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Nondestructive testing and assessment of consolidation effects of earthen sites

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ABSTRACT

Earthen sites are widely distributed throughout China, and most of them belong to archaeological sites with significant values, which not only directly witness the origin, formation and development of Chinese civilization, but also possess important values for conservation and exhibition. Many researches and practices on their conservation and consolidation have been carried out; however, the consolidation effect is mainly judged by visual observation and expert evaluation. Scientific assessment of conservation and consolidation effects is a challenging issue. Many instruments in other fields cannot be directly applied to the conservation of cultural relics due to their peculiarity. In order to assess the effects of field conservation experiments, this paper tries to understand the consolidation effects at Liangzhu site using nondestructive or micro-damage methods, including thermo-physical parameters testing, infrared thermal imaging, high-density microelectrode resistivity testing, portable microscope observation, and hydrophilic and hydrophobic testing, and thereby explores the practicable methods for evaluating the properties of consolidation materials for earthen sites treatment.

1. Introduction

Ancient architectures in China were mainly built of timber and earth. Although most of wooden structures have been decayed or removed over times, a large number of earthen architectures are still preserved as earthen sites (Wang, 2013). The six groups of national key cultural relics announced by the Chinese government include 378 earthen sites distributed in 30 provinces. The most famous sites of them are the Banpo Village Ruins of the Yangshao Period at Xi'an, the Terra-Cotta Warriors and Horses site of the Qin Dynasty at Lintong, and the Han Dynasty Chang'an City in Shannxi Province; the Dadiwan Village Ruins of the Yangshao Period at Qing'an, the Qin Dynasty Great Wall site at Dingxi, the Jade Gate, Hechang City and Han Dynasty Great Wall sites near Dunhuang, the Suoyangcheng site at Guazhou, and the Camel City site at Gaotai in Gansu Province; the Khara-Khoto site at Ejin Banner in Inner Mongolia Autonomous Region; the Tangut King Tombs at Ningxia Hui Autonomous Region; the Ancient Jiaohe City site, the Ancient Gaochang City at Turfan, and the Ancient Loulan City in Xinjiang Uygur Autonomous Region; and so on. Researches on conservation and consolidation of earthen sites have been carried out extensively in China for over 20 years (Li et al., 1995, 2009a,b; 2011; Sun et al., 2008; Wang, 2008, 2010). Overseas studies on the conservation of earthen sites mainly focus on earth properties and compositions as well as condition evaluation, cause of deterioration, moisture monitoring, capping and consolidation (Coffman et al., 1990; Helmi, 1990; Ward, 1990; Carll and TenWolde, 1996; Rodriguez-Navarro and Doehne, 1999; Kuchitsu et al., 2000; Ziegert, 2000; Tolles et al., 2002; Fodde, 2006, 2008, 2010; Charnov, 2011; Snethlage and Sterflinger, 2011; Stephenson and Fodde, 2012). Few studies are conducted to evaluate the consolidation effect of earthen site based on nondestructive testing methods. Therefore, it is very difficult to quantitatively evaluate the consolidation effects in the field of conservation of earthen sites. The cultural relics are non-renewable resources, suggesting that only nondestructive or micro-damage

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testing methods can be used to evaluate the consolidation effects and the testing methods in civil engineering cannot be directly applied in this field. Based on the testing of consolidation effects at the Liangzhu site in Zhejiang Province, China, this paper explores the systematic and practical methods for evaluating the consolidated effects of earthen sites by testing the thermal conductivity, the temperature changes of both consolidated and unconsolidated areas, the micro-composition, the high-density microelectrode resistivity, the thermo-physical parameters, and the infrared thermograph with nondestructive and micro-damage methods.

2. Field nondestructive testing methods for evaluating consolidation effects of earthen sites

Fifteen types of consolidation materials, including 3%–5% high-modulus potassium silicate (PS), hydrophilic high-tensile silicon emulsion, 12% modified styrene acrylic acid, and 4% modified acrylic acid, were chosen to test the consolidation effects on the surface of the north wall of the Liangzhu site in Zhejiang Province, China, and a variety of nondestructive testing methods were used to verify the feasibility and reliability of these methods.

2.1. Measurement of thermo-physical parameters

Various thermal transfer phenomena can be observed in daily life, such as heat conduction. The thermo-physical parameters of the cultural heritage are often measured in the laboratory. Giorgi et al. (2002) tested the thermo-physical parameters of paper and canvas. Zhang et al. (2014) studied the relationships between water content and thermo-physical parameters of earthen sites in the laboratory. As for the consolidated earthen body, heat conduction refers to the phenomenon that the temperatures of different areas vary with the changes of external environmental temperature. However, the microstructures of the earthen body change after consolidation, causing different thermal conductions due to the difference of thermal conductivity. In this study, the portable thermal conductivity instrument (DECAGON KD2 Pro) was used to test the thermal properties of earthen sites. The 6 cm long single needle-type sensor (KS-1) was chosen to measure the thermal conductivity and resistivity of the earthen fabric, and the 3 cm long double needle-type sensor (SH-1) was used to measure the thermal diffusivity and specific heat capacity of the earthen fabric. The sensors installed are shown in Fig. 1. Four indices, i.e. thermal conductivity (K), heat capacity (C), thermal diffusivity (D) and thermal resistivity (R), were tested.

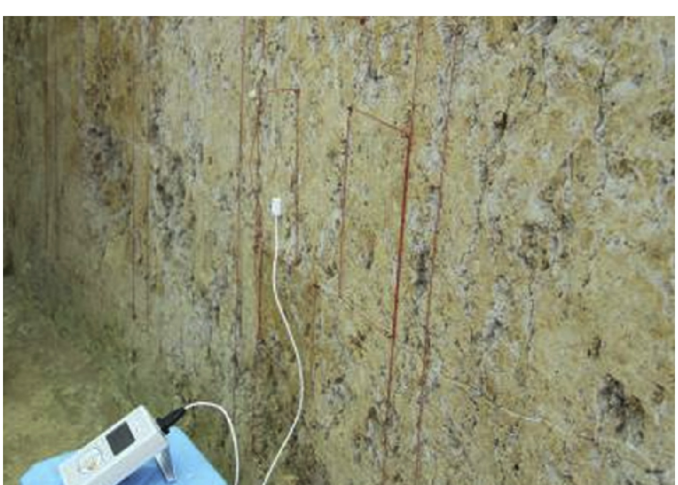

Fig. 1. Photo of field testing for thermo-physical parameters.

2.2. Infrared thermal imaging

Infrared thermal imaging refers to the technology of transforming invisible infrared radiation into visible images with an infrared detector. Such images are used to determine the surface temperature distribution of tested object and then to evaluate its condition. Infrared thermal technology has been widely used in investigation, monitoring and evaluation of cultural heritage. Grinzato et al. (2002), Avdelidis and Moropoulou (2004) and Kordatos et al. (2013) investigated the condition of ancient buildings, murals and historic monuments by the infrared thermal technology. Bodnar et al. (2012) applied the infrared thermography to restore mural paintings. In this paper, M7500 thermal imager was used for testing (Fig. 2). The temperature data of the tested object collected by the thermal imager are input into a computer through a necessary interface, and then they are processed and analyzed in field or in the control center. Software of MikroSpec™ R/T that is compatible with M7500 series is used in the testing. Through the Ethernet, users can perform remote control to select cameras, modes, temperature range and lens, analyze and monitor the custom areas or any specific zone. Testing should be carried out in the morning or at nightfall as possible considering the relatively large changes in environmental temperature.

2.3. High-density resistivity testing

High-density resistivity testing has been successfully applied to many engineering investigations on water and moisture. Its basic principle is completely the same as that of the regular resistivity testing. The only difference is that more electrodes are selected in the high-density resistivity testing, which is a kind of electric detection methods based on the resistivity discrepancy of rock or soil mass. Putting all the electrodes on the lines to be tested in field, the electronic switch and engineering measurement instrument can realize rapid and automatic data collection. However, all the electrodes have to be tapped into the earthen body in current high-density resistivity testing, and this would cause great damage to the earth body. In order to protect the earthen sites, Dunhuang Academy in cooperation with the Qingdao Jiaopeng Institute of Technology Engineering developed electronic lines at a spacing of 5 mm instead of traditional electrodes which to some extent damage earthen fabric. As a result, high-density resistivity testing can be

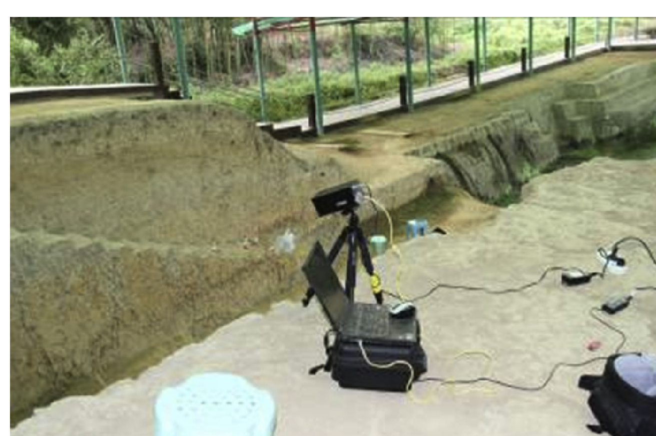

Fig. 2. Field testing photo of infrared thermal imaging.