

## Research Article

# Experimental Study on Mechanical Deformation Characteristics of Inclined and Straight Alternating Pile Groups

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In order to investigate the bearing characteristics of inclined straight alternating pile groups under vertical and horizontal loads, the indoor model test of  $2 \times 2$  inclined straight alternating pile groups with two layers of soil on low pile caps was carried out, the manufacturing method of inclined straight alternating pile groups was studied, and the test scheme was reasonably designed. In the test, the fast maintenance load method was used to simulate vertical loads, and the horizontal force loading frame was designed to simulate horizontal loads. The experimental data were obtained by pasting strain gauges on the pile body, and the computer was used to process the data according to the mechanical formula. The distribution of axial force, lateral friction resistance, and end resistance of each characteristic pile of the pile group foundation was obtained, and the settlement law of the pile group was analyzed. At the same time, combined with the test data and the existing theories, the interaction mechanism between pile caps, piles, and soil of inclined and straight alternating pile groups is discussed. The load sharing characteristics between piles and pile caps are analyzed, and the horizontal load is in the proportion between straight piles and inclined piles. The stress characteristics of straight piles and pile groups in the pile group system are compared and analyzed, and some valuable conclusions are obtained.

## 1. Introduction

In recent years, inclined piles have been widely used in bridge wharf, offshore drilling platform, and large-scale transmission line tower foundation projects [1–4]. Its good pullout resistance and compression resistance can better meet the requirements of horizontal bearing capacity, but at present there is little research on the mechanism of loading and deformation of inclined piles and inclined pile groups in China, and the axis of inclined piles is not perpendicular to the ground plane, which makes the bearing and deformation behavior of inclined piles more complicated than that of straight piles, so it is of great engineering practical significance to carry out the research of inclined and straight alternating pile groups [5, 6]. In terms of existing theory, Zhao et al. tested the load-displacement and pile strain of inclined-inclined, inclined-straight, and straight-straight

double piles with caps and straight piles under horizontal load and got the conclusion that the horizontal bearing capacity of load-displacement and pile strain of inclined piles are obviously better than those of straight piles [7, 8]; Zhang et al. [9, 10], Binu et al. [11], Kong et al. [12], Lu et al. [13], and Shao et al. [14], respectively, studied the vertical bearing capacity of inclined piles through model tests, which is of great significance for understanding the bearing and deformation characteristics of inclined piles. Ashraf and Ahmed [15], Kong et al. [16] and Shibata et al. [17], respectively, designed model tests to preliminarily study the side friction resistance of the inclined single pile in homogeneous sandy soil and homogeneous soft soil.

According to the existing pile foundation theory and system, an indoor model test was carried out to analyze the stress and deformation of  $2 \times 2$  inclined and straight alternating pile groups in three layers of soil with low pile

caps. Combined with relevant theoretical analysis, the workability of inclined and straight alternating pile groups in different soil layers under vertical and horizontal loads was studied, the distribution of axial force, side friction resistance, and end resistance of each characteristic pile group foundation was obtained, and the settlement law of pile groups was analyzed. On this basis, the characteristics of load sharing between piles and pile caps and the characteristics of horizontal load sharing between straight and inclined piles were analyzed, and some valuable conclusions were obtained.

## 2. Model Test of Inclined and Straight Alternating Pile Groups

**2.1. Test Summary.** The soil box used in the test is 2 m long, 1 m wide, and 1 m high. The surrounding area is built with bending beams for testing, and the interior is leveled with cement mortar. The box is stable and reliable, and the size is sufficient to meet the test requirements. The soil in the test is divided into two layers, with clay at the upper part and sand at the lower part (30 cm sand filled at the bottom to eliminate the boundary effect at the bottom), as shown in Figure 1, which is a schematic diagram of the vertical and horizontal loading test of two layers of soil inclined and straight alternating pile groups with low pile caps.

In the open air environment, the vertical loading of the soil box is realized by stacking heavy objects, and the loading method of quickly maintaining the load is adopted. In this model test, a horizontal force loading frame is designed by ourselves, which converts the gravity of heavy objects into horizontal force through two pulleys and applies horizontal load to the inclined and straight alternating pile groups. The middle of the rope is connected with an axial force meter to measure the horizontal force. The experimental data were obtained by attaching strain gauges to the pile body and connecting them to strain gauges. The data were processed by computer according to the mechanical formula to obtain the internal force variation curve of pile groups.

**2.2. Fabrication of Model Piles.** Considering various factors, the length of the vertical pile and inclined pile in the test is 750 mm and 770 mm, respectively. The diameter of the pile is 32 mm, and the included angle between the inclined pile and vertical direction is  $11.3^\circ$ . The pile is made of PVC pipes with an outer diameter of 32 mm and an inner diameter of 25 mm, the elastic modulus of the pile body material is 3200 MPa, and the pile cap is poured with C30 concrete. The pile heads are arranged in a  $2 \times 2$  arrangement on the bearing platform, the size of the bearing platform and the pile spacing are shown in Table 1.

The materials required for making the pile group model are stones, ordinary portland cement, river sand, and PVC pipes. Use a hand saw to process the PVC pipe into the required pile length. The four piles are connected into a whole with a certain amount of flexible wires, with a pile spacing of 150 mm (center distance), and the lower part of the pile is also

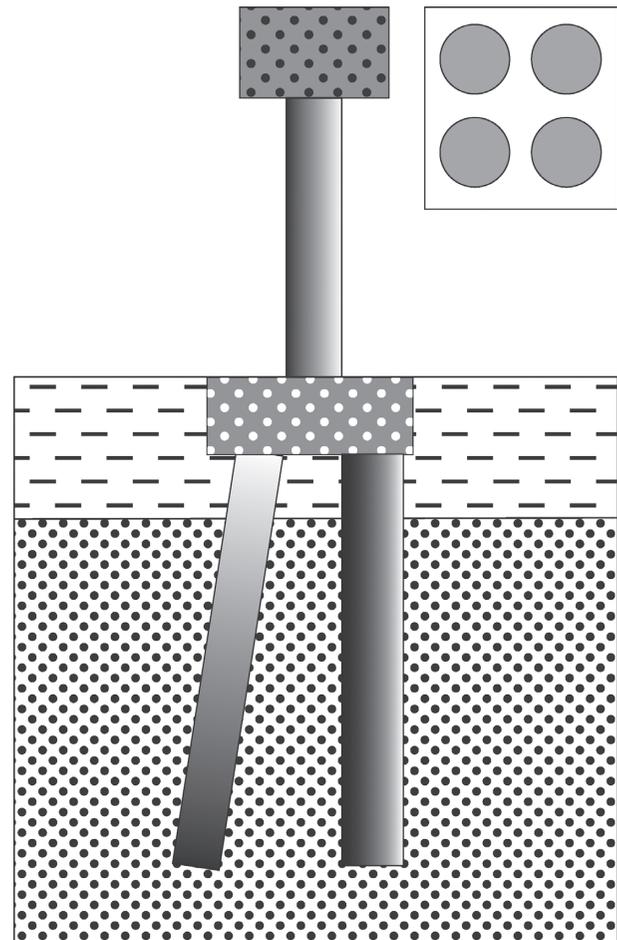


FIGURE 1: Schematic diagram of the model test of inclined and straight alternating pile groups with two layers of soil under low pile caps.

connected into a whole, so that the included angle between the vertical pile and the horizontal pile is  $11.3^\circ$ , the upper and lower parts of the pile are connected well, and the lower part of the pile is wrapped with adhesive tape to be fixed. There is a rectangular concrete block for waste test next to the soil box, and it is piled into a square model slot with 250 mm side length. Put the glass in the lower part of the model slot and pay attention to the fact that the model slot should be square without inclination and firm. Sieve stones with a 1.5 cm sieve to remove impurities and sieve sand with a 1.5 mm sieve are used. Mix stones, sand, cement, and water evenly according to the proper proportion to make concrete. Pour the concrete into the model slot of the pile cap for 1.5 cm and place a 20 cm long wire evenly in the vertical and horizontal directions with a spacing of 1 cm.

When the depth of concrete reaches 3 mm, put the model pile is fixedly placed in the model slot, add the iron wire again when the depth is 6 mm, and continue pouring concrete until the pile cap is 750 mm thick. Pay attention to keep the vertical pile upright, fix the upper part, and then stand still for 3 days to dismantle it. Pay attention to adding water for maintenance during this period. After the pile group is formed and removed from the mold, it is taken

TABLE 1: Bearing platform size layout (mm).

Pile center spacing		Cap size	Protective layer thickness
Longitudinal bridge direction	Transverse direction		
150	150	230 × 230 × 75	24

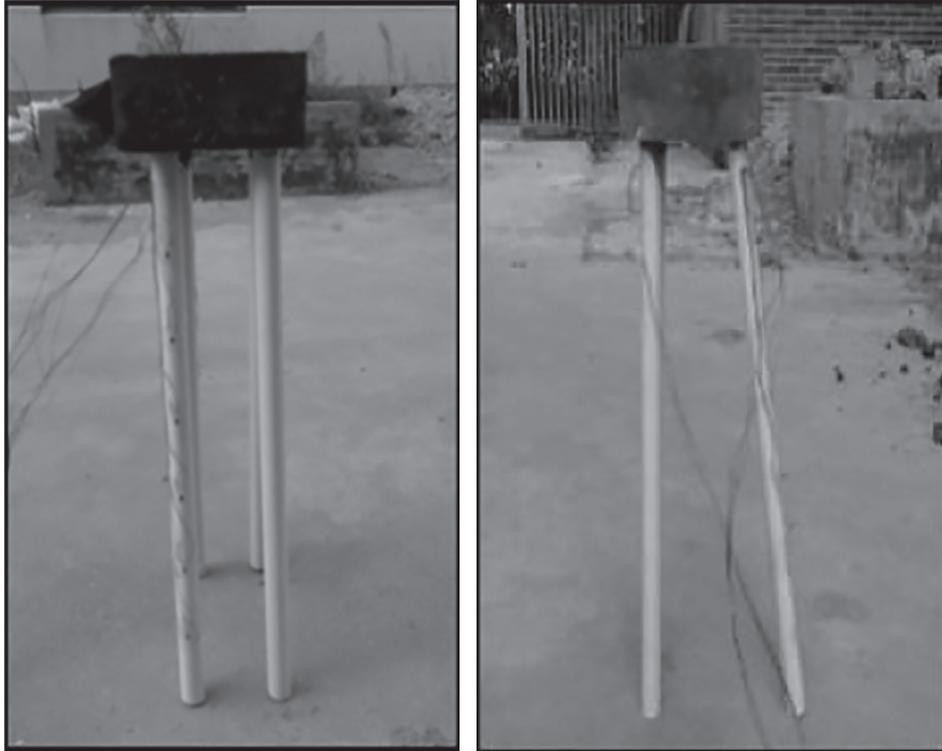


FIGURE 2: Model of inclined and straight alternating pile groups.

indoor and cured in a constant temperature environment of 20°C for 7 days. The model pile is shown in Figure 2.

**2.3. Sticking of Strain Gauges.** The strain gauge used in this test is BX120-3AA strain gauge produced by Xing tai Strain Gauge Factory. Its technical parameters are as follows: resistance is 120 ( $\pm 0.1\%$ )  $\Omega$ , grid length and grid width are 3 mm × 2 mm, sensitivity coefficient is 2.05 ( $\pm 0.28\%$ ), and strain gauge measurement range is 1–20000 microstrains. After the 2 × 2 oblique and straight alternate pile group model of the low bearing platform is completed, the strain gauges are pasted. The length of the inclined pile and straight pile is 70 cm, and one inclined pile and one straight pile on the same side are selected as test piles. Six strain gauges are arranged on each pile with the length of the straight pile, two test points numbered 1# (on the inner side of the pile group) and -1# (on the outer side of the pile group) are arranged from top to bottom 10 cm away from the top, and two strain gauges are sequentially numbered every 10 cm downward. Similarly, two strain gauges are pasted on the inclined pile at the same depth as the straight pile, the strain gauges on the inner side of the pile group are numbered 7# to 12#, and the strain gauges on the outer side of the pile group are numbered -7# to -12# from top to bottom.

Saint-Venant's principle in elastic mechanics shows that stress concentration exists in the stressed member near the stressed position; therefore, the strain gauge should be stuck slightly away from the end of the model pile so as to avoid reading deviation caused by stress concentration. The strain gauge distribution is shown in Figure 3.

#### 2.4. Foundation Preparation and Model Pile Arrangement.

The soil in this model test is divided into two layers, the upper layer is 35 cm thick clay layer and the lower layer is 70 cm thick sandy soil layer, of which the thickness from sandy soil layer to pile bottom is 35 cm and the thickness of sandy soil layer laid at the bottom to reduce the boundary effect is 35 cm.

According to the control of water content and density, after reshaping the soil, the soil is compacted in layers in the soil box while ensuring the uniformity of the soil. In order to eliminate the bottom boundary effect, the lower sand layer is laid to a thickness of 35 cm and vibrated in two layers. Then, according to the size of the soil box and the influence range of the boundary effect, select the appropriate position to place the model pile and then carry out the positioning of the model pile and the laying of the soil. After 35 cm of sand at the bottom of the pawnshop, one

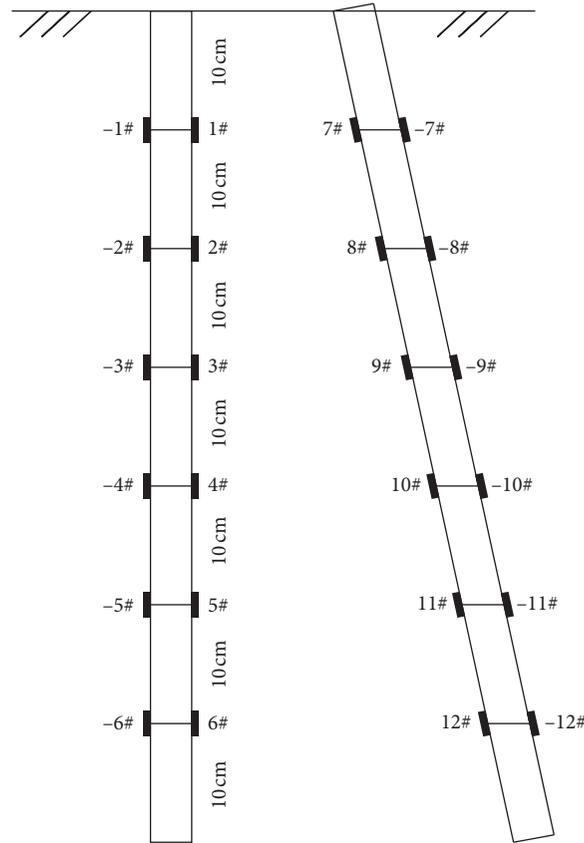


FIGURE 3: Strain gauge distribution diagram of pile groups with low pile caps.

TABLE 2: Performance parameters of soil.

Name	Proportion ( $G_s$ )	Water content (%)	Void ratio $e$	Cohesive strength $c$ (kPa)	Internal friction angle ( $\phi^\circ$ )
Sandy soil	2.91	4.2	0.68	0.15	28.2
Clay	2.68	15.6	0.71	20.3	14.2

person centralizes the model pile and the other adds sand layer by layer, each layer is about 10 cm, and tamps the sand with a rubber hammer.

When the model pile is in place, the vertical position of the model pile is strictly guaranteed, and when sand is laid, the pile body is ensured to be natural so as to avoid stress caused by deformation and displacement of the pile body in the construction process. After laying 3 layers, let the pile bury 35 cm (half of the pile length) and replace the clay layer. The clay layer is laid about 35 cm in total, slightly above the bottom of the pile cap, and is evenly laid and compacted in three times. When the top layer of clay is laid close to the cap, fill the bottom of the cap with earth and replace it with sand if necessary to ensure even and close contact between the cap and the soil layer. After the model pile is in place, the soil is properly consolidated for 3 days by stacking around the pile. The clay and sand samples used in the model test were selected to carry out conventional geotechnical tests in the geotechnical laboratory of the Shandong University of Science and Technology, and their main physical and mechanical properties were obtained as shown in Table 2. The

picture taken when the model pile is in place in the soil is shown in Figure 4.

**2.5. Model Experiment Process.** The loading method of this test adopts the rapid maintenance loading method, and the loading and strain measurements of the pile group model are realized by stacking concrete blocks. During vertical loading, steel plates are added to the upper part of the bearing platform to increase the stacking area, and a displacement dial indicator is installed at the top of the bearing platform.

On the second day after the completion of vertical loading, horizontal loading shall be carried out, and static loading frame shall be used when horizontal loading is applied. The horizontal static loading frame is mainly composed of I-beams welded and fixed to the edge of the model slot by screws. Two pulleys and wire ropes are used to convert the weight gravity into horizontal load. The horizontal loading frame can be added with sand as a weight, the loading process is easy to control, and the load can be stably maintained. By installing an axial force meter at the joint



FIGURE 4: Layout of the model pile in soil.

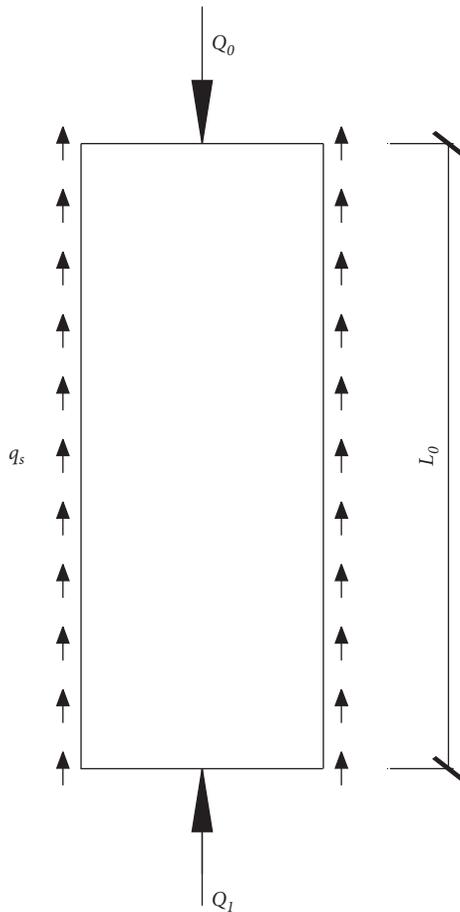


FIGURE 5: Pile stress unit.

between the steel wire rope and the loading point, the applied horizontal load can be monitored.

During horizontal loading, special hoops are made to bear the horizontal load and apply the horizontal load evenly to the bearing platform. The axial force meter is placed on the wire rope, which is connected with the hoop and the bucket through two pulleys. The horizontal loading is divided into five stages: the first stage 100 N, the second stage 200 N, the third stage 300 N, the fourth stage 400 N, and the fifth stage 450 N. After each stage was loaded for 5 min, the strain value tended to be stable and the data were recorded by taking photos. When unloading, unload according to the

same load level, maintain for 5 min, and take photos to record data. During horizontal loading, pay attention to keeping the wire rope and two pulleys in a straight line and keeping the wire rope level.

#### 2.6. Data Calibration and Measurement Data Processing.

The data measured in the model test include the strain value of the pile body of the model pile and the settlement of the pile cap. Bearing platform settlement is read out by a dial indicator. The axial force of the pile body can be obtained by calibration or according to the calculation formula of material mechanics.

2.6.1. Calculation of Axial Force of Pile Body. According to the stress-strain relationship in material mechanics, the stress of the pile body is

$$\sigma = E \times \varepsilon, \quad (1)$$

where  $\sigma$  is the stress of the pile body, kPa;  $\varepsilon$  is the strain of pile body; and  $E$  is the elastic modulus, kPa, of the pile material.

The axial force  $Q$  of the pile body is

$$Q = \sigma \times A, \quad (2)$$

where  $A$  is the cross-sectional area of the pile body,  $m^2$ .

2.6.2. Calculation of Pile Side Friction. Taking any pile body unit, as shown in Figure 5, according to the static balance, the pile side frictional resistance  $Q_s$  can be obtained by the following formula:

$$q_s = \frac{Q_0 - Q_1}{L_0 \times D \times \pi}, \quad (3)$$

where  $q_s$  is the average value of pile side friction resistance, kPa;  $L_0$  is the length of the pile body unit, m;  $D$  is the diameter of the pile, m; and  $Q_0$  and  $Q_1$  piles are the axial forces on the upper and lower sides of the pile stress unit, kN.

2.6.3. Calculation of Bending Moment of Pile. According to the definition of the bending theory and moment of inertia, the moment  $M_i$

$$M_i = EI \frac{\varepsilon_{li} - \varepsilon_{yi}}{d}, \quad (4)$$

TABLE 3: Load settlement.

Load level	Pile top load (N)	Single-stage settlement (mm)	Cumulative settlement (mm)
0	0	0	0
1	165	0.43	0.43
2	330	0.37	0.8
3	660	0.87	1.67
4	990	0.88	2.55
5	1320	0.9	3.45
6	1650	0.91	4.36
7	1980	0.92	5.28
8	1650	-0.19	4.92
9	1320	-0.17	4.64
10	990	-0.28	4.42
11	660	-0.22	4.4
12	330	-0.02	3.97
13	165	-0.43	3.75
14	0	-0.14	3.61

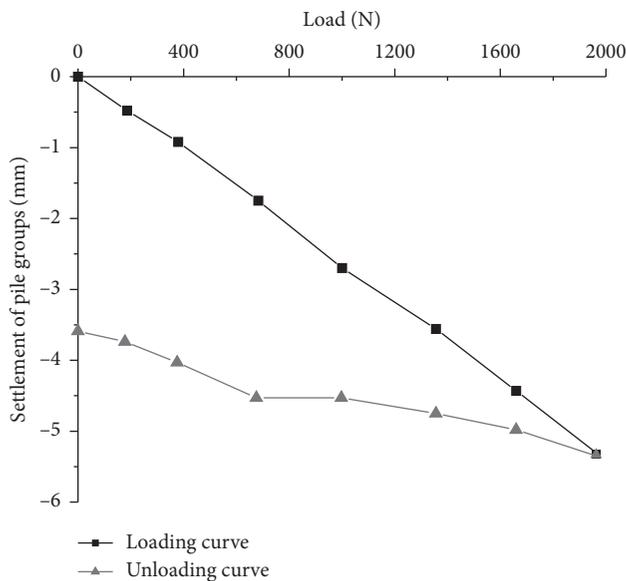


FIGURE 6: Variation curve of settlement: loading and unloading of pile caps.

where  $EI$  is the flexural rigidity of the section;  $\varepsilon_{li}$  and  $\varepsilon_{yi}$  are the compressive and tensile strains at each measuring point of the cross section, respectively, and  $d$  is the pile diameter. The outer diameter of the pile is 32 mm, the inner diameter is 28 mm, and the pile length of the leaking cap is 70 cm.  $A = (\pi(D^2 - d^2))/4$ , bringing in  $A = 188.4 \text{ mm}^2$ . The elastic modulus  $E$  of the PPR tube is 0.7–1.4 GPa, and  $E$  is 1.4 GPa.

### 3. Analysis of Experimental Results

**3.1. Analysis of Vertical Loading Test Results.** During the vertical static load test of  $2 \times 2$  inclined and straight alternating pile groups with two layers of soil and low pile caps, we obtained the settlement-load curve at the center of the pile caps and the axial force curve of straight piles along the pile body at different load levels and the axial force curve of inclined piles along the pile body at different load levels. The bending moment of inclined pile under vertical load is

generated, and the distribution of bending moment of inclined pile under vertical load is obtained.

The observation data of the settlement of the test pile caps under the vertical load of the  $2 \times 2$  inclined and straight alternating pile groups with two layers of soil are shown in Table 3, and the relationship between the vertical settlement of the pile caps and the unloading of the loading load step by step is shown in Figure 6. During the loading process, the vertical settlement of the pile cap is linearly related to the loading load, which is consistent with the straight line section of the  $P$ - $S$  curve of the settlement of a single pile. During the loading process, the curve changes in a straight line, and there is no stage of gradual acceleration of settlement. This shows that the maximum vertical load applied is small, the foundation deformation is in the elastic compression stage, and the pile caps with low pile caps play an inhibiting role in controlling the settlement of pile groups during the loading process. During the unloading process, the approximate linear rebound of pile caps begins, and generally, the curve rises faster as the load decreases. When unloading is about to be completed, the pile caps will rise faster than before. The reason for this analysis is that a large elastic deformation was restored in the later stage of unloading.

As can be seen from Figure 7, under the action of vertical load, the group pile side friction in cohesive soil decreases slightly with the increase of depth when the load is small and decreases rapidly with the increase of depth when the load is large. The greater the load, the greater the side friction resistance in cohesive soil. In sandy soil, the side friction is almost zero because the PPR pipe is smooth, the density of newly filled sand is not high, and sandy soil has no cohesion.

As shown in Figure 8, the variation curve of the axial force of the straight pile under different load levels along the pile body causes smaller strain, larger fluctuation of strain value, and slightly larger error when the load is smaller. The obvious regularity can be seen from the figure when the load is large: due to the location of monitoring points, the data processing is from 10 cm to 60 cm below the pile cap, and the axial force changes approximately linearly in the upper half of the pile body, which can reflect that the pile side resistance of the upper cohesive soil plays a role. In the lower half of the pile, i.e., sandy

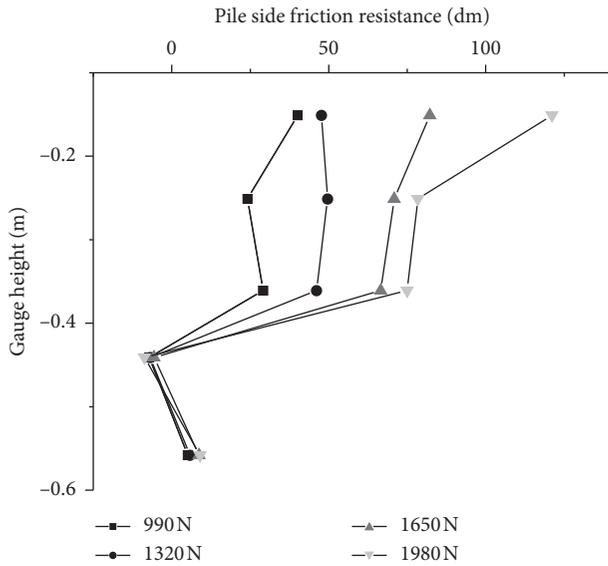


FIGURE 7: Change curve of pile side friction resistance.

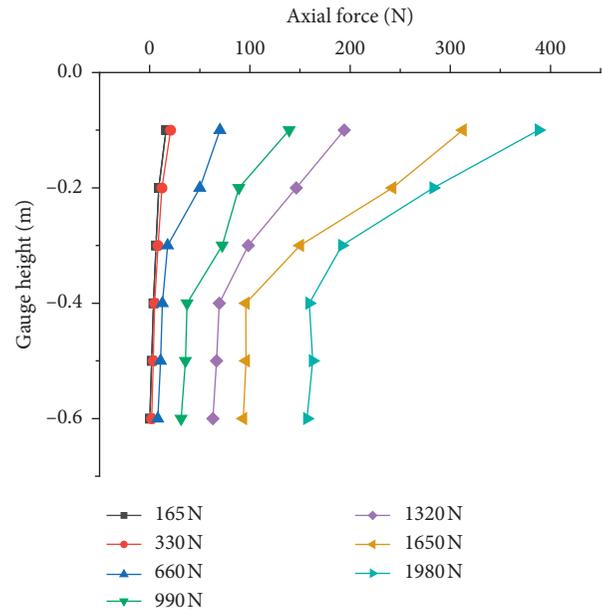


FIGURE 9: Variation curve of axial force of the inclined pile along pile height.

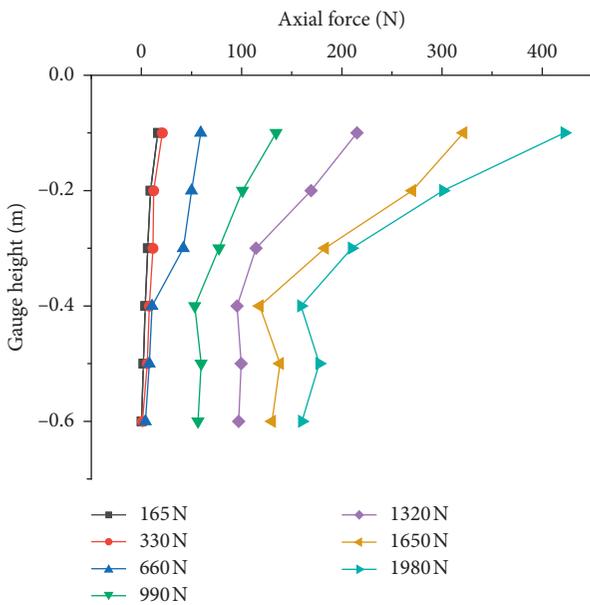


FIGURE 8: Variation curve of axial force of straight pile along pile height.

soil, the axial force of the pile is approximately the same, indicating that the lateral friction resistance of sandy soil to the pile is very limited, the pile end has a certain supporting force, and the pile end shows the nature of friction pile.

As shown in Figure 9, the variation curve of the axial force of the inclined pile along the pile body under different load levels is slightly smaller than that of the straight pile, and the variation law is very similar to that of the straight pile. This shows that the vertical stress deformation of the inclined pile is not different from that of the straight pile when the angle of the inclined pile is relatively small, and the axial force of the inclined pile is reduced by about 20% when the load is large.

In the process of vertical loading, the bending moment produced in straight piles is very small, while that produced

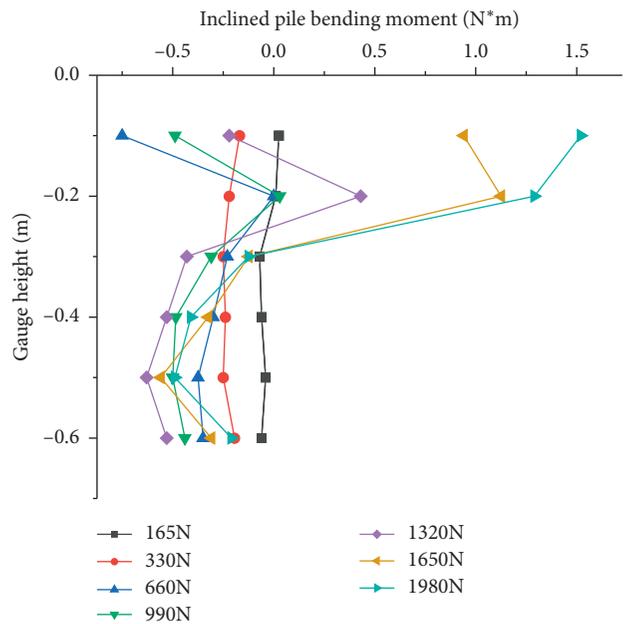


FIGURE 10: Curve of bending moment of the inclined pile under vertical load.

in inclined piles. The curve of bending moment of the inclined pile along the pile body is shown in Figure 10. As shown in Figure 10, the bending moment of inclined piles under different loads is basically zero at the top of the pile when the load is relatively small, the inside of the pile is pulled, the bending point is concentrated on the 0.2 m to 0.3 m pile section, and the maximum bending moment appears at 0.5 m on the ground of the pile cap. With the increase of the load, the bending moment at the top of the pile becomes larger and faster, showing tension at the

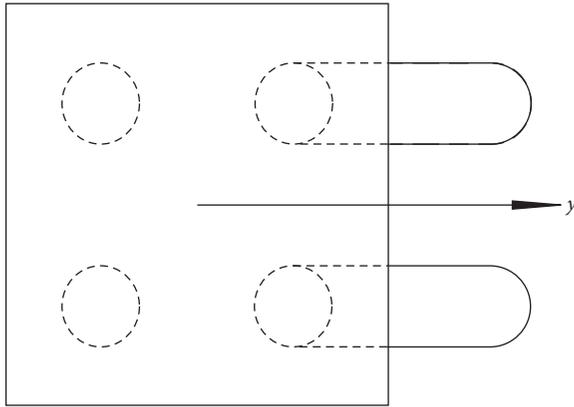


FIGURE 11: Plan layout of pile groups.

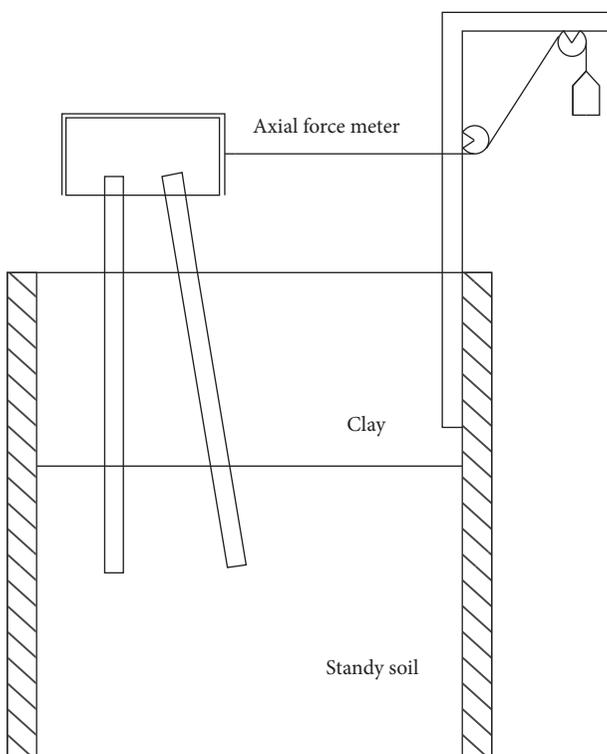


FIGURE 12: Schematic diagram of horizontal loading of pile groups with low pile caps.

outside, the reverse bending point of the pile moves down, and the maximum bending moment appears at the pile end.

According to the curve of bending moment, it is judged that the lateral soil of the pile produces outward horizontal reaction to the pile body, which is consistent with the actual situation. The bending moment along the pile body caused by inclined pile compression is small, and the influence of bending moment on straight pile can be basically ignored.

**3.2. Analysis of Horizontal Loading Test Results.** Figure 11 shows the plane layout of the  $2 \times 2$  inclined and straight alternating pile groups, showing the  $y$  direction. When loading along the  $y$  direction, the inclined pile is a negative

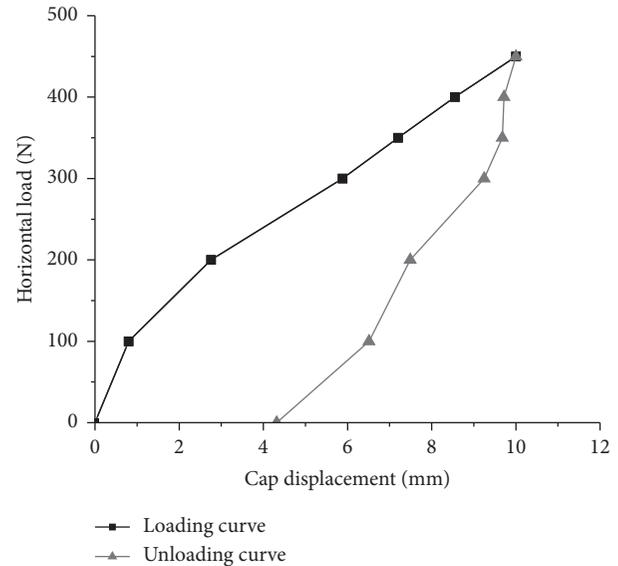
FIGURE 13: Displacement-load curve of pile caps when pile groups are loaded along  $y$  direction.

TABLE 4: Table of horizontal displacement of pile caps.

Loading series	Horizontal load (N)	Horizontal displacement (mm)
0	0	0
1	100	0.74
2	200	2.67
3	300	5.86
4	350	7.21
5	400	8.65
6	450	10.14
7	400	9.87
8	350	9.76
9	300	9.25
10	200	7.53
11	100	6.44
12	0	4.37

inclined pile. When loading in the opposite direction in  $y$  direction, the inclined pile is a positive inclined pile.

Figure 12 is a schematic diagram of a horizontal loading test. In this test, loading and unloading tests were carried out along the  $y$  direction and  $y$  direction, respectively. Loading and unloading along the  $y$  direction, the horizontal displacement-load curve of the center of the inclined and straight alternating pile caps and the distribution law of bending moment along the pile body under different load levels are obtained. When loading along the reverse direction of  $y$ , the distribution of bending moment along the pile body under different load levels is obtained. The bending moments of positive inclined pile, negative inclined pile, and straight pile are compared and analyzed through the bending moment diagram.

Figure 13 and Table 4 shows the displacement-load curve of the  $2 \times 2$  inclined and straight alternating pile groups with two layers of soil and low caps loaded along the  $y$  direction. It can be seen that the inclined pile groups have higher horizontal stiffness when the horizontal load is small, while the horizontal

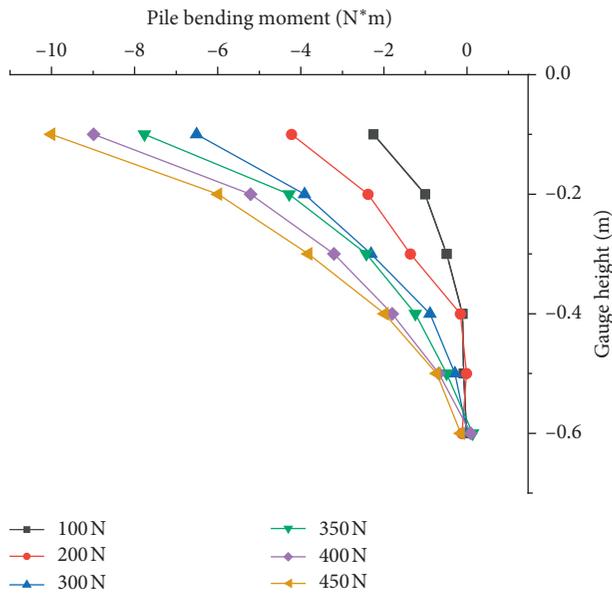


FIGURE 14: Curve of bending moment of the negative inclined pile loaded in  $y$  direction of two-layered soil groups with low pile caps.

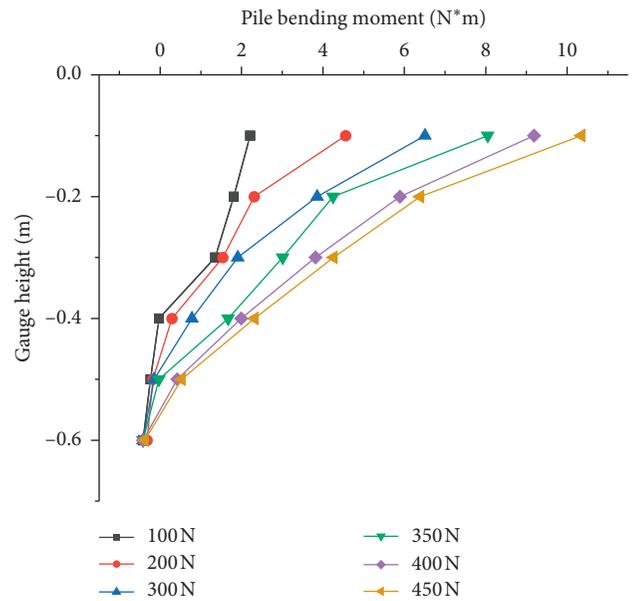


FIGURE 16: Curve of bending moment of straight pile loaded in the reverse direction of  $y$ .

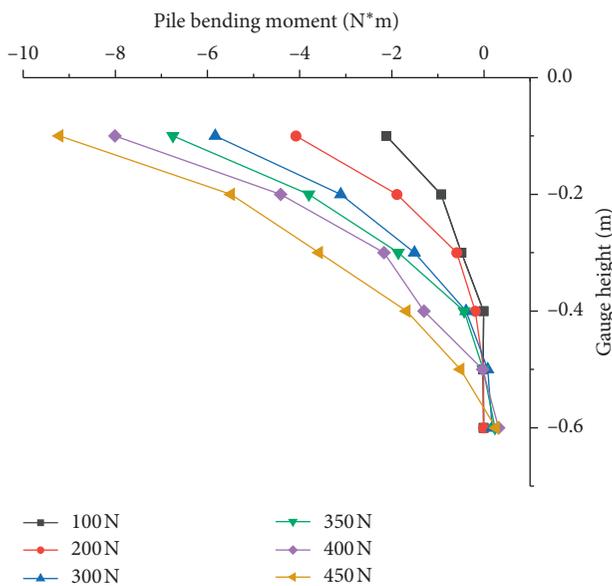


FIGURE 15: Bending moment curve of the straight pile under horizontal loading in  $y$  direction of two-layered soil pile groups with low pile caps.

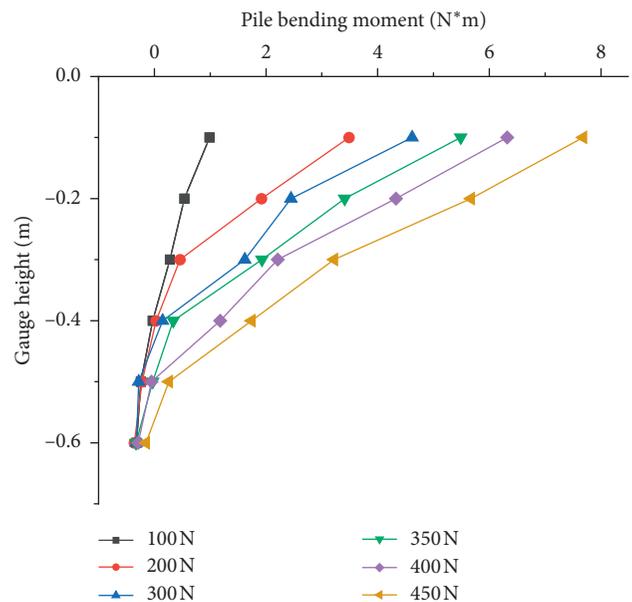


FIGURE 17: Curve of bending moment of positive inclined pile loaded in the reverse direction of  $y$ .

stiffness of the pile groups decreases and tends to be stable when the horizontal load gradually increases, and the load-displacement curve shows a double fold line shape. The main reason is that when the inclined pile group is subjected to horizontal load, the pile head of the foundation pile is subjected to axial load along the pile axis and radial load perpendicular to the pile axis under the action of the pile cap due to the fixed connection between the pile head and the pile cap.

The horizontal component of axial load can resist part of external load, so its load-displacement curve is related to axial stiffness and load distribution. When the first and

second loads are applied, the horizontal component of the axial load on the foundation piles resists most of the applied horizontal loads, so the horizontal stiffness of the pile caps is relatively high.

Figures 14 and 15 are curves of bending moments of inclined piles and straight piles under different loads when  $2 \times 2$  inclined and straight alternating pile groups with two layers of soil and low caps are loaded along the  $y$  direction, respectively. Figures 16 and 17 are curves of bending moments of inclined piles and straight piles under different loads when  $2 \times 2$  inclined and straight alternating pile groups

with two layers of soil and low caps are loaded in the direction opposite to  $\gamma$ . The positive and negative bending moments are specified by structural mechanics: the bending moment makes the pile rotate clockwise to be positive, and the bending moment makes the pile rotate counterclockwise to be negative.

As can be seen from Figures 16 and 17, the distribution characteristics of bending moments of the normal and inclined piles are as follows: when the pile group is loaded in the reverse direction of  $\gamma$ , the maximum bending moments of both the normal and inclined piles occur at the pile head. It can be seen that the maximum bending moments of the normal and inclined piles are smaller than those of the straight piles, the bending moments of the straight piles extend deeper than those of the normal and inclined piles, and the bending moments of the normal and inclined piles along the pile body are smaller, which is mainly due to the decomposition of the forces of the pile caps to the normal and inclined piles into axial tensile forces and forces perpendicular to the piles, thus weakening the bending moments. The reverse bending point of the positive inclined pile is 0.4 m–0.5 m, and the reverse bending point of the straight pile is 0.4 m–0.55 m.

According to the comprehensive analysis of Figures 14–17, when the load levels are the same, the bending moment of the positive inclined pile is smaller than that of the straight pile, and the bending moment of the straight pile is smaller than that of the negative inclined pile. The horizontal force of the negative inclined pile is greater than that of the straight pile, and the straight pile is greater than that of the positive inclined pile. Negative inclined piles are more sensitive to the load-bearing behavior. It can be considered that the horizontal load-bearing capacity of groups of negative inclined piles and straight piles is smaller than that of groups of positive inclined piles.

#### 4. Conclusions

- (1) The horizontal bearing capacity of the positive inclined pile is larger than that of the negative inclined pile in the lower sandy soil layer of the upper cohesive soil for the  $2 \times 2$  inclined and straight alternating pile group with low pile caps. The existence of the inclined pile in the inclined and straight alternating pile group helps to improve the horizontal bearing capacity of the pile group. In the inclined and straight alternating pile group model test, the horizontal load share of the inclined pile is larger than that of the vertical pile, and the bending moment caused in the positive inclined pile is smaller than that of the negative inclined pile.
- (2) The vertical bearing capacity of straight piles of  $2 \times 2$  inclined and straight alternating pile groups is larger than that of inclined piles, and the maximum axial force generated by straight piles is about 20% greater than that of inclined piles under the maximum load. The load sharing ratio between pile caps and piles under low pile caps of inclined and straight alternating pile groups is increasing with the increase of load, and the pile bears 80% of the load when the load is maximum.
- (3) Settlement rule of pile caps under vertical load of  $2 \times 2$  inclined and straight alternating pile groups: when the load is small, the pile caps are approximately linearly sinking, and when the load increases to a large level, the settlement of pile caps shows a curve change trend, and the settlement increment increases.

#### Data Availability

The data used to support the findings of this study are included within the article.

#### Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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