Academic Journal of Engineering and Technology Science
ISSN 2616-5767 Vol.4, Issue 5: 44-47, DOI: 10.25236/AJETS.2021.040508

Study on Estimation Method of Ground Settlement around Pile Foundation Caused by Dewatering

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Abstract: *According to the character that the seepage amount of pile foundation is large during the construction period in karst water-rich area, and take the fact that the drops of water level lead the settlement of the ground around the pile foundation into account, a method of surface settlement estimation based on diving full well and steady seepage was analyzed. According to the seepage theory, the effective stress increment of soil unit around the pile foundation was deduced. By means of the double integral within the scope of two-dimension range, the settlement due to seepage effect and its estimation formula of surface around the pile foundation was analyzed. On the basis of real project of NO.3 section of Hechi-Du'an Expressway in Guangxi Zhuang Autonomous Region, the ground settlement was forecasted through the way of field measurement and formula estimation respectively. Facts and figures show that the measured value is consistent with the estimation value, but within the scope of 3m apart from the pile edge, the measured value is greater than the estimation value. The result can provide certain reference for the forecast of ground settlement created by dewatering.*

Keywords: *Pile foundation, Ground settlement, Seepage, Estimation method, Karst area*

1. Introduction

The pile foundation is buried underground, and it has to pass through the complex underground soil layer in the process of excavation. In areas with abundant groundwater, the pile foundation is easily affected by groundwater and other bad geological bodies [1-2]. The excavation of the pile hole provides a free surface for the lateral movement of the soil around the hole and a new path for the seepage of groundwater. Compared with large-scale foundation pit, the excavation area of pile foundation hole is smaller. Relevant research and engineering practice show that the lateral displacement and vertical settlement of the soil around the pile hole caused by soil excavation are small, and the settlement caused by precipitation seepage of groundwater should be mainly considered in actual analysis and estimation [3]. Pumping water in the pile foundation hole leads to the drop of groundwater level, which on the one hand makes the pore water pressure dissipate and transfer to effective stress, which increases the effective stress of the self-weight of the soil unit around the pile and makes the soil particles contact more closely. On the other hand, according to seepage theory, vertical seepage under the action of water head difference will also exert hydrodynamic pressure on soil particles, which will cause additional settlement of soil particles under the action of seepage [4]. The increase of the effective weight stress and the vertical hydrodynamic pressure will cause the soil particles to become more dense and consolidated, and show settlement in the vertical direction. Obviously, the settlement of the soil is directly related to the stress change of the soil unit, and pumping water in the pile hole will inevitably cause the groundwater level to drop, and then cause the stress change of the soil around the pile hole.

According to seepage and consolidation theory, this paper studies the surface settlement of soil around pile foundation hole under the condition of dewatering in the hole. The incremental changes of self-weight effective stress and seepage effective stress under precipitation seepage are analyzed, and the settlement estimation formula of the surface around the pile hole under the influence of dewatering in the hole is obtained. The actual engineering test shows that the estimation method has certain validity and reference.

2. Variation of Seepage Effective Stress

It is assumed that along the horizontal surface and the vertical depth is X and Y direction respectively. Take any soil element at the depth of h in the soil. The length of the element in X, Y and Z

directions is dx, dy and 1 respectively. The original groundwater level depth is h_0, and the hole depth is H. The soil below the groundwater level is in a saturated state. The bulk density of the soil within h_0 and the soil below the groundwater level are γ_0 and γ' respectively, and the pore water pressure is σ_ω. During excavation, the influence of construction dynamic load on the initial stress of soil around the pile hole is not considered [5].

According to the seepage theory, when groundwater generates seepage, it will exert hydrodynamic pressure on soil particles. When the direction of hydrodynamic pressure is downward, soil particles will sink under the action of water pressure and become more dense [6]. The subsidence value of soil particles is obviously related to the hydrodynamic pressure. As for the calculation of hydrodynamic pressure, Lianju Yuan and others think that the hydrodynamic pressure acting on the soil unit is related to hydraulic gradient, which can be calculated by Formula 1 [7].

$$D_\omega = i\gamma_\omega \tag{1}$$

Where i is the hydraulic gradient and it is dimensionless. D_ω gives soil particles additional seepage effective stress. In order to calculate this stress, it is assumed that seepage only occurs in the vertical direction. At this time, the seepage effective stress can be calculated by estimating the ratio of hydrodynamic force acting on the volume to the flooded area, as shown in Formula 2.

$$\sigma_D = DV / A \tag{2}$$

Where V is the product of area A and vertical path, and vertical path can be calculated by formula 3. Where f(X) is the precipitation funnel curve function, and X is the horizontal distance.

$$h_{\mathrm{P}} = h - f(\mathrm{X}) \tag{3}$$

Combining the above three formulas, the expression of effective seepage stress can be obtained, as shown in Formula 4.

$$\sigma_D = i\gamma_\omega[h - f(\mathrm{X})] \tag{4}$$

3. Estimation of Ground Settlement

3.1. Analysis of Total Settlement

Assuming that the soil particles around the pile hole are in continuous contact with each other in the vertical direction, when the unit soil is compressed vertically, the upper one of the unit will move downward at the same time and interact with each other in turn and eventually spread to the surface. According to the random medium theory, it can be known that the accumulation of small vertical compression in soil will produce a small unit concave on the surface, which is expressed by W_d and the vertical settlement value of the concave center can be estimated by formula 5 [8].

$$W_d = \frac{\tan\beta}{h} e^{-\frac{\pi \tan^2\beta(\mathrm{X}-X_0)^2}{h^2}} \tag{5}$$

Where β is the influence range angle of the stratum where the pile hole is located, which can generally be obtained from the previous geological survey data. X_0 represents the distance between the edge in the horizontal direction of the unit body and the edge of the pile hole, unit: m.

Obviously, if the two-dimensional reintegration estimation of the concave of all micro-units within the scope of the precipitation funnel is carried out in the region composed of X and Y axes, the ground settlement within the scope of the precipitation funnel can be estimated, that is, the total surface settlement can be expressed by Formula 6, where d_s is the vertical micro-compression of soil caused by precipitation seepage, and its expression is shown in Formula 7 [9-10].

$$W = \iint_\Omega W_d \, ds dx \tag{6}$$

$$ds = \frac{ia[h - f(X)]\gamma_\omega + 2a(h - h_0)\gamma_\omega}{1 + e_0} dh \tag{7}$$

Where a is compaction factor and it is dimensionless.

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3.2. Classification Estimation Analysis of Ground Settlement

In the process of precipitation seepage, the settlement of soil around the pile hole is contributed by two parts, one is the increment of self-weight effective stress, and the other is the increment of seepage effective stress. The funnel curve of soil around the pile changes with the continuous precipitation. The soil above the funnel curve will become sparse, and the soil below the funnel curve is in the seepage state. Therefore, the settlement of soil between the original water level and the funnel curve is caused by the increment of self-weight stress, and the soil particles become more dense. For the soil below the funnel curve to the top of the water level in the hole, the settlement is due to the seepage hydrodynamic pressure.

Therefore, when estimating the ground settlement, the funnel curve should be taken as the dividing line, and the soil around the pile should be divided into upper and lower regions for two-dimensional reintegration calculation to estimate the ground settlement of the soil.

For the part of the soil between the original water level line and the funnel curve, the integral interval of X and Y direction is (0-R) and (h_0-f(X)) respectively. At this time, formula 8 can be used to estimate the settlement value of this part.

$$W_1 = \int_0^R \int_{h_0}^{f(X)} \frac{\tan\beta}{h} e^{-\frac{\pi \tan^2\beta (X - X_0)^2}{h^2}} \bullet \frac{2a(h-h_0)\gamma_\omega}{1+e_0} dhdx \tag{8}$$

For the soil between the funnel curve and the top surface of the water level in the hole, the integral intervals in X and Y direction is (0-R) and [f(X)-(H−h_0)] respectively and then the settlement value can be estimated by Formula 9.

$$W_2 = \int_0^R \int_{f(X)}^{H-h_0} \frac{\tan\beta}{h} e^{-\frac{\pi \tan^2\beta (X - X_0)^2}{h^2}} \bullet \frac{ia[h - f(X)]\gamma_\omega}{1+e_0} dhdx \tag{9}$$

4. Engineering Example

According to the above analysis, based on a pile foundation project of Hechi-Du'an Expressway in Guangxi Zhuang Autonomous Region, the above estimation formula was used to estimate the ground settlement under the condition of dewatering in the hole.

The above estimation formula is only derived formula. If manual estimation is used, the workload is too large and the actual feasibility is too low. Therefore, the computer language of C++ was used to compile the estimation reading program in the actual estimation.

The pile hole was located in a farmland. The surrounding area was rich in groundwater and was susceptible to atmospheric precipitation. In the actual excavation, the water inflow in the hole was large. In order to ensure the stability of the hole, the construction group decided to pump and reduce the pressure in the hole. In order to analyze the effectiveness of the estimation results, the monitoring method of ground surface settlement value was used to verify the estimation results. In order to prevent the influence of surface subsidence on the observation datum points, the datum points were arranged on the stable bedrock in the actual monitoring, and these points were set up according to the relevant provisions of the measurement specifications, so as to verify the stability of the observation through joint measurement.

The observation points were set from the edge of the pile hole. Theoretically, the first observation point should be set at the edge of the pile hole, but this setting method was not conducive to the actual construction operation. Therefore, the first observation point was set at 2m away from the edge of the pile hole.

The final results show that the measured values were generally close to the estimated one. Figure 1 shows the farmland surface cracking caused by dewatering in the pile hole. This picture shows that the ground around the pile foundation has produced obvious settlement and cracking. This shows that when there is obvious seepage in the pile foundation hole, special attention should be paid to the settlement of the surface.

Karst strata are widely distributed in southwest provinces of China. Underground water is often rich and prone to seepage and surface settlement. In the excavation construction, the surface settlement should be estimated and observed in time.

Figure 1: Surface settlement and cracking

5. Conclusions

The engineering practice shows that large water gushing is easy to occur in the construction of pile foundation in water-rich areas. Based on this, this paper analyzes the estimation method of ground settlement around the pile hole caused by dewatering in the pile foundation hole according to the seepage and consolidation theory. The real project shows that the estimation method is practicable.

In addition, it should be noted that the influence of soil particle loss in the soil around the pile on surface settlement cannot be ignored in the near range of pile hole.

Acknowledgements

This work was supported in part by the Science and Technology Research Project of the Education Department of Jiangxi Province under Grant GJJ204903.

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