Study on Time-Space effect and earth berm of foundation pit

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Abstract: Excavation to the bottom of the pit after the expiry date, due to time-space effect, the shear strengths of soil are decrease, which produce safe hidden trouble. The mechanism of supporting structure and backfill of earth berm is analyzed in the paper. Combined with a commercial and residential complex foundation pit in Wuhan as the engineering background, according to the shear strength index of the soil after the foundation pit is retrieved from the foundation pit monitoring data after placing, the safety of the foundation pit is calculated. Calculated by finite element software, The stability coefficient of foundation pit decreases and the horizontal displacement exceeds the allowable value in the code if no action is taken after placing. After reasonable slope top width and slope ratio were adopted to backpressure backfill of the pit, the construction of residential property adjacent to commercial plot should continue until completion. The foundation pit monitoring data are normal during the time, which indicated that the bottom earth berm with back pressure can reduce the horizontal deformation and increased stability of the foundation pit, this method can provide some reference for similar foundation pit treatment.

1. Preface

China’s real estate and traffic municipal construction in full swing for nearly thirty years, there are more and more foundation pits adjacent to the subway and viaduct. At present, the foundation pit around the subway is getting deeper and deeper, the construction period is getting tighter and faster, How to control the deformation of the foundation pit around the subway not to exceed the allowable value, is the construction unit facing severe problem. Due to the change of planning or the shortage of capital chain, the foundation pit has been excavated to the foundation floor of some projects, but the construction of the underground structure has been delayed, and the soil of the foundation pit has been placed for more than the period of validity of the foundation pit. Therefore, the safety of the foundation pit itself and the surrounding environment need to be re-evaluated and demonstrated.

Many scholars have explored the space-time effect theory of foundation pit to analyze the stability and deformation of foundation pit. The theory and practice of time and space effect law in foundation pit excavation are applied by Liu jianhang⁴, the deep foundation pit of basement of high-rise building adjacent to subway tunnel is analyzed with the monitoring data to achieve the purpose of protecting the environment safely and economically. Based on the principle of controlling the deformation with the space-time effect proposed for the rheological properties of soft soil, this paper discusses the excavation technology of controlling the deformation of deep foundation pit with the space-time effect.
2. The mechanism and the analysis model of earth berm

2.1. Calculation model of earth berm

In the passive area above the bottom of the foundation pit, the excavation depth of the foundation pit is reduced due to the existence of an earth berm, which is similar to “pit in a pit” in a calculation, as is shown in figure 1. The existence of an earth berm not only increases the earth pressure on the excavation site of the foundation pit but also restricts the horizontal displacement of the retaining pile to some extent and provides a certain horizontal resistance[4]. Because of the dead weight of earth berm, the horizontal foundation bed coefficient of the soil at the excavation side is increased compared with that of the soil without earth berm.

As shown in Fig. 1, \(Z_0\) is the height of the earth berm, \(H_1\) is the distance between the top surface of the earth berm and the top of the crown beam, and \(H\) is the excavation depth of the foundation pit. The horizontal foundation bed coefficient at any depth \(Z\) is determined according to the following equations:

\[
0 \leq z \leq z_0, \quad k = mz
\]

\[
z_0 \leq z \leq z_c, \quad k = m(z - z_0)
\]

Equations (1) and (2), \(m\) is proportional coefficient of foundation bed coefficient with depth.

2.2. Mechanism between earth berm and retaining pile

When the earth berm is at the bottom of the pit, with the increase of earth berm height, the cantilever height of the retaining pile becomes smaller and the embedded bottom height becomes larger, which is beneficial to increasing the stability of the supporting structure. At the same time, with the
construction of earth berm at the bottom of the pit, the proportion coefficient m at the same depth increases, and the horizontal foundation bed coefficient increases. When elastic resistance analysis is adopted, a spring can be set in the range of the earth berm to reflect the limiting effect of the earth berm on the horizontal displacement of the retaining pile, and the foundation bed coefficient K reflects the influence degree of the earth berm on the horizontal lateral displacement.

3. Project profile

3.1. The surrounding environment
The complex project consists of a residential portion (7 residential 54-storey buildings), commercial malls (29 floors of apartments, 31 floors of office buildings, and 6 floors of shopping malls). The residential basement has 2 floors, and the commercial basement has 3 floors. The north side of the third-floor basement is adjacent to the south side of the second-floor basement. Among them, the residences of Building 8# and Building 9# are located in the PN section on the north side of the foundation pit of the commercial plot, with a distance of 8.04m. 10# and 11# residential buildings are located in the MN section of the foundation pit of the commercial plot, with a distance of about 1m, as shown in Figure 2.

![Figure 2. Foundation pit of commercial plot](image)

The east side of the foundation pit is about 5.0m away from the land use red line, and outside the land use, red line is Jiangcheng Avenue. The south side of the foundation pit is about 5.0m away from the land use red line, and the subway station is outside the land use red line. The west side is about 6m outside the red line for its own houses; The excavation depth of the foundation pit is 15m−16.3m, the perimeter of the foundation pit is about 870m, and the area is about 39,000 square meters. The surrounding environment of the project is complex and severe, and the safety level is level 1.
3.2. Engineering geology and hydrology conditions

3.2.1. Engineering geology. The soil layer distribution is shown in Table 1.

Table 1. The soil layer distribution

| Formation number | $\gamma$ kN/m$^3$ | C kPa | $\phi$ (°) | m (MPa/m$^2$) | $f$ kPa | $f_A$ kPa | $E_s$ MPa | $P_s$ kPa |
|------------------|-----------------|-------|--------|-------------|--------|----------|---------|---------|
| 1 Mixed fill     | 18              | 4     | 20     | 6400        | 25     |          |         |         |
| 2-2 Silty clay   | 17.4            | 11    | 6      | 1220        | 20     | 60       | 3       |         |
| 2-2 Silty clay   | 18.4            | 25    | 14     | 5020        | 30     | 130      | 6.5     | 1.3     |
| 3-1 clay         | 19.2            | 37    | 16.2   | 13191.84    | 50     | 350      | 14      | 3.2     |
| 3a Silty clay    | 18.7            | 31    | 15     | 7320        | 40     | 200      | 9       | 2.1     |
| 3-2 Silty clay   | 18.6            | 29.5  | 14     | 5470        | 35     | 180      |         |         |

3.2.2. Hydrological conditions. The groundwater in the proposed site is mainly the upper stagnated water in ① layer of mixed fill and the bedrock fissure water and karst water in ④ layer. Because the bedrock is about 25m deep from the bottom of the pit, deep well dewatering is not considered in the design of this foundation pit.

3.2.3. Project situation. The project is a commercial and residential complex, and the construction unit will first construct the residential buildings. Considering the change of architectural planning and the requirement of sunshine, the spacing of residential buildings was adjusted from 45m to 55m. While the construction of residential buildings began first, only to adjust the main structure of commercial land. Given the situation that the construction had already begun, the main structure of commercial land should also be adjusted. The foundation pit of the commercial plot has been constructed, and the earthwork has been excavated to the bottom of the basement slab of the negative third floor. Due to the shortage of funds, the construction of the basement has been delayed for more than two years, which has exceeded the one-year validity period of the foundation pit.

Due to the long time of soil in the foundation pit, the space-time effect of the foundation pit is strong, and the cohesion and internal friction Angle of soil shear strength decrease. However, the 8~10# residential buildings adjacent to the north side of the foundation pit are still under construction, and the overloading on the north side of the foundation pit of the commercial block is getting bigger and bigger. Moreover, because it is difficult to calculate the additional load transmitted by the wind load of high-rise residential buildings to the retaining pile during the construction period, the risk on the north side of the foundation pit is getting bigger and bigger. Therefore, it is necessary to evaluate and analyze the safety of the foundation pit and take corresponding countermeasures.

4. Commercial land foundation pit design calculation analysis

4.1. MN, NP Profile of foundation pit

As shown in Fig. 2, MN is the cross-section of the north side of the commercial foundation pit adjacent to Building 10,11# of the residential building, and NP is the cross-section of the north side of the commercial foundation pit adjacent to Building 8,9# of the residential building. Due to the space-time effect, the shear strength and other mechanical indexes of foundation pit soil decrease. The foundation pit was monitored for two years after it was shut down. Based on the monitoring data of the horizontal and vertical deformation of the foundation pit and the variation of the axial force of the pile with time, the soil parameters of the foundation pit are inverse analyzed. By comparing the data of the finite element simulation analysis with the monitoring data, the soil parameters after aging are
obtained for calculation and analysis. Fig. 3 shows that the soil layer is 3a silty clay layer from the basement floor of the second floor to the bottom floor of the basement floor of the third floor of the residence. The shear strength index during foundation pit excavation $c = 31 kPa, \phi = 15^0$ and after that placement $c = 25 kPa, \phi = 12^0$ (here C is the cohesion and $\phi$ is the internal friction) Angle.

As is shown in Figure 3, the MN profile is set with a diameter of 1.2m, a spacing of 1.6m, and a pile length of 15m was set. NP profile is set with a diameter of 1.0m, a spacing of 1.3m, and pile length of 16m. The foundation pit design software is used to analyze the first working condition (began to excavation supporting structure of foundation pit construction, as shown in figure 3a), the second working condition (foundation pit place two years later, considering time-space effect), the third working conditions (the bottom passive area is one level of the slope), the fourth working condition (the bottom passive area is two levels of the slope) calculation and analysis respectively, calculation of profile as shown in figure 3, the calculation results of MN(NP) section are shown in Table 2.

| Calculate indicators | 1Working condition | 2Working condition | 3Working condition | 4Working condition |
|----------------------|--------------------|--------------------|--------------------|--------------------|
| lateral /mm          | 37(32)             | 275(100)           | 38(34)             | 39(36)             |
| stability factor      | 1.581(1.824)       | 0.481(1.145)       | 1.636(1.69)        | 1.6(1.75)          |
| moment/kN.m           | 990(697)           | 3415(1235)         | 1078(821)          | 1156(905)          |

As shown in Table 2, the data of normal conditions (the first working condition) meet lateral<40mm, stability>1.5, meet specification requirements. In the case that the foundation pit has been placed for two years and the basement floor has not been constructed, the calculation is carried out according to the parameters retrieved from the monitoring data, lateral>40mm, stability<1.5, This not only has a great impact on the safety of commercial plot foundation pit but also has a great safety hidden danger to the stability of 8~10# residential buildings under construction.

In order to ensure the safety of foundation pit and adjacent residential buildings in commercial plots, the foundation pit bottom of commercial plots can be reinforced by adding inclined bracing or passive zone. After expert argumentation, the foundation pit bottom back pressure backfill is finally chosen. Backpressure reinforcement is divided into one and two-level backpressure. According to the literature [3], the displacement of retaining pile top and the bending moment of pile body decrease with the increase of m (m is proportional coefficient). As illustrated by the third and the fourth working conditions, when the width and height of earth berm soil are the same, horizontal deformation of the foundation pit with one level of the slope is slightly smaller and the stability coefficient is slightly larger. Both of the two earth berm methods can ensure the stability of the foundation pit, and
the deformation does not exceed the allowable requirements of the code. Comprehensive comparison, the bottom of the pit adopts a level earth berm.

The bottom of the pit was backfilled by backpressure on April 28, 2020, the soil quality and construction quality of backpressure soil has a significant influence on the effect of backpressure soil. When earth berm with backpressure is at the bottom of the pit, it is recommended to use clay-soil earth berm. Meanwhile, the compaction coefficient should not be less than 0.9, and the earth berm slope should not be greater than 1:1.0. The construction should be carried out in strict accordance with this requirement. After the earth berm with backpressure, the construction of the 8–9# buildings around the north side of the foundation pit continued from the 23rd floor until the completion of the house at the end of December 2020 (a total of 54 floors). Third-party monitoring units monitored the whole foundation pit. The deformation monitoring data of the north side of the foundation pit is shown in Figure 4.

According to the monitoring data in Fig.4, from 2020.5.5 to December 25, the horizontal deformation on the north side of the foundation pit continued to increase, showing rapid progress in the previous time deformation. After 2020.8.22, the deformation increase decreases, but does not exceed the early-warning value of foundation pit deformation.

5. Conclusion
In this paper, the north side of a deep foundation pit of a commercial plot in Wuhan is analyzed. When the foundation pit exceeds its expiry date, the shear strength of soil decreases due to the space-time effect. In order to ensure the safe operation of the foundation pit itself and the surrounding buildings and traffic, some measures must be taken for foundation pit.

Through the calculation and analysis of the four working conditions, it is concluded that the effect of earth berm of one level slope is better than two level slope when the top width and height of the earth berm are the same. In the foundation pit engineering with large excavation area, the design and construction are carried out by reserving the earth berm inside the foundation pit without considering the horizontal support, which has a good economic effect. The foundation pit is backfilled with earth berm, which has good safety. The adjacent residential buildings continue to be constructed and the monitoring data are good. This method can provide reference for similar projects.

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References:
[1] Liu jianhang. Theory and practice of space-time effect in foundation pit engineering of soft soil[J]. Chinese journal of Rock Mechanics and Engineering, 1999, 8 (18): 763~770.
[2] Jia jian. The practice of “Time and Space Effect” in soft clay excavations[J]. Chinese Journal of Underground Space and Engineering, 2005, 1(4): 490-493.
[3] ZHENG Gang, CHEN Hong qing, LEI Yang, LIU Chang. A study of mechanism of earth berm and simplified analysis method for excavation[J]. Rock and Soil Mechanics, 2007, 28 (6): 1161-1166.
[4] CHEN Le-yi ZHOU Li WU Bing. Numerical Analysis of Deformation of Foundation Excavation Considering Influences of Time-effect[J]. Journal of Nanchang Hangkong University: Natural Sciences 2013, 27(3): 87-97.
[5] ZHANG Zhuang, MENG Xian-guo, QIN Yong-jun, XIE Liang-fu. Analysis of Space-time Effect of Deep Foundation Pit Deformation in Soil-rock Composite Stratum[J] Science Technology and Engineering, 2019, 19 (25): 325-332.
[6] Liu Yawen, Wang Fei, Peng Gengsheng, Guo Zhiming, Liang Jinjun. Analysis of Deformation Features by using the rule of Time-space Effect in Soft Soil Area [J]. Transportation Science and Technology, 2015 (5): 65-68.
[7] Zhang Ying, Fan Yiqun. Design optimization and reflection of deep foundation pit with complex boundary considering space-time effect [J]. Urban Roadways, Bridges and Flood Control, 2015, 6(6): 153-158.
[8] Yangyujiang, Shao yapping. Application of pit splitting technique in deformation control of deep and large foundation pit in saturated soft clay [J]. Geotechnical Engineering Technology, 2020, 34 (6): 321-328.
[9] WANG Guozuo, YOU Bo, ZHOU Jianzhong, XU Jie. Construction Organization and Practice on Earth Excavation of Deep-Large Foundation Pit Adjacent to Subway According to Principle of “Time-Space Effect” [J]. Foundationbed and Foundation Building Construction.
[10] ZHU Zhurong, LIU Ying, LIU Baozhan. The research of time-space effect on earth pressure in deep excavation[J]. Sichuan Building Science, 2014, 40(4): 153-155.