

# Analysis of influence of seepage on stability of foundation pit

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**Abstract.** Numerical analysis is executed to deep foundation pit by using the finite element software. In combination with the site data, the consequences with the consideration of groundwater seepage are contrasted to the consequences without the consideration of groundwater seepage including the stability of the foundation pit. The analysis indicates that the result with the consideration of seepage is relatively close to the site data. Compared with the result without consideration of groundwater seepage, the maximum horizontal offset of the pile increases approximate 5mm and the location of the maximum horizontal displacement moves 2m down. So seepage is harmful to the retaining structure of foundation pit and should be considered in the design of foundation pit.

## 1. Introduction

As China's real estate market continued to hot in recent ten years, in order to make full use of urban space and improve the carrying capacity of land resources, the three-dimensional development of city was more and more urgently needed [1,2], and people began to seek space for development in the air and underground[3]. Currently various types of underground space has been developed in the world's major cities[4], such as the multi-storey basement of high-rise building, underground railway and underground stations, underground parking garage, underground streets, underground shopping malls etc [5]. The common characteristic of developing underground engineering is to excavate the soil mass and result in a large number of foundation pit [6, 7]. Excavation and dewatering of deep foundation pit on pervious foundation will result in consolidation of soil and flow of pore water, water movement in pores tends to be strong because of difference of percolation water head [8], which affects internal force and deformation of enclosure system, the stability of the foundation pit and the surrounding structure. So it is necessary to consider the influence of seepage.

## 2. Engineering survey

### 2.1. Project introduction

According to the survey report, the foundation pit engineering  $\pm 0.00$  is equivalent to the Yellow Sea elevation +4.65, base height is -12.30 m, design relative elevation of site natural floor is -1.15 m, and excavation depth of foundation pit is 11.15 m. The safety grade of foundation pit sidewall is two and importance coefficient is 1.0.



## 2.2. Engineering geology and hydrogeology condition

**2.2.1. Engineering geological condition.** The site is mainly alluvial formation of Quaternary Holocene strata, including sandy soil and cohesive soil. The distribution of soil layers is as follows:

(1) Plain fill: brown, tan and which is made up of silty clay. Its part is crushed stone and concrete pavement and a small amount of plant roots, loose structure~ slightly dense, thickness of the layer is generally 0.40~2.30 m.

(2) Silty clay: tan, grayish yellow, wet, plastic and soft plastic, relative elevation of floor is 0.06~2.12 m, thickness of the layer is generally 0.50~2.60 m.

(3) mucky silty clay: gray brown, brown grey, saturated, flow plastic, local soft plastic, local pinch a small amount of thin powder or silt, relative elevation of floor is -8.31~-5.10 m, thickness of the layer is generally 5.50~9.00 m.

(4) Silty clay soil: gray, brown gray, very wet, slightly dense, containing mica debris, medium uniform, shake response is rapid, initial and dry strength are low, relative elevation of floor is -10.20~-7.18 m, thickness of the layer is generally 7.80~11.60 m.

(5) Silty sand and silt: brown gray, gray, saturated, slightly dense, the mineral composition is W quartz, feldspar, relative elevation of floor is -18.43~-16.18 m, thickness of the layer is generally 0.80~4.00 m.

(6) Powder and sand: brown gray, gray, saturated, medium dense, a small amount of sand particles, medium uniformity, relative elevation of floor is -28.17~-24.18 m, thickness of the layer is generally 6.00~11.50 m.

(7) Silty clay with fine sand and silt: powder, fine sand gray, saturated, slightly dense, particle composition uniformity, relative elevation of floor is -26.29~-25.93 m, thickness of the layer is generally 0.7~1.2 m.

(8) Powder and fine sand: brown gray, bluish grey, saturated, medium dense, particle composition of medium uniform and partial clay or silty clay.

**2.2.2. Hydro geological condition.** This site groundwater of project is mainly the pore diving, there is weak confined water in the local and the bedrock contains a small amount of bedrock fissure water. Shallow groundwater belongs to seasonal changes. Geological data display that the average depth of groundwater in the site area is 0.20~2.40 m, the annual average stable water level of groundwater in the site area is 0.60~1.60 m.

## 2.3. Supporting scheme of foundation pit

As mentioned above, the groundwater level of the project is seriously affected by the surrounding water, and the ground water level is higher and larger precipitation depth. So pit dewatering and well dewatering combined with single row of soil cement mixing makeup water is used. In order to reduce the impact on the surrounding environment of the project design, focusing on the internal bracing wall type support, mainly in the following two forms: Filling pile with internal support and SMW with internal support.

## 2.4. Horizontal displacement monitoring

Taking measuring point 1 and 2 as an example, the article selected that pit excavation has been completed. The monitoring data is taken as reference when the displacement variation of pile body has stabilized. The monitoring depth is below pile top 10 m. The horizontal displacement of the pile is shown in Table 1. Table 1 shows that the horizontal displacement of the retaining structure increases from ten millimeters in the excavation to dozens of millimeters after the excavation. The maximum horizontal displacement is 24.73mm. Pile horizontal displacement increases with pile length and then decreases.

**Table 1** The horizontal displacement of pile changes with depth

Distance (m)	Displacement(mm) Measuring point 1	Displacement(mm) Measuring point 2
0	18.37	17.43
1	19.78	18.74
2	20.83	20.11
3	21.94	21.42
4	23.01	22.60
5	23.96	23.82
6	24.72	24.71
7	24.24	24.73
8	23.98	23.75
9	22.18	23.09
10	21.64	21.56

### 3. Software modelling

#### 3.1. Calculation profile

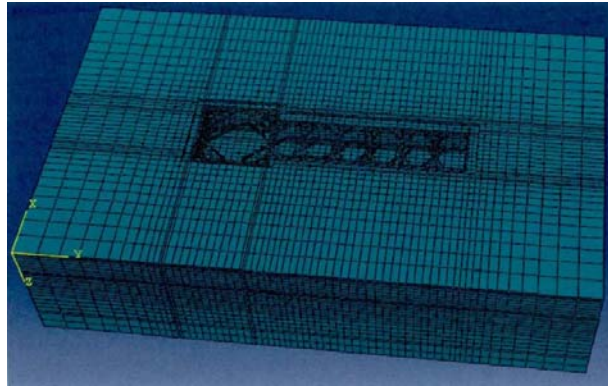
Considering the influence of foundation pit excavation on surrounding soil disturbance range and seepage effect on environment, the depth of 3D model is 40 m, Plane size is 100 m x 150 m. In the calculation process, the mixing piles and soil mass are analyzed as the whole. In the model of foundation pit, the soil mass is analyzed by Mohr-Coulomb model and other supporting structures are analyzed according to elastic body. The parameters required for this model are shown in Table 2. Parameters include thick layer, average severity, natural moisture content, void ratio, cohesion, friction angle, compression modulus.

**Table 2** Physical and mechanical parameters of soil

Name of soil layer	1(m)	2(kN/m <sup>3</sup> )	3(%)	4(-)	5(KPa)	6(°)	7(MPa)
① Plain fill	0.8	19.0	-	-	-	-	-
② Silty clay	1.8	18.2	34.7	0.963	24	6.1	3.8
③ Muddy silty clay	7	18.4	41.3	1.143	8	3.0	2.8
④ Silty clay soil	2.9	18.3	32.4	0.908	17	18.1	4.6
⑤ Silty sand clay	9.6	18.7	28.8	0.798	5	28.1	11.2
⑥ Powder sand	8.7	18.9	26.1	0.741	6	30.0	11.8
⑦ Silty~clay	1.3	18.6	28.9	0.839	5	27.6	11.5
⑧ Powder~sand	7.9	19.1	25.6	0.755	6	28.0	12.6

#### 3.2. Modelling calculation

With the existence of assumptions and parameters of each index, we have established three dimensional finite element models by software. The scope of the calculation model is from outside the pit edge line outward extending about 40 m and size is 100 m \* 150 m \* 40 m. The studied foundation pit is nearly symmetrical, the total length of X axis is 19.30 m and the total length of Y axis is 73.62 m. Limiting the bottom displacement of the model and the horizontal displacement of each side is 0, the upper surface is a free boundary without any constraints. The calculation model is shown in Figure 1.

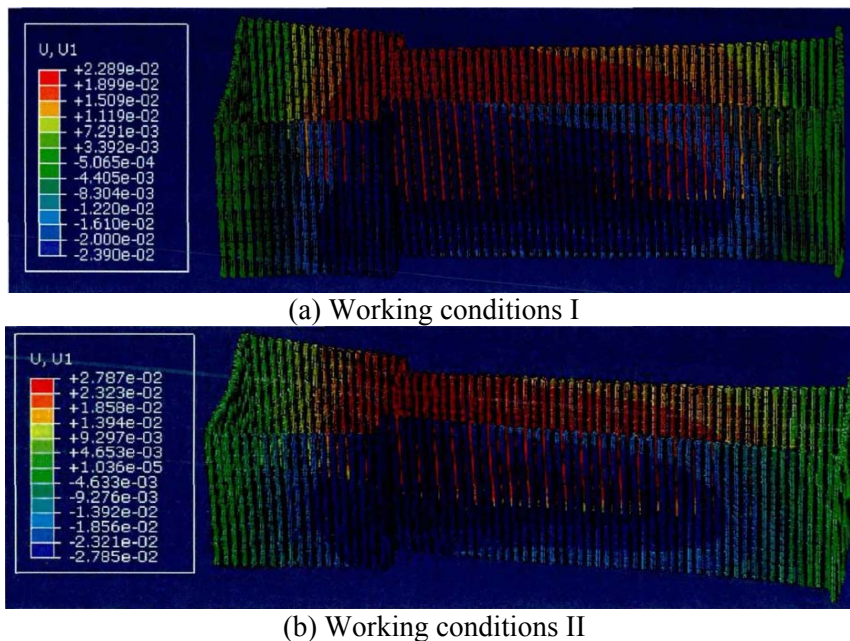


**Fig. 1** The map of simulation grid

#### 4. Calculation results and analysis

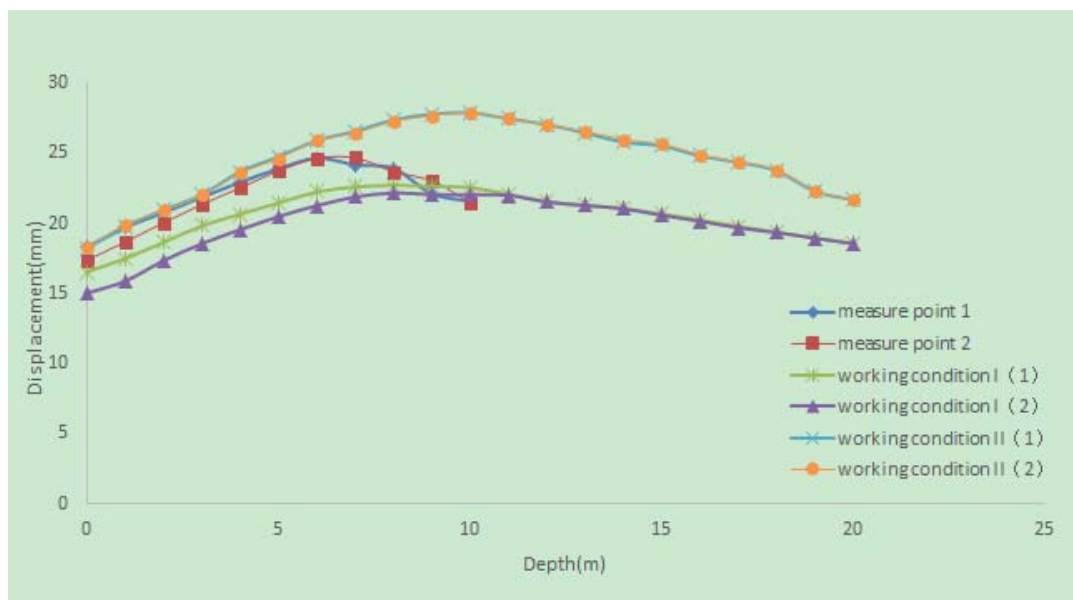
In order to study the influence of seepage on foundation pit deformation and stability, the following models are calculated by two conditions, one is to consider only the excavation and without considering changes in groundwater level, known as the working conditions I ; the other is to consider the excavation and precipitation, that is, the calculation of the use of soil dry weight and set the initial water table and precipitation wells, known as the working conditions II. With the development of the excavation and dewatering, firstly, unsteady seepage is formed in soil and after the excavation has been completed for some time, stable seepage field is formed in the soil. Through the comparison of two conditions, the influence of seepage on the deformation of foundation pit and retaining structure is analyzed.

Figure 2 gives the horizontal displacement nephogram of pile body about working conditions I and II when the final excavation depth is reached. From the picture we can see that deformation of pile tip is basically consistent about working conditions I and II, deformation is internal development of the pit and the horizontal displacement value displayed in the working conditions II is larger than the horizontal displacement value displayed in I.



**Fig. 2** Horizontal displacement of pile

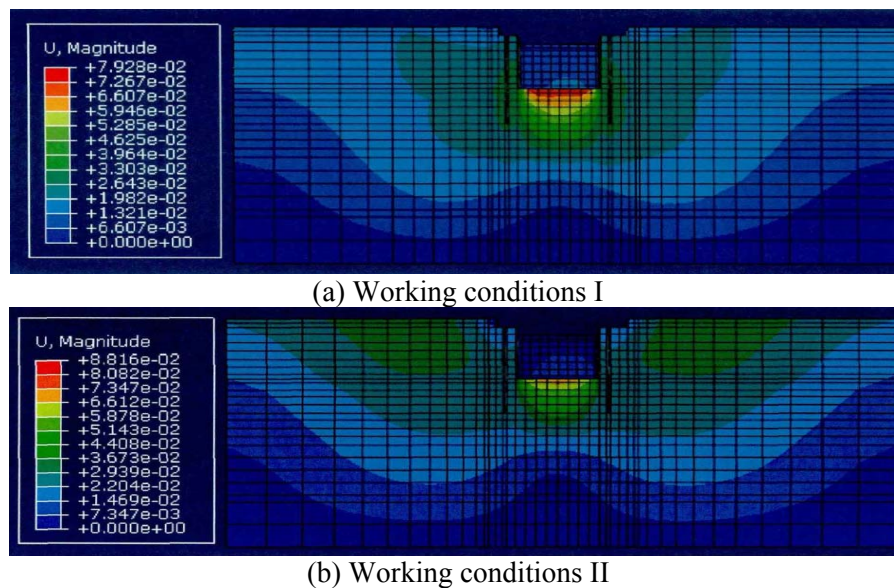
Figure 3 gives the curves of horizontal displacement of pile with depth about inclined hole 1 and 2 when the final excavation depth is reached, including working conditions I, II and field monitoring data. From the picture we can see that deformation of retaining pile is small at both ends and the middle is big, the upper part of the pile displacement and field monitoring conditions of II are close to the values, obvious deviation of central stiffness settings may be decided by the relatively small of the second supporting of the simulation; the overall horizontal displacement of pile body under working condition II is larger than the horizontal displacement of pile body under I, the seepage makes the retaining piles and the soil around the pile move towards the pit. The maximum horizontal displacement of I occurs at a depth of about 8m, about 22mm, and the maximum horizontal displacement of II occurs at a depth of about 10m, about 27mm, they all occur in the bottom of the pit position. But the maximum horizontal displacement of II increases 5mm, and moves down 2m, and the deviation of horizontal displacement about working conditions I and II increases at first and then decreases. The variation trend of deviation and seepage force is same and the influence of seepage on horizontal displacement of pile body is larger.



**Fig. 3** The curves of horizontal displacement of pile with depth

Figure 4 gives the total displacement nephogram of the symmetrical surface of the foundation pit about I and II when the final excavation depth is reached. From the picture we can see that the total displacement of pit under working conditions I is obviously less than the total displacement of foundation pit under working conditions II. The deformation of foundation pit caused by excavation under working conditions I is limited in certain area of foundation pit and the deformation of foundation pit caused by excavation under working conditions II extends to the ground. The displacement nephogram is similar to the continuous sliding surface formed by the whole shear failure of foundation pit.





**Fig. 4** Nephogram of total displacement of symmetric surface of foundation pit

## 5. Conclusion

From the results of two working conditions considering seepage and non-seepage we can see that the simulated data considering seepage flow are in agreement with field monitoring data and the horizontal displacement of retaining wall structure considering seepage are bigger than conditions without seepage. It shows seepage should be taken into account when the deformation of foundation pit and retaining structure is analyzed.

## References

- [1] Hou Xueyuan, Liu Guobin. Some views on the development of urban foundation pit engineering. *Construction Technology*. Vol.29 (2000) No.1, p.0005-03.
- [2] Wei Junjun, Zhang Liwei. Seepage stability analysis of foundation pit. *Journal of Water Resources and Architectural Engineering*. Vol.10 (2012) No.3, p.0079-04.
- [3] Yang Yue, Hou Gongyu. Influence of seepage on deformation and stress of foundation pit. *Journal of Shenyang Jianzhu University (Natural Science)*. Vol.29 (2013) No.6, p.1053-06.
- [4] Qian Deliang, Li Juncai. Deformation analysis of foundation pit under seepage. *Journal of Nanjing University of Technology*. Vol.37 (2015) No.1, p. 015.
- [5] Chen Guoqing, Pan Yikai. Analysis and treatment of flooding accident in a deep foundation pit. *Journal of Water Resources and Architectural Engineering*. Vol.14 (2016) No.5, p. 044.
- [6] Cao Liqiao. Finite element method analysis of bottom upheaval of deep foundation pits in soft-clay ground due to excavation. *Chinese Journal of Geotechnical Engineering*. Vol.35 (2013) No.2, p. 94-97.
- [7] Ma Shaokun, Shao Yu. Deformation of deep foundation pits due to excavation considering change of void ratio and permeability coefficient with depth. *Chinese Journal of Geotechnical Engineering*. Vol.37 (2013) No. 2, p. 80-84.