empirical techniques of traditional architecture, thus, by employing variable non-destructive geographical investigation, it is to objectively study the underground characteristics of the constructed cultural heritage. This study is to discuss its subject, the ground characteristics of the main body construction, which makes up the Gate. The result of this research will make a critical contribution to management system of the Gate, and further inform the scientific conservation of other cultural heritages preserved in underground.

2. Methods and Data Processing

2.1 Investigation Sites

The investigation to understand the ground characteristics of the main body construction of the Gate was a non-destructive geophysical investigation. The surveys part took place at S-1 that cut across the Gate, S-2 the north of the main body construction, S-3 the south of the main body construction and S-4 the wall section east of the Gate. The seismic refraction and electric sounding surveys were conducted at E-1, E-2 and E-3 (Figure 1, 2).

Figure 1. Traversing pathways of geophysical investigation around the Sungnyemun Gate.

Figure 2. Overview of geophysical investigation (L1) Seismic survey (Center), (L2) Refraction survey (North), (L3) Electrical survey (South), (L4) Refraction survey (East).

2.1.1 Refraction Survey

A refraction survey is to investigate the physical characteristics of the ground's elasticity by generating an artificial earthquake, so any vibration nearby can cause a detection of noise, lowering the credibility of the test. Therefore, to minimize noise reception from micro-vibration, the refraction survey on the lower ground of the main body construction of the Gate was conducted at nighttime, when vehicle traffic was minimal and the subway not in service. The equipment used for the elastic sounding survey was StrataView R48 by Geometrics of USA and as for the receiver, a geophone with 50 Hz.

The elastic sounding survey is to record, using a geophone, artificially generated signals of elastic waves installed on the earth surface, and from it, it is to analyze the velocity and the ground structure of elastic waves. The oscillating device of elastic waves generates P-wave as it hits the plate fixed onto the earth surface with a sledge hammer. It is a five-oscillation method whose oscillation hits the both sides, the center twice and the middle for every spread on the lateral line. The receiver of elastic waves is installed with 48 geophones at 1-meter intervals.

The lateral lines of the refraction survey are: S-1 traversing the Gate, S-2 in the north near the main body construction, S-3 in the south, S-4 at the wall ground east of the Gate. To investigate the stratum structure of the lower ground of the main body construction of the
Gate, the lateral lines of S-2 and S-3 were installed near the main body construction. The earth surface of S-1 that passes through the Gate and S-2 lateral line north of the main body construction were covered with cement, so geophones were drilled into the surface.

2.1.2 Electrical Survey

The vertical electrical survey is SuperSting R8 of 56 multiple channels, a swift system with automatic measurements. The survey method is generally categorized into horizontal and vertical sections depending on the purpose of the investigation. Horizontal survey is to survey the horizontal change of an underground structure by fixing the interval of current electrodes and potential electrodes, and by moving all electrodes along the fixed lateral line to conduct an investigation. Contrarily, vertical survey is to investigate vertical distributions of electrical resistivity by increasing the interval with the center of current and potential electrodes fixed, and by observing the change of reactions.

Because of the above difference, in conducting electrical Survey, it is important to choose a suitable electrode configuration befitting the survey purpose. Electrode configurations are shown in the diagram including various electrode arrays and apparent resistivity used in electrical resistivity. Currently most electrical surveys are made with dipole array, Schlumberger array and Wenner array. For the electrical survey of the Gate, electrodes were arranged with a dipole-dipole force to obtain apparent resistivity. The lateral line of the vertical electrical survey was installed the same as the lateral line of the elastic sounding survey, except for the east wall section. The electrical survey was measured at all measuring points. Using 28 electrodes, the survey obtained a maximum of 169 apparent resistivities on 1 lateral line.

2.2 Date Processing and Analysis

2.2.1 Refraction Results

Seismic survey, one of main geophysical survey techniques, measures the velocity of seismic waves per underground medium. The ultimate purpose of a seismic wave survey is to figure out the form of an underground structure and the property of its ground. The values of the property influence, directly and indirectly, the velocity of seismic wave velocity, so the measurement of the seismic velocity becomes a crucial date in predicting the property of the underground medium. Seismic velocity is utilized in estimating the rigidity, fissure and fragmentation, degree of fissure, weathering effects of the material that makes up the underground bed of rocks, and by comparing with the result of a boring investigation, a prediction on the change of geological features in the horizontal direction can be made to a certain extent.

Processing of a seismic survey is to interpret date using a Pickwin program. Manually generated seismic waves arrive at the receiver past the underground medium. The first vibration of seismic waves is P-wave, so generally the first arrival time of the P-wave, the seismic wave arriving at the fastest on the seismic wave tomography is used. By collecting and reverse-calculating the first arrival time of the P-wave arrived at each receiver, the distribution of the seismic velocity indicating the heritage of stratum of the cross section was compiled (Figure 3 to 6).

The S-1 lateral line of the ground that passes the Hongyemun of the Gate is distributed with a weathered rock layer with a seismic velocity at 700 m/s at about GL(-) 4.0m, a soft rock layer with 1,200 m/s at GL(-) 10.0m, and a medium-hard rock layer with 1,900 m/s at GL(-) 20.0m. Along the S-2 lateral line in the north of the

Figure 3. Distribution of seismic velocity (S-1).

Figure 4. Distribution of seismic velocity (S-2).
main body construction of the Gate, the distribution of the weathered rock layer is not uniform and shows some differences per section.

The lateral 0 to 12 m section at GL(-) 1.5m and 40 to 48m section at GL(-) 1.0m record 700 m/s, a faster velocity of seismic waves than the neighboring ground. The 2-3 lateral lines in the south of the main body construction of the Gate showed the distribution of the seismic velocity, 700 m/s at GL(-) 1 to 3m. The S-4 lateral line in the east of the Gate showed a medium-hard rock layer with 1,900 m/s at GL(-) 5 to 15m in the 29 to 44m section, whose underground structure is slanted along with the mountain slope.

2.2.2 Electrical Results

The electrical survey on the ground of the main body construction of the Gate was conducted along the E-1 lateral line that passes the Hongyemun; the E-2 lateral line in the north ground near the main body construction, and the E-3 lateral line in the south. Each receiver was installed with an interval of 1.5 to 2.0m, and the electrode configuration was a diopole-diopole force, a method of using a pair of potential electrodes (I) arranged outside another pair of current electrodes (V) in Figure 7. The interval of potential electrodes and current electrodes is placed afar so it would become an integer multiples of (2l) in Figure 7.

The electrical resistivity \( \rho_e \) of the ground of the main body construction of the Gate;

\[
\rho_e = -2\pi(n-1)n(1+1/l)\frac{\Delta V}{I}
\]

(1)

Here, 2l(n-1) is the distance between the potential electrode and the current electrode, \( \frac{\Delta V}{I} \) is the value of resistivity obtained from the field test. The date obtained from the electrical survey can be stored in computer, and the data is converted to a diagram showing the model of two-dimensional electric resistivity distribution on the geological structure of the ground of the Gate (Figure 8 to 10), using the Res2dinv Ver. 3.33 program developed by Loke & Barker (1995).

The E-1 lateral line that passes the Hongyemun of the Gate shows the boundary of resistivity, high and low, at about 2 to 3 meters deep from the surface. And at 10m and 25m points of GL(-) 6m, show relatively higher resistant ranges distributed than the surrounding area. This can be predicted as an abnormal range of a possible underground cavern or rock mass, which shows differences in resistivity caused by underground medium.

The E-2 lateral line in the north of the Gate is distributed with high resistivity at 5m, 12m, 18m, 31m and 41m points. Due to the differences in resistivity values, it is decided that the ground medium is relatively more...
rigid than the surrounding area. The E-3 lateral line in the south of the Gate is distributed with low resistivity at 6.0 to 9.0m, 17.0 to 21.0m and 26.0 to 36.0m points at about GL(-) 2.5m. It is decided that the underground medium of the ground of the main body construction is not uniformly distributed but of different forms.

3. Underground Condition

3.1 Underground of the Gate

The excavation survey conducted by the Korea National Research Institute of Cultural Heritage took three years from 2008 to 2010, from the south of the main body construction of the Gate to the northern surface at 3-meter intervals parallel to the main body construction (Figure 11). The excavation survey exposed the foundation stone and confirmed the foundation.

The foundation of the main body construction of the Gate was confirmed to be the long rectangular stones and the core pebbles which supported the flat foundation boulder in the southern ground. This foundation was, as confirmed, additionally constructed outside the main body construction of the Gate with a width of about 0.6 to 1.5m. Unlike the foundation in the south, the foundation in the north of the Gate was newly constructed in middle of Joseon Dynasty (16th to 17th century) in addition to the foundation built in early Joseon Dynasty (15th century), according to the maintenance record from early and middle Joseon Dynasty.

In the north of the Gate, the boundary of the foundation made with the stone stylobates and the core pebbles was confirmed in the soil stratum whose the left and right ends were at GL(-) 1.2 to GL(-) 1.5m points. As the condition of the soil stratum showed, at the time of initial construction, a new foundation was built on the long rectangular stones, and inside, fragments of white celadon from middle Joseon Dynasty (16 to 17th century) were found.

It became known that the long rectangular stones of the fortress built at the same height of the long rectangular stones of the main body construction of the Gate from early Joseon Dynasty were demolished in middle Joseon Dynasty and on top of that a new foundation was built to construct the fortress (Figure 12).
3.2 Main Stone Construction

The gatehouse of the Gate is a wooden architecture and a load transfer mechanism, which delivers force, from the roof of the upper part through the beam, the pillar and the cornerstone, past the interior of the main body construction to the ground. The weight of the gatehouse is dispersed by delivering it to the ground through the consolidated layers of the interior of the main body construction, which makes it possible to maintain the stature of the Gate. However, the second floor gatehouse, a wooden architecture, was completely burnt down from the 2008 arson attack, leaving behind only part of the first floor (Figure 13).

Korea’s ancient stone and wooden buildings deliver their weight to the lower part of the ground by the weight of the building’s own, live load, wind power and other external forces. The foundation of the lower part absorbs force and disperses it to the ground. In case of wooden buildings, the weight of the upper part is carried down to the lower part of the ground through its roof, beams, pillars, foundation stone and foundation.

The support system of the weight of the upper part in the stone and wooden buildings augmented the foundation, and to improve the supportive power the foundation was installed. The types of the basic foundation in cultural heritage included wooden piles foundation, sand foundation, rubble foundation, plate foundation and rectangular stone foundation. The ground of the main body construction of the Gate is confirmed to be various in construction style over time as it was made of wooden piles foundation and rectangular stones foundation using core pebbles (Figure 14).

4. Discussions

The ground structure of the main body building of the Gate was investigated by non-destructive geophysical surveys, direct boring investigation and excavation survey through the cross section of the soil stratum. The seismic wave refraction survey, part of the geophysical investigation, showed a weathered rock layer (landfill and weathered residual soil) and three rock layers of weathered rock, soft rock and medium-hard rock in the ground of the main body construction of the Gate and the lower ground of the section scheduled for fortress restoration.

The seismic velocity of the S-2 lateral line in the north of the Gate at 12m and 40m points, GL(-) 1.0m was measured faster than the surrounding area. This led to a discovery that the boundary of the main body construction of the Gate and the fortress section had the core pebbles which were 1.0 to 1.8m higher than the main body construction section (Figure 15).

Figure 16 shows the condition of the core pebbles exposed during the surface labeling during the geophysical survey and excavation survey. The depth of the consolidation layer left of the Hongyemun was GL(-) 2.0m, the consolidation layer at the end of the east side was GL(-) 1.2m. The core pebbles at the boundary of the main body construction, the west-north of the Gate and the fortress showed a difference in height, GL(-) 3.0m, GL(-) at 1.2m.
and 1.8m, respectively. This coincided with the distribution of seismic velocity and the cross section of the soil stratum from the excavation survey (Figure 16 and 17).

Figure 17 confirms that the consolidation layer of the southern ground of the Gate, or the west of the main body construction and the fortress boundary was at GL(-) 2.7m, and the consolidation layer of the eastern fortress GL(-) 2.4m, and the depth of the consolidation layer left of the Hongyemun was GL(-) 2.9m. The flat foundation boulder of main body construction was confirmed at GL(-) 2.4m, and underneath the flat foundation boulder was distributed with a consolidation layer using the core pebbles. Therefore, the distribution of seismic velocity from the seismic survey and the location of the core pebbles in the lower part of the main body construction of the Gate confirmed during the excavation survey did match.

The electrical survey was an effective survey to investigate the weak zone containing moisture in the ground. However, the underground of the cultural heritage site is constructed on the consolidation layer which utilizes rigid rocks from the surface. The consolidation layer built for a cultural heritage shows relatively higher resistivity, the distribution range, the depth and width of the consolidation can be inversely confirmed. The foundation of a cultural property starts with various core pebbles and soil mix to build a consolidation layer of a fixed depth, over which is installed with a flat foundation boulder.

But, the flat foundation boulder, south of the Gate was covered with landfill as time went by, and so it became higher at about 2.4m above the lower part than when it was first built. The distribution of electrical resistivity in the ground of the main body construction of the Gate was very mixed up, which made it difficult to interpret. But, a seismic survey was conducted along the same lateral line whose result was used for a comparative analysis to obtain more credible data.

5. Conclusions

The geophysical investigation was to analyze the characteristics of the underground medium through the non-destructive seismic wave survey and electrical survey on line-1 that traverses the Gate, line-2 and line-3 near the main body construction. It can be known that line-2 in the north of the Gate, at the connecting ground of the main body construction and the fortress, has a relatively higher resistivity in seismic velocity and electrical resistivity. Such a phenomenon was influenced by the core pebbles used in the consolidation layer as in the case of the ground of a cultural heritage built on the rigid soil of the ground.
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medium or rocks; therefore, through comparative analyses of various geophysical investigations for the purpose of investigating the ground characteristics of a cultural property can offer more clear and credible interpretations.

This research on the ground characteristics of the main body construction of the Sungnyemun Gate was part of the restoration project of its fire damage which included geophysical surveys of the surrounding area and the excavation survey. Because of the Cultural Properties Protection Law, the ground of a cultural heritage is not permitted for direct investigation, excavation and drilling investigation; however, non-destructive geophysical surveys were utilized to fully understand the characteristics of the ground. Therefore, it is considered that non-destructive geophysical investigations offered a foundation for making more precise interpretations of the ground condition of the cultural heritage by way of the research on the ground characteristics of the main stone body construction of the Gate.

6. References

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