Discussion on Negative Skin Friction of Piles in Collapsible Loess

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Abstract: The negative friction resistance of pie foundation is a neglected problem in the foundation engineering, especially in the loess subgrade area of northwest China. The article begins with an introduction to its formation mechanism and influential factors, then it analyzes theoretically and ensures the neutral point location of negative friction resistance. Next the paper combines the majority of researches to conclude the neutral point of self weight collapsible soil layer which ranges between 0.6 to 0.75 l0. What's more, according to the theory of elastic force transfer model, it states the calculation of the negative skin friction by adopting effective stress method.

Keywords: Formation mechanism; Influencing factors; Neutral point location; Calculation

1. Introduction

As a form of bearing foundation, pile foundation is widely applied on condition that bearing capacity is high in building land or the geological setting of horizontal load is not good. It has a lot of advantages including high stiffness, high bearing capacity, good stability, small settlement and so on, and will gain considerable economic results and technical measures. In the northwest collapsible loess region, the superiority of pile foundation will be showed clearly when other foundation treatments can not meet the demand of local geological conditions and collapsibility.

When it comes to the treatment and application of pile foundation in collapsible loess subgrade, Mingzhen Liu proposed the computational problem about negative skin friction by integrating the place containing self-weight collapsible loess[1]. Jingjing Qi, a student of Zhejiang University, she concluded the distribution of pile side negative frictional resistance and influence factors of bearing capacity through a submerging test under the collapsible loess[2].All of the above researches have analyzed the effect of negative skin friction in the collapsible loess. Aiming at the collapsible loess subgarde of West Highway in Ningxia, the paper discusses the pile foundation calculation of negative skin friction.

2. Concept Introduction of Pile Skin Friction

When two kinds of objects are contact and produce relative displacement, the friction force is generating. Similarly, relative displacement occurs between the soil around pile and pile side, that is to say, there is a zone of negative friction in pile side. When the pile of soil is subjected to the upper load which is passing through the pile foundation, the pile of soil prevents the pile foundation from sinking, in the other words ,the soil around pile has a strong supporting role to pile foundation, which is known as the positive friction, as Figure 1. If the soil around pile caused sink by geological subsidence, it gets downward movement relation in relation to the pile side, that is, the force acting on the unit area of the pile is called negative skin friction, as shown in Figure 2.The positive friction can hinder the pile sinking, which is beneficial to the bearing capacity of the pile foundation, however the negative frictional resistance can accelerate the sinking of the pile, resulting in the drop-down load, which is not conducive to pile foundation.

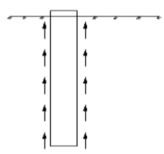

Figure 1. Schematic diagram of positive friction

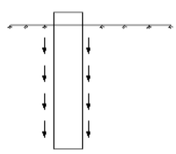

Figure 2. Schematic diagram of negative friction

3. The Formation Mechanism and Influencing Factors of Negative Skin Friction

The generation of negative skin friction increases the burden of pile and reduces the bearing capacity, it is necessary to point out that the negative skin friction is not an essential attribute to the pile foundation, and if the negative skin friction exists a bad layer, it should be considered in the design calculation.

3.1 Formation mechanism of negative skin friction

The collapsible loess is different from the general cohesive soil in nature, there are some characteristics to collapsible loess , such as structural properties, incomplete consolidation, collapsibility, and the multi-arch tunnel of highway has complex excavation steps and structure stress, however the sensitivity of the water is high, when the loess meets water, it will produce a large deformation, lead to structure changes and the carrying capacity rapid declines, it is easy to produce negative skin friction after pile foundation engineering operations, and the location distribution of the negative friction is based on the relative displacement between the pile of soil and the pile side. The neutral point position is shown as Figure 4.

Assuming that the soil around piles and pile side are on the same plane ,as Figure 3. AB indicates the settlement curve of the soil around pile. CD indicates that the pile foundation is subjected to the downward displacement due to the upper load, including the its own compression displacement Ss and the pile of tip displacement Sp, in the end, the curve AB intersects curve CD at point O, the point relative displacement between the pile side and the pile of soil is zero, the frictional resistance at the point is also zero., the side frictional resistance of pile is shown as Figure 5, so the point is called the neutral point, the maximum axial pressure at the point is N, such as Figure 6.

above the neutral point, the amount of soil subsidence is more than the displacement of pile body and the soil around pile makes an negative effect on friction of pile side; below the neutral point, the amount of pile soil subsidence is less than the displacement, soil around pile makes an positive effect on friction of pile side, as shown in Figure 4.

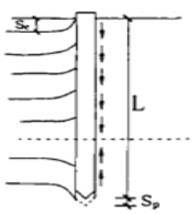

Figure 3. Distribution of negative skin friction

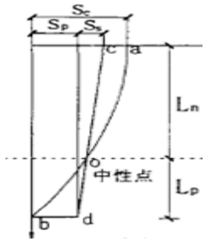

Figure 4. Theneutral point position

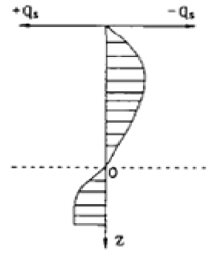

Figure 5. Side frictional resistance of pile

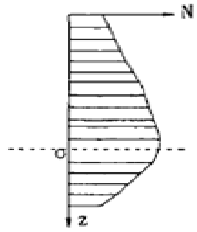

Figure 6. Axial pressure of pile

3.2. Negative friction resistance factors

Many factors affect the negative skin friction of collapsible loess subgrade, mainly divided into the following two categories.

1) Pile type

On the same site of collapsible loess layer, the pile type is different, and the negative skin friction resistance is different. For example, it is easy to compact in the process of precast pile, the compaction of solid soil adhered to the surface of pile side, which formed a certain area of shell, becoming a part of the pile body and increasing the surface area of pile side.

When the loess is immersed in the scope of activity section pile, the pile side around soil is also associated with the sinking, thereby affecting the pile body, so the negative skin friction resistance of precast pile in the unit area is larger than that on the surface of the pile[3].

2) The amount of collaspsibility influence

In general, the bigger settlement around the pile of soil is, the higher the negative skin friction of pile sideis[3]. But the experiment shows that there is no certain proportion relationship between the settlement and the negative skin friction. For example, the amount of collapsibility in Lanzhou test area is 75.4cm,the amount of collapsibility in xi 'an test area is 2.9cm,but the negative skin friction of pile foundation which is measured in lanzhou is 2 times than xi 'an’s, it indicates that the size of the negative skin friction is influenced by the shear strength of the soil.

The greater thickness of the soft soil is, the greater the negative skin friction formed .The higher compressibility of soft soil layer is, the greater the negative skin friction formed. The greater amount of collapsibility is, the greater the negative skin friction formed[4].

3. The calculation method of negative skin friction

3.1. Neutral location

The depth of neutral point Lnis connected with geological conditions, the nature of the soil, the type of pile and bearing layer and so on[5].In theory, the settlement of pile and the pile sinking can be determined according to the condition, however in fact the position of the neutral point can not be calculated accurately. As shown in fig.4,the smaller settlement Sp of pile tip is, the bigger Ln is, so as if Sp=0, then Ln=1, the negative friction is took possession of whole pile side.

About the location change of neutral point, some foreign researchers, at the beginning ,believe that the location of neutral point is changing, end with stable at a certain point, generally 0.7~0.8 times the length of the pile[6] The literature[7] also considers that the neutral point is usually located in the 0.77lo~0.80 lo of the self weight collapsible loess. In China, by doing many experiments, GuangyuLi[8]prove that the neutral point of the single pile negative friction resistance is 0.66 times of the length of the pile. According to the code of pile foundation, the depth of the neutral point about clay soil and silt soil is generally at 0.5~0.6l0, and the depth of the neutral point is 0.6~0.7l0 when the pile crosses the self weight collapsible loess layer[6]. According to the collapsible loess field test of negative skin friction resistance and the existing research results, In the literature, it is considered that the depth of neutral point is usually at 0.6~0.8l0 in the self weight collapsible loess layer and the bedrock of the force bearing layer[10]Therefore, the depth of the neutral point is generally in the range of 0.6~0.75l0 in the area of the self weight collapsible soil layer.

3.2. Calculation of negative friction resistance

The negative friction calculation of pile foundation has been paid attention to by the engineering circles, the domestic and foreign experts, and they have done a lot of theoretical research and experimental analysis. The main types are: experience and effective stress method, load transfer method, elastic theory analysis method, finite element software analysis method. Among them, Johanessen and Bjerrum combined with most effective stress method, they put forward the effective stress method which is more classic, and becoming a wide application in the actual project[11]. Although load transfer method has been stressed, its model only based on any point pile displacement and the shear stress, and it is not relate to other points of stress, and also did not take into account the soil continuity, the paper combined analysis model level of elastic theory with effective stress method to explain the calculation of negative skin friction.

1) Negative friction force transfer model

Let's assume that the pile soil have settlement, take away the convex micro unit of soils from distance r, thickness dr, height dz of pile side ,then we analyzed the unit, as shown in its force of Figure 7.

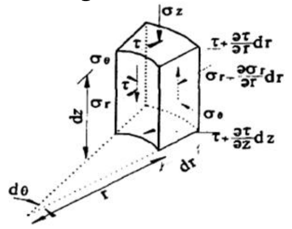

Figure 7. Stressstate of soil element in pile

Because σ_z , τ force changed in the vertical direction and horizontal direction is so small, we ignore the influence between radial force and tangential force, the balance equation is:

$$\frac{\partial(r\tau)}{\partial r}+r\frac{\partial(\sigma_z)}{\partial r}=0 \quad (1)$$

Randolph.M.F. and Wroth.P.C put forward that when the pile is subjected to the load, the change of the pile side friction in the vertical direction is less than that in the radial direction, also to reply $\partial(\sigma_z) << \partial(r\tau)$

Therefore, the formula (1) is $\frac{\partial(r\tau)}{\partial r}=0$

According to the boundary conditions: $r=r_o$, $\tau_o=q_s$,

So it is $\tau=\frac{q_s r_0}{r}$

For calculation of shear strain $r=\frac{\tau}{G_s}=\frac{\partial_\delta}{\partial_\gamma}+\frac{\partial_u}{\partial_z}$

alone the depth change, U represents radial displacement and it is too small, so the formula type into: $r=\frac{\tau}{G_s}=\frac{\partial_\delta}{\partial_\gamma}$

It is that $\frac{q_s r_0}{G_s r}=\frac{\partial_\delta}{\partial_\gamma}$

Integration, it is $\delta=q_s r_0\int_{r_0}^{r_m}\frac{d_r}{G_s r}$

It is based on elastic theory assumes that the transfer function expression of pile negative friction is formed.

2) Effective stress method[9]

Above the neutral point, negative skin friction standard of the i layer soil around single pile can be calculated and the following formula is

$$q_{si}^n=\xi_{ni}\sigma_i^{'} \quad (2)$$

If the backfill, self weight collapsible loess, the less consolidated soil layer or the lower water exists, negative skin friction can be calculated by the following formula, it is derived: $\sigma_i^{'} = \sigma_{ri}^{'}$

if the ground is distributed in space as large area:

$$\sigma_i^{'} = p + \sigma_{ri}^{'}$$

$$\sigma_{ri}^{'} = \sum_{m=1}^{i-1} \gamma_m \Delta z_m + \frac{1}{2}\gamma_i \Delta z_i$$

Where: q_{si}^n -the soil pile standard value of the negative friction resistance on the *i*th layer; When the formula (2)calculated value is bigger than the standard value of positive skin friction, the standard value of the positive friction resistance is designed;

ξ_{ni} -soil of pile negative friction coefficient on the *i*th layer according to the Table 1.

$\sigma_{ri}^{'}$ -The average vertical effective stress caused by the self weightloesson the *i*th layer. The group peripheral pile is calculated from the original ground surface, the group internal pile is calculated from the bottom of the pile cap

$\sigma_i^{'}$ -Average effective stress of soil of pile i on the ith layer;

γ_i, γ_m -Gravity degree of the *i*th soil layer and gravity degree of *m*th soil layer ,the underground water level is taken as the floating weight

Δz_i, Δz_m -Thickness of the *i*th soil layer and thickness of the mth soil layer

p -Uniformly distributed load on the ground

Table 1. Negative friction coefficient ς_n

Soil type	ς_n
Saturated soft soil	0.15~0.25
clay and silt	0.25~0.4
sand	0.35~0.5
self-weight collapse loess	0.20~0.35

Calculated by considering the effect of the drop-down load imposed on the pile

$$Q_g^n = \eta_n \cdot u \sum_{i=1}^{n} q_{si}^n l_i \quad \eta_n = S_{ax} \cdot S_{ay} / \left[\pi d \left(\frac{q_{si}^n}{\gamma_m} + \frac{d}{4} \right) \right]$$

the determination of mechanical parameters about exterior and interior are also in accordance with Terzaghi theory

For soft clay layer[12], it calculated by the formula $f_n = q_u / 2$ or $f_n = c_u$

Where: q_u -Unconfined compressive strength of soil

c_u -The undrained shear strength of soil, it can be used to determine the site of the cross

For the sandy soil $f_n = N/5+3$

N- $N_{63.5}$ standard penetration number

4. Conclusion

The paper introduced negative frictional resistance of pile foundation production mechanism and influence factors for collapsible loess subgrade, and the neutral point of negative friction was introduced in detail. The calculation method of effective stress of negative skin friction was also discussed in hopes of providing a reference for scholars.

At the same time, this is a very complex problem which involves pile negative friction resistance and the calculation of down load, the calculation of settlement is also influenced by the factors of pile and soil. Therefore, it is so difficult for apply theory to practice. There are some common problems in negative friction resistance, and it needs to be further researched and enhanced.

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