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Field test study on soil squeezing effect of H-type prestressed concrete revetment pile

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Abstract. The pretensioned H-type prestressed concrete revetment pile is a new product specially developed for the protection of coastal dykes in rivers and lakes. Its cross section is H-shaped, and the H-type revetment pile is also a soil squeezing pile. The excess pore pressure and soil displacement caused by the soil squeezing effect of H-shaped piles are deeply analyzed. The influence range of excess pore water pressure is 14~15d, and the excess pore water pressure completely dissipates after 6d. The farther the vertical distance from the pile tip is, the less obvious the horizontal displacement is. In a row of piles. In the process, it will cause repeated uplift and settlement; However, after the erection, the law of vertical deformation is reflected in the near settlement and the far uplift.

Keywords：squeezing effect; H-shaped pile; pore excess water pressure; numerical simulation; soil displacement. (key words).

1. Background

With the rapid development of waterway engineering construction and the in-creasing requirements of energy conservation and environmental protection, the low-efficiency, low-quality and high-energy-consumption block stone materials used on a large scale in the early days can no longer meet the needs of the current large-scale upgrading of inland waterways. Tensioned H-shaped prestressed concrete revetment pile is a newly developed new product specially designed for river and lake coastal dike protection, and its cross section is H-shaped. The protection wall of the bank embankment constructed by the H-shaped revetment pile is improved several times in the performance of flood control and lateral earth pressure resistance, and the bank embankment is environmentally friendly and beautiful, so the construction period is greatly shortened and the cost can be greatly reduced. In inland waterway, the H-shaped revetment pile is rarely used in China, and it is a new type of revetment structure. Therefore, although it has many advantages, in essence, the H-shaped revetment pile is also a soil squeezing pile, so it will inevitably produce soil squeezing effect and affect the surrounding environment. Therefore, this paper first introduces the general situation of H-shaped pile engineering and test, and then makes an in-depth analysis of the excess pore pressure and soil displacement caused by the soil squeezing effect of H-shaped pile.

2. Test on site

2.1 Engineering situations

Study on the Key Technology of Application of H-shaped Prestressed Concrete Ecological Bank Protection Pile in Inland Waterway Construction The design of the second phase trial section of Hujiashen Line is located on the left bank of the west channel of the newly built Zengjiafan Bridge in Hujiashen Line, with pile numbers K9+530~K9+980 and a total length of 450m.

This section of the channel is now reconstructed according to the planned Grade III channel standard. The bottom width of the planned channel is 45m and the water depth is 3.2m A total of 301.66m revetment is to be reinforced in this project. A total of 1 bank protection and edge sealing

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is reinforced. Reed is planted behind the reinforced revetment and flood control wall, and the total green area is about 150m^2.

2.2 Test situations

In this project, the first pore water pressure measuring point is buried at a distance of 2.4m from the H-shaped revetment pile, which is marked as U1; Bury the second pore water pressure measuring point 5.3m away from the H-shaped revetment pile, marked U2, and each hole is buried with one pore water pressure gauge at 1,3,5,7m away from the surface.

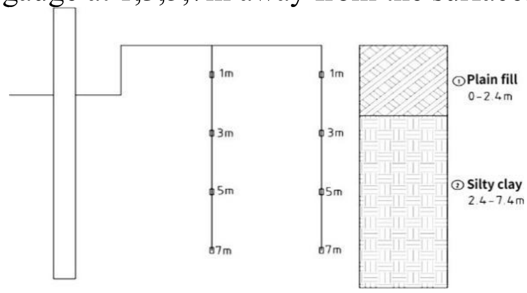

Figure 1. Buried profile of pore water pressure gauge.

The horizontal displacement of soil is monitored by inclinometer. Due to the existence of the original revetment, it is impossible to drill a inclinometer between the H-shaped revetment and the original revetment. Therefore, the inclinometer is buried 2m away from the H-shaped revetment. The measuring point number of the hole is CX1, and the buried depth of the inclinometer is 14m. The inclinometer is PVC pipe with a diameter of 70mm, and its inner wall has two pairs of vertical guide grooves with a depth of 3m.

For vertical deformation observation, firstly, set an observation point far enough away from the construction, which is the reference point for vertical displacement monitoring. At the same time, set an observation point 1.2, 2, 3.4 and 4.8m away from the H-shaped pile, and drive the settlement nails, which are marked as CJ01~CJ04. On the day of pile sinking, a total of three times were monitored, and then the settlement monitoring was conducted once a day. According to the gradual reduction of vertical deformation, the monitoring frequency was once every two days, once every three days and once a week, and the monitoring was stopped until the change value of each measuring point was less than the error value.

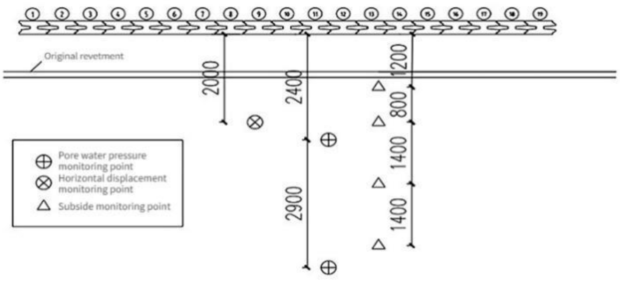

Figure 2. On-site instrument layout (unit: mm).

3. Analysis of test results

3.1 Excess pore water pressure

Hammer pile driving will destroy the interaction between particles severely, which will cause the pore water pressure in the clay layer around the pile to rise sharply, but the excess pore water pressure will dissipate quickly. Therefore, it is necessary to continuously observe the pore water pressure within the influence range during pile driving.

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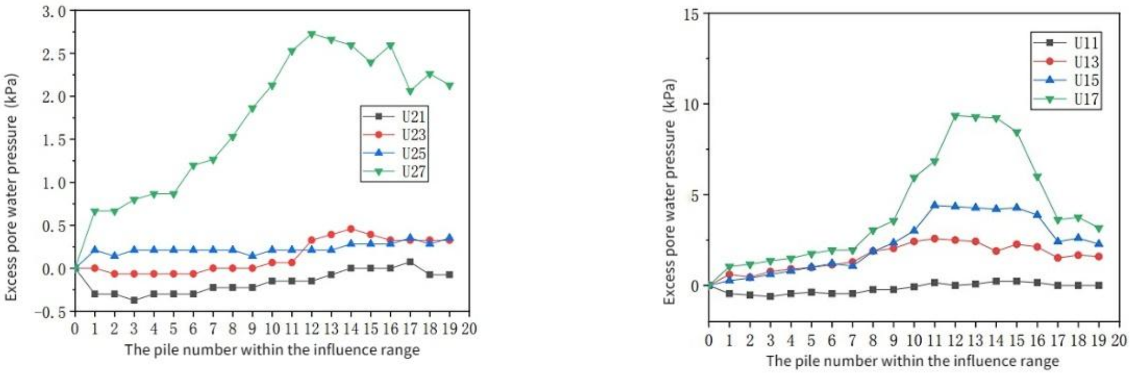

Pore pressure measuring point1 Pore pressure measuring point2

Figure 3. Variation of pore water pressure with pile driving.

When piles 1-11 are driven, the pore water pressure of each measuring point increases continuously, but it increases slowly when piles 1-7 are driven. The excess pore water pressure of each depth at measuring point 1 does not exceed 2kPa, the maximum value is 1.94kPa of U17, and the excess pore water pressure of each depth at measuring point 2 does not exceed 1.5kPa, the maximum value is 1.27kPa of U27. However, when the No.8-No.11 pile was driven in, it began to increase sharply, and this law was particularly evident at U17 and U27. After the pile driving of No.11 pile was completed, the excess pore water pressures at the two places reached 6.85kPa and 2.53kPa respectively. It can be seen that in the process of pile row construction, the construction of piles will increase the pore water pressure of the adjacent section soil, and the closer the distance is, the greater the influence will be, but there is a certain influence range. According to the measured results, the influence range is about 6~7m, and the equivalent diameter of the H-shaped pile is 0.414m through calculation. Therefore, in this project, the influence range of soil squeezing effect caused by H-shaped pile driving is 14~15d. Compared with other scholars' conclusions, Tang Shidong [1] and others studied the squeezing effect of single pile in soft soil foundation, and the influence range of excess pore water pressure was 20r_0, that is, 10d, and the influence range estimated by cylindrical hole expansion theory was about 8.3d；; Chen Dayong [2] obtained the influence range of 12.5d through the study of static pressure pile driving in soft soil area, and Hu Xiangqian [3] obtained the influence range of 24d through the study of pore water pressure distribution and dispersion law caused by pile driving in saturated soft clay after setting drainage boards. The reason for this difference is that the permeability of muddy soft soil is weaker due to the difference of soil quality, although the squeezing effect is more intense. However, the influence range is limited, and although the latter is saturated soft clay, the water permeability is enhanced by setting drainage boards, and the change of induced pore water pressure is transmitted further, but the excess pore water pressure caused is relatively small, and the influence range of H-shaped pile driving and soil squeezing effect lies between the two.

When the No.12 pile was driven, all the measuring points reached the peak value of excess pore water pressure, among which U17 and U27 were the maximum values of excess pore water pressure of the two measuring points, which were 9.35kPa and 2.73kPa, which showed that the excess pore water pressure increased sharply. On the one hand, the foundation soil was squeezed due to the sinking of the H-shaped pile, resulting in a severe soil squeezing effect. On the other hand, the impact of the pile hammer can also have a vibration effect on it. These two influences both lead to the sharp increase of the excess water pressure of the soil around the pile, which leads to the partial destruction of the original structure of the foundation soil, the decrease of effective stress and the decrease of strength.

According to the previous analysis, the excess pore water pressure at the cross section should still be increased by the pile behind the 12th pile. However, according to the measured results, the excess pore water pressure at each point at the cross section drops slowly during the pile driving after the 12th pile. The analysis shows that the generation and dissipation of excess pore water pressure is a very fast process during the pile driving by hammering, and the generated excess pore

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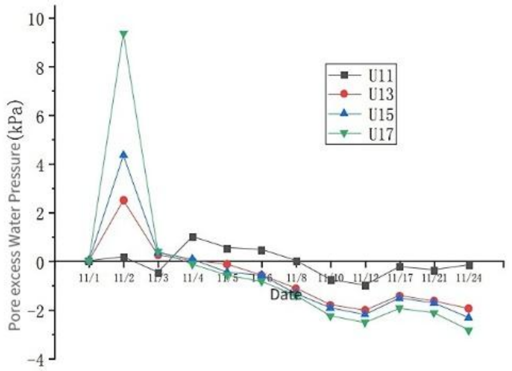
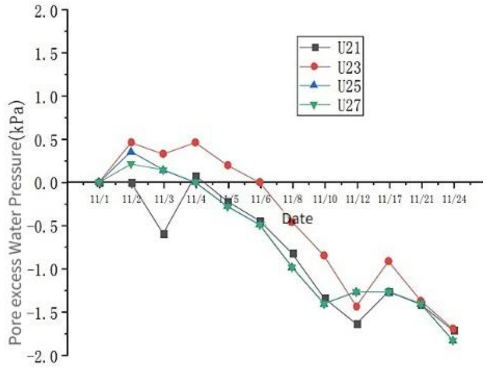
water pressure dissipates rapidly in this process, although the subsequent piling still causes excess pore water pressure.



Pore pressure measuring point1



Pore pressure measuring point2

Figure 4. Dissipation of pore water pressure.

After 1 day, the dissipation rate of excess pore water pressure at 7m of U2 measuring point reached 86%, and the excess pore water pressure dissipated quickly in many places. After 4 days, the pore water pressure in other places can be regarded as completely dissipated, except at the measuring point of U1 1m. After 6 days, all excess pore water pressure completely dissipated. Compared with the research on soil squeezing effect of PHC pipe piles by Yang Shengbin, Li Youdong [4] and Li Guowei [5], their soil is also silty clay, and the excess pore pressure of this project dissipates very quickly.

Comparing the dissipation of pore water pressure at the same depth between the two measuring points, it can be seen that the excess pore water pressure generated at each point of the No.1 measuring point is larger, while the dissipation speed of the excess pore water pressure at the shallow foundation is slower, while there is almost no difference between the deep foundation and the No.2 measuring point. Therefore, the effect of radial distance on the dissipation of excess pore water pressure is more obvious in the shallow foundation.

After the excess pore pressure completely dissipates, the pore water pressure at each point fluctuates, even at some measuring points, the pore water pressure exceeds the value just after the dissipation. At this time, the change of pore water pressure has nothing to do with the soil squeezing effect, but depends on the rise and fall of the groundwater level. The final excess pore water pressure is negative, because the pore volume decreases with time, the soil particles are arranged more densely, even exceeding the original compactness, and the final pore water pressure is less than the initial pore water pressure.

3.2 Soil horizontal displacement

In order to study the change of horizontal displacement of soil at different depths during piling, the driving speed of No.9 pile was controlled during driving, and the change of horizontal displacement at different depths when the pile was driven into soil for 1~6m was studied.

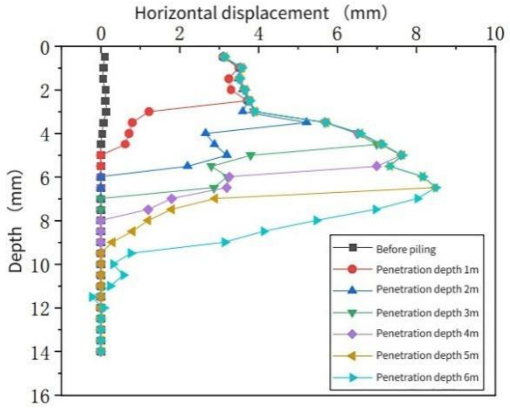


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Figure 5. Horizontal displacement of soil at different depths during pile sinking in stages.

When the depth is small (< 7m), the horizontal displacement of each measuring point is sensitive to the jacking depth and fluctuates greatly; The greater the depth (> 7m), the more stable the soil will be, and the less obvious the displacement law will be, due to the pressure of overlying water and soil. However, the horizontal displacement of soil at different depths is basically consistent with the increase of jacking depth, as follows:

(1) Take the horizontal displacement change of each depth when the pile is driven into 1m as an example. Because the height difference between the top of soil layer and the top of earth surface is about 1.7m, the elevation of pile bottom is already 1.7m below the earth surface when the pile tip touches the soil surface at the beginning of pile sinking. Therefore, when the depth of H-shaped pile reaches 1m, it is found that the change is the most dramatic when the depth below the earth surface is 2.7m or above. There is a sudden change in horizontal displacement at the penetration depth of the pile tip. This is because the pile tip discharges the soil outward during the driving process. When the saturated soft soil is penetrated, the soil is compressed, and the volume of the compressed soil shrinks little or even does not shrink, so the soil squeezing effect is obvious. There is a slight change between 2.7 and 4.7m. On the one hand, it is affected by the change of the strain state of the upper soil; on the other hand, the farther away from the vertical distance of the pile tip, the less obvious this effect is. Therefore, when the pile is driven into 1m, the soil below 3m depth is hardly affected, and the affected range is about 2m, and the depth is small. This rule basically holds true at all depths. Compared with the driving depth of pile, it is found that during pile driving, the soil around the pile is squeezed out, and the area with large horizontal displacement is mainly concentrated near the pile, and it decreases with the increase of distance from the pile tip, but it has no effect after reaching a certain range.

(2) During the continuous penetration of the pile, the horizontal displacement of the soil above the pile tip will continue to increase, but it is relatively limited. The maximum cumulative horizontal displacement of each depth just after the pile driving of No.9 pile is completed is not much different from the value just after the pile tip is penetrated. Among them, the cumulative horizontal displacement at the depth of 6.5m is the largest, reaching 8.51mm. The law of small top and small bottom and big middle has been reflected in the process of piling. At the same time, the soil below 10m is almost unaffected or has little influence. It can be seen that the vertical influence range of pile driving on the horizontal displacement of soil is within 10m below the surface of soil.

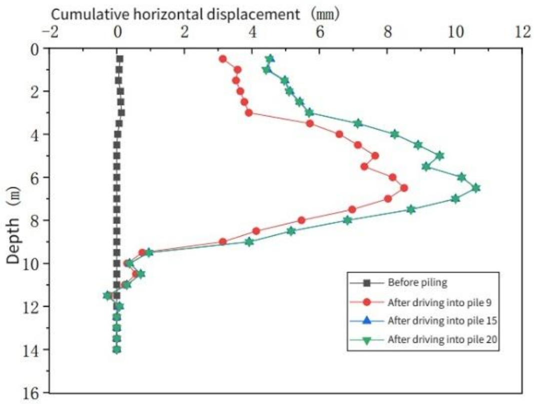

Figure 6. Horizontal displacement of soil at different time on piling day.

After the pile driving of No.9, which is facing the horizontal displacement measuring point, the horizontal displacement of the soil is still increasing. It can be seen that the construction of adjacent piles also has influence on the soil of this section, and this influence will decrease as the construction gradually moves away from this section. After the pile driving of No.15 is completed, the cumulative horizontal displacement of each depth reaches the maximum value at this stage, while the law of the depth direction remains unchanged. The accumulated horizontal displacement

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at 6.5m reaches the maximum value of 10.63mm This depth range belongs to silty clay, and its lateral stiffness is relatively small. The magnitude and speed increase of horizontal displacement of soil are larger than those of both sides. After driving into No.20 pile, the horizontal displacement of this section was measured again, and the soil at each depth moved back to different degrees. This shows that (1) the boundary of the influence range of soil horizontal displacement lies between No.15 pile and No.20 pile, that is, the horizontal influence range of pile driving on soil horizontal displacement is about 3 ~ 5.5m. (2) In the process of piling and squeezing the soil, the excess pore water pressure also dissipates continuously. When the construction is far away from the section, the dissipation process begins to occupy the main guide, which is reflected in the new compactness of the soil and the slow movement back.

It can be found that the soil around the pile is not all uplifted, and the measuring points CJ03 and CJ04 are uplifted, while the measuring points CJ01 and CJ02 are sunk. This is because piling will cause a large uplift, but once piling is stopped, the uplift will decrease in a short time, and finally settle slowly, so repeated uplift and settlement will be caused in the process of piling.

This is different from the construction method of static pressure pile. In this project, the H-shaped pile is statically pressed for a short distance, and then the construction is carried out by hammering. Such hammering will bring vibration effect to the soil, even the surrounding buildings and environment, and such vibration effect [6] will cause uneven settlement of the foundation. According to Yao Daoping's research [7], piling vibration is a kind of impact vibration, which is caused by the radiation of vibration waves all around. The isoseismal line is a closed ring, just like the ripples formed by throwing stones into the lake, spreading from the center point to all sides. In the process of pile driving, the energy of a hammer is fixed. If the distance of a hammer driving into the pile is shorter, it means that the harder the soil is, the greater the energy is transferred to the foundation soil, and the stronger the vibration is, even exceeding the influence of soil squeezing effect. However, the energy of static pressure pile driving is consumed on the relative deformation of pile soil. In the end, whether the vertical displacement of each measuring point is reflected as settlement or uplift depends on which side is dominant, namely, compaction effect and vibration effect. The vibration of the surface in the distance is smaller, and the transmission of compaction effect makes the surface in the distance uplift. The nearby ground surface not only descends under the influence of piling vibration, but also attracts the soil around the pile and makes it flow into the pile pit during the sinking process, which is the reason why the soil still subsides even if there is soil squeezing effect.

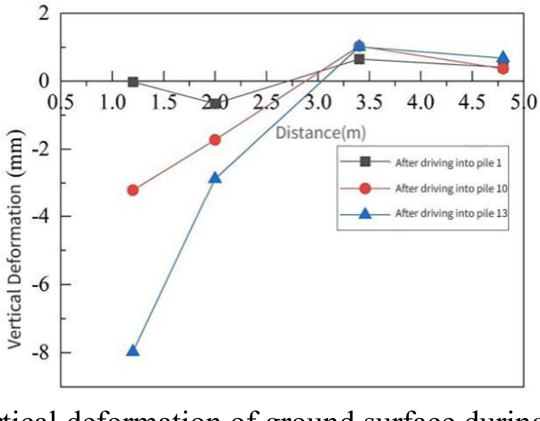

Figure 7. Vertical deformation of ground surface during pile sinking.

After piling, the influence of soil squeezing effect gradually dissipated, but the uneven settlement of the foundation continued to develop. At the same time, with the dissipation of excess pore water pressure, the soil particles rearranged compactly, and the settlement rate was very fast at first, then became slow, until the final settlement was completed, which lasted for 20 days. As shown in Figure 7, the maximum settlement point was CJ01, and the final settlement amount was 22.30mm, And the smallest point is only 0.47mm of CJ04, which shows that the uneven settlement of

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foundation of H-shaped pile is obvious in the process of piling construction, and if it is not controlled, it will have adverse effects on surrounding buildings.

4. Conclusion

This paper mainly relies on Hujiashen Phase II (left bank of the west channel of Zengjiafan Bridge, pile number K9+530~K9+980) project, and carries out on-the-spot tests on the three indexes of excess pore water pressure, horizontal displacement and vertical displacement generated in the process of pile driving. The conclusions are as follows:

a. The influence range of excess pore water pressure caused by piling in this project is 14-15d. During pile arrangement construction, the pile construction will increase the pore water pressure of the adjacent section, and the closer the distance is, the greater the influence will be. When piling No.12, all measuring points will reach the peak of excess pore water pressure. The excess pore water pressure in this project is generated and dissipated quickly; The excess pore pressure completely dissipates after 6 days, and the soil is arranged more densely after the excess pore pressure dissipates, which makes the excess pore pressure negative.

b. Through the measurement of the horizontal displacement of the soil of single pile driven by stages, it is found that the farther the vertical distance from the pile tip is, the less obvious the horizontal displacement is. The horizontal displacement of the soil above the pile tip will continue to increase, but it is limited; The horizontal displacement at the driving point of the pile tip suddenly changes; There is a slight change within 2m below the pile tip; The depth is basically unaffected.

c. In the process of piling, it will cause repeated uplift and settlement; However, after the construction is completed, the law of vertical deformation is reflected in the near settlement and uplift in the distance, which is related to the superposition of soil squeezing effect and vibration effect. Finally, because of the dissipation of excess pore water pressure, the soil particles are rearranged and compacted, and all the soil bodies are settled.

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