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A foundation treatment optimization approach study in hydraulic engineering

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Abstract. To reach a better foundation treatment project, an optimized analysis of composite foundation was studied in the field of hydraulic engineering. Its unique characteristics in hydraulic engineering were concluded. And, the overall and detailed analysis of the composite foundation model established was carried out. The index parameters of the vertical reinforced rigid pile composite foundation were formulated. Further, considering the unique role of cushion in hydraulic engineering, its penetration and regularity were analyzed. Then, comparative and optimized analyses of cushion multistage physical dimensions and multistage material characteristics were established. The parameters of the piles distance were optimized and the multilevel scientific and reasonable parameters information was obtained. Based on the information of these parameters, the practical application was verified. It effectively supported the effective application of vertical reinforcement rigid pile composite foundation in hydraulic engineering. The service mechanism of composite foundation was fully analyzed.

Keywords: optimization analysis; foundation treatment; vertical reinforcement; hydraulic engineering

1. Introduction

1.1 Composite foundation

The concept of composite foundation was proposed by Japanese scholars in the early 1960s. At that time it was a mathematical model of a sand type foundation. With the development of foundation treatment technology, the concept of composite foundation has been recognized and deepened by the engineering and academic circles (Cheng *et al*. 2018, Miles *et al*. 2017, Lin *et al*. 2017, Papaleontiou *et al*. 2012, Zhu *et al*. 2010). The rigid pile composite foundation is a kind of artificial foundation with a high stiffness concrete pile or high standard CFG pile (Cement, coarse aggregate, gypsum, grade III or more than grade III fly ash, if necessary, a proper amount of pumping agent and fly ash activator are mixed in proper proportion, and forced mixing with water) as the vertical reinforcements. Between the pile top and the foundation of this artificial foundation, graded sand gravel flexible cushion layer is laid a certain thickness. It is designed to adjust the load sharing between the pile and soil and increase the friction of the base (Wang *et al*. 2012, Liu *et al*. 2006, Chi *et al*. 2003, Rowe *et al*. 1980, Akpinar *et al*. 2014). The rigid pile composite foundation is a transitional foundation between the natural foundation and the traditional pile foundation. The characteristic of this composite foundation is "rigid". Compared with flexible piles, it has stronger pile strength and can exert the lateral resistance of piles. According to the direction of foundation reinforcement, it can be divided into horizontal and vertical reinforced composite foundation. As shown in Fig. 1.1.

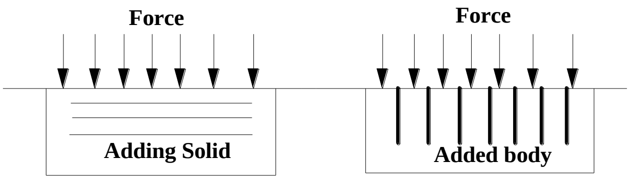

Fig. 1.1 Composite foundation of horizontal reinforcements and vertical reinforcements

The theory of composite foundation has attracted great attention at home and abroad of geotechnical engineering and academia. In related academic journals, there are many papers have introduced the latest research results of composite foundation and the calculation methods of various composite foundation designs, which made the theory of composite foundation developed and perfected. Because China is a developing country and the soft soil is widely distributed, the project needs to promote the development of foundation treatment technology (Randolph *et al*. 2003, Hassiotis *et al*. 1997, Lotfi *et al*. 2012, Mroueh *et al*. 2002).

Juran I and Riccobono (Bergado *et al*. 1994, Lee *et al*. 2003, Eestimation *et al*. 1976, Geddes *et al*. 1996) carried out an indoor model study on the sand pile soil complex and the gravel soil complex. With the composite soil as a whole, the characteristics of the composite soil under the stress boundary conditions and the displacement boundary conditions are studied. In laboratory experiments, the method of embedding micro soil pressure gauge under the bearing platform and sticking strain sheet on the side wall of cement soil pile is adopted. The distribution pattern of

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base pressure and load transfer law of cement soil pile reinforced by mixing pile and the relationship between the pile length and the displacement rate, the bearing capacity and the deformation characteristics are studied. Because the length of the simulated pile is short, the axial force of the pile is evenly distributed along the depth. So, two groups of pile group pile composite foundation field tests were carried out in the Nanjing Puzhen vehicle factory. The deep deformation characteristics of the composite foundation are measured by embedding the deep settlement scalar, and the load sharing ratio of the pile and soil is measured.

The key to the study of composite foundation lies in the load transfer mechanism, the distribution of additional stress and the characteristics of the composite foundation. However, the analytical method used in the study of this problem and the indoor and outdoor testing methods have their own limitations, which make it difficult to continue the research. The numerical simulation method, represented by the finite element method, can simulate the physical geometry characteristics and various working conditions of the composite foundation. It can show the stress field and displacement field of the whole computing domain, avoid the restriction of model size, shape and load parameters, and simulate the "test conditions" and "test plans" which are difficult to get in laboratory and field. The unavoidable interference and influence encountered in general tests are eliminated. The test results can truly reflect some phenomena, rules and mechanisms, and it has wide space in engineering. However, numerical simulation requires the establishment of realistic mechanical and numerical models, including the geometric models, constitutive models and loading models of pile and soil between piles. And the simulation is directly related to the correctness of the calculation results. Using the finite element program, the axial force and settlement characteristics of the rigid pile composite foundation under the vertical load are calculated and analyzed. The changes of the axial force and foundation settlement of the pile, such as the thickness, modulus, pile length, modulus and pile spacing of the cushion are discussed. On this basis, the selection principle of the design parameters of the rigid pile composite foundation is discussed. The influence of the change of the thickness and modulus of the cushion on the vertical bearing behavior of the rigid pile composite foundation is proved (Caetta *et al*. 1989).

Ellison (Ellison *et al*. 1971) first uses two-dimensional axisymmetric finite element method to analyze the load transfer mechanism of bored pile in hard clay. For the first time, the contact element is applied to the pile side and the pile end, and the tension crack outside the pile end is successfully analyzed through the displacement difference between the upper and lower contact surfaces of the contact unit. And it is pointed out that the rupture zone will not extend to the upper side of the pile tip. Hopper (Hooper *et al*. 1973) discussed the finite element calculation of the pile group in the high-rise building. And Desai (Desai *et al*. 1974) carried out the finite element analysis of the pile group with the bearing platform. The group piles considered can be tilted and bear the bending moment and horizontal force simultaneously. And, the Ramberg-osgood nonlinear model is used in soil. In order to analyze the action characteristics of pile groups more accurately, especially the load transfer characteristics between pile and soil, Ottaviani (Ottavianvi *et al*. 1975) uses three-dimensional finite element method to analyze the elastic analysis of the group piles for 3 3 and 5 3. It is also proved that there is a small stretch stress zone outside the pile tip, and the eight node cube element is used. Zheng Dongming and others (Zheng *et al*. 1999) used eight-node axisymmetric finite element to analyze the different thickness of cushion. The relationship between the stress ratio of pile and soil and the thickness of the cushion, and the change of the axial force of the pile under the different thickness of the cushion are calculated. In the calculation, the cap and pile body is considered to be linear elastic body, and Duncan-Chang nonlinear model and Drucke-Prager ideal elastoplastic model are used separately for the soil and the cushion. And, dislocation is not caused in the pile and surrounding soil.

1.2 Prestressed concrete pipe pile

Prestressed concrete pipe pile is a hollow cylinder with high speed centrifugal steam curing process with pretensioned prestressing, high efficiency water reducing agent and high speed centrifugal steam curing process. It is a force member that passes the load of the building to the foundation with a certain bending and compression resistance. In 1894, Hennebigue invented the precast concrete pile. In 1915, Australian W•R•Hume invented the method of centrifugal compacting concrete, and soon used it to manufacture circular tubular piles, conical piles and concrete poles. Japan, the United States, Canada, Italy and other countries are the countries that study, produce and use more prestressed concrete pipes and piles. Since the late 80s, developing countries such as China, Malaysia and Philippines have also popularized the application of prestressed concrete pipe piles. Generally speaking, Japan has made great efforts in the research, design, construction and application of prestressed concrete pipe piles. Japan has gained a lot of experience and was the leading country in the related technology of prestressed concrete pipe. In 1915, Australia invented concrete products produced by centrifugation. The centrifuge concrete pipe pile (RC pipe pile) was built in 1934. In 1962, the prestressed concrete pipe pile (PC pipe pile) was developed. In 1982, the standard of HSA5337 "pretensioning centrifugal high strength concrete pipe pile" was set up.

Further, starting from the analysis two major effects of prestressed concrete pipe pile, soil plug effect and squeezing soil effect, the stress behavior of prestressed concrete pipe pile and its unique bearing mechanism were analyzed in detail. This paper sums up the results of vertical static load test of prestressed pipe pile, analyzes the difference between actual bearing capacity and calculation bearing capacity of tubular pile, and puts forward a modified formula of empirical formula for technical specification of building pile foundation. By comparing the calculated value with the actual value, the practical meaning of the modified formula is validated. Junhwan Lee and others have better analyzed the bearing capacity of closed and open tubular piles in sandy soil by indoor model tests and field tests (Niemunis *et al*. 2015), and discussed the relationship between the ratio of static piercing end resistance and lateral friction resistance of closed tubular pile tests and sand compaction, and the relationship between fill ratio and compactness of open pipe pile. Jin Xingping analyzes the influence of the properties of the soil at the pile end, the properties of the pile-side soil, the elastic modulus of the pile body, the thickness of the wall of the prestressed pile, the diameter of the prestressed pile, and the depth of entry holding layer on the bearing capacity of prestressed pipe piles through the calculation of load transfer and measured data (Zheng *et al*. 1999). The calculation formula of vertical bearing capacity of prestressed pipe pile is estimated by the correlation analysis of cone tip resistance, side wall resistance and prestressed pipe pile end resistance.

1.3 Key research

From the previous research summary, it can be seen that in the hydraulic engineering, the relevant data of the design calculation of the composite foundation of prestressed concrete pipe piles (PC pipe piles) is less, and there is a lack of analysis of actual engineering application cases. On the other hand, in the soft soil area of the hydraulic engineering, the foundation soil is poor, and prestressed concrete pipe pile composite foundation as a form of rigid pile composite foundation, because of its construction speed, the construction method is simple and mature, short duration, reliable quality, convenient inspection, to adapt to the many advantages of strong, good earthquake resistance, has been applied more and more widely in the engineering construction, has broad prospects for development. Therefore, it is necessary to study the application mechanism of PC tubular pile composite foundation in hydraulic engineering, at first, this paper sums up the differences between PC pipe pile foundation and the current open research foundation (Chen *et al*. 2016, Yang *et al*. 2017a, Zhang *et al*. 2017, Yang *et al*. 2017b, Yang *et al*. 2016, Huang *et al*. 2017, Huang *et al*. 2018, Jia *et al*. 2017).

(1) Due to the water existence in hydraulic engineering, not only the load is increased, but also the anti-seepage effect of the cushion material should be considered. Geotextiles, elastoplastic clays, cement-soils and other materials can be selected. The recommended materials are sand, coarse sand and other materials.

(2) The foundation treatment is generally treated according to the pressure size and form of the base of the upper building. In the design of civil engineering and highway subgrade, the foundation bears vertical loads, and horizontal loads don't need to be considered in most of them. However, due to the existence of earth pressure behind the wall in hydraulic engineering, the effect of horizontal loads must be considered in the foundation treatment of wing walls.

(3) The foundation settlement difference control in hydraulic engineering is stricter than normal civil construction. This is because the bottom of the hydraulic structure is generally provided with water stoppage. If the settlement difference is too large, the water stoppage will be torn and damaged.

Although the prestressed concrete pipe pile technology is widely used, its theoretical research is still lagging behind, especially in the more complex water conservancy projects. This article is based on the above characteristics to explore the mechanism and practical application of composite foundation in hydraulic engineering, mainly including the following research areas:

Firstly, the prestressed pipe pile foundation model of hydraulic project is established by means of graded loading, and the new idea of calculating the ground stress and calculating the external force was considered to study the stress and strain behavior of soil and pile body.

Secondly, the cushion is a key technology for composite foundation design, and setting the cushion layer plays an important role in adjusting the coordinated deformation ability and stress distribution of soil between piles. Therefore, in this paper, the cushion service mechanism of composite foundation was studied. Based on the stress ratio, share ratio of pile load, maximum settlement and floor differential settlement, reasonable values of physical dimensions and material properties of the cushion were obtained.

Finally, in light of the above analyses, a field test plan was designed in conjunction with actual engineering. The axial bearing capacity of pipe piles was analyzed from the test method and test process, and the characteristic values of the vertical bearing capacity of the composite foundation were obtained. The finite element model simulations were simultaneously used to verify the field test, which fully confirmed the reasonable conclusions obtained in this paper.

2. Index establishment

2.1 The establishment of prestressed pipe pile composite foundation model

Considering the development of the constitutive model in geotechnical engineering, numerical calculations are not only applied on a large scale, but also have accumulated rich experience, this paper mainly uses numerical calculation methods for analysis and research. The soil is a non-linear material. Its elasticity is not only related to the size of the load, but also related to the loading path. The stress-strain relationship of it is obviously non-linear.

The linear elastic model has a large error, which is not applicable to the current large-scale projects. The elasto-plastic model is theoretically more reasonable than the non-linear elastic model, so the Moore Coulomb model in the elasto-plastic model is used in this design. Compared to soil, the stiffness of reinforced concrete pile foundations and superstructures is much greater than that of soils. In general, if the stiffness differs by more than two orders of magnitude, the effect of the deformation of the pile on the soil is negligible, so the constitutive model of the pile and the upper structure can be taken as linear elasticity.

In the pile-soil composite foundation, the material properties of the pile body and the pile side soil are very different, so under certain conditions, there may be relative displacement on the contact surface. In order to fully reflect the interaction characteristics such as the interaction between the pile body and the soil on the contact surface,

Table 2.1 Static calculation table for model parameters of pile-soil composite foundation

Name	E (Mpa)	υ	ρ (kN/m^3)	C (kPa)	φ (°)
Bottom plate	25000	0.28	2.45	~	~
Pile body	32000	0.162	2.55	~	~
Cushion layer	170	0.210	2.22	800	30
Soil between piles	8.35	0.275	1.93	30	14.875

Notes: E-Elastic modulus; υ-Poisson ratio; ρ-Density; C-Cohesive force; φ-Internal friction angle;

the interaction must be set. The model is composed of two parts, soil and upper parts. During the assembly process, the binding constraint is set at the contact surface to ensure the transmission of force. The “master-slave” contact algorithm is used in this paper. There are two contact pairs in the whole model, namely the pile side and the soil around the pile, the pile end and the pile end soil. The main control surface is the pile survey surface and the pile end surface, and the subordinate surface is the soil between the pile and the pile end soil. The “face-to-face” contact has a coefficient of friction of 0.5.

The simulation is carried out in the form of a graded load and the basic load at each stage is generally imposed at 1/10 to 1/15 of the estimated ultimate bearing capacity of the single pile. Calculate the ground stress firstly and the external force secondly.

The application of initial stress field is a key factor in the finite element analysis of geotechnical engineering, and the reason for the application of ground stress is as follows: The geometric model we have established generally corresponds to the size of the actual project, however, actually the foundation soil has a larger initial stress that is not affected by gravity. The foundation soil was gradually formed today's size under the influence of gravity and similar boundary conditions some years ago, however, we do not know the shape and size of the foundation soil before it is forced. The current geometric model is the actual size of the foundation soil, and it will become a smaller or inconsistent foundation soil after stress, which is inconsistent with the actual situation, so we must have the analysis step of the ground stress before the calculation.

Only vertical displacement is allowed for both sides of the boundary. Therefore, the displacements are set to be U_x=0 and U_y=0. The bottom boundary is a fixed-end constraint, U_x=0, U_y=0 and U_z=0. No rotation is allowed. The quality of grid division is directly related to convergence of the model and the output results, so the grid division in the finite element simulation is very important. The whole model adopts entity unit with three-dimensional and eight-node. The length of pile L=8.5 m; the diameter of the pipe pile d_1=0.5 m; the length of the mattress layer L=2.1 m, the width b=1.8 m, the height h=0.3 m, the material is cement soil; the length of backplane L=2.1 m, the width b=1.75 m, the height h=0.3 m.

The model consists of four parts including the pile body, the foundation soil, the cushion layer and the upper structure. The linear elastic model is adopted in the pile and the bottom plate. And the foundation soil and the cushion layer adopt the elastoplastic constitutive model of the Monhr-coulomb. The concrete material parameters are shown in the following Table 2.1.

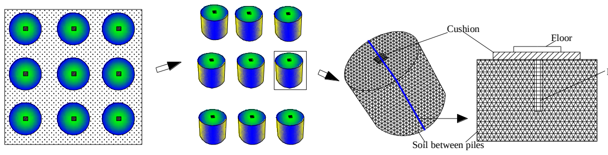

Fig. 2.1 Pipe pile model in a hydraulic project

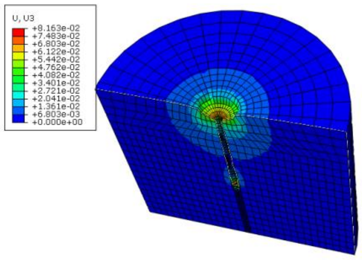

Fig. 2.2 Total warp U_3 (Vertical settlement)

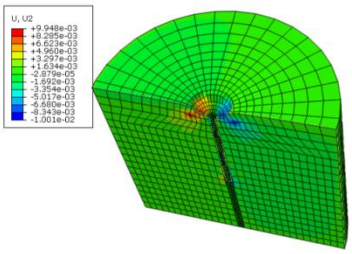

Fig. 2.3 Total warp U_2 (Horizontal offset)

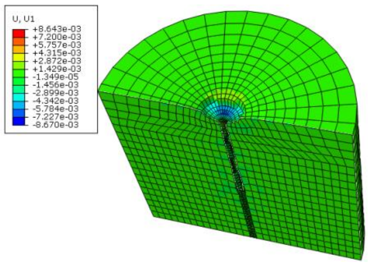

Fig. 2.4 Total warp U_1 (Horizontal Shift)

2.2 Global Analysis of the model

After calculating based on the model mentioned above, the displacement cloud charts of the foundation soil are formed.

(1) The most values of U_2 and U_1 occur at the center of the top layer of the foundation soil, range from about 8.3 mm to 9.2 mm. The regularity of the lateral movement of the surrounding soil is the upper surface moving inward with the settlement of the bottom plate which is about 5.25 mm. Therefore, it is necessary to consider the lateral deformation of the pile body.

(2) Under the loading function, the maximum settlement of soil is 81.9 mm, located in the middle of the model. The stress effect range is within the range of the center with a radius of 3m and U_3=0 in other parts;

The results of the soil deformation are shown below. As

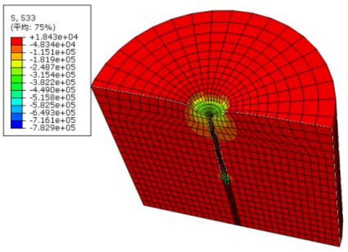

Fig. 2.5 Soil stress S33(Vertical stress)

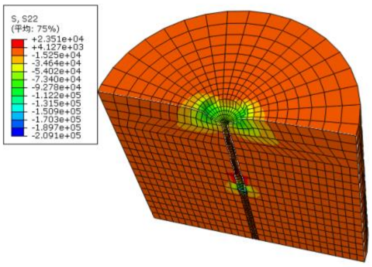

Fig. 2.6 Soil stress S_{22} (Horizontal stress)

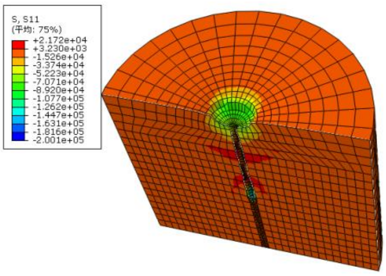

Fig. 2.7 Soil stress S_{11} (Horizontal stress)

shown in the paper, S is used to refer to the stress. 1, 2, and 3 are used to refer to x, y, z direction. Conclusions can be drawn from the stress cloud:

(1) The load transfer effect of the pile is obvious. The maximum compressive stress occurs at the top of the piles under the mattress layer and the bottom of the pile under the soil layer. And the maximum crushing stress occurs at the bottom of the pile which is about 800Kpa.

(2) Beyond the 3 m range of the surrounding soil is pulled, but the tensile stress is not large. The horizontal stress of the surrounding soil is very small.

2.3 Index formulation of prestressed pipe pile composite foundation for water engineering

Pile-Soil stress ratio:

The important characteristic of the pile in the composite foundation is different from the free one. The reason is that the full exertion of the soil bearing capacity of the pile, a large vertical stress increment is produced on the pile side, which makes the bearing characteristic of the pile different from that of the free single pile. As shown in Fig. 2.8.

$$n = \frac{\sigma_p}{\sigma_s} \tag{1}$$

where, n-Pile-Soil stress ratio;

σ_p-Pile top stress (kPa);

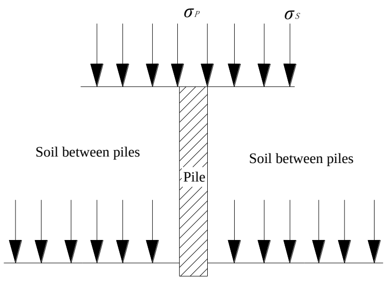

Fig. 2.8 Pile stress in composite foundation

σ_p-Surface stress of soil between piles (kPa);

Under normal circumstances, the pile-soil stress ratio is related to the material, the length and the replacement rate of the pile. When other conditions are the same, the greater the stiffness of pile material is, the greater the stress ratio of pile and soil is; the longer the pile is, the greater the stress ratio of pile-soil is; the smaller the replacement rate is, the greater the stress ratio of pile and soil is.

Replacement rate m:

In a composite foundation, a pile and its assumed soil is a composite soil unit. In this composite soil unit, the ratio of the broken area of the pile A_P and composite soil unit area A (the sum of the section area of the pile and soli) is called the area replacement rate, and the m represents

$$m = \frac{A_p}{A} \tag{2}$$

where, m-Replacement rate of composite Foundation;

A_p-Sectional area of the pile (m^2);

A-Composite soil unit area (m^2);

In practical engineering, due to the variation of soil lithology, the inhomogeneity of superstructure load, the size of the basic plane and other factors, it is impossible that the whole foundation are equal spacing of the pile. For the composite foundation, the section area of the pile and the basis of the total area of the composite soil equivalent to the ratio of the area, called the average area replacement rate.

Pile-Soil load sharing ratio:

In the composite foundation, the pile-soil load can be used to represent the pile-soil stress ratio, and the pile-soil load sharing ratio can also be expressed by δ_p and δ_s

$$\delta_p = \frac{P_p}{P} \tag{3}$$

$$\delta_s = \frac{P_s}{P} \tag{4}$$

where, P_p-Pile bearing load (kN);

P-Total load (kN);

P_s-Soil load bearing between piles (kN);

δ_p-pile-soil stress ratio;

δ_s-pile-soil load sharing ratio;

After the average area replacement rate m, the load-sharing ratio of pile-soil and the stress ratio of pile-soil can be expressed mutually. Pile-soil stress ratio is

$$n = \frac{\sigma_p}{\sigma_s} = \frac{(1-m)\delta_p}{m\delta_s} \tag{5}$$

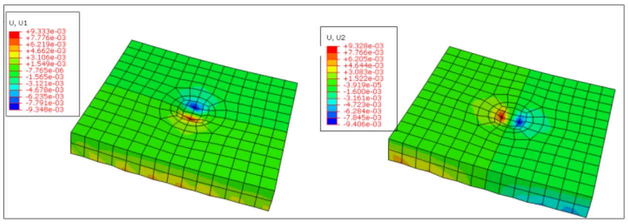

Fig. 3.1 Cushion deformation cloud (U_2 and U_1)

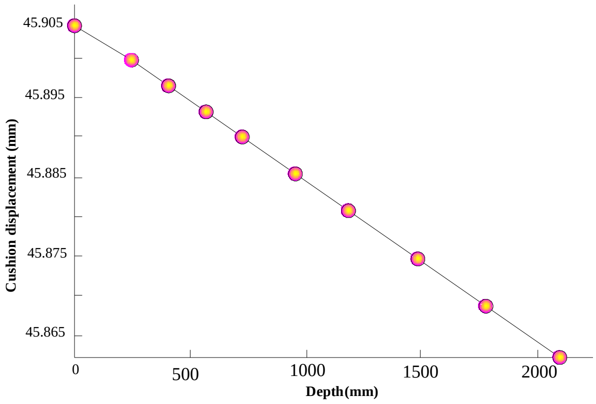

Fig. 3.2 Cushion vertical displacement change along horizo ntal line of Fig. 3.1

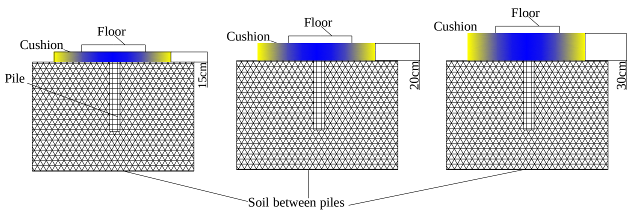

Fig. 3.3 15 cm, 20 cm, 30 cm cushion models

3. Cushion action mechanism and penetration rate

3.1 Cushion penetration and overall deformation analysis

The pile-soil composite foundation mainly adjusts the load sharing ratio of pile and soil through cushion layer. The deformation of piercing must be produced in the cushion because of the difference of modulus between pile and soil. The Fig. 3.1 shows that the middle displacements of the cushion are larger and the displacements of the two sides are smaller. The Fig. 3.2 shows that the cushion penetration is obvious, and the maximum amount is about 46mm.

3.2 Optimization analysis of the physical dimensions and material properties of the cushion

In order to consider the effect of different cushion thickness, the paper establishes the 15 cm, 20 cm and 30 cm cushion models, as shown in Fig. 3.3.

Cushion thickness is a key factor in prestressed pipe pile foundation. To study its optimized physical size, three different types of cushions were presented in Fig. 3.3. Index factors, stress ratio, pile load sharing ratio, the maximum

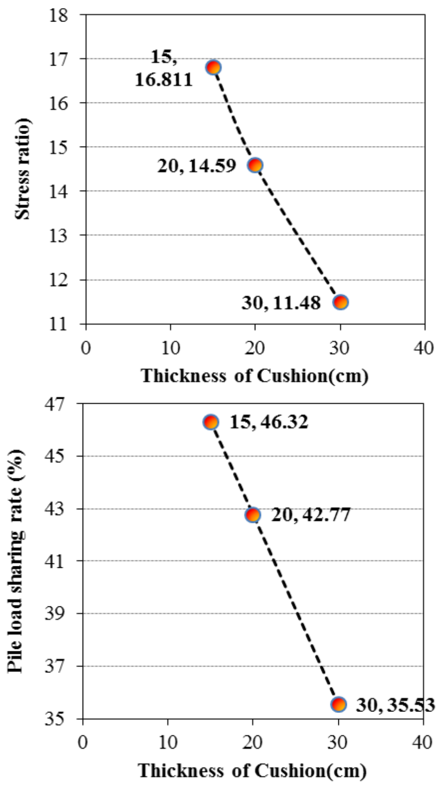

Fig. 3.4 Stress ratio and pile load sharing ratio change with cushion thickness

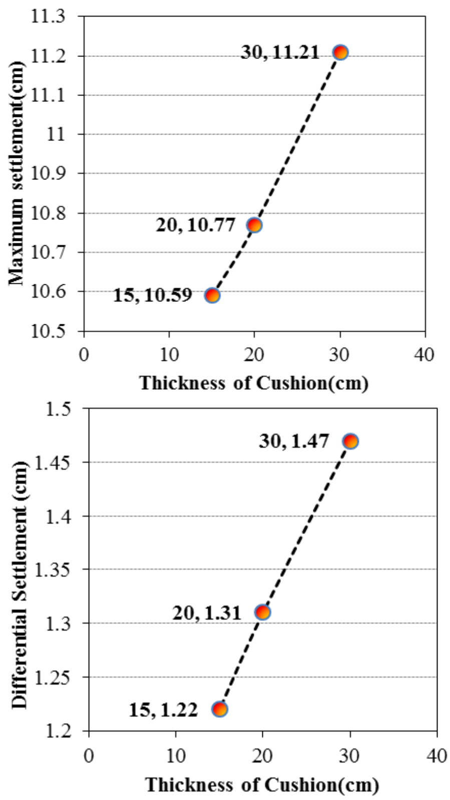

Fig. 3.5 The overall maximum settlement and differential se ttlement of the floor with the thickness of the mattress layer

settlement and differential settlement of the floor were selected to analyze the effect of the cushion thicknesses.

Four above index factors were calculated with the 15 cm, 20 cm and 30 cm cushion thicknesses in Fig. 3.3. Fig. 3.3 is a detailed description for above content.

Based on Fig. 3.3, the aforementioned model is used to calculate the results which are shown in Fig. 3.1 and Figs. 3.4-3.5. As you can see, with the thickness of the cushion increasing, the average stress ratio of pile and soil and the share rate of pile load are decreasing. The overall maximum settlement and the differential settlement of the floor are increasing. From the effect of the cushion of prestressed pipe pile, in the pile- soil composite foundation, the load action of the superstructure is transmitted from the bottom plate to the mattress layer, then from the mattress layer to the pile and the soil between the piles,. When the modulus of the pile and the soil and cushion of the pile satisfies the requirement, the penetration mode will be produced in the composite foundation, that is, the stiffness of the pile is greater than that of the cushion, the stiffness of the cushion is greater than the rigidity of the soil, and the cushion is flowing to the soil. At the initial stage of the load of the superstructure applied to the composite foundation, the load passes through the thicker part of the cushion to the pile, then through the thin position of the soil to the pile. The smaller the thickness of the cushion is, this stress with the stiffness of the difference in the size of the phenomenon is more and more obvious. With the increase in load and soil consolidation and settlement between piles, the load on the pile becomes larger and the weight of the soil is gradually reduced. And as the load of the pile increases, the soil is consolidated and sunk.

The thrust deformation in the pile top makes the soil bearing pressure become larger. the deformation of the pile penetration into the cushion is further increased with the soil between the piles being further compressed and consolidated. The thrust deformation of the pile and the compression deformation of the soil between the piles undergo a cyclic. The balance of the coordination process is related to the deformation coordination capacity of pile and soil, the modulus ratio of pile and soil, the capacity coordinate deformation of cushion which is cushion thickness and etc. The cushion can guarantee the load of pile and soil, adjust the load sharing ratio of pile and soil, and reduce the stress concentration of pile top on the base surface. As a function of stress diffusion, based on the analysis of this point, in the research of prestressed pipe pile composite foundation of hydraulic engineering, it is suggested that the mattress layer should be designed as the best state for thickness of 30 cm.

Further, considering different materials of cushions have different effects on the above four parameters in hydraulic engineering (average stress ratio of pile and soil, overall maximum settlement, pile load sharing ratio, bottom floor differential settlement). After summing up the analysis, as the water exist in hydraulic engineering, which increases the load and cushion layer needs to consider seepage prevention. Therefore, cushion material needs to have anti-seepage effect in water engineering which can be set for geotextile, elastoplastic clay, cement soil and other materials. However, the suggested materials for cushion layer are gravel, coarse sand and other materials. According that different materials of cushions may be used in water engineering, detailed analysis has been made and its model is shown in Fig. 3.6.

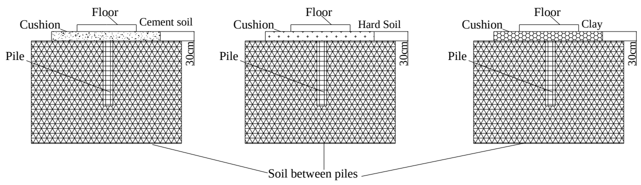

Fig. 3.6 Models of prestressed tubular pile foundation under three different cushions

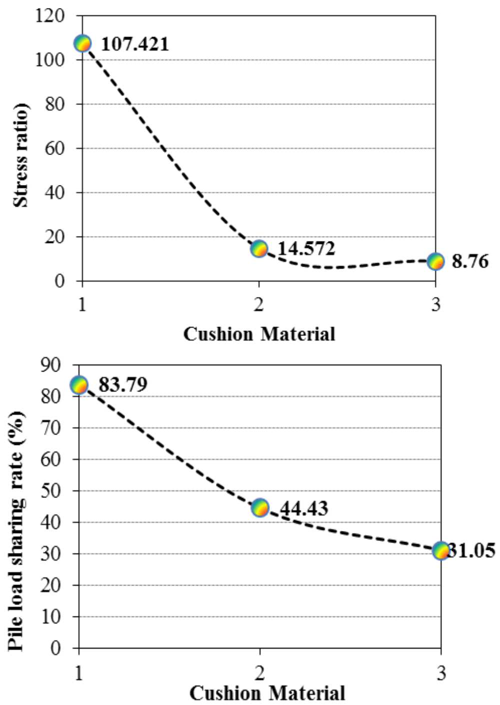

Fig. 3.7 Stress ratio and pile load sharing ratio change with cushion material

Based on Fig. 3.6, calculate the results by the aforementioned model shown in Fig. 3.7 and Fig. 3.8. Where, 1 represents cement soil, 2 represents the hard soil and 3 represents clay. As the figures show, as the cushion stiffness increases, the load cannot be effectively distributed between the pile and soil which is mainly borne by the pipe and the stress ratio increases to 107.421%. As the cushion modulus decreases, that is, the material becomes from soil into clay, the cushion penetration deformation gradually increases. The corresponding stress ratios become 14.572 and 8.76. And when the soil cushion is to the clay cushion, the penetration deformation increases slightly , and the load sharing ratio of the pile is changed which decreases from 44.43% to 31.05%, less than the amount of water and soil changes.

3.3 Optimization analysis of pile spacing under 30 cm cushion

Basing on the 0.5 m pile diameter mentioned above, the specific distributions of the maximum settlement of the pile, the differential settlement of the floor, the average stress

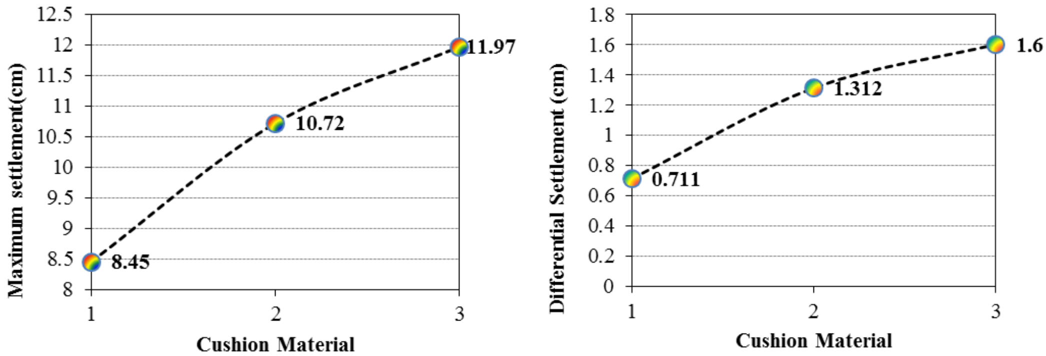

Fig. 3.8 The overall maximum settlement and the differential settlement of the floor with the mattress layer material changes

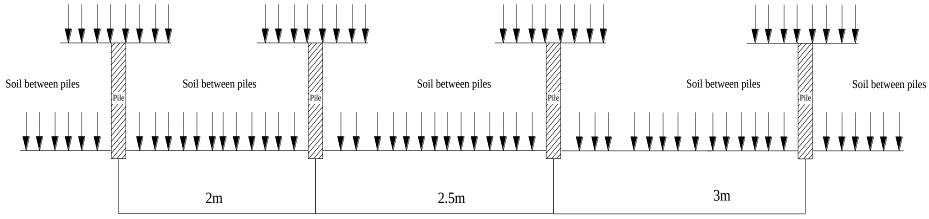

Fig. 3.9 Models of different pile spacing under 30 cm cushion

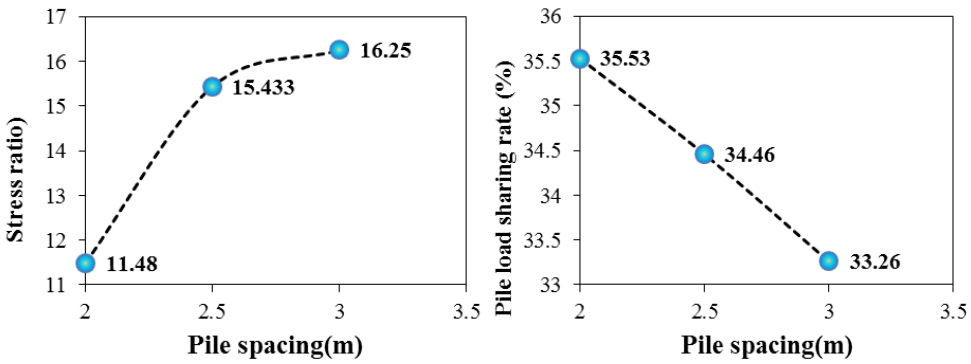

Fig. 3.10 Stress ratio and pile load sharing rate with pitch change

ratio of pile and soil and the load sharing ratio of the pile are established under fourfold diameter of the pile, five times the diameter of the pile, six times the diameter of the pile, just as shown in Fig. 3.9.

From Fig. 3.10 and Fig. 3.11, it can be seen that there are different degrees of difference in pile-soil stress ratio, pile-soil pile load share ratio, overall maximum settlement and floor differential settlement under different pile distances. For the pile-soil stress ratio, the overall maximum settlement, and the floor difference, it increases with the increase of the pile spacing, and the pile load sharing rate continuously decreases with the increase of the pile spacing. Therefore, it is advantageous that the stress borne by the pile is continuously increased and the stress assumed by the soil is continuously reduced, and the load sharing rate of the pile and soil pile is continuously reduced. However, the overall maximum settlement and floor differential settlement have been increasing. From the control of base settlement, it should be controlled as much as possible. Therefore, based on the idea of optimization, it is recommended to choose five times the pile diameter, which is more appropriate.

4 Application analyses of prestressed pipe piles in hydraulic projects

4.1 Static load test analysis of piles

Based on the foregoing analysis conclusions, the objective of the static load test with piles is to obtain a complete and reliable load-settlement relationship curve, and then determine the bearing capacity of the pile. The pile static load test is the most reliable method to determine the axial bearing capacity of piles, and it is also an important method in the quality inspection of piles. The test results reflect the working properties of the piles. The static load test is carried out strictly in accordance with the relevant specifications. The experimental device is mainly composed of a loading system and a measurement system. The loading system is composed of a jack and its reaction system, and the latter mainly includes a main beam, a secondary beam and an anchor pile, which can provide reaction force should be greater than 1.2 to 1.5 times the estimated maximum load. As using engineering piles as anchor piles, the number of anchor piles shall not be less than four, and the amount of

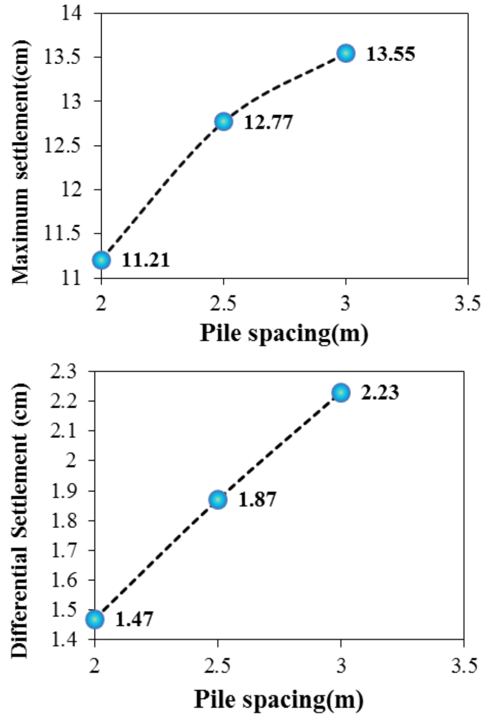

Fig. 3.11 Overall maximum settlement and floor differential settlement changes with pitch

anchor piles lifted shall be tested during the test. The reaction force system may also use the pressure platform reaction force device or anchorage pile pressure combined reaction force device. As using a weighted platform, the required weight must be greater than 1.2 times the estimated maximum load, and the weight should be added once before the start of the test and placed on the platform evenly and stably. The measuring system is mainly composed of the stress ring on the jack, the strain-type pressure sensor, the dial indicator or the electronic displacement meter, etc. The load size can be measured using the pressure gauge connected to the jack and converted according to the rate curve of the jack. The composite foundation bearing plate can be round or square, and the area is the processing area borne by one pile. Field test conditions are shown in Fig. 4.1.

Gradual loading is generally adopted, and the basic load at each level is generally imposed at 1/10 to 1/15 of the estimated ultimate bearing capacity of a single pile. The first-stage load can be doubled, and the pile top settlement can be measured at intervals of 5, 10, 15, 30, 60, 90,…minutes after each stage of loading. As the settlement of the top of the pile per hour does not exceed 0.1 mm and occurs twice in a row, it is considered that the settlement has reached a relatively stable level, and the next level of load can be added. The load may be terminated when one of the following conditions is met, and the static load of the pile composite foundation is terminated under the following conditions:

(a) Subsidence increases sharply and the soil is squeezed out or there is a pronounced bulge around the pressure plate.

(b) The cumulative settlement of the sedimentation plate has exceeded 6% of its width;

(c) When the ultimate load is not reached, the maximum loading pressure is greater than 2 times the design pressure. The number of unloading stages can be half of the number of loading stages, and the same amount is carried out. Each unloading stage is half an hour apart, remembering the rebound amount, and the total rebound amount is recorded three hours after the unloading of the full load.

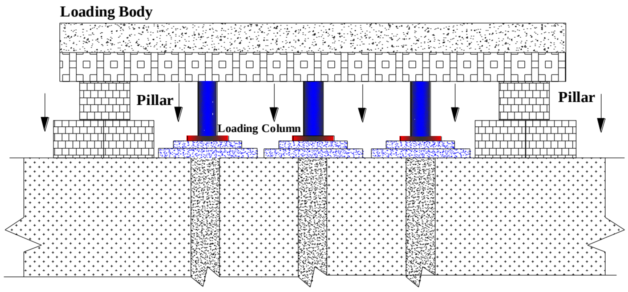

Fig. 4.1 Simulation of static load test

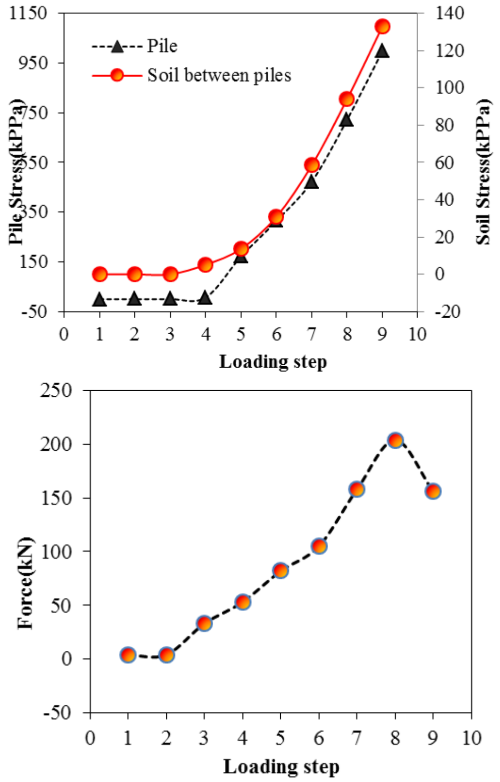

Fig. 4.2 Variation of pile stress and soil stress with load steps

A vertical bearing capacity of composite foundation was tested. In Fig. 4.1, the pile length and pile spacing is separately 8.5 m and 2.5 m and the pile top elevation is 1.5 m. The pressure plate size is 3.74 m^2 and the cushion thickness is chosen as 0.3 m. The cement mixing ratio is about 8.9%. The actual field test result of vertical bearing capacity of composite foundation is 198.25 kPa.

4.2 Finite element simulation analysis

The load-bearing ratio of pile-soil can be seen from Fig.

4.2: with the increasing of external load, the load assumed by the pile is gradually increased, the load assumed by the soil becomes larger, and the share ratio between pile and soil still increases, which is exactly the opposite of the pile foundation. In this way, through the adjustment of the cushion, the bearing capacity of the soil is fully utilized, so that the soil bears a part of the load and the resources are not wasted. This also illustrates the key technology of the cushion layer in the composite foundation.

According to the requirements for the static load test of a single-pillar composite foundation, the load is applied in 9 applications. When it is added to the 9th time, the displacement of the bottom plate exceeds 10 cm, and the static load test is terminated. The ultimate value of the ultimate bearing capacity of the composite foundation is 204.197 kPa, which is basically consistent with the actual field test result of 198.25 kPa. It fully verifies the consistency and scientificity of the experimental and theoretical analysis, and also shows that the foundation treatment has reached the requirements.

5. Conclusions

The differences between the prestressed pipe pile composite foundation and other fields in the field of hydraulic engineering are analyzed and studied. The vertical reinforcement rigid pile composite foundation is introduced into the hydraulic engineering field. Then, the prestressed pipe piles for hydraulic engineering are built. Meanwhile the related index system and calculation method are built and the model is analyzed as a whole. Based on the unique position of the cushion layer in hydraulic engineering, its mechanism of action is analyzed, and the penetration amount and overall deformation characteristics are analyzed. The physical dimensions and material property dimensions of the cushion layer are optimized and analyzed. The physical dimensions of the pile pitch are further analyzed. Based on above content, it is applied to the actual hydraulic project:

Firstly, the foundation model of prestressed pipe piles for hydraulic projects is established, and the new ideas of calculating the ground stress and calculating the external force are adopted. The analysis shows that the maximum settlement of the soil is located in the middle of the model. The law of lateral displacement of the surrounding soil is that the upper surface moves inward with the settlement of the floor, and the lateral deformation of the pile needs to be considered.

Secondly, based on the stress ratio of pile and soil, replacement ratio, load-sharing ratio of pile-soil load, etc., the action mechanism of cushion in pile-soil composite foundation is analyzed. Because of the difference in modulus between piles and soils, there must be centimeter-level piercing deformation in the cushion layer.

Thirdly, different thick cushion thickness comparative analysis model is established. Based on the four parameters of stress ratio, pile load sharing ratio, overall maximum settlement and floor differential settlement, a comparative analysis is conducted. Based on the analysis of the effect of stress diffusion, it is recommended that the cushion layer is designed to be 30 cm thick in the optimal condition for the study of prestressed pipe pile composite foundation in hydraulic projects.

Fourthly, a multi-material property cushion material analysis model for hydraulic projects has been established. From the angles of stress ratio, share of pile load, maximum overall settlement and differential floor settlement, considering the requirements of seepage control, the advantages and characteristics of cement soil, hard soil, elastoplastic clay and other materials are analyzed, and the conclusion of choosing cemented soil is given.

Finally, it is suggested that the spacing of prestressed pipe piles in the field of hydraulic engineering should be five times the pile diameter. The above research findings were applied to practical project. It is proved that the model of the hydraulic engineering and stress pipe pile foundation put forward in this paper is scientific and reasonable, and has a good application and promotion value.

For future work, the more filed tests of the conclusive parameters of this paper should be carried out in practical projects. It is also important for future work for conducting systematized theory and application frames of prestressed pipe pile composite foundation in hydraulic engineering.

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