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The Influence of Ground Settlement Caused by Shield Construction Under Different Geological Conditions

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The Longjiang Railway Station to Yunnan Road Station of Nanjing metro line four crosses three different geomorphic units.The Peck formula is fitted to the measured data of the effective monitoring points during the construction of the shield. By analyzing the typical curve, the shape characteristics of the settlement on different geomorphic units are obtained. Statistically analyzed the large number of width coefficient of settlement and its control parameters by fitting. Obtain the empirical value of the width parameters of the settlement under each geomorphic units. And predict the impact range of the settlement under different geomorphic units. The average width settlement value of the Yangtze River floodplain is 12M and the K value is 0.381.The average width settlement value of the ancient Qinhuai River is 11.3M and the K value is 0.313.The average width settlement value of the first grade terrace of the Yangtze River is 9.96M and the K value is 0.303.

1. Introduction

Nanjing is located in Ningzhen combined with the low hills and the valley plain of the lower reaches of the Yangtze River, with complex geological and geomorphic conditions. There are various kinds of rock and foundation soil that make up the building foundation and showing completely different engineering characteristics (Luo, 1998). There are three-fourths area located in the Yangtze River and the Qinhuai River ancient river area. The stratum is weak and the engineering geological conditions are poor. Because of the excessive or uneven settlement during construction, the safety and operation of existing buildings, urban underground and underground pipelines will be affected. Therefore, the research of settlement and deformation in the construction process of subway engineering in Nanjing area has attracted the attention of the industry. For the study of surface settlement, the theoretical method, numerical simulation analysis method or empirical formula method (Jiang et al., 2004) (Kasper and Meschke, 2006) are often used. In the analysis of the influence factors, we considered the influence of the buried depth or the construction factors mostly, and the effects of the geological conditions and their changes are seldom considered. The construction parameters of the shield method are complex and changeable, and there are great differences in different regional geological conditions. The theory method can not be applied to the prediction and research of the ground settlement caused by shield construction in different areas and different geological conditions. The field measured data is often more valuable. Zhu Caihui and Lining (Zhu and Li, 2017) studied the maximum settlement value, settlement width coefficient and ground loss rate of subway tunnels under different Overburden ratio, different Stratigraphic conditions and construction methods. Overburden ratio Stratigraphic conditions based on the measured settlement data of the subway. But all of them are analyzed in the area unit, but not by the geomorphic units. In fact, the geological conditions of the same geomorphic units in different regions are often similar, and it is more scientific to study the law of the settlement in the form of a geomorphic unit. This paper combines the soil characteristics and the surface subsidence monitoring data in the different geomorphologic units of the Longjiang Railway Station - Yunnan Road Station of Nanjing Metro Line 4 based on this background. Study the influence range of surface settlement under different geomorphic units and the relationship between the parameters and the settlement is set up. Therefore, the applicability of the traditional empirical formula in soft soil area is corrected, which can more accurately reflect the range and extent of settlement under differrent geomorphic units by shield construction.

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1.1 Ground settlement caused by construction of shield method

1.2 Monitoring point layout

The section of Longjiang Railway Station to Yunnan Road Station. Setting up a group of surface settlement monitoring sections with a length about 30m perpendicular to the line each 10 meters along the middle line of the tunnel in encrypt area of end well and each 30 meters in driving section. There are 7 monitoring points on each section, as shown in Figure 1.

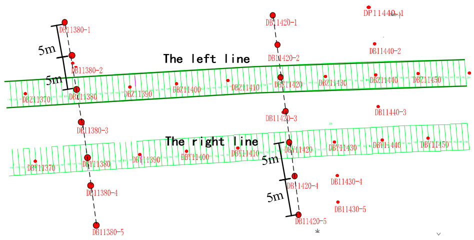

Figure 1: Site monitoring point schematic diagram

1.3 Research of settlement sink wide under different geomorphic units

The settlement of the ground surface caused by the shield machine in the course has three dimensional space effect, and the settlement range is gradually increasing from bottom to top, and eventually tends to be stable. The size of the settlement is related to the shield tunnel distance and the largest amount of settlement is in the vault of the lining. Settlement attenuates with the increase of the shield tunnel distance. As shown in Figure 2, the settlement sink curve is conforming to normal distribution on the cross section. The width of the curve is influenced by the depth of the tunnel and the geological conditions. In 1969, Peck(Peck, 1969) first pointed the theory of transverse distribution of surface settlement similar to normal distribution curve in the Mexico Institute of geotechnical studies, and gave the estimation formula of transverse settlement:

$$S(x) = S_{max} \exp\left(\frac{X^2}{2i^2}\right) \tag{1}$$

$$(x) = S_{max} \exp\left(\frac{X^2}{2i^2}\right) \tag{2}$$

$$B=2.5i \tag{3}$$

In the formula: *S(x)*—Ground settlement caused by formation loss distance from the middle axis of the tunnel at point X, *m*; ; S_{max} is maximum lateral settlement of surface caused by the loss of the stratum,*m*; *x* is the distance to the axis of the tunnel, *m*; *i* is the width coefficient of the surface settlement sink, *m*; *R* is the radius of tunnel excavation, *m*;V_S is stratum loss for the unit length of the tunnel,m^3/m;B is the width of the settlement sink, *m.*
Based on the experience of O 'Reilly and New in the London region, There is a simple linear relationship between and *i* and the depth of the tunnel Z_O:

$$i = KZ_0 \tag{4}$$

In the formula: K value depends on the properties of the soil, which is called the width parameter of the sink. According to the actual engineering experience of the London area, it is generally believed that the value of the cohesionless soil is between 0.2~0.3; For hard clay, it is about 0.4~0.5;For soft clay, it can be 0.7.
Due to the influence of the formation thickness, the tunnel curve section and the former tunnel in the left or right line affected the another side. The curve of the actual settlement sink is asymmetrical. Therefore, this paper adopts the Gauss peak function which has the normal distribution property and the settlement slot deviation can be considered in Formula 1. It can be considered as the supplement and optimization of the Peck formula, which is more consistent with the engineering practice.

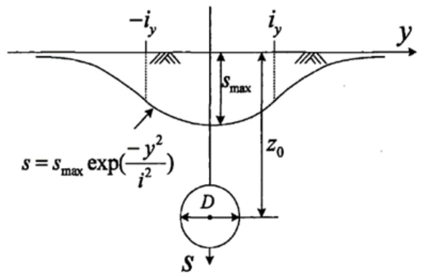

Figure 2: Settling tank schematic diagram

$$y = y_o + Aexp\left(-\frac{(x - x_c)^2}{2w^2}\right) \tag{5}$$

In the formula: *x* is the horizontal distance from the settlement point to the axis of the tunnel,m; y is the settlement of cross section, mm;y_o, A, x_c, w is fitting coefficient,for y_o, if $x \to \infty$, then $y = lim_{x\to\infty}\left(y_o + Aexp\left(-\frac{(x-x_c)^2}{2w^2}\right)\right)$。 So y_o is the settlement of the measured points away from the center line of the tunnel,mm;Derivation of *y* for derivative, if $y' = 0$,get $x = x_c$, x_c is the distance from settlement point corresponding to the maximum settlement to the center line of the tunnel, *m;* y_o+A is the maximum settlement *Smax* , *mm* ; *w* is a parameter that mainly affects the width of the settling tank. *i* is width coefficient of the sink

After sorting out all the cross section monitoring data in the geomorphic unit, and eliminating a small number of invalid data, we use Orgin software to fitting, and select the typical settlement sink curve to analyze.

As in Figure 3, the settlement sink in the floodplain of the Yangtze River is deep and wide, The width of the settlement sink before the reverse bending point is narrow, and it increases rapidly after the reverse bending point. Table 1 is a typical settlement curve fitting coefficient, The reference coefficient X_C shows that the right line construction after the left, the maximum settlement value of the left line shifted to the right side of the axis.

Table 1: Typical cross section settlement fitting parameters of the Yangtze river flood plain

	y_o	A	X_C	i
Left 11260	-25.12 ± 2.62794	-50.17069 ± 3.57722	0.56427 ± 0.26752	3.77475 ± 0.33539
Right 11260	-22.19631 ± 3.96452	-45.97635 ± 5.47277	-0.36379 ± 0.44717	3.75939 ± 0.54093
Left 11330	-11.88939 ± 1.40906	-38.53586 ± 2.06048	0.50656 ± 0.20253	3.56442 ± 0.2268
Left 11330	-11.51679 ± 2.67796	-43.78996 ± 4.35649	-0.08154 ± 0.39669	3.13665 ± 0.34517

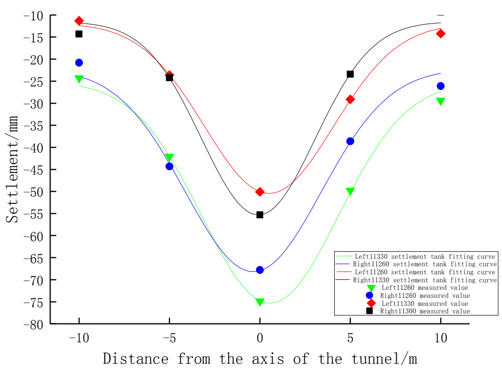

Figure 3: Typical settlement tank fitting curve of the Yangtze river flood plain

According to the fitting results, replace *i* the into formula (3) and get the sink width *B* , place it into formula (4) get the Parameter *K* of controlling the width coefficient of the settling tank, As shown in Figure 4.

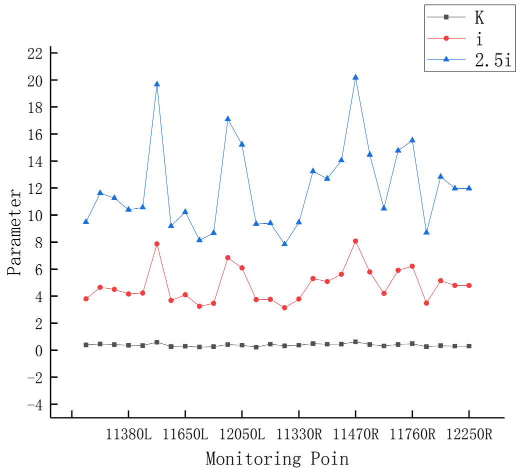

Figure 4: Settlement tank width parameter of the Yangtze river flood plain

According to the principle of statistics, for the all fitting number of the settlement sink width coefficient parameter K and the width coefficient I of the Yangtze River floodplain are described by descriptive analysis. As a result of Table 2,It can be seen that the average value of the parameter K determining the width coefficient of the sink is 0.3813,The standard deviation of the average value is only 0.0188 and the variance is only 0.0099.It shows that the mean value is very descriptive. The K=0.3813 in formula（4）when estimation of the width of the settlement sink in the flood plain of the Yangtze River.

Table 2: The Yangtze river flood plain settlement tank width coefficient and coefficient parameters descriptive statistical

	Mean statistical value	Mean standard deviation	variance
Parameters of the width coefficient of the sink K	0.381308	0.018813	0.009910
Width coefficient of sink i	4.799061	0.252475	1.784827
Sink width 2.5i	11.997654	0.631188	11.155167

Typical cross section settlement fitting parameters of ancient Qinhuai River in Table 3, The shape of the settlement sink of geomorphic unit in the ancient Qinhuai River is similar to that of the floodplain of the Yangtze River, that is deep and wide. The difference is that the width of the sink is more uniform, and the width is increased from the bottom to the top, and the width is slightly smaller than that of the floodplain of the Yangtze River, as shown in Figure 5.

Table 3: Typical cross section settlement fitting parameters of ancient Qinhuai River

	y_o	A	x_c	i
Left 12500	-3.20553 ± 1.67789	-26.19862 ± 1.50772	0.75313 ± 0.12648	5.55965 ± 0.41076
Right 12500	-2.8274 ± 5.94675	-17.13869 ± 5.70891	-1.74348 ± 1.07006	5.01294 ± 2.35428
Left 12535	-3.23556 ± 0.83334	-27.36356 ± 1.03621	0.1313 ± 0.14034	4.05162 ± 0.19642
Right 12535	-0.38128 ± 0.1792	-31.6748 ± 0.20248	0.44177 ± 0.02316	4.27842 ± 0.03746

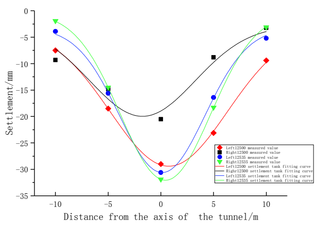

Figure 5: Typical settlement tank fitting curve of acient Qinhuai riverway

As in Figure 6. With the descriptive analysis, the width of the settlement sink parameter values are very concentrated of the geomorphic unit of the ancient QinHuai River ,The results are as shown in Table 4, the average value of parameter K is 0.3122, the average standard error is only 0.0203, and the variance is only 0.0075.

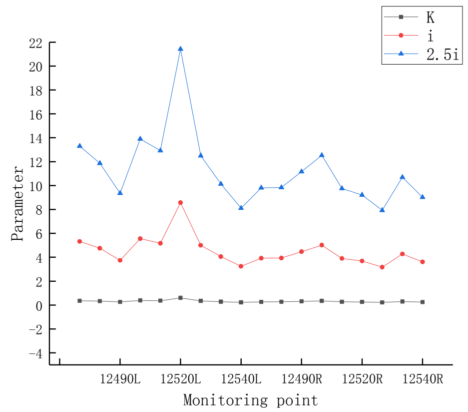

Figure 6: Settlement tank width parameter table of acient Qinhuai riverway

Table 4: The acient Qinhuai riverway settlement tank width coefficient and coefficient parameters descriptive statistical

	Mean statistical value	Mean standard error	variance
Parameter of width coefficient of settling sink K	0.312192	0.020389	0.007483
Width coefficient of sink i	4.520346	0.291520	1.529715
Sink width 2.5i	11.300864	0.728801	9.560721

As in Figure 7, the settlement sink of the first grade terrace Yangtze River Terrace is shallow, The depth is the smallest among the three geomorphic units. The width of the settling tank is relatively small, all around 9.96M.It can be seen that the influence of surface settlement under this geomorphic unit is less than other two geomorphologic units.

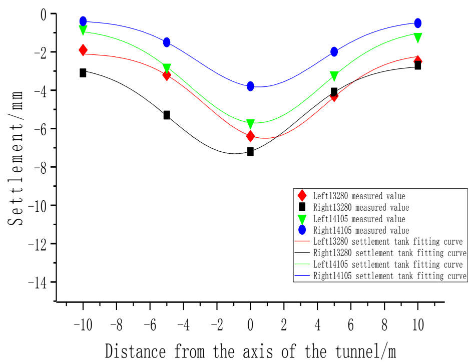

Figure 7: The Yangtze river first grade terrace settlement tank fitting curve

Coefficient of settling tank and its control parameter K of the Yangtze river first grade terrace geomorphic units shown in figure 8 and Table 5, The average value of K under this geomorphic unit is 0.3032, the average standard error is only 0.0137, and the variance is only 0.0123.

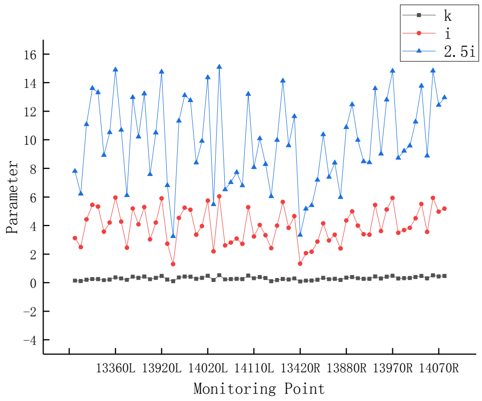

Figure 8: Settlement tank width parameter of the Yangtze river first grade terrace

Table 5: The Yangtze river first grade terrace settlement tank width coefficient and coefficient parameters descriptive statistical

	Mean statistical value	Mean standard error	variance
Parameter of width coefficient of settling sink K	0.303160	0.013672	0.012337
Width coefficient of sink i	3.983825	0.149719	1.479444
Sink width 2.5i	9.959562	0.374298	9.246523

2. Conclusion

By analyzing the fitting curve of the settlement sink, it is found that the width and depth of the settlement sink under each geomorphic unit is in the same order. The geomorphic unit of the Yangtze River floodplain > Qinhuai River ancient river geomorphic unit > the Yangtze river first grade terrace unit.
The settlement sink in the floodplain of the Yangtze River is deep and wide, The width of the settlement sink before the reverse bending point is narrow, and it increases rapidly after the reverse bending point. The average value of the sink width is 12M, and the value of K is 0.381 when calculating.
The depth shape of settlement sink in the ancient QinHuai River is larger but the width is less than the floodplain of the Yangtze River. The average value of the sink width is 11.3M, and the value of K is 0.313 when calculating.
The depth of the settlement sink on the first grade terrace unit of the Yangtze River is very shallow, and the width of the settlement sink is relatively smaller. It is around 9.96M and the value of K is 0.3032 when calculating.

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