The Settlement of the Nearby Pipelines Caused by the Deep Metro Foundation Pit Excavation

Zhijia Peng*

China Communications Construction First Highway Engineering Group Co., Ltd.; Beijing, 101102, China

* Corresponding author's e-mail address: 664830889@qq.com

Abstract. When the deep foundation pit is excavating, it will cause stratums settlement, thereby affecting nearby buildings and pipelines under surface. In this paper, based on the e-p curve obtained from the compression test, the calculation method of tangential compression modulus under arbitrary pressure is derived. According to the overburden pressure at the midpoint at each stratum, the compression modulus of each stratum under the current state is calculated. According to the elastic modulus obtained from the reloaded compression test of some strata, the ratio of elastic modulus to tangential compression modulus of the stratum is obtained, and the elastic modulus of different depth strata is calculated as a calculation parameter. The comparison between the numerical calculation results and the field monitoring shows that the elastic modulus determined in this paper is suitable to the actual situation. Based on this, the settlements of two pipelines that are 16.5 meters and 31.6 meters away from the north edge of the foundation pit and have a depth of 3.92 meters and 1.45 meters respectively are analyzed. The result shows that the pipeline settlement will not exceed the threshold value and be in safe.

Keywords: deep pit; pipeline deformation; numerical calculation

1 INTRODUCTION

With more and more metro construction in China, the deep excavation in complex surrounding environment has become more and more common. The impact of deep excavation on the surrounding environment has also attracted researchers' attention. The numerical analysis method has become an effective method to study complex deep foundation pits, but still has the problems of difficult model selection and inaccurate parameters such as how to take suitable parameters and mechanical model. Zheng Gang [1] studied the influence of foundation pit excavation on adjacent pile foundations with the numerical analysis method. Li Guodong [2] studied the deformation law of the construction of deep foundation pits for metros, is also taken the numerical method. Dai Xu [3] studied the influence of the construction of the shaft of Jiamenqiao Station on the adjacent pipelines of Beijing Metro Line 12 with Flac3D

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which is a influence software in geotechnique field. Wang Zhongnan [4] studied the influence of the pile-anchor support system of adjacent structures. Cheng Hongmei [5] analyzed the stability of deep foundation pit excavation. Many foreign scientists have also conducted research on this[6-7]. It can be seen from the above that the numerical analysis method has become an effective method to study complex deep foundation pits, but still has the problems of difficult model selection and inaccurate parameters such as how to take suitable parameters and mechanical model.

For the underground pipelines around the foundation pit, through the surface displacement, it cannot directly estimate the deep displacement. In this paper, the numerical method is taken to analyze the displacement of the pipelines at a certain depth caused by deep foundation pit excavation. And the monitoring data of surface displacement was used to check the numerical calculation results.

2 ENGINEERING BACKGROUND

The research subject of this paper is a certain subway station in Shijiazhuang City in China. The total length of the station is 198.8 m, the width of the standard section is 19.7m. The foundation pit is about 17.036mn deep, and 23.8m wide. The form of the main foundation pit retaining structure is bored piles and steel supports. The space between the bored cast-in-place piles is 1.3m, the diameter of the piles is 0.8m, and the length is 20.7m. A crown beam is set at the top of the pile, and the lateral internal supports are Ø609*16 and Ø800*16 steel pipe, and is connected by two I45b beams.

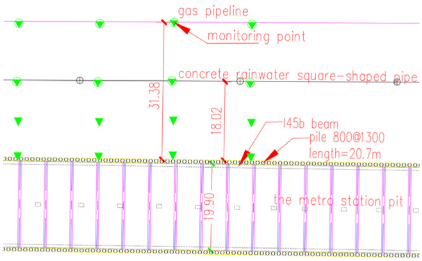

Fig. 1. The situation of tubes on north of the pit

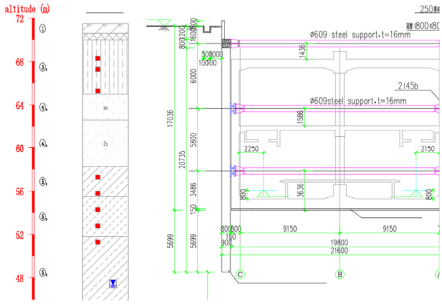

Fig. 2. The tubes on north of the pit

There is a gas pipeline on the north side of the foundation pit, 31.58 meters away from the pit wall, which is a DN159 steel pipe, with medium pressure, and is at a depth of 1.45 meters underground. On the north side, 16.5 meters away from the pit wall, there is a concrete rainwater square-shaped pipe, and the concrete square pipe is (W×H 3600×2800 (inside net space)), and the buried depth of the inner bottom is 3.92 meters as shown in Figure 1.The situation of foundation pit support and stratum conditions is shown in Figure 2.

3 CALCULATE METHOD

3.1 Basic Model and Calculation Steps

In order to make the model closer to the actual situation, a model with a width of 12.0m is used, and at the width direction, the possible influence range of foundation pit excavation is 44.0 m at each side. A numerical model of 3D is constructed with the finite difference method, taking the most commonly used MC model. The initial gravity stress field is calculated according to the stratum self-weight. Considering that the pile foundation is constructed before the excavation. After the pile was constructed, the stress field are changed, and then re-balanced again. For the simulation of the excavation part, it is divided 1 to 4 excavation stages. Each step of excavation is according to 1.0 to 1.5m, which is divided into four steps. When excavating to 1.0m below the lateral support location, the lateral support is applied, and the connection effect of the I-beam is considered.

3.2 The Elastic Modulus of the Stratum

When performing uniaxial compression, if the test process is in the elastic stage, the relationship between the elastic modulus and the compression modulus under the lateral restriction effect is as follows:

$$E = (1 - \frac{2\mu^2}{1 - \mu})E_S \tag{1}$$

Among them, μ is the Poisson's ratio, E_s is the compression modulus, and E is the elastic modulus. When μ = 0.3, E = 0.74E_s. In actual calculation, formula (1) cannot be directly used, because there is plastic deformation during the compression process, resulting in the actual E being larger than the calculation result of formula (1).

From soil mechanics, it is known that for normally consolidated cohesive soil, the e-log P curve should be a straight line and can be expressed as:

$$e = M + N \log(p) \tag{2}$$

Then

$$\frac{de}{dp} = \frac{N}{P} \tag{3}$$

For the same soil sample, M and N are constants witch can be calculated through the e-log P curve. Under the condition of lateral restriction compression, the vertical strain can be expressed as:

$$\Delta\epsilon = \frac{\Delta s}{h} = \frac{e_1 - e_2}{1 + e_2} \tag{4}$$

Δs is the compression of soil, and h is the initial height of the soil sample before loading. e_1, e_2 are the porosity ratios under the initial pressure and after the loading. According to the definition of the compression modulus,

$$E_s = \frac{\Delta p}{\Delta\epsilon} = \frac{p_2 - p_1}{e_1 - e_2}(1 + e_1) = \frac{dp}{de}(1 + e_1) \tag{5}$$

When calculating the tangent compression modulus at a certain point of the curve, e_1 can take the value of the porosity ratio under the current stress state, which can be obtained by formula (2). By bringing formula (2) into formula (5), the expression of the current tangent compression modulus is obtained:

$$E_s = \frac{dp}{de}(1 + M + N\log P_i) = \frac{P_i}{N}(1 + M + N\log P_i) \tag{6}$$

P_i is the vertical stress in the middle part of the stratum, and it can use the self-weight stress. The e-p curves of the ③$_1$, ⑤$_1$ cohesive soil and ⑤$_2$ silt clay of the stratum have been completed by the indoor compression test, as shown in Figure 3.

In different samples in the same soil layer takes the average value. And taking the least square method, the corresponding straight line is fitted to obtain the values of M and N, as shown in Figure 4. Since the stratum of this foundation pit is in a normal consolidation state, according to the depth of the stratum, the overburden pressure on the center of the stratum depth is taken as the average overburden pressure of the local stratum, and it can be brought into formula (4) to calculate the compression modulus of the current state. The compression modulus of the same layer of soil under different overburden pressures should also be different. Indoor rebound and recompression tests were carried out on the samples of ⑤$_1$ and ⑤$_2$, and the recompression elastic modulus E_r of ⑤$_1$ (at 15.0m) and ⑤$_2$ (at 17m) were obtained, which were 25.6MPa and 45.9MPa respectively. Since the excavation of the foundation pit is an unloading process, using the rebound and recompression modulus E_r as the calculated modulus, the $E_r/E_s = 2.7 \sim 3.2$.

According to the relationship formula : $E = \alpha E_s$, for the stratum of this foundation pit, α can be taken as $\alpha = (3.2+2.7)/2 \approx 3.0$.

For sand, it is obtained according to the standard penetration test by Parry:

$$E_s = 2.8N_{63.5}(MPa) \tag{7}$$

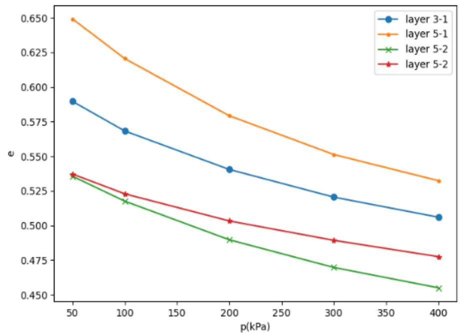

Fig. 3. the e-p figure for layers(③$_1$\⑤$_1$\⑤$_2$)

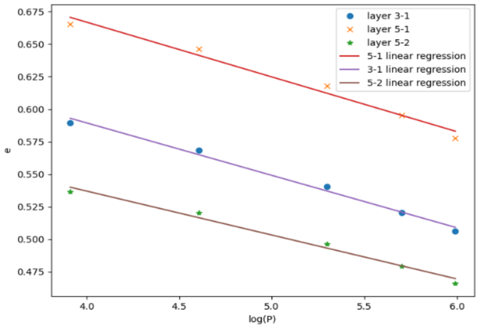

Fig. 4. the e-log(p) linear regression

Among them, $N_{63.5}$ is the standard penetration blow count. The elastic modulus of the sand layer of ④$_1$, ④$_2$, and ⑥$_1$ is calculated, and the calculation process and results are shown in Table 1.

Table 1. Soil layer elastic modulus calculation table

stra-tum	profundity(m)	P(kPa)	M	N	E_{s1-2}(MPa)	E_s(MPa)	$N_{63.5}$	E(MPa)
③$_1$	1.⑤6.5	72.25	0.89	-0.045	5.0	2.828	-	8.484
⑤$_1$	13.2-16.0	266.54	0.75	-0.04	6.0	9.611	-	25.6*
⑤$_2$	16.0-19.7	330.4	0.67	-0.034	7.0	14.441	-	45.9*
⑤$_1$	19.7-26.3	431.55	0.75	-0.04	11.0	16.199	-	48.6
④$_1$	8.9-13.2						30	84.0
④$_2$	6.⑤8.9						27	75.6
⑥$_1$	26.③36.5						33	92.4

Note:* is the test value.

4 CALCULATE RESULTS CHECKED BY THE ON-SITE MONITORING DATA

Since the actual monitoring time lags behind the excavation, the calculated value should be slightly larger than the actual monitoring value. The comparison results are shown in Table 2. When the excavation is to 13.1m to the third layer of support, the comparison of the surface settlement monitoring results and the calculated results is shown in Figure 5. The calculated results and the monitoring results are more consistent, and the difference between the two is not more than 0.95mm. The comparison shows that the calculated results are reasonable and can correspond to the on-site results.

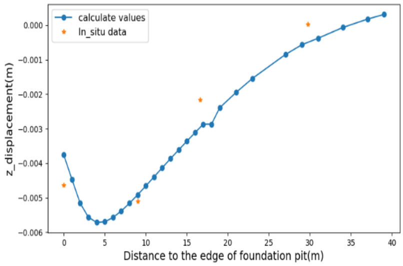

Fig. 5. Comparison of surface subsidence between monitoring data and calculation results（dig to 13.1m）

Table 2. Comparison subsidence between monitoring and calculated results

Distance to edge of the pit / Depth	0.0m		9.0m		16.6m		30.0m	
	Insi-tu val-ue	Calcu-lated result	Insi-tu val-ue	Calcu-lated result	Insi-tu val-ue	Calcu-lated result	Insi-tu val-ue	Calcu-lated result
Excavate to 13.1m	4.63	3.76	5.09	4.91	2.16	3.11	-0.03	0.37
Excavate to 17.0m	8.89	5.07	7.40	7.10	3.73	4.40	0.25	0.38

5 ANALYSIS OF THE IMPACT OF THE DEEP FOUNDATION PIT EXCAVATION PROCESS ON THE PIPELINES

Since the pipeline is buried underground, it is difficult to obtain accurate measurements of the settlement at the bottom of the pipeline. Based on the surface settlement monitoring and numerical calculation results. estimating the settlement situation at a certain depth underground is a method that can be used for reference.

5.1 The Gas Pipeline Settlement Analysis

On the north side of the foundation pit, there is a gas pipeline 31.6m away from the foundation pit wall, which is a DN159 steel pipe with a buried depth of 1.45m. Without considering the resistance effect of the gas pipeline on settlement, the settlement at each point at different distances from the foundation pit at a depth of 1.45m represents the settlement of the layer where the pipeline is located. At the horizontal survey line at a depth of 1.45m below the ground surface, the settlement at different stages of excavation is shown as follows in Figure 6.

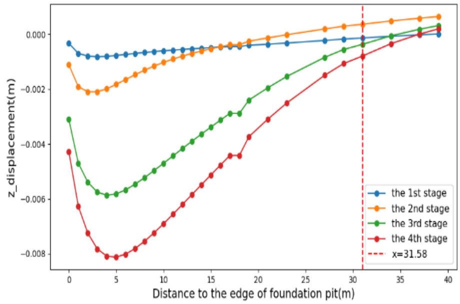

Fig. 6. Settlement deformation at depth of 1.45m

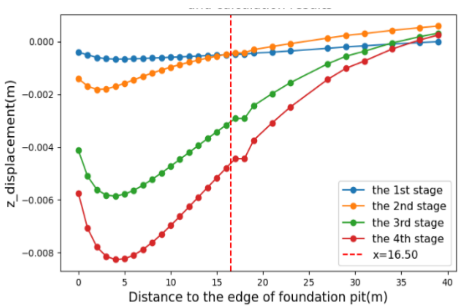

Fig. 7. Settlement deformation at depth of 3.92m

The calculated value of the surface settlement at 31.6m away from the foundation pit wall is -0.84 mm, and the maximum actual monitoring value is -0.74mm, which is 0.1mm larger than the actual monitoring value, indicating that the calculated result is reliable. According to the calculation, the settlement in the first stage of excavation is -0.131mm, in the second stage, it has a slight rebound upwards to 0.37mm, in the third stage, the settlement is -0.362mm, and in the fourth stage, the settlement is -0.788mm, which is slightly larger than the monitored surface settlement. After the final excavation is completed, the pipeline deformation does not exceed 1mm, and the impact of foundation pit excavation on the pipeline is relatively small.

5.2 Settlement Analysis of the Rainwater Square Pipe

On the north side, 16.5m away from the foundation pit wall, there is a concrete rainwater pipeline, (W×H=3600 × 2800 (inside net space)), with buried depth of 3.92m. After the excavation is completed, the calculated result is shown in Figure 7. After the excavation is completed, the surface monitoring settlement amount is 3.73mm, and the calculated result is 4.40mm, which is 0.67mm larger than the monitoring result. It can be seen that the excavation in the first and second stages has less impact on the pipeline. When the excavation reaches the third stage, the settlement increases sharply, and the final settlement amount can reach 4.40mm. The settlement at the pipeline meets the requirement of not being more than 2cm.

6 Conclusions

- Tangent compression modulus is derived and calculated with the compression modulus under the current state of the local stratum according to the measured e-p curve data. Referring to the recompression elastic modulus of some soil layers obtained from the test, the elastic modulus values of different depth strata were given.
- The numerical calculation results were checked according to the surface monitoring data. The check shows that the numerical analysis results are basically consistent with the surface monitoring results, and the determined elastic modulus is in line with the actual situation.
- The numerical calculation results were used to analyze the possible settlement of two pipelines with distances of 16.5m and 31.6m from the edge of the foundation pit, and a depth of 3.92m and 1.45m. The calculation shows that the pipeline settlement will not exceed the required threshold.

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