Intelligent Monitoring Technology for the Impact of Deep Foundation Pit Excavation on Adjacent Facilities

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2023 2nd International Conference on Automation, Robotics and Computer Engineering (ICARCE) | 979-8-3503-0834-1/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICARCE59252.2024.10492559

***Abstract*—Selecting a typical archaeological construction field, based on water system and hydrogeololgy conditions on the site, monitoring technology and numerical calculation were used to simulate the foundation settlement and deformation values of existing buildings during the excavation construction process. This research concluded that the settlement differences did not exceed the standard limit. It also showed that the monitoring values are consistent with the numerical calculation values. The purpose is to detect construction safety and ensure the normal use of adjacent buildings after the completion of archaeological projects. The research can provide construction reference for the restoration of ancient city, moat dredging, relics excavation and urban infrastructure.**

Keywords—Monitoring technology, ruins excavation, settlement deformation, numerical simulation.

I. INTRODUCTION

The site of ruins located on the south bank of Huai River, was the ancient capital city. Its construction period was from 1369 to 1375, and then the project was suddenly halted. At the time of suspension, the project was "almost completed". From records and investigations, it can be seen that the completed buildings include palaces, altar temples, city walls, central government offices, military defense stations, and a number of municipal buildings. Most of these buildings still exist [1].

The following is the overall situation of the project site.

The representative ruins are Palace City moat and Jinshui bridge. The excavation showed that the moat bank was about 10 meters away from the city wall, with a depth of 7 meters and a silted soil thickness of nearly 4 meters. In 2018, a total of 7 bridge foundations, 1 river channel, 1 water-saving gate, and 1 ancient road were excavated and cleared.

The dredging of the moat, excavation of Jinshui bridge ruins, and subsequent deep excavation, will all have an impact [2] on existing ancient buildings, ancient city walls and modern buildings.

During the earthwork excavation process, the ground deformation value in the adjacent area is relatively large. For adjacent buildings, if the allowable deformation is exceeded, it may affect their daily use. The possible damage to the surrounding caused by excavation construction mainly includes three aspects. Firstly, adjacent ground structures may tilt or even collapse due to ground deformation [3]; The second is to cause cracks in ground facilities; The third is to cause the phenomenon of groundwater flowing sand, which in turn causes damage to underground ruins, and so on. Therefore, it is necessary to conduct risk detection and assessment.

This study combines the actual project of the restoration and construction of Zhongdu city. From the perspectives of on-site measure, numerical calculation, and verification of buildings, a systematic and effective prediction and evaluation is conducted to investigate the safety impact of archaeological excavation on adjacent structures [4]. The research results can provide methods for archaeological excavation, historical research, site park planning, etc. They can also provide technical support and construction basis for the expansion and protection of ancient city, as well as for infrastructure and urban construction.

II. TOPOGRAPHIC AND GEOLOGICAL CONDITIONS

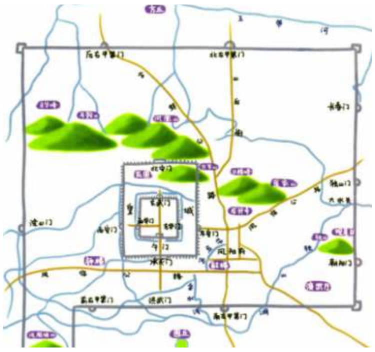
A. Terrain Characteristics around the Excavation Project

The geographical location of Zhongdu city is quite unique in its rare "five mountains and two rivers". The three mountains and three north-south axes form opposite scenery. A square moat surrounding the imperial city was constructed by utilizing the water collection (Fig. 1(a)). Although the imperial city was abandoned, the collected water was introduced into the circular moat, which then crossed the southern part of the city to form the "Suilong River" in the pattern of the central capital city (Fig. 1(b), (c)).

This research selects an old site of a river channel at Jinshui Bridge to study the impact of deep excavation and dredging work on onshore buildings [5], including the ancient city wall and an adjacent building (an abandoned industrial building of three story frame structure).

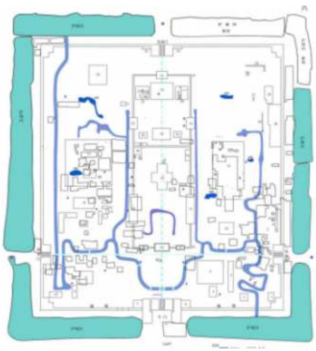
According to relevant data and actual geological exploration [6-8], the groundwater type in the selected area is upper stagnant water, with a buried depth of 1.11-3.69m and an elevation of 17.05-25.12m. The aquifer is mainly composed of miscellaneous fill and clay layers.

The dynamic characteristics of groundwater mainly manifest as changes with seasonal atmospheric precipitation and surface leakage, and are influenced by changes in the surface environment. The ground permeability is strong, and due to excessive exploitation of production and domestic water in the area, as well as the reduction of vertical infiltration and replenishment of atmospheric precipitation, the upper stagnant water level shows a downward trend, without a significant multi-year continuous upward and downward trend.



(a)

(b)



(c)

Fig. 1. Schematic diagram of the geographical water system (a), satellite cloud map (b), and exploration plan (c).

According to the survey and existing hydrogeological data, the historical highest water level along the section is close to the natural ground (including upper stagnant water), and the highest water level elevation in the past 3 to 5 years is about 16 to 24 meters.

Evaluation of water corrosiveness: Regional groundwater has no corrosiveness to traditional building materials such as bricks and stones, weak to modern reinforced concrete structures, slight to steel bars in reinforced concrete under alternating dry and wet conditions, and slight under long-term immersion conditions.

B. *Analysis Ideas*

Based on the characteristics of this project, relevant numerical calculations and on-site measurement will be carried out. One is to use numerical analysis software to establish a model to simulate the settlement impact of the excavation construction process on the target building (Fig. 2). On the other hand, Electronic Total Station (Leica TCR1202) is used to measure each column foundation of the target building and calculate the relative settlement [9] and settlement difference of the longitudinal adjacent column foundations before and after construction (Fig. 3).

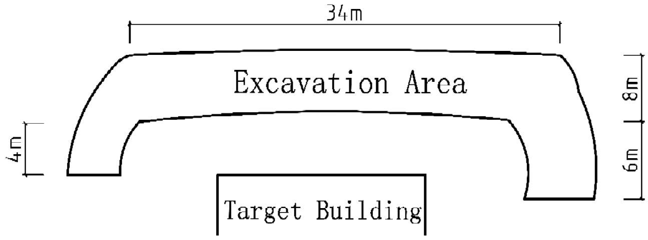


Fig. 2. Excavation area and adjacent building.

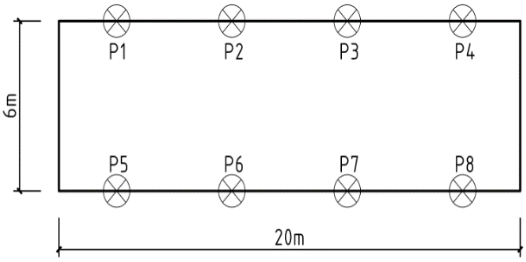


Fig. 3. Settlement observation points.

III. Numerical Simulation

A. *Calculation Model*

Use finite difference software FLAC3D 6.0 to simulate and analyze the settlement features of the foundation in the construction area, and calculate the deformation value of the column foundation caused by construction. The scale of the FLAC plane model is X×Y×Z=60m×35m×15m, with a calculation grid of approximately 150000 hexahedral units. The model ensures that the overall internal unit size can transition reasonably to accurately reflect the impact of excavation disturbance on the foundation [10]. Set horizontal X-direction constraints on the left and right sides of the model, horizontal Y-direction constraints on the front and rear sides, vertical constraints on the bottom surface, and free constraints on the upper surface.

B. *Calculation Parameters*

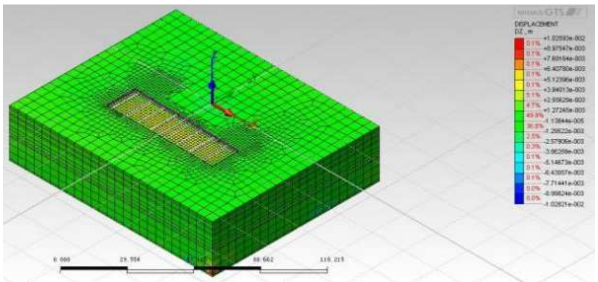
During the simulation process, the soil layer is simulated using solid units, and the soil layer conditions and simulation parameters are shown in table I.

TABLE I. Soil Layer Conditions

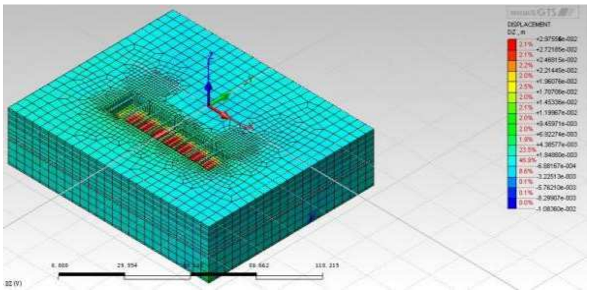
Geotechnical Name	Soil layer thickness-m	Density -kN/m^3	Coherence force-kPa	Friction angle-°	Deformation modulus-MPa	Poisson's ratio
Artificial filling soil	1.2	18.6	17	12	2.2	0.39
Clay	3.2	19.3	25	9	6.5	0.34
Clay	1.3	19.1	45	11	10.0	0.32
Compeletly weathered sandstone	3.1	19.7	32	12	32.0	0.30
Strongly weathered sandstone	3.4	21.8	121	25	45.0	0.22
Moderately weathered sandstone	5.4	23.6	141	30	108.0	0.21

C. *Stratum Settlement Cloud Map*

According to the on-site construction process, the key process of excavating the soil layer is divided into six stages. (1) the excavation depth of the first layer is 1m. (2) the excavation depth of the second layer is 2m, and slope protection treatment is carried out. (3) the lateral excavation of the third layer is stopped, and the longitudinal excavation depth is 2m. When it reaches the groundwater layer, light well point precipitation and drainage treatment are carried out, and the phenomenon of sand flow is observed. At the same time, the groundwater level is detected. (4) The fourth layer is excavated to a depth of 1m, reaching the predetermined depth. (5) The west side is horizontally excavated to a depth of 4m, reaching the same depth. (6) The east side is horizontally excavated to a depth of 6m, reaching the same depth. In Fig. 4, the coordinates in each diagram and the black line in Fig. 4(d) indicate the location of the existing building.



(a)



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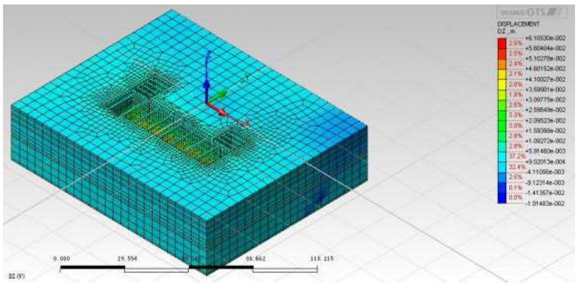

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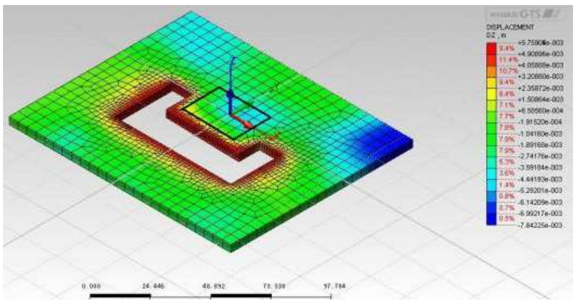


(d)

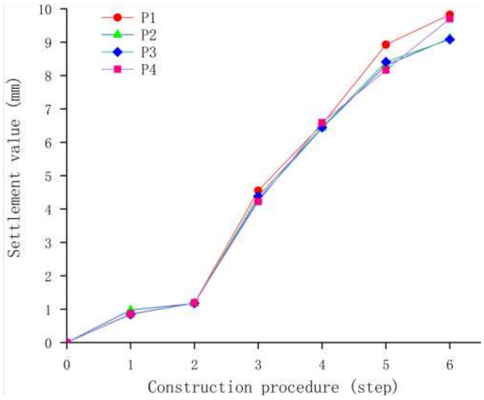
Fig. 4. Some of the stratum settlement cloud maps (a-stage 1, b-stage 3, c-stage 5, d-the final settlement map of the surface).

IV. Results and Analysis

A. Analysis of Simulated Settlement Values

During the construction simulation process, a total of 8 settlement observation points were set up on the column foundation (Fig. 3). The cumulative settlement of each measurement point extracted from the numerical simulation settlement cloud map is shown in Fig. 5.

From Fig. 5, it can be seen that the deformation field of adjacent buildings is affected by the excavation of the ruin site. The deeper the soil layer is excavated, the more obvious the deformation of adjacent buildings is. The deformation of adjacent buildings caused by soil layer excavation is manifested as vertical settlement and inner movement [11]. When excavating to the bottom of the pit, the maximum vertical displacement caused was 6.534 mm, which occurred at observation point P1; The maximum settlement of the building occurs after excavation on both sides of the soil layer, with a maximum vertical displacement of 9.825 mm. It also occurs at point P1 near the bottom of the pit. The minimum settlement is 7.284 mm, which occurs far from the deep foundation pit, at the observation point P7.



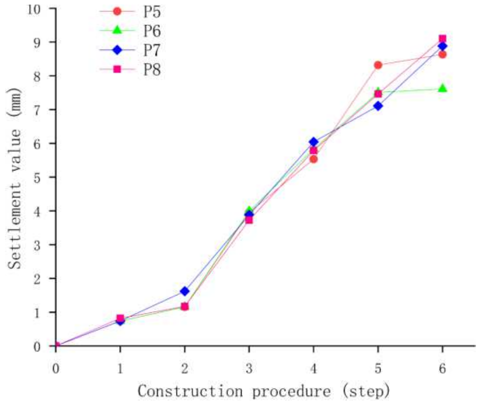


Fig. 5. Settlement of observation points under different construction steps.

B. Analysis of on Site Survey Values

To evaluate the safety of adjacent buildings during construction, the relative settlement and settlement difference of each measuring point are accumulated [12-13]. Based on the relative settlement and settlement difference before and after construction, the values of longitudinal adjacent column foundations are obtained. The specific results are shown in tables II and III, where L is the distance between adjacent measurement points, that is also the distance between adjacent column foundations.

TABLE II. SETTLEMENT DIFFERENCE BEFORE CONSTRUCTION

Measure point	Relative settlement (mm)	Distance (m)	Settlement difference (‰L)
P1	17	6.0	0.67
P5	13		
P2	8	6.0	1.33
P6	0		
P3	15	6.0	1.00
P7	9		
P4	1	6.0	0.83
P8	6		

TABLE III. SETTLEMENT DIFFERENCE AFTER CONSTRUCTION

Measure point	Relative settlement (mm)	Distance (m)	Settlement difference (‰L)
P1	29.94	6.0	0.49
P5	27.02		
P2	23.61	6.0	0.93
P6	18.01		
P3	21.58	6.0	1.24
P7	14.13		
P4	26.60	6.0	1.17
P8	19.56		

During the daily use of buildings, there are different degrees of settlement between the column foundations (table II). Before construction, the maximum relative settlement of building column is 17mm, the distance between column foundations is 6m, and the maximum settlement difference of adjacent column foundations in the longitudinal direction is 1.33 ‰ L, and the minimum is 0.67 ‰ L.

The actual survey is almost consistent with the numerical simulation trend (table III). The maximum relative settlement of building column foundation after construction is 29.94mm, which still occurs at point P1. The maximum settlement difference between adjacent column foundations in the longitudinal direction of the building is 1.24‰L, and the minimum is 0.49‰L.

Considering the deformation of the building caused by the construction, the maximum settlement difference of the adjacent column foundation is 1.33‰L, and the minimum settlement difference is 0.49‰L, which does not exceed the settlement difference limit of 2‰L specified in the code (GB50007-2011). It means that the project can ensure safe use of adjacent buildings in the process of ruins excavation.

C. Result Analysis

(1) This research concludes that the maximum and minimum settlement differences caused by the adjacent column foundations do not exceed the standard limit of 2‰L between adjacent column foundations. It indicates that the construction process of the archaeological excavation project did not affect the normal use of the target building.

(2) This research shows that the monitoring values are consistent with the basic trend of the numerical calculation values, indicating that the numerical model is nearly accurate and the selected calculation parameters are reasonable.

(3) If the impact of river dredging on the adjacent ancient city wall is examined, the above method can be used. Fengyang ancient city is planning to construct a creative landscape pattern that takes into account the ancient city's water veins, water conservancy irrigation, urban water supply and drainage, etc. It can be foreseen that the amount of river dredging, regulation, and excavation work is huge, so this evaluation method will be widely used.

V. CONCLUSION

Selecting a typical archaeological construction ruin, according to the literature and field survey, based on the water system and hydrological address of Zhongdu ancient city, by detecting, calculating, and numerically simulating adjacent buildings during excavation, the impact of earthwork excavation on adjacent buildings and structures can be evaluated. This method is simple and reliable, and can provide reference for similar large-scale deep excavation projects.

FUNDING STATEMENT

This work was financially supported by Chinese Ministry of Education Project "Fengyang Mingzhongdu Water System Research" [Grant No. 19YJCZH237].

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