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Key Technologies for In-Situ Conservation of Sites in Site Display Projects

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Abstract: The protection and display of ruins has received more and more attention and importance due to its inheritance, education and economy. This paper relies on the DeShouGong site protection and display project to carry out research on the key technology of earth site protection under the humid environment in the south, and integrates and applies the protection technology of the Southern Song Palace site to provide a reference sample for the protection of the same type of site in the humid area in the south.

Keywords: Site Protection; Humid Environment; Large-Span Steel Structure; De Shou Palace

1. Introductory

Site display is an effective way to protect and sustainably display and utilize archaeological sites, and its construction and development can effectively protect and pass on cultural heritage resources, improve the public's knowledge and understanding of history and culture, and promote cultural tourism and social and economic development [1]. The protection of cultural heritage, together with that of natural heritage, has attracted the attention of all mankind, and China has been paying more and more attention to the protection of heritage [2, 3]. Earthen sites, as a type of natural heritage, are characterized by the nature of the earth, which results in lower strength and poorer water stability performance of the site itself. In arid and semi-arid regions, the conservation techniques for earthen sites are relatively mature and successful, but there are fewer relevant studies on the conservation of earthen sites in humid environments [4]. Conservation of earth sites in humid environments is a highly targeted and complex task, affected by many factors such as the geographical environment and the structural characteristics of the sites, and there is no set of mature and standardized conservation techniques and reinforcement materials. At the same time, the earth site generally covers a large area and is directly connected to the ground, how to carry out the site display protection, has important theoretical significance and practical value.

Based on this, this study relies on the Deshou Palace site protection and display project to study how to carry out the protection of earth sites under humid environments, and to integrate and apply the relevant technologies for the protection of the Southern Song Dynasty palace sites, which will not only provide sufficient technical support for the relevant projects in the future, but also enhance the domestic technical strength in the protection of the sites of the Southern Song Dynasty, and provide samples for the restoration and protection of the same type of sites in the humid areas of the South.

2. Project Overview

The site of Deshou Palace is an outstanding representative of the palace architecture and royal gardens of the Southern Song Dynasty, with important historical value, artistic value, scientific value and social value. The De Shou Gong site display project is located in Shangcheng District, Hangzhou City, Zhejiang Province, China, and the project is divided into two parts, the center and the west, as shown in Fig. 1. The project focuses on the protection and display of the ruins, and takes into account the functions of recreation, education, culture, and so on. Sites in the construction area are divided into two categories: those that have been archaeologically excavated and are proposed to be exposed for display; and those that have been archaeologically excavated and are proposed to be scientifically backfilled.

Figure 1:DeShouGong Ruins Museum

3. Difficulties in site protection

Deshou Palace site is located in Shangcheng District, Hangzhou, belongs to the typical subtropical monsoon climate, the average annual temperature is 17.8 ℃, the average relative humidity is 70.3%, the annual precipitation is 1,454 mm, the water table and the air humidity is high. Groundwater level changes dynamically with seasons and climate, during the survey period, the water level of all the boreholes in the site is buried between 2.10 m and 2.50 m, and the annual variation of the general groundwater level is around 1.00 m. Water damage to sites is the most serious public nuisance, and therefore, control of the water environment is a major focus and challenge for the conservation of earthen sites in wet environments.

In order to maximize the protection of the site, this project was designed to use a large-span steel structure as the main body of the site protection shed, as shown in Figure 2. Some of the regional steel trusses have a mass of about 65 t per truss and a span of 43.16 m. The steel trusses have a mass of about 1.5 t per truss and a span of about 2.5 m. Simultaneously, the project is located in the city center, and the transportation of large materials is impractical, necessitating disassembly prior to entry for on-site assembly. Construction is constrained by a limited working space, exacerbated by the challenging requirement for elevated loads in the designated archaeological site area, where the underground consists entirely of preserved relics. Furthermore, any mechanical equipment is strictly prohibited from entering the archaeological exhibition zone, adding a significant layer of complexity to the construction process.

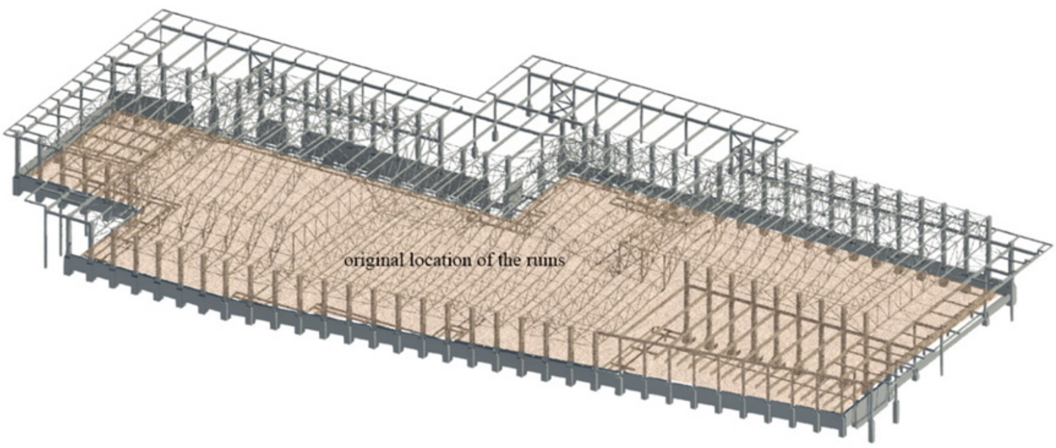

Figure 2:Steel Structure Protection Shelter in the West Area of Deshou Palace Ruins

4. Key technologies for in-situ conservation of sites

4.1 Technologies for controlling the water environment at the site

The conservation and excavation of cultural relics are intricately linked to the aquatic environment, a relationship characterized by its close and complex nature. The three states of water and the transitions between them can significantly impact the deterioration of cultural heritage materials [5]. If the Deshou Palace site is subjected to water damage, an analysis of water sources reveals three main aspects: atmospheric precipitation from above, lateral groundwater seepage along the sidewalls, and capillary rise of groundwater from below. Based on the origin of water, a combined approach involving water insulation, water diversion, and water-resistant measures is employed as a comprehensive treatment strategy.

Water insulation measures: The combination of the TRD (cement-stabilized soil continuous wall) water-stop curtain with the impermeable wall of prefabricated panel walls, along with the glass canopy situated on the walls, serves to obstruct external groundwater supply to the archaeological pit. This approach aims to reduce soil moisture content and control water levels within the pit. Considering the geographical location of the site, historical relics, soil conditions, and surrounding environment, the project adopts the TAD construction method for channel-type cut-and-assemble underground continuous walls supported by piles. Reinforcement at corners is achieved through a comprehensive approach involving full-circumference high-pressure jetting method piles (MJS). The TAD construction method involves inserting rectangular concrete prefabricated panels measuring 1000 mm*400 mm into the channel-type cut-and-assemble cement soil continuous wall (TRD), creating a reinforced concrete underground continuous wall that integrates soil retention and water-stopping functions. This design effectively intercepts the infiltration path of excessively high groundwater from the sidewalls into the archaeological exhibition area, thereby mitigating damage caused by lateral groundwater seepage to the archaeological site. Moreover, relevant studies indicate that the TRD construction method minimizes disturbances to the surrounding environment and reduces the construction's impact on the archaeological site [6, 7].

Figure 3: TAD Method Pile Construction

In addition, a protective glass canopy is installed to shield the archaeological site from atmospheric precipitation, aiming to maintain internal humidity conditions. In accordance with preservation requirements and variations in meteorological conditions, a comprehensive approach involving natural ventilation, mechanical ventilation, and a full-air HVAC system is employed to provide cooling and heating to the protected area of the archaeological site, ensuring the preservation of humidity.

Water diversion measures: Based on the general soil bearing capacity and elevated groundwater levels in the burial area of the archaeological site, flood-cutting trenches are strategically established around the distribution area of the site. This is aimed at preventing inundation and internal flooding of the site caused by the rising groundwater levels in surrounding rivers and channels during the rainy season. The waterproof isolation strip measures 1 m to 1.2 m in width and 1 m to 1.5 m in depth.

Waterproofing measures: In light of the specific circumstances uncovered following the excavation of the Deshou Palace archaeological site, reinforcement measures are implemented on the site's surface by means such as spraying, watering, or pressure injection of strengthening materials to prevent the site from collapsing or weathering due to water infiltration. Simultaneously, protective measures are taken, including appropriate backfilling protection, surface cleaning, microbiological treatment, application of desalination patches, adhesive reinforcement, grouting reinforcement, and pedestal restoration. These protective measures ensure the timely cleaning of cultural relics, restoring them to their original appearance, and providing suitable protection to prevent further deterioration of cultural heritage due to viral invasion.

Figure 4:Spraying reinforcing materials and surface tamping

4.2 Large steel structure lifting technology

In order to minimize the impact of construction on the original site of the archaeological remains and ensure the safety of construction hoisting, a feasibility analysis for the lifting of large-scale steel structures was conducted prior to construction. The engineering calculations in this study utilized the finite element analysis software Midas Gen v8.21. The load considered only self-weight, with a dynamic load factor of 1.4. It was found that the maximum stress in the structural members during the construction process was 25.3 N/mm², the maximum structural displacement was 9.8 mm, and the deflection-to-span ratio was 1/2876. These results indicate that the construction requirements are met.

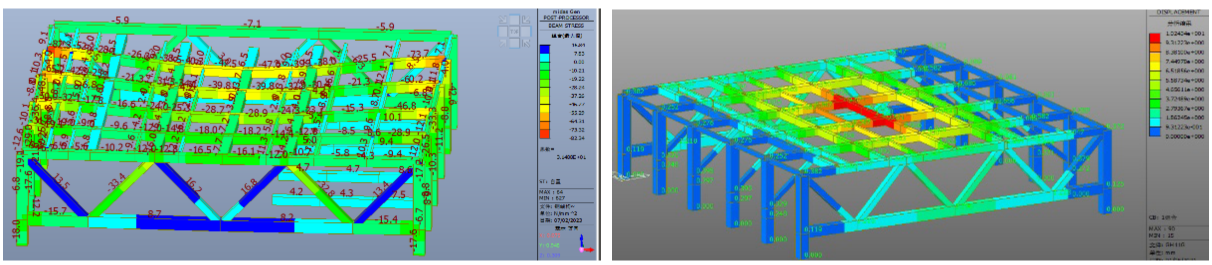

Figure 5:Finite element analysis

The main machinery employed in this project includes crawler cranes with capacities of 150 t and 400 t. Given the substantial mechanical loads involved, foundational load unloading measures are necessary. The 400 t crawler crane utilizes a hardened road surface, with steel plates laid under the tracks during construction. Similarly, for the 150 t crawler crane, steel plates are placed under the tracks during construction. Lift load verifications are conducted for both cranes to ensure the effectiveness of the foundational load unloading measures without impacting the archaeological site. For the 400 t crawler crane verification: The total weight of the crawler crane is 355 t, with an additional counterweight of 150 t, and the lifted component weighs approximately 65 t. The most critical load is determined when the lifting boom and the body form a 60° angle, and utilizing the moment distribution method, the maximum lifting ground load is calculated to be 5700 kN. During crane operation, the construction load on the floor surface is 17.8 kPa. The archaeological layer is approximately 4.0 m below the ground surface. According to the principle of additional stress, the maximum additional stress occurs at the center of the hardened floor during crane operation. Considering a stress coefficient of 0.5 for the archaeological site, the calculated additional stress at the center of the hardened floor is 16.7 kPa, meeting the requirements. The same method is applied to calculate the 150 t crawler crane, and the results meet the specified criteria. The lifting construction involves the determination of crane parking locations, material storage yards, and pre-assembly sites. The precise calculation of site area and load values must be established and discussed by all parties before construction can proceed. Prior to lifting, foundational treatments are necessary to ensure that the foundation meets the required load values for lifting. Slopes affected by construction operations should be addressed and protected in advance, and the construction boundaries need to be clearly defined. Before lifting steel components, appropriate lifting points should be selected and verified. For components with low lateral stiffness and a large width-to-thickness ratio of the web, measures should be taken to prevent distortion, damage, and local deformation of the components. In areas where archaeological sites have been discovered, a specialized plan for cultural relic protection should be prepared in advance during the construction process. This is to prevent damage to the archaeological site, such as crushing of sites and slope displacement, caused by lifting operations.

4.3 Welded reinforcement of steel structures on the site display area

In the vicinity of the archaeological site exhibition area, a ring of steel columns has been installed, while no steel columns are positioned within the site. Above the archaeological site at an elevation of 5.05 m, there exists a single-story steel structure floor beam. Due to the large span of the steel platform beam, significant deflection is observed after lifting, and the steel beam, yet to undergo reinforcement, exhibits notable flexural deformation. Complicating matters further, no scaffolding or supports are permitted above the archaeological site. Consequently, during the construction process, welding reinforcement to the steel beam poses considerable challenges, given the necessity to ensure that the deformation of the steel beam conforms to specified requirements.

After thorough research and discussion, it has been decided to employ a non-ground-supported steel structural reinforcement system. Steel pipe supports are positioned at the ends of the reinforced steel platform beams, and diagonal steel pipe braces are installed at one-quarter of the beam length from the platform beam's ends. This structural system is employed to reduce the span of the steel beams, minimizing construction deformations. Subsequently, after adjusting the elevation of the steel beams to the design height through two sets of supports, welding reinforcement is applied to the beams. Once the steel beams are securely fixed, the two sets of supports are removed.

Figure 6:Non-ground-supported steel structural reinforcement system

4.4 Mobile platform construction techniques over the site

The elevation of the ceiling of the archaeological protection hall is 11.6 m, while the average elevation of the archaeological site surface is 6.58 m. A glass platform is situated above the archaeological site (ground level of the first floor), with an elevation of 8.1 m. In the middle, there is a void exposing the archaeological site for transparent exhibition. During the construction of pipelines, equipment, and other installations on the upper portion, the lower archaeological site surface has been exposed, and no additional construction loads are allowed on the archaeological site surface. Therefore, a construction mobile platform has been designed to provide a working surface, primarily utilizing the steel frame of the on-site constructed glass platform as a base and incorporating tracks. The main framework employs hollow steel square pipes welded with rollers, facilitating horizontal movement above the archaeological site.

Figure 7:Movable platform

5. Summary

During the archaeological site protection phase of the Deshou Palace project, excellent impermeability results were achieved without compromising the integrity of the architectural relics using the TAD method piles and MJS method piles. The project employed advanced techniques such as large-span steel structure lifting for site protection and welding reinforcement for the steel structure in the exhibition area, ensuring construction safety through condition simulation, stress calculations, and the implementation of non-ground-supported diagonal bracing. This approach minimized the impact of construction on the archaeological site and enhanced the final product quality. Simultaneously, the construction technique of an overhead movable platform above the archaeological site was employed to ensure the completion of the glass platform construction without direct contact with the archaeological area. The comprehensive archaeological site protection technologies mentioned above demonstrated favorable results in practical engineering applications, providing valuable insights for similar projects focused on the protection and exhibition of soil archaeological sites.

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