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# Study on the influence of pile sinking speed on pile sinking characteristics and bearing characteristics of sandy soil foundation

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***Abstract:*** *Static piles are widely used in practical engineering due to their safety, environmental protection and high efficiency. In the penetration stage and static load stage, the static pile will affect the stress, strain, pile sinking characteristics and bearing characteristics of the soil around the pile, and it is of practical value to study the bearing characteristics of the pile in the sinking stage and the static load connection stage of the static pile. Based on the indoor model test, the pile pressing force, end resistance, and side friction resistance of the static pile in the penetration stage and the ultimate bearing capacity, end resistance, and side friction resistance of the pile in the static load stage are analyzed. By controlling the consolidation degree of sand soil foundation and the settlement rate of pile, the influence of it on the pile sinking stage and static load stage was discussed. The test results show that the resistance at the end of the pile always accounts for more than 85% of the total resistance, and the bearing characteristics of the end-bearing pile are reflected in the sand hydrostatic pile. In the penetration stage of pile, the pile pressing force and end resistance are positively correlated with the degree of consolidation, and negatively correlated with the penetration rate. The lateral friction resistance is positively correlated with the degree of consolidation and negatively correlated with the pile sinking rate. In the static load stage, the pile pressing force and end resistance are positively correlated with the degree of consolidation, and negatively correlated with the penetration rate. The frictional resistance of the pile side is positively correlated with the penetration rate, and the ultimate bearing capacity and the resistance of the pile tip are negatively correlated with the velocity.*

***Keywords:*** *sand; model test; degree of consolidation; load-bearing characteristics; Pile sinking rate*

## 1. Introduction

As an efficient and environmentally friendly engineering pile foundation technology, the static pile is widely used in the construction of urban infrastructure, compared with hammering pile, the construction of the static pile will not produce noise pollution and vibration, the impact on the surrounding environment and the life of residents is small, and the disturbance range and degree of the soil around the pile are also smaller, which further improves the reliability and efficiency of the construction. The static pile test is a common method to evaluate the bearing capacity and settlement performance of the foundation, but the consolidation degree and pile sinking speed of the sandy soil foundation may have a significant impact on the test results. Therefore, it is of great research background and practical significance to study the static pile test of sand foundation under different pile sinking speed and consolidation degree to understand the mechanical properties of sand, guide the construction of static pile and improve the foundation design and construction specification.

Sand soil foundation is a common type of foundation, and the hydrostatic pile in the sand soil foundation contains the pile-soil interaction problem under multi-field multiphase coupling, and the researchers have adopted a variety of methods and experiments to conduct in-depth research on the static pile problem. Luo et al. [1] believe that the distortion and subsidence of the structure around the pile will cause the change of the transverse load along the strike of the pile and the circumferential direction of the pile, resulting in the loosening of the shallow soil and the compaction of the deep soil. Zhou Jian et al. [2] found that there is an extreme value in the resistance of the pile end through the indoor model experiment of the sand static pile. Cooke [3] showed that the increase of pile end resistance and pile side friction resistance were helpful to improve the ultimate bearing capacity of the pile. Kou Hailei et al. [4] proposed that the existence of residual stress at the pile end is conducive to the exertion of the resistance

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of the pile end through the study of PHC pipe pile static pile. Zhang Xiangyu et al. [5] carried out indoor simulation tests on saturated silty soil foundations with different overconsolidation ratios and hydrostatic piles with different pile surface roughness, and found that the residual stress of friction piles at the end of friction piles with different overconsolidation ratios was smaller than that of normal piles. Yu Feng et al. [6-7] conducted in-situ experiments in the study of residual stress of hydrostatic piles, observed the changes of pile stress, and found that the residual stress of construction will occur after the pile sinking is completed. They also carried out in-situ tests on hydrostatic piles in sandy soils, and observed that the residual stress on the pile side gradually disappeared or gradually stabilized with the extension of the telogen period. Lv Qingxian et al. [8] studied the pile sinking behavior of the hydrostatic pile in sand and the influence of the pile sinking speed on its performance by applying different pile sinking velocities to the hydrostatic pile model, and analyzed the relationship between the pile pressing force and the end resistance in detail, in order to obtain more optimized research results. Jiao Yongzhi et al. [9] successfully developed a test device and method for the vertical bearing characteristics of a single pile under the condition of multiple unloading, which has the characteristics of simple operation and precise control, which can carry out constant force loading and uniform loading of model piles, realize the preparation of samples of different consolidated soils, and achieve higher accuracy and reliability in the test.

Lim et al. [10-11] conducted an in-depth study on the shear bearing capacity and the timeliness of the bearing capacity of the sand hydrostatic pile, and obtained the correlation between the increase of the lateral friction resistance of the pile and the increase of lateral stress during the shear process of pile sinking. Zhao Xianqiang et al. [12] revealed the difference in the pile sinking mechanism of static piles in cohesive soil and sandy soil by studying sand hydrostatic piles. Zhou Yundong et al. [13] conducted a true triaxial test study on saturated sand soil by using the vibrating sand rain method, and found that the reliability and repeatability of the test results could be improved by using the layered vibrating sand rain method. Pu Jialiu et al. [14] used the sand rain method to simulate the bearing capacity performance of shallow foundations, and found that the density of the sample was closely related to the drop distance and sand table hole. Kou Hailei [15] found that when the open concrete pipe pile is statically pressed into the medium dense sand soil foundation, the pile pressing force is negatively correlated with the penetration rate, and the penetration rate has an important impact on the ultimate bearing capacity of the open concrete pipe pile.

Under the same degree of consolidation, the bearing capacity, deformation performance and settlement performance of sand may be different. The pile sinking speed may affect the interaction mechanism between the pile and the soil. By studying the static pile test under different pile sinking speed and consolidation degree conditions, we can gain an in-depth understanding of the behavior characteristics of sandy soil foundation under different mechanical environments, including load-displacement response, pile resistance distribution, soil deformation characteristics, etc. Pile sinking speed that is too fast or too slow may lead to inaccurate test results and affect the safety and stability assessment of the foundation. Unreasonable consolidation conditions may lead to inconsistencies between the test results and the actual engineering conditions. Reasonable selection of pile sinking speed and consolidation degree has an important impact on the quality and effect of static pile construction.

## 2. Overview of the trial

### *2.1 Static pile driver*

In this paper, a pile foundation model experimental device is adopted, and the test device is composed of a model box, a servo motor, a model pile, a controller and a data acquisition instrument, as shown in Figure 1, Figure 2 and Figure 3. The model box is divided into three parts: upper, middle and lower, and the upper part is a servo motor and a sensor, which can realize constant rate or constant stress loading; The middle part is a model box, with an inner diameter of 20cm and a height of 48cm; The lower part is a consolidation device and a consolidation sensor. The diameter of the pile is 2.5cm, which is located in the center of the model box, 18.75cm away from the inner wall of the model box, and the influence of boundary effect can be ignored by 7.5 times of the pile diameter. The device can accurately simulate the sandy soil foundation under different stress paths, realize the control of different consolidation degrees of soil, and record the changes of soil consolidation pressure, side friction resistance, pile tip resistance, pile root pressure and pile sinking displacement in real time during the static pile pressing process.

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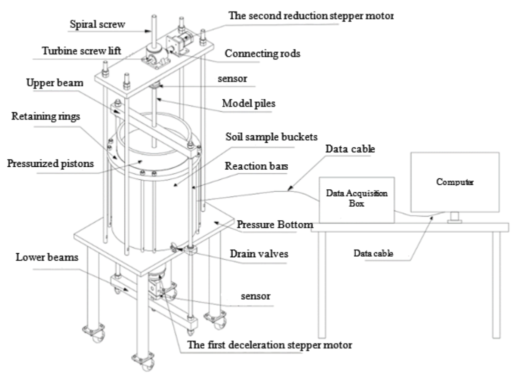


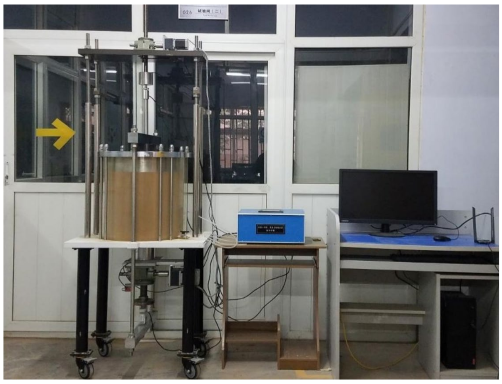

*Fig. 1 Schematic diagram of the model test device Fig. 2 The physical diagram of the model test device*

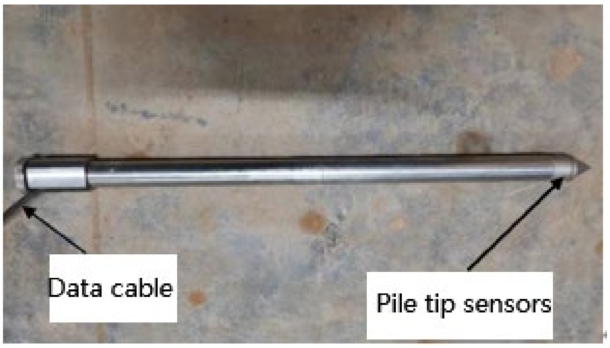


*Fig.3 Physical diagram of model pile*

### *2.2 Preparation of test sand samples*

The sand soil foundation is prepared by the sand rain method, and the sand rain method sample making instrument is shown in Figure 4. The sand is made of river sand from a place in Zhengzhou, and the particle analysis test, specific gravity test and relative density test are carried out according to the "Geotechnical Test Method Standard" [16], and the basic physical indicators are shown in Table 1, Table 2 and Figure 6. When filling, the amount of sand is estimated, the sand is divided into eight parts by the four-point method [17], and each part is paved in layers by the density control method, the drop distance is controlled at 20cm, the filling height of each layer is 2cm, the size of the sand hole D is not less than 4 times the maximum particle size of the sand particle Dmax, and the sand hole will not be arched or blocked [18], and the size of the sand outlet is set at 6mm, the hole spacing is 15mm, and the filling weight is 8.4kg. After the soil sample is prepared, it can be allowed to stand for 7 days, and the relative compactness is measured with a static cone detector after standing, and the pile sinking test can be carried out if the test requirements are met.

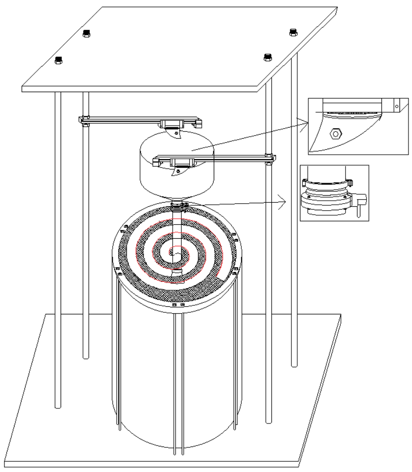

*Fig.4 Sand box structure diagram Fig.5 Sand samples are taken by four-point method*

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*Table 1: Parameters related to test materials*

| Average particle size ($d_{50}$) | Inhomogeneity factor ($C_u$) | Curvature coefficient ($C_c$) | Max/Min dry density ($\rho_{d\max} / \rho_{d\min}$) | Maximum/minimum dry porosity ratio ($e_{\max} / e_{\min}$) | Internal friction angle ($\phi$) | Specific gravity($G_s$) | Severe ($\gamma$) |
|---|---|---|---|---|---|---|---|
| 0.82 | 6.125 | 1.659 | 1.96/1.4 | 0.87/0.34 | 33 | 2.62 | 18 |

*Table 2: Particle gradation of test materials*

| Particle size(mm) | >2.5 | 2.5~2.0 | 2.0~1.0 | 1.0~0.5 | 0.5~0.2 | 0.2~0.15 | 0.15~0.075 | <0.075 |
|---|---|---|---|---|---|---|---|---|
| Proportion (%) | 0 | 3.2 | 23.94 | 35.04 | 26.58 | 5.6 | 1.54 | 4.1 |

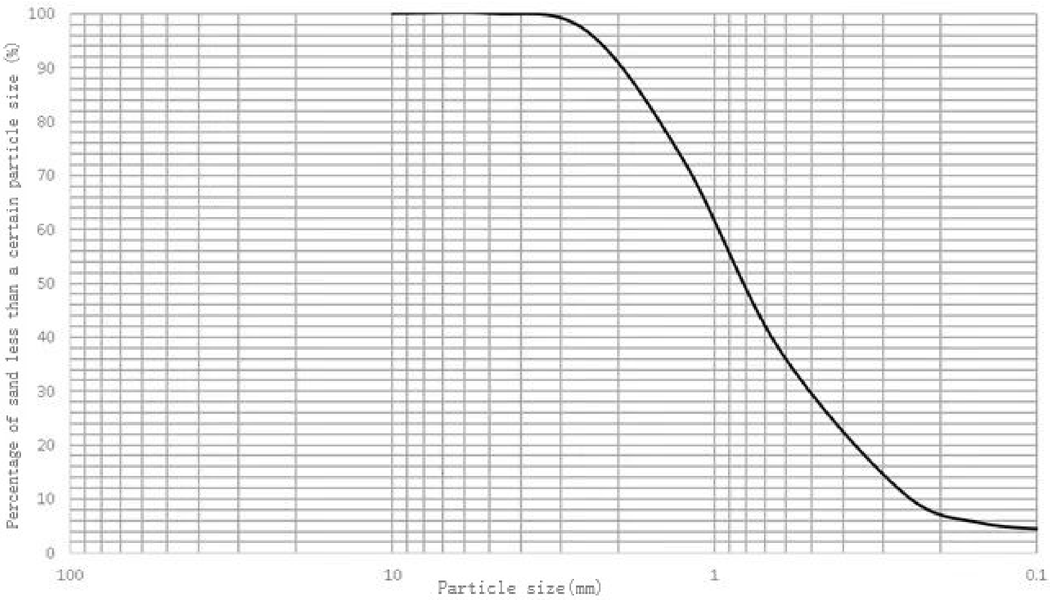


*Figure 6: Gradation curve of sand particles*

### *2.3 Pilot arrangement plan*

#### *2.3.1 Purpose of the test*

Through the indoor model test, the changes of pile pressing force, pile side resistance and pile end resistance during the pile penetration process and in the static load stage were explored under different penetration rates and different consolidation ratios. In order to achieve this goal, we conducted four sets of model tests, analyzed and verified whether these data are suitable for model test studies of sand hydrostatic piles. By fully analyzing these model test data, we aim to determine the trend of pile pressing force, pile side resistance, and pile end resistance under different conditions, and explore the relationship between them.

#### *2.3.2 Test steps*

(1) Preparation of the test loading system

Before performing the test, each calibrated probe is connected to the servo interface, and the instrument is assembled to ensure that all components are securely installed. Subsequently, the software was adjusted, the corresponding worksheet was established, and the initial data was zeroed to ensure the accuracy and reliability of the test data.

(2) Preparation of soil samples:

The sand sample will be divided into eight parts according to the quartering method. Each sample will be layered according to the sand and rain method, and the filling mass of each layer will be

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maintained at 8.6kg, and the filling height of each layer will be 2.5cm. Each time you load, you should ensure that the falling distance of the filling is controlled within 20cm, and the sand is slowly dropped by means of fixed falling distance and fixed speed to ensure that the relative density of the sandy soil foundation can be kept stable.

(3) Consolidation process:

After the preparation of the sandy soil foundation is completed, the pistons and upper and lower beams of the test unit are installed, and then the consolidation pressure of the upper part is applied to the sand body step by step. Specifically, two sets of sand foundations will first be consolidated to 20 kPa normally, while the other two groups will be consolidated vertically to 40 kPa and then unloaded to a vertical consolidation pressure of 20 kPa. The consolidation process of drying sand will be loaded in stages, which are 10 kPa, 20 kPa and 40 kPa, respectively.

(4) Penetration of piles:

After the consolidation of the sand is completed, the insertion of the pile is carried out. Set the speed of the pile to 1 mm/min and 3 mm/min respectively.

(5) Static load test:

When performing the static load test, the same amount of loading will be used. The value of each loading stage will be taken as 1/10 of the maximum pile end pressure, while the first loading value will be set to 300 KN, which is twice the staged load. Each level of loading needs to occur twice in a row when the settlement per hour is less than 0.1 mm before the next level of load can be applied. At the time of unloading, the unloading value of each level will be taken 2 times the staged load at the time of loading, and the unloading of each level will be maintained for one hour until the unloading reaches 0. Each unloading level is maintained for a period of not less than 3 hours.

The specific scheme for the indoor model test is shown in Table 3.

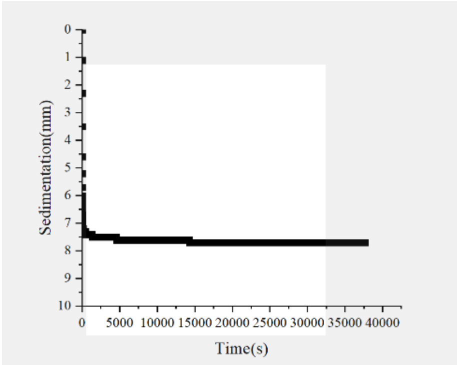
*Table 3 Test protocol table*

| Instrumentation speed mm/min | Soil consolidation pressure/kPa | Unloading vertical pressure/kPa | Static pressure pile sinking | Static load test | Purpose of the experiment |
|---|---|---|---|---|---|
| 1 | 20 | 0 | After each level of load is applied, it is stable for 6 hours, and then the next level of load is applied, and the last level of load is stable for 24 hours | The static load test is performed after the telogen period of 7 days | The bearing characteristics of hydrostatic piles with different insertion speeds in dry sand foundation with different overconsolidation ratios were studied |
| 1 | 40 | 20 | | | |
| 3 | 20 | 0 | | | |
| 3 | 40 | 20 | | | |

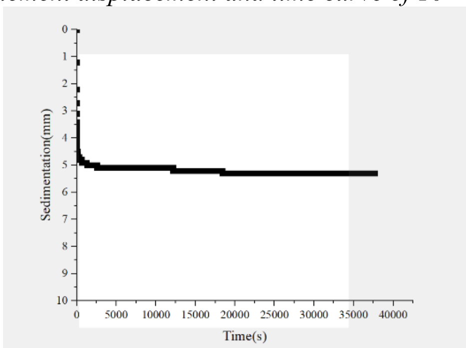
## 3. Test results and their analysis

### *3.1 Soil consolidation*

The consolidation process of drying sand in the model box adopts a hierarchical loading method, which is 10kPa, 20kPa and 40kPa respectively, and each level of load consolidation is 6h, and the last level of load is consolidated for 24h. Fig. 7 is the relationship between the settlement displacement of the last stage of consolidation of the soil with time. As can be seen from Fig. 7(a) and Fig. 7(b), the sand in the model box has been consolidated and stabilized.




*a. Settlement displacement and time curve of 10→20kPa*




*b. Settlement displacement and time curve of 20→40kPa*

*Fig. 7: Displacement and time curve of sand settlement*

### *3.2 Analysis of the results of the sinking process of hydrostatic single pile*

#### *3.2.1 Analysis of the impact of end resistance*

Fig. 8 shows the variation curve of pile end resistance with pile sinking depth during pile penetration, and it can be seen from Fig. 8 that the pile end resistance increases nonlinearly with the increase of pile sinking depth in dry sand foundation. After the pile sinking, the final resistance of the friction pile with a velocity of 1 mm/min and 3 mm/min under OCR=1 was 2115N and 2080N, respectively, and the end resistance increased by 1.67%, and the final resistance at the speed of 1 mm/min and 3 mm/min under OCR=2 was 2689N and 2413N, respectively, and the end resistance increased by 11.44%. The depth of the pile penetration is less than 10mm, and the resistance of the pile end is basically the same. Below the penetration depth of 10 mm, the resistance of the pile end increases significantly under different penetration rates. The results show that the influence of pile insertion speed on pile end resistance is significant, and the pile end resistance is negatively correlated with the insertion speed. This is due to the fact that the friction on the side of the pile is usually small at the beginning of the insertion and does not change significantly with the insertion speed. The rapid pile insertion speed will cause the dynamic response of the foundation soil, including the vibration and deformation of the soil, and this dynamic loading will lead to the change of the relative position between the soil particles, reduce the internal friction angle of the soil, and reduce the resistance of the pile end.

At the same time, it can also be seen from Fig. 8 that the pile end resistance increases with the increase of soil consolidation, and the influence of the degree of consolidation on the friction resistance of the pile end is more significant when the pile insertion speed is 1mm/min, that is, the slower the pile insertion speed, the greater the consolidation degree, and the greater the end resistance. Outside the penetration depth of 10 mm, the resistance of the pile end of the soil with different degrees of consolidation is about the same, and the resistance of the pile end increases significantly under different degrees of consolidation beyond the penetration depth of 10 mm, and the increase of the end resistance increases gradually with the increase of the penetration depth of the pile. This is due to the fact that the greater the degree of consolidation of the soil, the greater the occlusion force between the particles, resulting in the increase of friction, the greater the force required for the pile to penetrate the soil, and thus the greater the resistance of the pile tip.

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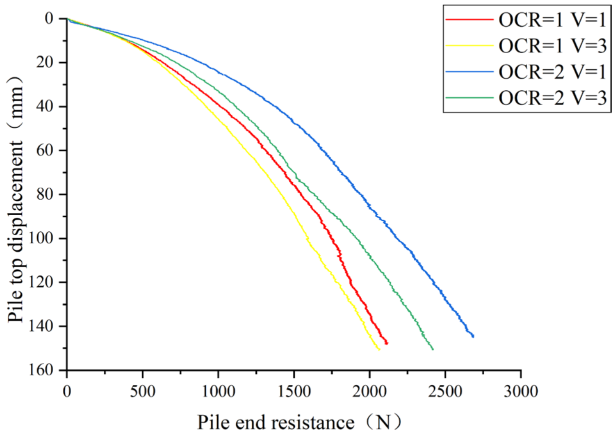


*Fig. 8: Displacement of pile end resistance with pile top during pile insertion*

### *3.2.2 Analysis of the influence of side friction resistance*

Fig. 9 shows the variation curve of pile side friction resistance with the depth of pile sinking during pile penetration. It can be seen from Fig. 9 that in the dry sand foundation, the friction resistance of the pile side increases nonlinearly with the increase of the pile depth of the pile sinking. After the pile sinking, the final side friction resistance of 1mm/min and 3mm/min under OCR=1 is 262N and 177N, respectively, and the lateral friction resistance increases by 33%, and the final lateral friction resistance is 305N and 213N, respectively, and the lateral friction resistance increases by 48.02% when the velocity is 1mm/min and 3mm/min under OCR=2, respectively, indicating that the influence of pile insertion speed on lateral friction resistance is more significant. The penetration depth of the pile is within 10mm, and the friction resistance on the side of the pile is basically the same. Below the penetration depth of 10 mm, the friction resistance of the pile side increases significantly under different penetration rates. This is due to the fact that the friction on the side of the pile is usually small at the beginning of the insertion and does not change significantly with the insertion speed.

Compared with OCR=1, the lateral friction resistance of the pile increases with the increase of soil consolidation, and the effect of consolidation on the lateral friction resistance is more significant when the pile insertion speed is 1mm/min. The penetration depth of the pile is within 10mm, and the friction resistance on the side of the pile is basically the same. Below the penetration depth of 10 mm, the friction resistance of the pile increases significantly under different degrees of consolidation, and this increase becomes more and more obvious with the increase of the penetration depth of the pile. This is due to the increase of the degree of consolidation of the soil is usually accompanied by the improvement of the compactness of the soil, the higher compactness will increase the contact point between the soil particles, the occlusion force between the particles will be enhanced, the soil will be more closely arranged, and the soil stiffness will be improved, resulting in the increase of friction resistance between the pile and the soil. The increase of the consolidation degree of the soil also leads to the increase of the stiffness of the soil, and the harder soil will exert greater resistance to the pile, and the pile side friction resistance will be higher during the pile insertion process.

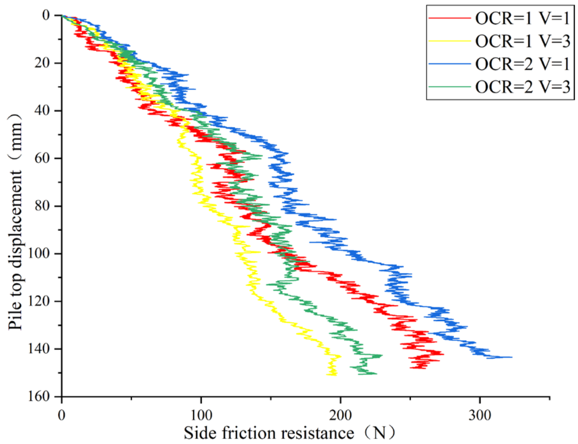


*Fig. 9: Displacement diagram of side friction resistance with pile top during pile insertion*

#### *3.2.3 Analysis of the influence of pile pressing force*

Fig. 10 shows the variation curve of pile root pressure with the depth of pile sinking during pile penetration. It can be seen from Fig. 10 that the pile pressing force increases nonlinearly with the increase of pile sinking pile depth in dry sand foundation, and after the pile sinking is over, the final pile pressing force of 1mm/min and 3mm/min under the condition of OCR=1 and OCR=2 is 2377N, 2257N, 2994N, 2626N, respectively, and the pile penetration depth is within 10mm, and the pile pressing force is basically the same. Below the penetration depth of 10 mm, the pile pressing force increased significantly under different penetration rates. The results show that the larger the penetration rate in the sandy soil foundation, the smaller the pile pressing force. This is due to the fact that in a dry sand foundation, when the pile sinking speed is fast, the soil particles may not have time to rearrange and compact, and the soil remains relatively loose, which will lead to less frictional resistance between the pile and the soil, resulting in a lower pile pressing force. When the degree of consolidation increases, the influence of the velocity on the pile pressing force is more significant, the speed is 1mm/min, the pile pressing force increases by 25.96%, and the speed is 3mm/min, and the pile pressing force increases by 16.34%.

Compared with OCR=1 and OCR=2, it can be found that the pile pressing force is proportional to the degree of soil consolidation. The depth of pile penetration is less than 10mm, and the influence of consolidation is small. Below the penetration depth of 10mm, the pile pressing force increases significantly with the increase of consolidation, and this increase becomes more and more obvious with the increase of the penetration depth of the pile. The increase of the consolidation degree of the soil also leads to the increase of the stiffness of the soil, and the harder soil will exert greater resistance to the pile, and the pile pressing force will be higher in the process of insertion.

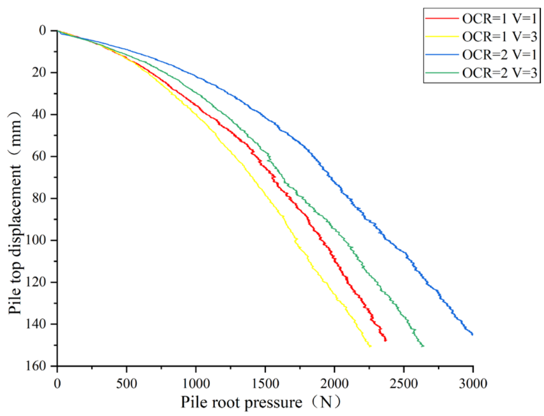


*Fig. 10: The variation of pile root pressure with the displacement of the pile top during the pile insertion process*

### *3.3 Analysis of the influence of pile end resistance in the static load stage*

#### *3.3.1 Analysis of the impact of end resistance*

Fig. 11 shows the variation curve of the resistance of the sinking pile end with displacement in the static load test. As can be seen from Figure 11, the magnitude of the resistance at the end of the static load phase is inversely proportional to the penetration rate. Under the conditions of OCR=1 and OCR=2, the pile penetration rate of pile sinking is 1mm/min and 3mm/min, and the final static load test pile end resistance is 2077N, 2020N, 2583N and 2134N, respectively. After the same rest time, the resistance at the end of the pile increased by 2.82%, 21.04%, 2.38% and 8.38%, respectively. This is because in the case of dynamic loading, the dynamic response of the foundation soil will be caused, including the vibration and deformation of the soil. This dynamic loading will lead to a change in the relative position between the soil particles, which reduces the internal friction angle of the soil and thus the end resistance. Higher pile insertion speeds may cause rapid vibration and disturbance of the soil, resulting in loosening or rearrangement of the soil particles. This loosening state may reduce the compactness and shear strength of the soil, thereby reducing the bearing capacity and frictional resistance of the pile end.

Compared with the over-consolidation ratio OCR=1, the end resistance of OCR=2 increases significantly, and the pile end resistance is proportional to the degree of soil consolidation, which is due to the fact that the consolidation process of soil involves the rearrangement of soil particles, the increase of soil compactness, the improvement of soil shear strength, and the decrease of deformation capacity, resulting in the increase of the internal friction angle of the soil, which further increases the friction

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resistance of the pile end. At the beginning of the load, the displacement of the pile is less than 2mm, the resistance at the end of the pile is approximately linear, the resistance value at the lower end is basically the same under different influencing factors, and the growth rate of the resistance at the end is gradually slowed down when the displacement of the pile exceeds 2mm. Mainly due to the initial contact between the soil and the pile and the initial deformation of the soil, the resistance is mainly contributed by the frictional resistance and the elastic deformation of the soil. With the continuous increase of load, the soil continues to deform under the action of the load, the soil compactness increases, the frictional resistance and the shear strength of the soil gradually increase. At this time, the resistance at the end of the pile gradually becomes dominant. When the load reaches a certain value, the pile end resistance stabilizes to what is known as the "ultimate static resistance". At this stage, the pile end resistance no longer changes significantly, because the soil has been sufficiently deformed and has formed a state of equilibrium.

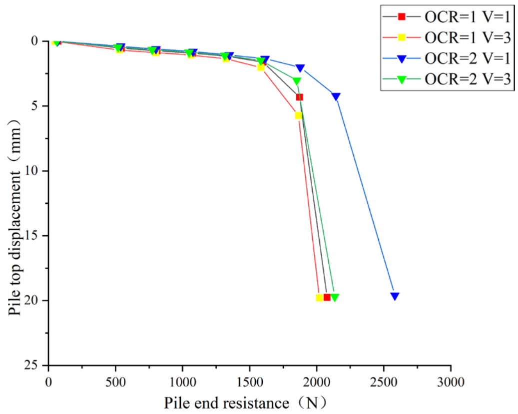


*Fig. 11: Variation of pile end resistance with pile top displacement in static load stage*

### *3.3.2 Side friction resistance analysis*

The static load is applied to the pile body and the lateral resistance of the pile is negative due to the presence of residual stress at the tip of the pile. As the static load is continuously applied, the resistance of the pile side will gradually increase. This is because the soil will be deformed, the compactness inside the soil will increase, and the frictional resistance and shear strength of the soil will gradually increase. Eventually, the resistance on the pile side will stabilize, i.e. it will no longer change significantly. At this point, the pile-side resistance reaches a stable state of the so-called static side resistance.

Fig. 12 shows the curve of the frictional resistance of the pile side with the displacement applied by the load. It can be seen from Fig. 12 that after the load is applied, the final side friction resistance of the friction pile is 219N and 231N at 1mm/min and 3mm/min under OCR=1, and the lateral friction resistance increases by 5.48%, and at 1mm/min and 3mm/min under OCR=2, the final lateral friction resistance is 258N and 263N, respectively, and the lateral friction resistance increases by 1.94%. It shows that the influence of the pile insertion speed on the lateral friction resistance in the static load stage is significant, and the pile side friction resistance is proportional to the pile insertion speed, which is because the high pile insertion speed in the early stage may lead to the increase of soil compactness, that is, the increase of soil compactness. This increases the frictional resistance inside the soil and therefore the pile side resistance. Secondly, the higher piercing speed may lead to the rearrangement of the particles inside the soil, thus improving the contact and mutual locking between the particles. At the initial stage of static load, the resistance of the pile side is negative, and the frictional resistance of the pile side increases linearly with the increase of the applied load. After the displacement of the pile exceeds 2mm, with the continuous application of static load, the resistance on the side of the pile will gradually increase, and the growth rate will gradually slow down and tend to be stable. This is due to the residual stress of the pile tip in the initial stage of load application, with the continuous application of static load, the soil will be deformed, the compactness of the soil will increase, the friction resistance and the shear strength of the soil will gradually increase, until the pile side resistance reaches the stable state of the static side resistance, and the pile side resistance tends to be stable.

At the same time, it can be seen from Fig. 12 that the frictional resistance of the pile side increases with the increase of soil consolidation. In the same state, the degree of consolidation of OCR=2 and OCR=1 has a significant effect on the side friction resistance, and the increase of OCR=2 is more and more obvious with the increase of the penetration depth of the pile. This is due to the increase of compaction and compactness and stiffness of the soil, which leads to the increase of friction resistance between the pile side and the soil. In the process of soil consolidation, the plastic deformation inside the

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soil is reduced, and the particles are rearranged, thereby reducing the plastic deformation and dissipation energy of the soil. This makes the transfer of the load to the soil more efficient and increases the frictional resistance of the pile side.

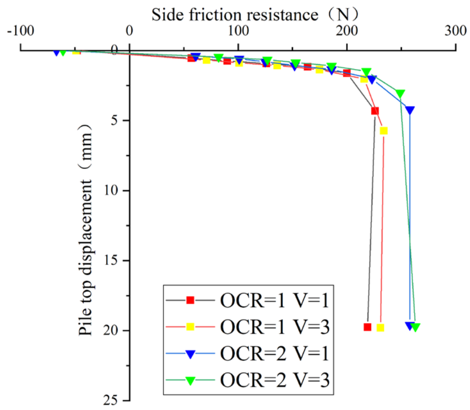


*Fig. 12: Variation of side friction resistance with load exertion*

### 3.3.3 Influence analysis of ultimate load

Fig. 13 Variation diagram of pile load displacement curve. It can be seen from Fig. 13 that the final pile pressing force of the friction pile is 2296N, 2251N, 2841N and 2397N under the condition of OCR=1 and OCR=2 at a speed of 1mm/min and 3mm/min, respectively, indicating that the ultimate load is inversely proportional to the pile insertion speed, that is, the greater the speed, the smaller the bearing capacity of the pile end. This is due to the fact that the higher pre-pile sinking speed may lead to a large relative movement between the soil particles during pile sinking, which may cause the loosening of the soil and produce a large deformation, so that the ultimate load decreases. In the static load stage, the load is applied to the pile in stages, and the load-displacement relationship of the pile is linear. When the initial load is applied, the displacement of the pile is less than 2mm, and the pile is in the elastic stage, and the displacement increases approximately linearly under the load. With the gradual increase of load, the displacement of the pile is greater than 2mm, less than 7mm, the particles inside the soil are rearranged, and gradually transition from elasticity to molding, the displacement velocity grows slowly, and when the maximum load at this stage is reached, the displacement will reach a relatively stable state. When the maximum load of the last step is applied, the displacement of the pile is greater than 7mm, the pile will reach the limit of its bearing capacity, the soil is sheared and destroyed, and the displacement growth rate is faster.

In the case of OCR=1, the effect of penetration rate on pile end load is not obvious, and this effect gradually expands with the increase of consolidation. Compared with OCR=1 and OCR=2, it can be found that the degree of consolidation has a positive correlation trend with the bearing capacity of the pile end. In the early stage of static load application, the influence of consolidation degree is small, and in the later stage of static load application, the pile pressing force increases significantly under different consolidation degrees, and this increase increases more and more obviously with the application of load. This is due to the fact that the consolidation of the soil in the early stage is usually accompanied by the compaction and the increase in the compactness of the soil. With the increase of compactness, the voids between soil particles decrease, and the shear strength and bearing capacity of soil increase accordingly. This leads to an increase in the ultimate load. A higher degree of consolidation is usually accompanied by a decrease in the relative movement between the soil particles, which increases the frictional resistance between the soil and the pile side. This means that the pile can transfer the load to the soil more efficiently, increasing the ultimate load. In the early consolidation process, the stability and strength of the soil are usually improved, that is, the resistance and deformation characteristics of the soil are improved. This increases the resistance of the soil to the load, further increasing the ultimate load.

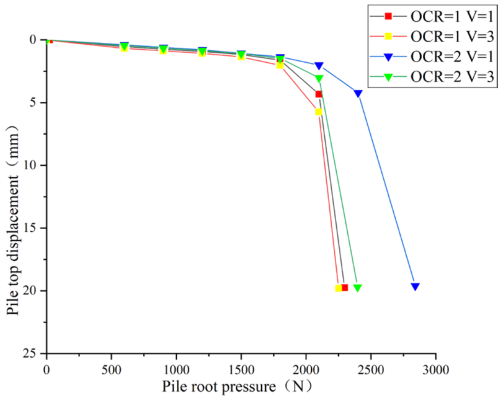


*Fig. 13 Variation of the load displacement curve*

## 4. Conclusion

The bearing characteristics of the static piles during the pile penetration process and the static load stage were studied through the laboratory model tests, and the effects of the pile sinking rate and sand consolidation degree were discussed. The main conclusions of this paper are as follows:

(1) In the whole stage of static pile penetration and static load, the ratio of pile side friction resistance to total resistance has been maintained at a low level, with the increase of pile penetration depth, the pile end resistance gradually decreases, but the pile end resistance still accounts for more than 85% of the total resistance, and the static pressure pile of sand soil foundation reflects the bearing characteristics of end-bearing piles. In sand hydrostatic piles, the pile sinking rate and consolidation degree will be affected to different degrees, and the influence of pile sinking rate on pile bearing characteristics is obvious.

(2) The increase of the consolidation degree of the soil makes the pile side friction resistance, pile end resistance and pile pressing force higher during the penetration of the soil pile. When the vertical load is applied in stages in the static load stage, the ultimate bearing capacity, lateral friction resistance and pile end resistance all increase with the increase of the overconsolidation ratio of the soil.

(3) The penetration rate of pile sinking has obvious effects on the pile sinking characteristics and bearing characteristics of static piles. In the process of pile penetration, the pile end resistance and pile pressing force are inversely proportional to the penetration rate, and the pile side friction resistance is inversely proportional to the penetration rate. In the static load stage, the ultimate bearing capacity and pile end resistance are inversely proportional to the penetration rate, and the side friction resistance is directly proportional to the penetration rate.

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