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Deformation Analysis of Micro Steel Pipe Pile Supporting Structure Considering Double Stiffness Model

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Abstract: On the basis of previous studies, this paper explains the working stress characteristics of micro steel pipe pile supporting structure, and puts forward a deformation calculation method considering anchor cable prestress. The working mechanism and mechanical properties of micro steel pipe pile supporting structure are expounded. A double stiffness calculation model considering anchor cable prestress is established, and the deformation calculation method of micro steel pipe pile supporting structure based on double stiffness model is deduced. The stiffness of the anchor cable obtained by this calculation method is smaller than that obtained by the current specification, thus increasing the size of the designed supporting structure and making the actual project safer.

In recent years, with the surrounding environment of foundation pit engineering becoming more and more complex, the construction space of foundation pit supporting structure has become more and more narrow, which makes it difficult for large construction machinery to enter the field, and some foundation pit projects do not even have the construction space of supporting piles. Therefore, it is an urgent need to find a new supporting structure with less space and simple construction technology for some narrow foundation pit projects. The micro steel pipe pile is in line with the above requirements because of its simple construction technology and small space occupied by construction machinery. However, due to its small bending stiffness and poor resistance to deformation, the application of hollow steel pipe in foundation pit engineering is limited. The prestressed anchor cable has the characteristics of actively changing the stress field and displacement field of the soil and limiting the strong deformation of the soil. Therefore, the prestressed anchor cable supporting structure of micro steel pipe pile can not only limit the displacement of soil, but also make the pile-soil-anchor work together to give full play to their respective advantages. It also overcomes the shortcomings of traditional concrete row piles, such as large amount of soil, large construction space and high cost, and is widely used in some slope and foundation pit projects.

For the mechanical behavior of micro steel pipe piles, Thompson [1] analyzed the deformation law of single and double steel pipe piles under horizontal load through experiments. Richards [2] et al. also analyzed the working performance of micropiles under lateral loading through experiments. Aomar Bensliinane [3]considered the dynamic response of reticulated micropile groups under vertical and horizontal earthquakes.

In recent years, with the application and promotion of micro pile, more and more experts and scholars on the basis of existing experience and traditional theory, the micro pile.

At present, the theoretical analysis methods for the deformation of the micro steel pipe pile supporting structure are mainly the limit foundation reaction method, the elastic theory method and the elastic-plastic foundation reaction method. These theories consider the stiffness of the anchor cable as a fixed value, without considering the change of the stiffness of the anchor cable and the surrounding soil before and after the prestressing. Therefore, starting from the prestress applied by the anchor cable, this paper studies the influence of prestress on the stiffness of the anchor cable before and after the prestress is applied, and proposes a deformation calculation method of the micro steel pipe pile supporting structure based on double stiffness, which provides a new idea for the deformation calculation of the micro steel pipe pile in the future [4-6].

1. Analysis of Working Principle of Steel Pipe Pile Supporting Structure

1.1. Characteristics of Micro Steel Pipe Pile

The diameter of the cast-in-place pile of micro steel pipe pile is generally between 100 mm and 300 mm, which belongs to the type of micro pile of ' small diameter and high strength '. It has some advantages of other micro piles and other special advantages due to the existence of steel pipe. In particular, when he is used as a supporting pile, he can easily enter the hard layer, and because of the radial restraint effect of the steel pipe on the concrete in the pipe, the three-way compression of the concrete in the pipe makes the steel pipe and the concrete in the pipe deform and bear the force together, so the overall strength of the steel pipe pile is also greatly improved compared with the concrete pile. At present, the micro-steel pipe pile is widely used in foundation pit support, foundation reinforcement, slope treatment and other projects with its main advantages. The main advantages of micro-steel pipe pile are:

(1) higher bearing capacity and smaller settlement ; due to the high yield strength of steel pipe, if the pile is in the bearing layer position, it can provide greater bearing capacity, and if it is a steel pipe pile with holes on the side of the pile, after pressure grouting, the slurry will penetrate into the soil around the pile, forming a composite pile larger than the pile diameter, improving the strength of the soil, increasing the friction resistance of the pile side, and also reducing the settlement of the pile.

(2) Good bending resistance; compared with the same diameter concrete pile or hollow steel pipe pile, it has greater bending resistance. The existence of concrete in the pipe reduces the possibility of local buckling of hollow steel pipe pile. The existence of steel pipe also improves the bending resistance of concrete, which makes this kind of micro steel pipe pile more suitable for horizontal load engineering.

(3) The pile size design is more flexible; according to different use requirements, the diameter of different piles and the thickness of steel pipe wall can be designed according to the site and load form, and the pile length can be changed on site by cutting and welding to meet the needs of the site.

(4) Construction is flexible and convenient, construction disturbance, engineering quantity is small; the concrete pile generally has a large diameter, a large amount of soil during drilling, and a large vibration and disturbance during drilling. The micro steel pipe pile can be used in the construction space.

1.2. Composition and Characteristics of Prestressed Anchor Cable Micro Steel Pipe Pile Supporting Structure

The supporting structure of prestressed anchor cable micro steel pipe pile is composed of two parts, as shown in figure 1, which are micro steel pipe pile and prestressed anchor cable ; the anchor cable is usually composed of free section, anchoring section and anchor head. The free section is generally steel strand or steel bar. The anchoring section fully bonds the rod body wrapped cement slurry with the soil, which is the bearing point in the anchor cable soil layer. The anchor head fixes the rod body and the pile; the steel pipe pile is usually composed of steel pipe, crown beam and concrete surface layer. After the borehole is placed in the steel pipe, the concrete should be poured into the steel pipe until the slurry return at the nozzle stops. It is necessary to note that there is another important member of the supporting structure-in-situ soil [7-9].

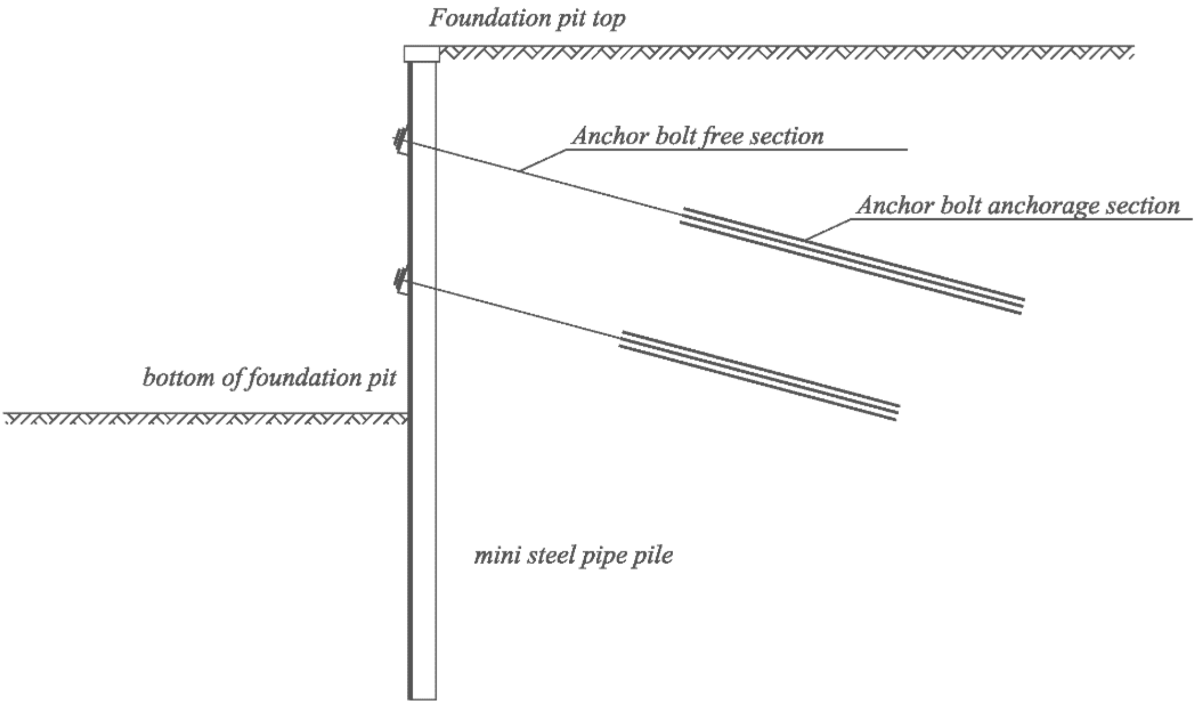

Figure 1: Prestressed anchor cable micro steel pipe pile supporting structure diagram

The prestressed anchor cable micro steel pipe pile supporting structure promotes its development and engineering application through its own superiority. Compared with ordinary concrete bored piles, the micro steel pipe pile supporting structure makes up for the shortcomings of traditional pile anchors through its construction space, construction period, load performance and mechanism. The advantages of traditional pile anchors are:

(1) The bending performance of the retaining pile is increased, and the deformation form of the retaining pile is changed, which greatly restricts the deformation of the foundation pit.

(2) It is not only suitable for the working conditions corresponding to the traditional pile anchor, but also more suitable for the narrow space of the site, the upper line of the foundation pit is close to the red line of the site, and the ordinary pile anchor cannot be constructed.

(3) Compared with ordinary pile anchor, it can save economy and shorten the construction period. The disturbance and vibration of the surrounding soil during construction are small, and the construction is convenient [10-11].

1.3. The Action Mechanism of Prestressed Anchor Cable Micro Steel Pipe Pile Supporting Structure

In the construction of foundation pit, the steel pipe pile is set up, and the foundation pit excavation can be carried out after the concrete reaches the strength. The construction of crown beam and anchor cable is carried out when the excavation reaches different heights. After the concrete of crown beam and the mortar of anchor cable reach the strength, the next excavation can be carried out. In the supporting structure of prestressed anchor cable micro steel pipe pile, both steel pipe pile and anchor cable are important force components. Because the anchoring section is in a stable soil layer, the soil and anchoring experience generate friction resistance. After the anchor cable is prestressed, the prestressing force will cause the rod body to pass through the waist beam. The steel pipe pile produces a tension in the direction of the outside of the pit. With the excavation of the foundation pit and the unloading of the soil in the pit, the soil behind the pile produces a certain displacement trend in the direction of the pit, that is, the earth pressure, the earth pressure and the resistance of the steel pipe pile, and the tension of the anchor cable are balanced. The deformation effect of the pile and the anchor cable is shown in Figure 2.

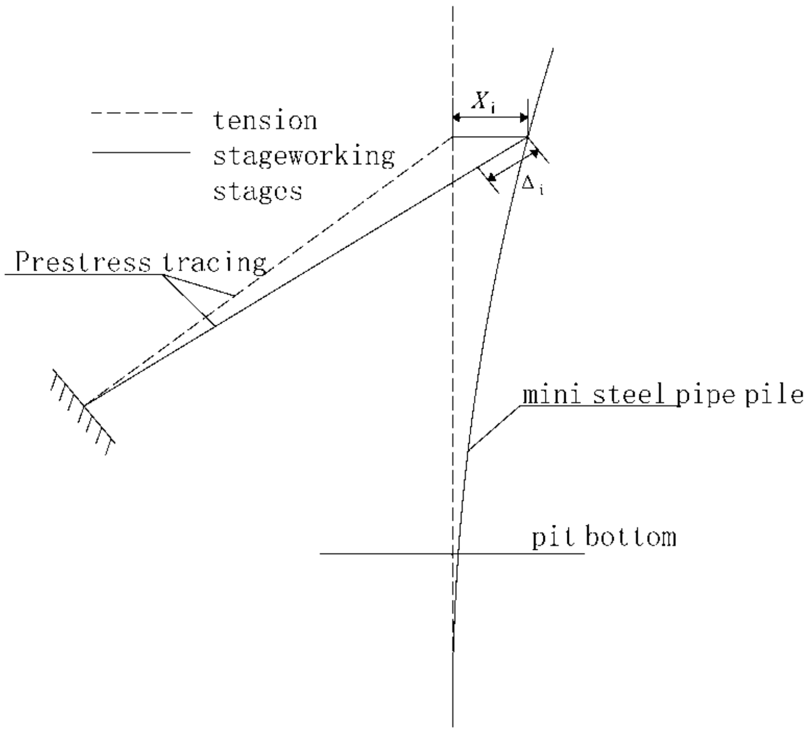

Figure 2: The interaction diagram of anchor cable and micro steel pipe pile

In the figure, Xi is the deformation of the pile body at this point, and Δi is the deformation of the anchor cable. Under the combined action of the anchor cable and the steel pipe pile, the soil pressure behind the pile is resisted. Compared with the cantilever pile, the supporting structure is more reasonable, the deformation is smaller, and the anti-overturning stability is greatly improved.

Prestressed anchor cable and steel pipe pile are common retaining systems, which provide anti-sliding force to prevent soil from sliding. The effect of prestressed anchor cable on steel pipe pile is mainly in two aspects [12]:

(1) The prestress makes the steel pipe pile change from the original free side compression to the retaining side compression, and the axial tension of the steel pipe pile increases, which improves its stiffness and horizontal resistance.

(2) Prestressing changes the mechanical model of the steel pipe pile cantilever, and reduces the internal force of the pile under the same sliding force, thus saving the economy.

The effect of steel pipe pile on anchor cable is as follows: with the increase of excavation depth of foundation pit, the soil pressure behind pile increases, and the deformation of pile to pit increases. The deformation of pile drives the deformation of anchor cable and the increase of axial force, which improves the stress relaxation phenomenon of prestressed anchor cable.

The role of the crown beam in the supporting structure cannot be ignored. The crown beam is a row of reinforced concrete coupling beams set on the top of the supporting pile to improve the overall stiffness and stability of the supporting pile and prevent the damage of the top edge of the pit. The crown beam plays a supporting and distributing role in the supporting structure, and transfers the force on the stronger supporting pile to the surrounding supporting pile to share together, so that a single supporting pile can be combined to resist the earth pressure. In some foundation pit design, anchor cable or internal support will be set at the crown beam. At this time, the crown beam is a flexural member, which plays a role in controlling the deformation of the foundation pit.

2. Double Stiffness Calculation Model Considering Anchor Prestress

2.1. Fulcrum Rigidity Coefficient

For the pile-anchor supporting structure, the elastic fulcrum method is mostly used to calculate the deformation of the supporting structure. The elastic fulcrum method regards the supporting structure as a vertically placed beam, and then establishes the deformation differential equation of the supporting structure according to the calculation principle of the elastic foundation beam, and then solves its deformation according to different boundary conditions. For the calculation of the support force Ti in the elastic fulcrum [13], the calculated displacement yi of the support point is subtracted from the displacement y0i before the support is set, and then multiplied by the stiffness ki of the support, as shown in Equation (1). This method is the total amount method, each step of the calculation load is the total load is not incremental load, so no superposition.

$$T_{\mathrm{i}} = k_{\mathrm{i}}(y_{\mathrm{i}} - y_{0\mathrm{i}}) + T_{0\mathrm{i}} \tag{1}$$

In the formula: ki is the spring support stiffness; yi is the calculated displacement of the support point; y0i is the displacement of the point before setting the brace; T0i is the pre-added axial force of the support.

In practical engineering, when the displacement is less than y0i, the stiffness of the support is not fully exerted, and the support only works when the displacement is greater than y0i. Therefore, if the stiffness ki is used in the actual calculation, the support stiffness is exaggerated, and the calculated displacement will be smaller, as shown in Figure 3.

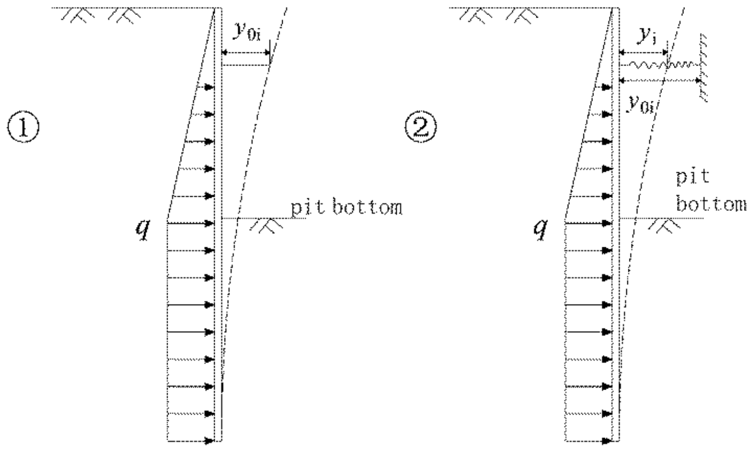

Figure 3: Support point displacement diagram

In Figure ①, the displacement of the support point is greater than or equal to y0i, so the corresponding stiffness is ki, and the stiffness is exerted. In case ②, the displacement does not reach y0i, so it is obviously inappropriate to use ki at this time. The equivalent stiffness ki needs to be used. The equivalent stiffness is obtained by repeated iterations of the displacement yi. The equivalent stiffness can be calculated according to the following formula:

$$k_i' = \frac{y_i}{y_i + y_{0i}} \cdot k_i \qquad (2)$$

For the first time, assuming y0i = 0, the displacement calculated by this formula is more reasonable.

After the anchor cable test in the loess layer, Wang Xiaoyong [14] et al.think that the anchor cable stiffness calculation given by the current specification is unreasonable, and the anchor cable stiffness obtained by the test is greater than the formula calculation result given by the specification. The anchor cable design in the loess area should be multiplied by the increase coefficient on the basis of the specification, and the increase coefficient is 1.25 ~ 1.40, which is more in line with the actual project.

Wang Hongxin [15] et al.proposed to simplify the unexcavated soil in the passive zone into two parallel springs during foundation pit excavation, as shown in Figure 4.

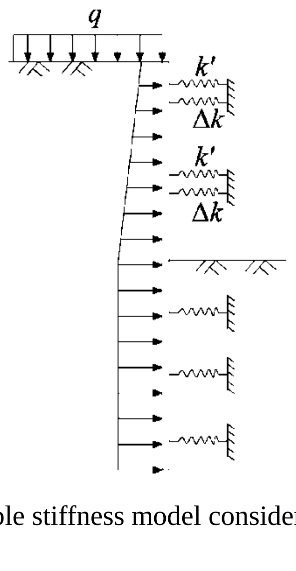

Figure 4: Double stiffness model considering excavation effect

Two springs simulate the stiffness of excavated and unexcavated soil respectively. This model is called double stiffness model, which can be expressed as:

$$K = k' + \Delta k = \beta K + (1-\beta)K \tag{3}$$

In the formula: K is the total stiffness of the excavated soil; Δk is the stiffness provided by the excavated soil; k′ is the constraint stiffness provided by the unexcavated adjacent soil; β= k′/K, is the residual stiffness rate.

Although the dual stiffness model can better reflect the actual situation, the β is difficult to determine.

2.2. Double Stiffness Calculation Model Considering Anchor Prestress

The construction and entering the working state of the prestressed anchor cable is not a one-step process, but a long process. In this process, the stiffness coefficient of the anchor cable cannot be simply determined as a constant value. Based on the in-depth study of many scholars in the previous section of this paper, a double stiffness calculation model considering the prestress of the anchor cable is proposed. This model is to decompose the force and stiffness of the anchor cable into three steps after the prestress is applied. The first step is that the anchor cable is applied to the state without considering the prestress. At this time, the anchor cable is like soil nailing, which is a passive force. At this time, there is a stiffness of the anchor cable k1; the second step is the process of applying prestress to the anchor cable. In the process of applying prestress, the anchor cable will have a stiffness of k2 ; the third step is to combine the first two steps into a whole, and the stiffness at this time is the total stiffness k after the final work of the anchor cable. The calculation model is shown in Fig.5.

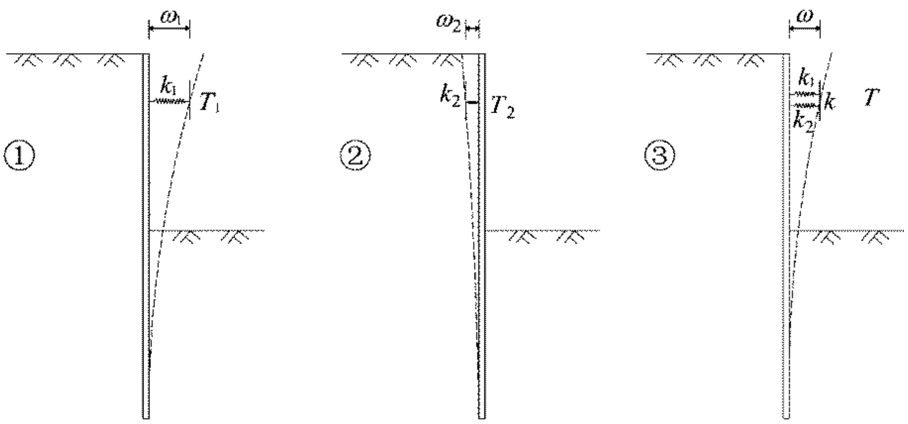

Figure 5: Double stiffness calculation model diagram

In Figure 5, ① The model is the working state of the anchor cable without prestressing, and the displacement corresponding to the fulcrum of the anchor cable is ω1; the stiffness of the anchor cable is k1; the axial force of anchor cable is T1. There are the following:

$$T_1 = k_1 \cdot \omega_1 \tag{4}$$

The model ② is the state of prestressing of the anchor cable. At this time, T2 is the prestressing force applied, ω2 is the displacement of the anchor head when prestressing is applied, and k2 is the stiffness of the anchor cable when prestressing is applied. There are the following:

$$T_2 = k_2 \cdot \omega_2 \tag{5}$$

The model ③ is the final working state of the anchor cable after prestressing, and T is the final axial force of the anchor cable. ω is the anchor head displacement in the final state ; the final anchor stiffness is k. There are the following:

$$T = k \cdot \omega \tag{6}$$

Due to the force balance of anchor cable in this process, the deformation coordination of pile anchor is:

$$T = T_1 + T_2 \tag{7}$$

The substitution (4) (5) (6) has:

$$k_1 \cdot \omega_1 + k_2 \cdot \omega_2 = k \cdot \omega \tag{8}$$

$$k = \frac{k_1 \cdot \omega_1 + k_2 \cdot \omega_2}{\omega} \tag{9}$$

In the formula: k is the final stiffness of the anchor cable, ω is the displacement of the anchor head in the final state, ω2 is the displacement of the anchor head when prestress is applied, which can be measured by the dial indicator, and the displacement is positive in the foundation pit; t2 is the applied prestress, so k2 can be obtained by Equation (5). k1 is the stiffness of the anchor cable when the anchor cable is not prestressed, so the kt in the following formula can be solved according to the stiffness formula given in the specification, which is k1.

$$k_t = \frac{3AE_s E_c A_c}{3L_f E_c A_c + E_s A L_a} \cdot \cos^2 \theta \tag{10}$$

In the formula: A is the cross-sectional area of the anchor rod body; Ac is the cross-sectional area of anchorage body; Lf is the free length of the anchor cable; La is the length of anchorage section; θ is the inclination angle of the anchor cable; Es is the elastic modulus of rod; Ec is the comprehensive elastic modulus of anchorage body.

$$E_c = \frac{AE_s + (A_c - A)\ E_m}{A_c} \tag{11}$$

In the formula: Em is the elastic modulus of the grout in the anchorage.

At this time, the elastic stiffness of the fulcrum (anchor cable) is obtained, that is, the stiffness coefficient of the anchor cable during the prestressing process of the anchor cable is considered in the final state. The stiffness coefficient obtained by this algorithm is closer to the real stiffness of the anchor cable during operation, which further improves the accuracy of the deformation calculation of the supporting structure and is more in line with the engineering practice. It provides a new idea for the deformation calculation of micro steel pipe piles and even traditional pile anchors in the future.

2.3. The Actual Engineering Verification of the Calculation Model

Zhang Haoshuang [16] tested and studied the stress and deformation of foundation pit supporting structure and anchor cable based on a practical project. The excavation depth of the foundation pit is 11.8m ~ 12.3m, and the prestressed anchor cable supporting structure of cast-in-place pile is adopted. A pile top anchor cable in the test section of Reference is selected for analysis and verification. The anchor cable selects three bundles of 15.2mm steel strands, steel strand fpy =

1320N / mm2, hole diameter 150mm, anchorage section 300mm, free section length 8m, anchorage section length 37m ; the stiffness coefficient of the anchor cable can be obtained by the standard algorithm, that is, Formula (10).

The prestress locking value of the anchor cable during the construction process is 400 kN, T2 = 400 kN, and the final axial force of the anchor cable is T = 500 kN. Because the displacement of the anchor head is not measured, the anchor cable is located at the top of the pile, and the displacement of the anchor head can be approximately equal to the displacement of the pile top = 20 mm. The final stiffness k considering the prestress of anchor cable can be obtained by combining equations (4-9). See Table 1 for details.

Table 1: Anchor stiffness

Method of calculation	Normative approach	Double stiffness calculation model
Anchor stiffness (MN / m)	8.51	5.0

It can be seen from Table 1 that the stiffness of the anchor cable obtained by the double stiffness calculation model considering the prestress of the anchor cable is less than that obtained by the standard method. That is to say, under the same load condition, the stiffness obtained in this paper will make the deformation calculation result of the supporting structure larger. In order to reduce the deformation, the engineering design will be relatively conservative, so the structure will be safe.

3. Deformation Calculation Method of Micro Steel Pipe Pile Supporting Structure Based on Double Stiffness Model

3.1 Establishment of Calculation Model

For the prestressed anchor cable supporting structure of micro steel pipe cast-in-place pile, the soil resistance method is used to solve the deformation, as shown in figure 6, the differential equation of the deflection of the supporting pile:

$$EI\frac{d^4y}{dz^4}+P=0 \tag{12}$$

In the formula: EI is the bending stiffness of the supporting pile; y is the horizontal displacement of the supporting pile; z is the distance from the calculation point to the top of the pile; p is the external force acting on the supporting pile.

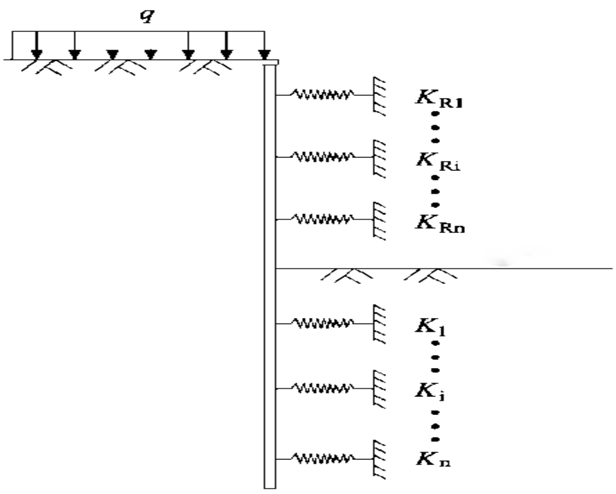

Figure 6: Supporting structure calculation model

Different assumptions about P have different solutions. There are three main solutions:

(1) Limit ground reaction method; this method obtains the horizontal resistance of the pile according to the limit state, assuming that the foundation reaction is only related to the depth:

$$P=P(z) \tag{13}$$

In the formula: P is the foundation reaction force on the unit area of the pile side.

(2) Elastic foundation reaction method:

$$P=kz^{n}y^{m} \tag{14a}$$

Or

$$P=K(z)\,y^{m} \tag{14b}$$

In the formula: k is determined by the elastic coefficient of the soil, K (z) is the horizontal reaction coefficient of the foundation, m = 1 is the linear elastic foundation reaction method, m ≠ 1 is nonlinear. Where n = 0 is Zhang's method, n = 1 is m method, n = 0.5 is C method.

(3) Composite foundation reaction method (p-y curve method) ; in this method, the plastic zone of the soil around the pile is calculated according to the limit foundation reaction force and the elastic zone is calculated according to the elastic foundation reaction force, which is closer to the reality, but it is difficult to divide the elastic-plastic zone.

3.2 Determination of Calculation Parameters

(1) Soil spring stiffness

For the determination of soil spring stiffness, the displacement of retaining pile can be solved by Boussinesq solution in elastic mechanics. When the concentrated force of an earth pressure spring is p, the pressure distributed in a circular unit area is q.

$$\mathrm{y}=\frac{dq(1-v_{\mathrm{s}}^{2})}{E_{0}}\omega \quad \text{or} \quad \mathrm{y}=\frac{dq(1-v_{\mathrm{s}}^{2})}{bdE_{0}}\omega \tag{15}$$

There is

$$K=\frac{p}{y}=\frac{bE_{0}}{\omega(1-v_{\mathrm{s}}^{2})} \tag{16}$$

E0 is the elastic modulus of soil; νs is the Poisson's ratio of soil, bd replaces the rectangular area; ω is the shape coefficient related to b/d, when b/d=1.0, ω = 0.88; when b/d=0.5, ω = 1.08.

(2) Anchor stiffness

The anchor stiffness KRi in Figure 6 is the total stiffness k of the anchor cable in the final work obtained by the simultaneous (4 ~ 9) in the double stiffness model considering the prestress of the anchor cable in Section 2.2 of this paper.

On the basis of summarizing the previous research results, this paper considers the influence of the prestress of the anchor cable, and the differential equation of the constant stiffness of the supporting pile is:

$$\begin{aligned} &EI\frac{d^{4}y}{dz^{4}}+K_{\mathrm{R}}y-p_{\mathrm{a}}^{\mathrm{u}}+R_{0}=0 && (0\le \mathrm{z}\le H) \\ &EI\frac{d^{4}y}{dz^{4}}+Ky-p_{\mathrm{a}}^{\mathrm{d}}=0 && (\mathrm{z}>H) \end{aligned} \tag{17}$$

In the formula: R0 is the anchor cable prestress; KR is the total stiffness of anchor obtained by the prestressed double stiffness model of anchor cable. K is soil spring stiffness; p_a^u, p_a^d is the active earth pressure above and below the excavation surface ; H is the excavation depth.

3.3. Establishment and Solution of Difference Equation

Because the solution of the above differential equation is more complicated, the solution of the difference equation can simplify the calculation process. For the retaining pile with constant stiffness, it can be divided into n units along the length, each unit length is, and two virtual nodes are established at the upper and lower ends. The bending moment, shear force and displacement of each element are Mi, Qi and yi, respectively.

Then there is a first-order central difference formula:

$$\left.\frac{dy}{dz}\right|_i = \frac{1}{2\lambda}(y_{i+1} - y_{i-1}) \tag{18a}$$

$$\left.\frac{d^2y}{dz^2}\right|_i = \frac{1}{\lambda^2}(y_{i+1} - 2y_i + y_{i-1}) \tag{18b}$$

$$\left.\frac{d^3y}{dz^3}\right|_i = \frac{1}{2\lambda^3}(y_{i+2} - 2y_{i+1} + 2y_{i-1} - y_{i-2}) \tag{18c}$$

$$\left.\frac{d^4y}{dz^4}\right|_i = \frac{1}{\lambda^4}(y_{i+2} - 4y_{i+1} + 6y_i - 4y_{i-1} + y_{i-2}) \tag{18d}$$

The symbolic meaning is the same as before.

After sorting the formula (18d) into the formula (17), we can get:

$$\begin{aligned} &y_{i+2} - 4y_{i+1} + \left(6 + \lambda^4 \frac{K_{Ri}}{EI}\right) y_i - 4y_{i-1} + y_{i-2} = \frac{\lambda^4}{EI}\left(p_a^u - R_0\right) && (0 \leqslant z \leqslant H) \\ &y_{i+2} - 4y_{i+1} + \left(6 - \lambda^4 \frac{K_i}{EI}\right) y_i - 4y_{i-1} + y_{i-2} = \frac{\lambda^4}{EI} p_a^d && (z > H) \end{aligned} \tag{19}$$

There are five unknowns in formula (19) and each node has only one equation, and boundary conditions need to be supplemented. At the ground, that is, the point of i = 0, it can be assumed that the bending moment and shear force of the pile top and the pile bottom are approximately 0, and the stress conditions M0, Q0, Mn, and Qn can be known. The following boundary conditions can be obtained from Equation (18b) (18c):

$$y_{-1} - 2y_0 + y_1 = \frac{\lambda^2}{EI} M_0 \tag{20a}$$

$$-y_{-2} + 2y_{-1} - 2y_1 + y_2 = \frac{2\lambda^3}{EI} Q_0 \tag{20b}$$

$$y_{n-1} - 2y_n + y_{n+1} = \frac{\lambda^2}{EI} M_n \tag{20c}$$

$$-y_{n-2}+2y_{n-1}-2y_{n+1}+y_{n+2}=\frac{2\lambda^3}{EI}Q_n \tag{20d}$$

The deformation y of the pile body of the supporting pile can be obtained by the simultaneous formula (19) (20), and the internal force of the pile body can also be obtained:

$$M_i=\frac{1}{\lambda^2}(y_{i+1}-2y_i+y_{i-1}) \tag{21}$$

$$Q_i=\frac{1}{2\lambda^3}(y_{i+2}-2y_{i+1}+2y_{i-1}-y_{i-2}) \tag{22}$$

4. Conclusion

Based on the working mechanism of micro steel pipe pile supporting structure, this paper summarizes the previous research results, and on this basis, the horizontal displacement calculation method of micro steel pipe pile supporting structure is studied and improved. The details are as follows:

(1) The characteristics of micro pile and micro steel pipe pile are described in detail. The composition and characteristics of prestressed anchor cable supporting structure of micro steel pipe pile; the working mechanism and stress characteristics of this kind of supporting structure in foundation pit support.

(2) A double stiffness calculation model considering anchor cable prestress is proposed. Combined with the anchor cable test in Reference, the fulcrum stiffness calculated by this calculation model is compared with the stiffness calculated by the specification method. The stiffness obtained in this paper is less than the stiffness obtained by the specification. That is to say, under the same load condition, the stiffness obtained in this paper will make the deformation calculation result of the supporting structure larger. In order to reduce the deformation, the engineering design will be relatively conservative, so the structure will be safe.

(3) Based on the double stiffness calculation model considering the pre-stress of the anchor cable, the deformation calculation method of the micro steel pipe pile supporting structure is given. The deformation differential equation considering the double stiffness is established and solved by the difference equation.

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