Research on Testing Heritage Stylobate with Non-destructive Testing (NDT) Technology—With an Example of Renovating Dazheng Hall in Mukden Palace

Xukang Zhang and Jing Yang

***Abstract*—Traditional way of stylobate repairing can only be qualitative analysis which are visually or empirically, deciding partial repair or comprehensive replacement. Internal damage remains unclearly and inaccurately that often result in the loss of historical information and over-repair of heritage.**

Paper aims to interpret with a typical example of Dazheng Hall, the palace used for holding ceremonies in Mukden Palace, Shenyang, whose stylobate faced with varying degrees of damage, such as foundation broken, frieze panel inclined and wall cracked.

Non-destructive Testing (NDT) Technology using in this project includes 3D scanning, ground penetrating, concrete ultrasonic testing and mineral element analyzing that can collect data more comprehensive than just using traditional methods, especially for internal damage. Then generating the quantitative analysis of damage category.

Furthermore, discussing cause of damage and moderately protection methods of the stylobate on the basis of testing. As well as providing references of repairing project of traditional Chinese stony heritage.

***Index Terms*—Dazheng hall, stylobate, non-destructive testing (NDT), process.**

I. Introduction

Shenyang is in the temperate sub-humid continental climate, with a harsh annual temperature difference, the lowest temperature can down to - 29 °C whereas the highest temperature can reach to 36 °C, and huge temperature difference between day and night. The average annual rainfall is about 850 mm. Combined with the long winter, the effect of frost heave is obvious.

Shenyang Imperial Palace, located in the old city center of the Ming and Qing dynasties, shenhe district in Shenyang, was the palace of the Qing imperial family before the Manchu conquest of China and the temporary palace after. It was founded in 1625 A.D., basically finished in 1636, large-scale renovated in Qianlong period and covers an area of about 60000 square meters so far. Since 1926, its buildings have been used as the Shenyang Palace Museum step by step. In 1961, it was designated by the state council of the People's Republic of China as the first key cultural relics site under the state protection and listed of "Imperial Palaces of the Ming and Qing Dynasties in Beijing and Shenyang" project in the *world heritage list* in July 2004.

The Dazheng Hall (Fig. 1) is located in the east road of Shenyang Palace Museum with the Eight Banners' Pavilion (Fig. 2). All of them were built around the 10th year of Tianming (1625). The Eight Banners' Pavilion are ten pavilions in front of the Dazheng Hall and forming an open space together. The complex is used for daily politics discussion and temporary military build-up. Its architectural form reflects the special political form of the Eight Banners system in the Later Jin dynasty that is an isolated case in the existing buildings [1].

Fig. 1. Picture of Dazheng hall.

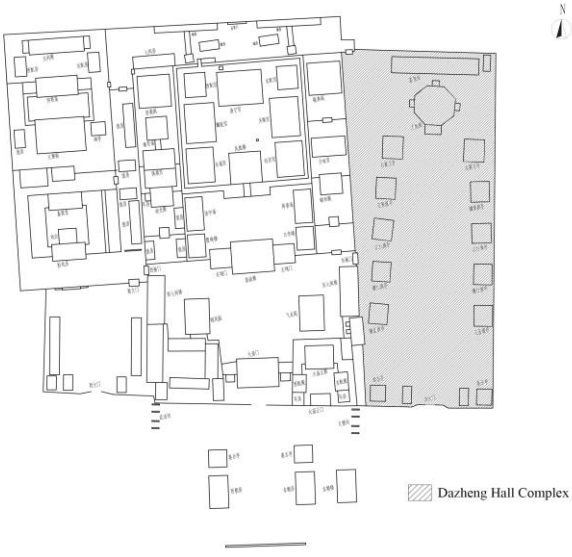

Fig. 2. Site of Dazheng hall complex in Shenyang imperial museum.

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There are some problems such as uneven settlement of stylobate, cracking and dislocation of masonry structure, incline of stony frieze panel existing influenced by its own gravity, rain, freezing and thawing, weathering erosion, etc. Combining observing, photographing, measuring, 3D scanning, ground penetrating radar exploring, concrete ultrasonic testing and mineral element analyzing tries to diagnose damage of stylobate all-side, the paper also considers if the process could be a well non-destructive testing process enough. For same methods using, paper just takes Dazheng Hall testing as an example.

II. Process

A. Observing and Photographing

Fig. 3. Part of photos and foundation broken.

The first step is using body and camera. Based on walking around and observing carefully with taking photos, there are several problems more than fissures, dislocation and absence of original component revealing (Fig. 3). The rich image data are of great benefit to the later work for memorizing and marking.

B. Measuring and 3D Scanning

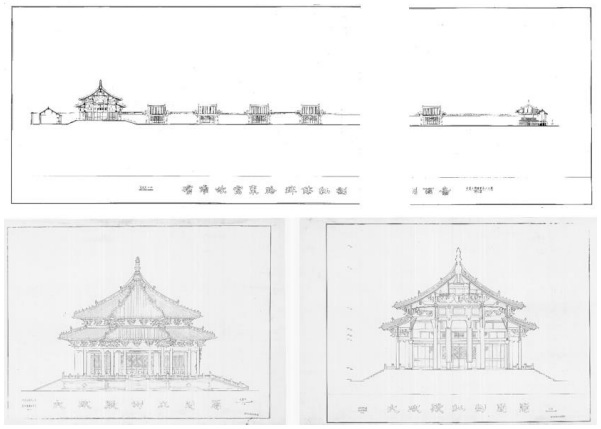

Fig. 4. Measuring pictures from 1964(bottom) and 1991(top) by school of architecture in Tianjin University.

School of architecture in Tianjin University has organized students measuring the Dazheng Hall in 1964 and the Eight Banners' Pavilion in 1991 (Fig. 4). However, due to limited conditions, only hand-painted paintings were available at that time. In 2017, group used 3d scanning in order to mark the stylobate of Dazheng hall more accurately and prepare data for the follow-up work. Based on both files above and regional measurement again, the CAD measuring pictures came out.

In the process of problem showing, figures of CAD provide convenience for marking problems and dimensional measurement. The point cloud pictures of 3D scanning (Fig. 5) provides accurate images and current situation [2].

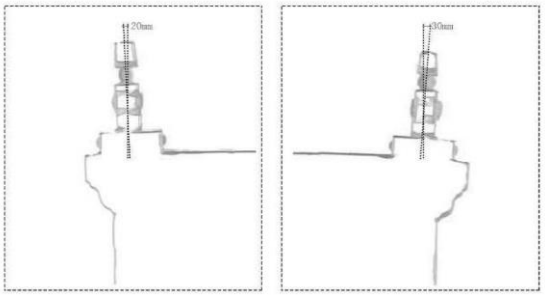

Fig. 5. Part of southwest and southeast stony frieze panel.

C. Ground Penetrating Radar Detecting

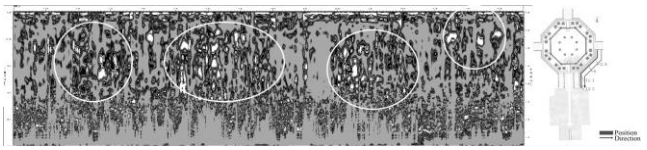

Fig. 6. Picture of southeast ground penetrating radar waveform.

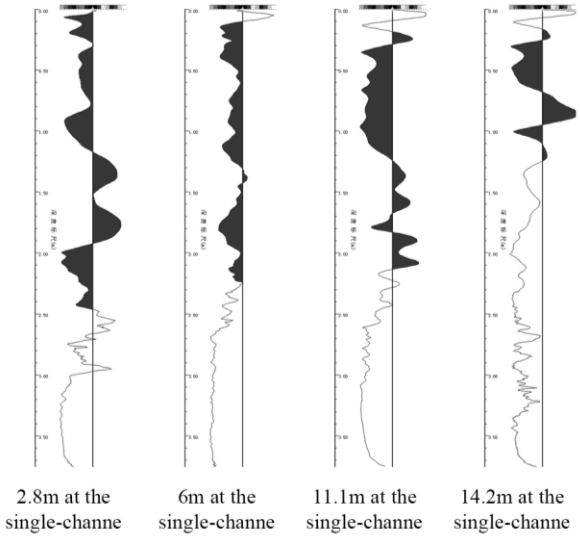

Fig.7. GPR detection analysis of the southeast of stylobate.

Ground penetrating radar uses electromagnetic waves and receiving reflected from the target body, which can visually represent the distribution of different media underground. When electromagnetic wave through the layered media, due to differences between the upper and lower dielectric properties, it generates reflection and refraction. Corresponding reflected wave is received to antenna and carries on the digital signal processing [3].

As shown in the Fig. 6 and 7, the ground penetrating radar scanned below stylobate at the southeast corner of Dazheng Hall from north to south. Clear information shows that there are empty phenomena existing approximately at the 2.8 meters depth below 800 mm to 3000 mm, 6 meters depth below 1000 mm to 3200 mm, 14.2 meters depth below 400 mm to 1300 mm.

The test result of GPR in ancient architecture is more accurate and feasible, providing a strong support for the protection and reinforcement of ancient architectures. However, it also has some limitations, with the increase of detection depth, the detection accuracy is reduced, further affecting the detection quality.

D. Concrete Ultrasonic Testing

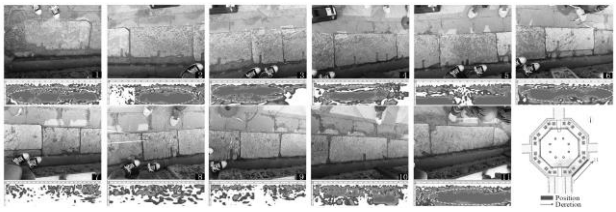

Fig. 8. Picture of southeast rectangular stones ultrasonic test.

Due to limitation of the antenna of the ground penetrating radar, detection accuracy of the relatively small rectangular stone slabs is unsatisfactory, whereas ultrasonic test is more accurate and objective. In addition to emitting ultrasonic waves, principle is similar to that of ground penetrating radar which uses wave emission and reflection to create highly readable images. Fig. 8 shows concrete ultrasonic testing southeast rectangular stones from southwest to northeast and dark color in the dotted oval means bad condition of stone. It can be seen that the overall texture of southeast rectangular stone slabs of the hall is relatively poor, among which the internal damage of the first, second, third, fourth, sixth and eleven stones are more serious [4].

E. Mineral Element Analyzing

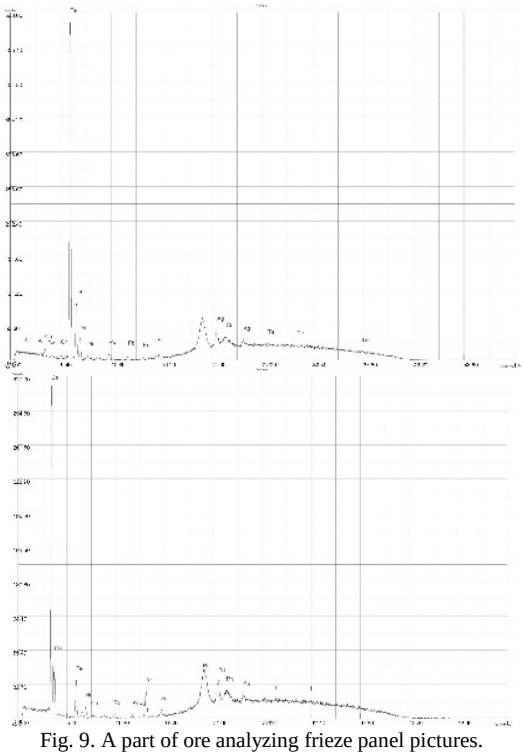

Fig. 9. A part of ore analyzing frieze panel pictures.

Mineral element analysis instrument use "intelligent dynamic tracking" and "standard curve of nonlinear regression technique". Results can display direct reading percentage. On the one hand, difference data in the same component can be distinguished some replacement information in this survey. On the other hand, influence of water solubility can be discussed by pictures from the chemical point of view [5].

Obtained information is as follows: the content of calcium elements in stone materials such as upper and lower fillet and fascia (cyma), rectangular stone is higher, and the content of iron elements in stone materials such as frieze panel and capital stone is higher.

III. Analyze

According to the analysis of the results of field investigation, in addition to the common problems of the damaged stone structure, there are many potholes on the surface of the rectangular stones of Dazheng hall. Due to historical reasons, its width is greater than upper eaves, which leads to direct erosion.

Based on figures from GPR detection and concrete ultrasonic test, fissure and structural joints containing certain moisture. As condensed water and rain to permeate stone inside, water content is raising. Because Shenyang Imperial Palace is located in the cold region, so freezing effect on the erosion of stylobate is obvious. When temperature drops in winter, water inside freezes and volume increases, causing pressure to stone. When the pressure exceeds capability of compressive strength of ordinary bricks and stones, further destruction will occur. The long frost period and the large daily average temperature difference in Shenyang area directly affect the water condensation and volatilization process in stones, resulting in the frequent alternation of dry and wet. Masonry has the property of moisture absorption to expand. So frequent expansion and contraction caused by dry and wet circulation result the surface of brick and stone loose and damaged, as well as lead to the mutual dislocation and deformation between blocks.

According to mineral element analyzing, the dissolution of water can separate the minerals contained in masonry into ions, especially of soluble minerals such as gypsum and rock salt. Water and carbon dioxide dissolved in water generate weak acid, which improves liable to dissolve rock that mainly consist of calcium carbonate, causing material loss and decreasing rock breaking strength. At the same time, water dissolution changes the narrow channel of rock fracture into a wider channel, which also creates conditions for other destructive actions.

As for testing result, compared to other directions, southeast of stylobate has more problems including entirety slightly inclined, a certain amount of foundation holes, slanting frieze panel, bad situation of rectangular stones like concrete pavement. The main reason of damage should be the damage of masonry components and rammed earth materials caused by weathering erosion and freezing-thawing cycle. In general, the Dazheng hall stylobate is partially buried, with water apron missing. Platform outside part of the eaves column is obviously sinking, and frieze panel is partially tilted. The stony parts are partially fractured and damaged, and the surface is seriously air-slaked. Stone fracture mainly occurs in the imperial pass and steps, damaged about 40%. The air-slake phenomenon mainly occurs in corner piers and rectangular stones, with damaged about 70%. The frieze panel was recently replaced by about 30%. Indoor and outdoor bricks are weathered and local fractured, about damaged 20%. Intermediate pier of xumizuo is in bad condition by weathering with damaged about 70% [6].

IV. Conclusion

Stylobate with non-destructive testing (NDT) technology can be divided outside and inside testing. For outside, it still relies on traditional methods mainly including observing, measuring and photographing and adds new 3D scanning. These works testing are for overall construct in the earlier stage and provide convenience to after. As for inside, advanced technology contains ground penetrating radar exploring, concrete ultrasonic testing and mineral element analyzing acting on part under the stylobate, rectangular stone and special accurate structure respectively. All of these processes make up a relative all-sided testing (Table I).

There are still some problems existing. For earlier stage, information getting and analyzing are by body. If using infrared thermography may provide more accurately pictures. More advanced technology can be try if necessary.

Just for detection, this progress might be enough. If for problems forming, maybe the maximum impact causing empty inside stylobate is freeze thawing, but how about wind action for the structure? A further work can continue.

TABLE I: Steps and Features

	Step 1	Step 2	Step 3	Step 3	Step 3
Method	Observing and Photographing	Measuring and 3D Scanning	GPR Detecting	Concrete Ultrasonic Testing	Mineral Element Analyzing
Function	Surface analysis and pictures preparation	Surface analysis and base map preparation	Inside detection	Inside detection	Inside detection
Inspection Area	All-sided	All-sided	Stylobate flanks	Rectangular stones	Special structure

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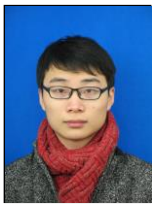

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Yang Jing, Wang Qiheng, *Interpretation of the Guangxu Reconstruction of Jingming Garden project -- based on the Study of Yangshi Lei files and Historical Photos*, Chinese gardens, 2012, no. 203, p117-120;

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Prof. Jing is also a member of China Forbidden City Society. She has get the first prize in the 10th young teachers lecture contest of Tianjin University; research and demonstration on key technologies of architectural heritage measurement, the second prize of Science and Technology Progress of the Ministry of Education in 2016, ranked 10th.