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Numerical simulation of the behaviors of test square for prehistoric earthen sites during archaeological excavation

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A B S T R A C T

During the process of archaeological excavation in the regions of Southeast China, collapse of test square usually occurs due to poor site-specific conditions. In this paper, the fast Lagrangian analysis of continua in three dimensions (FLAC3D) is employed to reveal the behaviors of test square. Taking the archaeological works in Liangzhu prehistoric earthen sites as the research background, the paper first introduces the geological setting, excavation procedure and monitoring scheme of the studied test square. Then, the deformation of four sides of the test square is modeled using FLAC3D. By comparison, it shows that the numerical results are consistent with the results from field monitoring. The result suggests that the numerical simulation can be effectively applied to representing the actual behaviors of the test square, which is helpful for determination of excavation scheme and stability evaluation of the test square during archaeological excavation.

1. Introduction

Prehistoric earthen site, invaluable cultural heritage in China, plays a key role in understanding the origin of Chinese civilization. After thousands of years, most of them are buried underground. Due to the absence of historical documents, archeological excavation becomes the only way to illustrate the prehistoric life and civilization process (Rotroff, 2001). Thereby, test square becomes the most popular structure to obtain archeological information in prehistoric archeology, mainly due to its standard profile resulting from the vertical wall surface. In addition, historical strata can be read and distinguished from four sides of rectangular test square, and the buried relics can be collected as well. It should be noted that the absence of collaboration between archaeologist and conservator is currently a challenging issue in archeological works. Archeologists tend to adopt the shape of test square according to archeological information distribution without considering the stability of test square; as a result, collapse of test square may occasionally occur (Ehrenhard, 1994; Charnov, 2011; Corfield, 2014). Failure of test square not only leads to the loss of prehistoric information, but also threatens the safety of archeologist and cultural relics. Therefore, stability of prehistoric earthen sites during excavation is becoming a hot issue. The principle of saving historic sites has gained interest and has been seen an increasing involvement by geotechnical engineers (Calabresi, 2013). It is worthy to make any effort to achieve a convincing explanation of the potential information loss caused and to propose schemes that are safe for the history of the sites.

In geotechnical field, test square in archeological excavation is basically using a method of simple foundation pit. In terms of foundation pit, various researches on theory and method of stability evaluation have been conducted for the purposes of the standardization of foundation pit design and construction. In the late 1980s, Finno et al. (1989) observed the performance of a deep excavation in soft-to-medium stiff, saturated clays in Chicago by measuring the three-dimensional (3D) surface and subsurface ground movements, pore water pressures, sheet-pile deformations, and strut loads. Lee et al. (1998) discovered the corner effects in strutted excavation. Hashash and Whittle (1996) and Hashash et al. (2006, 2008) predicted the ground movement for deep excavation in soft clay and proposed a novel approach to

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integrate the numerical modeling and field observation for deep excavations. Jen (2005) proposed design methods of deep excavations in clay. Kung et al. (2007) established a simplified model for wall deflection and ground-surface settlement caused by braced excavation in clays. Seo et al. (2009) analyzed different characteristics of ground movements of three deep excavation sites with mixed ground profiles. Currently, various design and construction standards for foundation pit in clay have been proposed in many countries. Unfortunately, less attention is paid to the stability of test square in archeological excavation. Although test square shares similar shapes with foundation pit in geotechnical field, it has its own special characteristics. For instance, in consideration of archeological requirements, test square is characteristic of vertical or step profiles, which should facilitate site excavation as possible and keep the cultural relics undisturbed due to the long-term exposure to archeological investigation (Rotroff, 2001).

A number of propping measures during excavation are also involved in foundation pit to reduce the exposure time and guarantee the pit stability (Salgado, 2008). Fruitful researches reveal that the performances of foundation pit are affected by many factors (e.g. pit geometries, construction methods, soil conditions, and retaining systems). In foundation pit, many empirical or semi-empirical approaches are derived from rectangular excavations (Ou et al., 1993; Hsieh and Ou, 1998; Wang et al., 2005, 2010; Tan and Wei, 2012; Tan and Wang, 2013), which provided references for the test square in archeological excavation. For conservation of intangible cultural heritages, it is needed to develop suitable stability evaluation approaches to ensure the safety of archeologist and cultural relics and to protect surrounding cultural information. Due to poorly documented field data, the behaviors of test square in prehistoric sites still remain unclear.

For this, the archeological excavations in Liangzhu prehistoric sites, China, provide a good opportunity. According to the principle for the conservation of heritage sites in China (ICCOMOS-China, 2015), a test square under the similar geotechnical setting was excavated based on the archeological procedure adopted for Liangzhu prehistoric sites. In order to better understand the behaviors of the test square, the lateral displacement and ground settlement were measured during excavation. Numerical simulation using FLAC3D was applied to modeling the whole excavation process, and then comparison between modeled and measured results was conducted to validate the feasibility of the established numerical simulation method.

2. Modeled test square for prehistoric earthen sites

2.1. Location and geometry

The Liangzhu prehistoric sites in Hangzhou, Zhejiang Province, China, are located at the lower reaches of Qiantang River on Southeast China. Liangzhu prehistoric sites sit on the flat alluvial plain, which is featured by high water tables and thick soft clay in the upper layers. Fig. 1 presents the location of Hangzhou in China. In view of the properties of cultural heritages, destructive testing is strictly forbidden on real archeological sites. Therefore, modeling test square with similar environments and strata is adopted to study the deformation and failure behaviors of cultural heritages during excavation. In this study, the experimental site is chosen on the basis of archaeometry and conservation technology of cultural relics, as shown in Fig. 2. The site is surrounded by one electrical pipeline in the proximity, open space on the north side, brick walls with 2 m in height on the south and east sides, and the laboratory building (10 m high) on the west side.

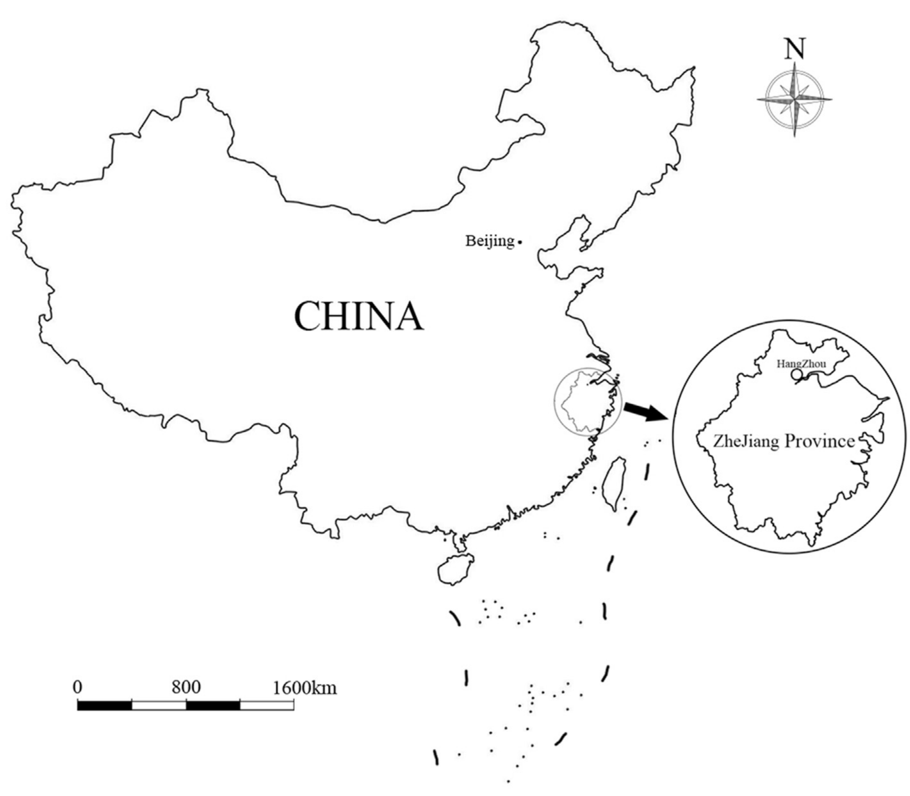

Fig. 1. Geographical location of Hangzhou, China.

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