Cases Study on Foundation Pit Design in Complex Environment of Urban Core Area

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Abstract With the degree of urban underground space developing in China, the scale and excavation depth of foundation pit is much larger, and the surrounding environment is also more and more complex. Therefore, five cases of foundation pit design in complex environment have been studied in this paper. Then combined with local engineering experience, a design scheme of foundation pit adjacent to important facilities which is suitable for Qianjiang New Town has been summarized. Finally, based on the five cases, a simple model to assessment the complexity of the surrounding environment is proposed.

Keywords Foundation Pit Design · Surrounding Environment · Engineering Geology · Complexity Level

1 Introduction

With the degree of urban underground space developing in China, the scale and excavation depth of foundation pit is much larger, and the surrounding environment is also more and more complex, as shown in Fig. 1. The blue area is the foundation pit of a 258-m building, which is surrounded by dotted with dense buildings, subway tunnels and various underground pipelines. All these above make the contradiction between engineering construction and surrounding environment increasingly evident. As a result, the foundation pit design needs to meet not only the strength and stability requirements, but also the deformation control requirements of the

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surrounding environment. Then the foundation pit design gradually changes from the traditional strength control to the deformation control. Finally, under the requirements of balance, safety, economy and convenient construction, the difficulty of foundation pit design gradually increases.

Amounts of research on foundation pit in simple environment have been published [2–7], but as for complex environments it should be further studied. Moreover, the effect of the characteristics of one single building on the foundation pit during excavation process has been discussed, and then a scheme of safety evaluation on foundation pit has been proposed [8]. However, as for various surrounding environments, it should be further extended and adjusted. Therefore, in this paper the authors have studied five typical engineering cases in Qianjiang New Town, the urban core area of Hangzhou City, Zhejiang Province, then summarized the characteristics of foundation pit design with complicated surrounding environment, and finally put forward a framework to distinguish the complex degree of surrounding environment.

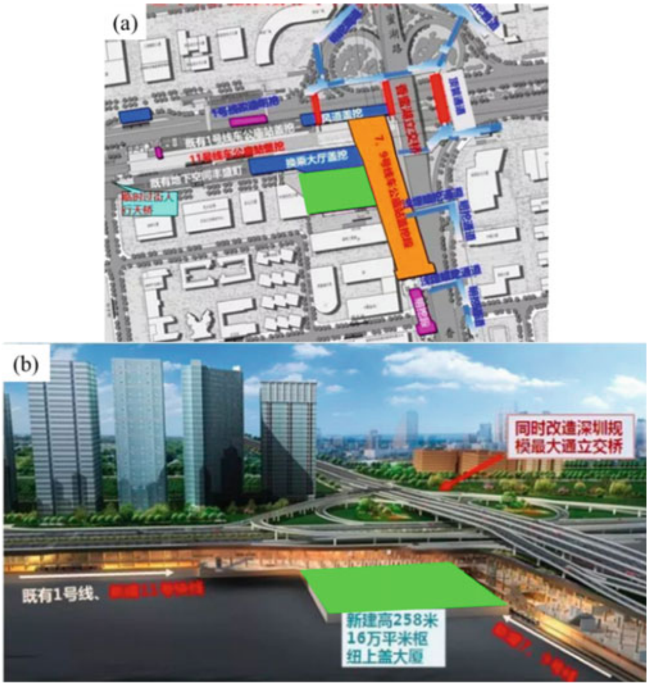

Fig. 1 Schematic diagram of surrounding environment of one foundation pit [1]: **a** plan sketch, **b** 3D diagram

2 Engineering Situation

2.1 Engineering Background

The cases in this paper are located in Qianjiang New Town, the urban core area of Hangzhou City, Zhejiang Province, China, as shown in Fig. 2. All these projects are in the north of Qiantangjiang, and the relationships between the foundation pits and there surrounding environments are also illustrated in Fig. 2.

Case a: Xinchen Business Center Project. This project consisting of two 18-story office buildings with a four-story basement, is located in the southwest of the intersection of Wangchao Road and Leiting Road. It is about 700 m away from Qiantangjiang.

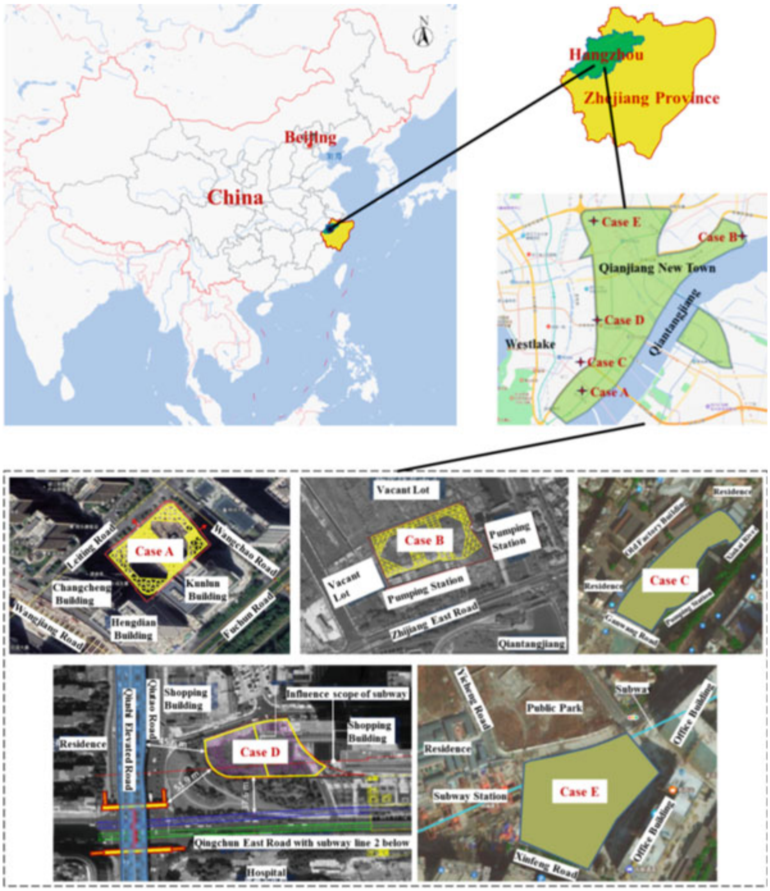

Fig. 2 Locations and surrounding environment of cases in China

The excavation depth, perimeter and area of its foundation pit are approximately 24 m, 392 m and 9690m^2, respectively.

In the east, there is Zhejiang Chouzhou Bank with a pile foundation and 3-story basement across Wangchao Road. In the north, there is Wangjiang International Building with a 2-story basement across Leiting Road. Changcheng Building with a pile foundation and a 2-story basement, Kunlun Center Building with a pile foundation and a 2-story basement, Hengdian Building with a pile foundation have been built in the west, south, and east of the construction site, respectively. Moreover, the three buildings are about 10.2 m, 18 m and 11 m away from the construction site, respectively.

Case B: Jiangchen Business Center Project. This project consisting of two tower buildings which are about 80 m high, is located in the northwest of the intersection of Hemu Port and Zhijiang East Road. Moreover, Qiantangjiang is acrossing the Zhijiang East Road. The excavation depth, perimeter and area of this project's foundation pit are approximately 15 m, 493 m and 13,100 m2, respectively. In the west and north, there are vacant lots, however, pumping station and related facilities which are 4 m away have been built.

Case C: Moyetang Parking Lot Project. The construction site will be built into a public park with a 2-story underground parking. It is located in the northeast of the intersection of Ganwang Road and Xinkai River. The excavation depth, perimeter and area of the foundation pit are approximately 10.4 m, 432 m and 7706 m^2, respectively. In the west, there are several old factory and residential buildings, which will be in a risk of damage during the construction process.

Case D: Qingchun Parking Lot Project. This project is 24 m high with a raft plate foundation and a 4-story basement, which is located in the northeast of the intersection of Qingchun East Road and Qiutao Road. The excavation depth, perimeter and area of its foundation pit are approximately 22 m, 310 m and 5547 m^2, respectively.

The surrounding environment is significantly complex, which is surrounded by roads, buildings, subway line and underground pipelines. In the west, it's Qiutao Road with Qiushi Elevated Road upside. In the south, it's Qingchun East Road with subway line 2 below it. What's more, the south part of the foundation pit is located with the influence scope of the urban rail transit safety protection zone [9]. A 5-story building with natural foundation has been built to the north side, while three 40-story buildings with a pile foundation and 4-story basement have been built to the east side.

Case E: Qiantang Business Center Project. This project consists of three 50 m high buildings with a 4-story basement and one 20 m high podium with a 2-story basement, located in the northwest of the intersection of Xinfeng Road and Yicheng Road. The surrounding environment in the north and west is less complex, where a public park and some residential buildings are found. However, two office buildings are building in the east and south, and the podium is just above the airport rail express, and the subway station with 3-story basement is on the left of the podium. Thus it is seriously important to protect the subway during the foundation pit design and construction progress.

2.2 General Situation of Engineering Geology and Hydrogeologic Situation

As known from the geological map of Hangzhou [10], it is divided into low hilly area, foothill valley area and plain area. Qianjiang New Town is located in the plain area, which is composed of three major layers from the ground down, namely soft and hard interbed, sand and gravel, and underlying bedrock. Combined with the properties of the soil and strata distributions in the field based on the above five cases, the strata of each case are simply reclassified, as shown in Fig. 3. Thus some conclusions can be drawn easily from Fig. 3.

Strata Characteristics. The strata of each case are similar, mainly composed of soft and hard soil layer. From the ground down, they are filled soil, silt soil, clay, sand and gravel, followed by bedrock layer. Silt soil layer is dominated by silt sand and sandy silt, clay layer is dominated by silt clay, while sand and gravel layer is dominated by silt sand and round gravel. It should be noted that in Case C bedrock layer has not exposed due to its shallow borehole depth. It can be found that for the five cases except for Case E, silt layer and sand and gravel layer share similar bury depths, respectively. The reason could be due to the relationship between the construction site distribution and Qiantangjiang.

Bearing Capacity Characteristics. The upper stratum is soft soil layer, which has weak foundation bearing capacity. Thus each building of the five cases adopts pile foundation, with sand and gravel or bedrock acting as the supporting layer.

Groundwater Characteristics. Each construction site has a high-pressure water level, and there are permeable layers such as filled soil, silt, sandy silt, and sand and gravel layer. The measured pressure head was buried about 8 m deep, and the static

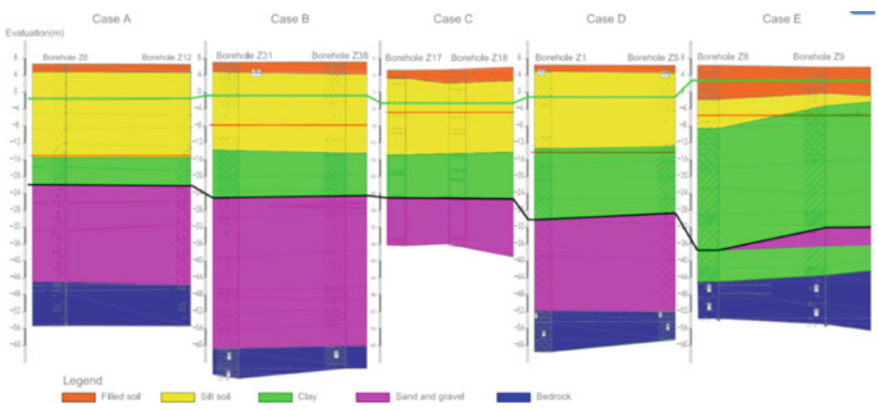

Fig. 3 Schematic diagram of engineering geological section (The blue line, the red line and the dark line represent the pressure water head, the bottom of foundation pit and the top surface of confined aquifer, respectively)

water level elevation was approximately 2 m underground. Based on calculation results, the foundation pit will suffer a risk by the confined water.

3 General Situation of Foundation Pit Design

3.1 Description

The surrounding environment of each case is diverse, the supporting scheme is different, and even the control requirements of deformation are different from each other. Figure 4. shows the comparison of each supporting system, where some design situations can be seen.

Case A, Case D and Case E adopt underground diaphragm walls and internal struts as the support structure. As for Case D, a row of TRD with shape steel inserted is added outside the foundation pit near the subway, which aims to control deformations. As for Case E, the north part is located just above the subway line, so high-pressure jet grouting piles are applied to reinforce the soil above the subway. Case B and Case C are supported by cast-in-place piles and internal struts, while double-row piles are constructed in the area near the old buildings and the pumping station to control the deformation, respectively.

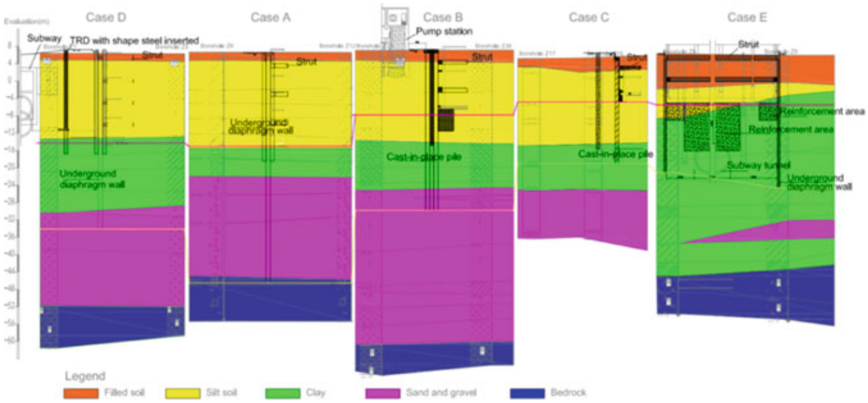

Fig. 4 Schematic diagram of support profile in each case (The red line and the yellow line represent the bottoms of foundation pit and the vertical support structure, respectively)

3.2 Summaries

Taking the excavation depth, surrounding environment, project characteristics and local engineering experience into account, the design and construction process of foundation pit should strictly control the deformation of the surrounding environment, which should refer to relevant specifications. Generally speaking, the vertical support structure for foundation pit can adopt cast-in-place pile, underground diaphragm wall, steel pipe pile, or sheet pile and so on. While the horizontal support structure usually utilize internal struts, which could be classified to reinforced concrete, steel pile and shape steel.

With the help of the unit (Zhejiang University Architectural Design and Research Institute Co., LTD.), the authors have summarized the design scheme of foundation pit adjacent to important facilities in recent projects of Hangzhou City, as shown in Table 1. Combined with the five cases in this paper and various local engineering experiences, the design scheme of foundation pit adjacent to important facilities which is suitable for Qianjiang New Town has also been presented in Table 2. What should be noted is that the scope of protection and relevant requirements of the important facilities are detailed in relevant policies and requirements, which are not described here.

4 Assessment Model of Surrounding Environment

Generally, the safety level of foundation pit is comprehensively determined according to the project characteristics, stratum situation, and surrounding environment, and

Table 1 Design scheme of foundation pit adjacent to important facilities in recent projects in Hangzhou

Adjacent facility	Excavation depth	Major strata characteristics	Supporting system	Control requirements of deformation
Subway	5m ~ 10m	Sandy silt	Cast-in-place piles and one internal strut of reinforced concrete	According to the related requirements (Zhejiang Provincial Department of Housing and Urban-Rural Development, 2017)
		Silt clay	Cast-in-place piles and two internal struts of reinforced concrete	
		Silt clay	Cast-in-place piles and one internal strut of reinforced concrete	
		Muddy clay	Cast-in-place piles and one internal strut of reinforced concrete	
		Silt clay	Slope setling design	
		Round gravel and strong-weathered rock	Slope setling design	
	10m ~ 15m	Silt clay	Cast-in-place piles and two internal struts of reinforced concrete	
		Round gravel	Cast-in-place piles and two internal struts of shape steel	
	15m ~ 20m	Muddy soil	(a) Underground diaphragm wall, one internal strut of reinforced concrete and two internal struts of shape steel. (b) Cast-in-place piles and three internal struts of reinforced concrete	
Electric power pipe	11m ~ 12m	Sandy silt	Cast-in-place piles and two internal struts of reinforced concrete	For underground high-voltage power pipelines, the safety distance must be greater than 2.0m and the deformation must be less than or equal to 20mm
Sensitive building	6m ~ 12m	Silt clay	Cast-in-place piles and one internal strut of reinforced concrete, low-pressure grouting reinforcement outside the foundation pit	For important buildings, the deformation must be less than or equal to 10mm
	14m ~ 15m	Muddy clay	Cast-in-place piles and three internal struts of reinforced concrete	
Railway	5m ~ 10m	Round gravel and strong-weathered rock	Cast-in-place piles and one steel incline strut, retain soils inside pit	Deformation is required to be controlled at 5mm

Table 2 Design scheme of foundation pit adjacent to important facilities in Qianjiang New Town

Excavation depth	Supporting system
<5 m, 5 m ~10 m	(a) If the geological condition is good and the site is permitted, slope, slope plus cement soil mixing wall, or composite soil nailing wall could be adopted (b) If the geological condition is general or the site is tight, piles plus one or two internal struts could be adopted (c) The deformation shall meet the relevant requirements
10 m~15 m, 15 m~20 m, 20 m~25 m	(a) Generally, piles and multi-internal struts should be adopted (b) If the geological situation is general or the site is tight, it is advisable to adopt the supporting structure of underground diaphragm wall with multi-internal struts or combined with the main structure (c) The deformation shall meet the relevant requirements

Note: (a) When there are important pipelines around or inside the foundation pit, the pipeline can be protected by soil reinforcement, pipeline relocation, additional support, pipe and soil isolation, isolation correction, information construction or other methods. (b) The partition method can be adopted to reduce the impact of foundation pit construction on the surrounding environment, and the partition wall can be reinforced by steel sheet pile, ground wall, root pile, stirring pile, grouting, etc.

then the supporting design and construction of foundation pit engineering are carried out. Among above, the complexity degree of surrounding environment greatly affects the safety level division of foundation pit. But existing specifications only classify it qualitatively [11, 12], or according to the facilities properties in the range of excavation effect [13]. However, this could be not economy if safety level is classified too high or too low. Therefore, based on the five cases above and the numerical model proposed by Feng Chunlei [8], this section proposes a simple model to quantify the complexity of the surrounding environment.

4.1 Parameters Description

The surrounding environment of each project in this paper is significantly complex, covering subway, pumping station, old building, underground pipeline, road and river. Due to the lack of a large number of data, statistical analysis of the data is not possible. Therefore, based on a simple two-dimensional finite element model, this section intends to analyse the excavation process of foundation pit with or without surrounding structures.

In the model, subway, pumping station, residence, road or pipeline is simplified into building. Building size A, stiffness E, and horizontal distance s from foundation pit are referred to as calculated parameters. The differential settlement, relative disturbance, tilt angle and torsion angle of the building during excavation process are referred to as the building deformation indexes, and the sum of their normalized values is the comprehensive deformation index, which could be used to measure the overall deformation situation of the surrounding buildings after excavation.

4.2 Model Framework Description

As shown in Table 3, in order to make the influence degree of each parameter on foundation pit excavation more intuitive, the influence degree of each parameter can be simply divided into three levels and assigned values. Considering different factors, the calculated values of three grades of each deformation parameter were averaged, and the absolute value of the difference between the maximum value and the minimum value of the average value was taken as the judgment standard of the influence of this factor on a certain deformation parameter.

Taking the differential settlement of building deformation index as an example, as shown in Table 4, Eq. (1) and Eq. (2), $\overline{a}_i(\delta^v)$, $\overline{b}_i(\delta^v)$ and $\overline{c}_i(\delta^v)$ are the average values of all calculated differential settlements of three influencing factors, namely building size ***A***, stiffness ***E*** and horizontal distance ***s*** from foundation pit, at each level (I = 1, 2, 3) respectively. $r_A(\delta^v)$, $r_E(\delta^v)$ and $r_s(\delta^v)$ are the influence degrees of the four influencing factors on differential settlement. The influence degree of other factors on deformation parameters can be calculated accordingly.

$$\overline{a}_i(\delta^v) = \frac{\sum_{i=1}^{3} s_i(\delta^v)}{3} \tag{1}$$

$$r_s(\delta^v) = Max\{\overline{a}_i(\delta^v)\} - Min\{\overline{a}_i(\delta^v)\} \tag{2}$$

After obtaining the influence degree of a factor on different deformation parameters, the average value of the influence degree of this factor on all deformation parameters is calculated, that is, the comprehensive influence index ***R*** of a factor on building deformation. For example, the comprehensive influence index ***R*** of the horizontal distance ***s*** between building and foundation pit on building deformation

Table 3 Influence degree classification of parameters on foundation pit excavation

Influent degree	A	E	s	Assignments
I	A_1	E_1	s_1	**1**
II	A_2	E_2	s_2	**2**
III	A_3	E_3	s_3	**3**

Table 4 Calculation value of the influence degree on differential settlement

i	A	E	s
1	$\overline{a}_1(\delta^v)$	$\overline{b}_1(\delta^v)$	$\overline{c}_1(\delta^v)$
2	$\overline{a}_2(\delta^v)$	$\overline{b}_2(\delta^v)$	$\overline{c}_2(\delta^v)$
3	$\overline{a}_3(\delta^v)$	$\overline{b}_3(\delta^v)$	$\overline{c}_3(\delta^v)$
$r(\delta^v)$	$r_A(\delta^v)$	$r_E(\delta^v)$	$r_s(\delta^v)$

Table 5 the relationship between Comprehensive deformation index and Safety evaluation index considering different parameters

Safety level L_j	A	E	s	Comprehensive deformation index F_j	Safety evaluation index S_j
L_1	**3**	**3**	**2**	F_1	S_1
L_2	**3**	**2**	**3**	F_2	S_2
L_3	**2**	**3**	**3**	F_3	S_3
L_4	**2**	**2**	**1**	F_4	S_4
L_5	**2**	**1**	**2**	F_5	S_5
L_6	**1**	**1**	**3**	F_6	S_6
L_7	**3**	**1**	**1**	F_7	S_7
L_8	**1**	**2**	**2**	F_8	S_8
L_9	**1**	**3**	**1**	F_9	S_9

is

$$R_s = \frac{r_s(\delta^v) + r_s(\Delta) + r_s(\alpha) + r_s(\beta)}{4} \tag{3}$$

where, $r_s(\Delta)$, $r_s(\alpha)$ and $r_s(\beta)$ are the influence degree of horizontal distance $\boldsymbol{s}$ on the relative disturbance, tilt angle and torsion angle of the building respectively.

By multiplying the assignment of the influence degree level in Table 4 with the comprehensive deformation index $\boldsymbol{F_j}$ of each influencing factor, as shown in Table 5 below, the safety evaluation index $\boldsymbol{S_j}$ of each scheme can be obtained.

4.3 Results

According to the safety level and the safety evaluation index of the surrounding environment under different schemes, as shown in Fig. 5., four regions can be divided into 3 types, namely, safe, relative safe and certain security risks. The specific descriptions can be seen in Table 6.

The above is only for the case that there is a single building around the foundation pit. When there are multiple construction facilities, it should be re-evaluated according to the above process, or the above safety evaluation indexes should be taken a weighted average according to the importance degree of subway, pumping station, road or other facilities, and then the safety level of the surrounding environment could be determined according to Table 6.

Fig. 5 Schematic diagram of the relationship between safety level and safety evaluation index

Table 6 Descriptions of Fig. 5

Classification of safety evaluation	Index		Description
	S_j	L_j	
Safe	$S_2 \leq S_j \leq S_3$	$L_2 \leq S_j \leq L_3$	The deformation of surrounding environment is **nearly not affected** by the excavation construction of foundation pit
Relative safe	$S_2 \leq S_j \leq S_3$	$L_1 \leq S_j \leq L_2$	The deformation of surrounding environment is **less affected** by the excavation construction of foundation pit
	$S_2 \leq S_j \leq S_3$	$L_2 \leq S_j \leq L_3$	
Certain security risks	$S_1 \leq S_j \leq S_2$	$L_1 \leq S_j \leq L_2$	The deformation of surrounding environment is **greatly affected** by the excavation construction of foundation pit

5 Conclusions

Based on several cases, this paper summarized the characteristics of engineering geology and foundation pit design in Qianjiang New Town. And then a simple model to assessment the complexity of the surrounding environment is proposed, which should be further discussed.

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References

1. Xiangsheng C (2018) Build urban rail transit with maximum efficiency (Report). China Urban Rail Transit Key Technology Forum, Beijing
2. Xiaobing X, Qi H, Tianming H et al (2022) Seepage failure of a foundation pit with confined aquifer layers and its reconstruction. Eng Fail Anal 138:106366. https://doi.org/10.1016/j.engfailanal.2022.106366
3. Yang Y, Changhong Y, Baotian X, Shi L, et al (2018) Optimization of dewatering schemes for a deep foundation pit near the Yangtze River, China. J Rock Mech Geotech Eng 10:555–566. https://doi.org/10.1016/j.jrmge.2018.02.002
4. Shuaihua Y, Zhuangfu Z, Denqu W (2021) Deformation analysis and safety assessment of existing metro tunnels affected by excavation of a foundation pit. Underground Space 6:421–431. https://doi.org/10.1016/j.undsp.2020.06.002
5. Chavdar K (2016) Some geotechnical characteristics of the subway construction in Sofia city, Bulgaria. Procedia Eng 165:290–299. 10.1016./j.proeng.2016.11.703
6. Andrey B, Alexander K, Vladimir K et al (2016) Evaluation of deformations of foundation pit structures and surrounding buildings during the construction of the second scene of the state academic Mariinsky theatre in Saint-Petersburg considering stage-by-stage nature of construction process. Procedia Eng 165:1483–1489. https://doi.org/10.1016/j.proeng.2016.11.883
7. Xiaolin Y, Buyu J (2012) Analysis of excavating foundation pit to nearby bridge foundation. Procedia Earth Planetary Sci 5:102–106. https://doi.org/10.1016/j.undsp.2020.06002
8. Chunlei F (2019) Study on the safety and control of deep foundation pit engineering in subway station based on complex stratigraphic conditions (Doctoral Thesis). Beijing Jiaotong University
9. Zhejiang Provincial Department of Housing and Urban-Rural Development. Technical code for protection of urban rail transit structures (DB33/T 1139-2017). China Building Materials Press, Zhejiang (2017)
10. Zhejiang university architectural design and research institute Co., LTD., Urban geological survey of Hangzhou (2008)
11. Ministry of housing and urban-rural development of the people's republic of China. Technical specification for retaining and protection of building foundation excavations (JGJ 120–2012). China Architecture Publishing & Media Co., Ltd., Beijing (2012)
12. Zhejiang provincial department of housing and urban-rural development. Technical Specification for Building Foundation Excavation Engineering (DB33/T 1096–2014). Zhejiang Gongshang University Press (2014).
13. Guangdong Provincial Department of Housing and Urban-Rural Development. Technical Specification for Building Foundation Excavation (DBJ/T 15-20-2016). Guangdong. China City Publishing House (2017)