The Lateral Bearing Behavior of Single Pile Considering Scour Effect

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Abstract. Three group model tests are designed to study the change law of lateral bearing behavior at different scour depths and the local scour is simulated by changing dimensions of scour hole. The favorable effect of remaining sand above the scour depth line is considered to get the calculation method of equivalent depth. Simulation was carried out using LPILE and the results were compared with those obtained from model tests. The results show that the equivalent scour depth formula derived based on the principle of invariable ultimate soil resistance is reliable, and the relative error between the LPILE calculated value and the test value is 13-17%, which indicates that the actual situation can be accurately predicted. The sensitivity of the scour depth, scour slope angle, and scour width parameters were analyzed to determine their effects on the scour hole and the validity of the theoretical equation; the results show that the impact of the three parameters decreased in turn, which can provide some reference for engineering design.

1. Introduction

Scouring can form a certain form of scour hole around the pile. Under the effect of scouring, the horizontal bearing capacity of pile decreases and the pile body displacement increases. When calculating the bearing capacity of horizontal piles, the traditional method is to remove all the rest soil and regard the local scour as the integral scour, but in fact the remaining soil still contribute to the horizontal bearing capacity; in addition, the stress history of soil has changed after scouring[1-4]. The traditional method ignores the effect of the scouring hole size and the stress history, leading to high redundancy of the pile length.

In this paper, the favorable effect of residual sand after scour is considered by calculating the equivalent depth on the basis of existing research. The authors consider the effect of the size, and deduce the theoretical equation for the lateral bearing capacity of single pile based on the modified p-y curves and the study by Reese[5-7]. Then, simulation was carried out using LPILE and the results were compared with those obtained from model tests.

2. Methods

For the calculation of pile foundation bearing capacity after souring, Lin revised the p-y curve by considering the depth, width, and slope of the hole, and deduced the limit resistance of soil calculation
formula on the basis of Reese’s research\textsuperscript{[8-10]}. Lin’s calculation model is shown in Figure 1 and Figure 2. This paper calculates $p-y$ curve of soil according to Lin’s research and API specification $p-y$ curve formula of sand pile. Then the pile foundation deformation, the bending moment and shear force distribution are obtained using LPILE software.

![Figure 1. Wedge failure models with scour hole dimensions](image1)

![Figure 2. Profile of wedge failure models](image2)

### 3. Model test

In order to research load-bearing characteristics change law of single pile foundation after scouring, three groups of different scouring depth model test were designed. The scouring depth respectively 0cm, 15cm and 30cm and the scouring area respectively 0 cm$^2$, $30 \times 30$ cm$^2$ and $60 \times 60$ cm$^2$. The pile is made from steel with the diameter of 6 cm and the tube wall thickness of 3mm. The bottom of the pile cap with 1cm thick steel plate, internal welding 1 cm thick lattice grid plate, to ensure the stiffness of pile cap is enough for easily apply load. The scour and loading of pile foundation is shown in Figure 3, structure of pile foundation and location of strain gauge is shown in Figure 4.

The static load test is conducted on a moving bed in a trough with 12 m long and 5 m wide, test boundary length $\times$ width=$5 \times 5$ m, soil thickness is 1.0 m, the test sand will be compacted by a rammer weigh 80 kg for each layer of 10 cm, strictly control the height of each layer after filling and the height after compacting to ensure the uniform density of soil samples. The experimental model using natural Yangtze River sand soil, of which the mid-value diameter $d_{50}$=0.204 mm, known from the natural sediment characteristics, the sediment’s density unit weight ($\gamma_s$)$_p$=26.5 kN/m$^3$, dry unit weight ($\gamma_d$)$_p$=14.6 kN/m$^3$, standard penetration test hammer number N=24. The test load is divided into 10 portions, the first level load is 0.5kN, increasing the load per level by 0.5 kN.
4. Results

4.1. p-y curve

The p-y curve of z point when scour depth is 0, 15, 30 cm are summarized in Table 1.

| Scour depth/cm | Depth below soil surface z/m | p-y curve |
|----------------|-------------------------------|-----------|
| 0              | 0.05                          | $p=4th(363y)$ |
|                | 0.15                          | $p=12th(363y)$ |
|                | 0.25                          | $p=21th(363y)$ |
|                | 0.35                          | $p=30th(363y)$ |
|                | 0.45                          | $p=37th(363y)$ |
|                | 0.55                          | $p=46th(363y)$ |
| 15             | 0.25                          | $p=21th(180y)$ |
|                | 0.40                          | $p=33th(180y)$ |
|                | 0.52                          | $p=43th(180y)$ |
| 30             | 0.30                          | $p=25th(180y)$ |
|                | 0.49                          | $p=41th(180y)$ |
|                | 0.62                          | $p=51th(180y)$ |

Figure 5. Comparison of calculated values and experimental values of load-displacement curve
4.2. Horizontal displacement of pile top
LPILE calculation value and experimental value of load-displacement curve is shown in Figure 5. The figure shows that LPILE calculation value accords well with those of experimental value, for the scouring depth in the same condition and at the same load level, LPILE calculating displacement value slightly greater than the experimental value. When the scouring depth \( S_d = 0 \), LPILE calculation error is 7.4%~21.4%; when \( S_d = 15 \text{ cm} \), LPILE calculation error is 11.2%~17.3%; when \( S_d = 30 \text{ cm} \), LPILE calculation error is 8.4%~23.5%.

4.3. Moment
Under the condition of different scouring depth, LPILE calculation value and experimental value contrast curve is shown in Figure 6. The figure shows that calculation value accords well with those of experimental value, the pile moment above soil surface has certain error, the maximum moment of pile error is 5%.

4.4. shear force
Under the condition of different scouring depth, LPILE calculation value and experimental value curve is shown in Figure 7. The figure shows that accord well with those of calculation value and experimental value.
5. Conclusions

Based on the existing research, put forward a single pile p-y curve calculation method which has considered the scouring action. This method take the local scouring equivalent for the whole scouring, according to the principle that the limit soil resistance at some point above the pile end is the same before and after equivalent, calculate the limit soil resistance expression for equivalent before and after, then simultaneous them to obtain the distance from soil surface to pile the end, then calculate the equivalent scouring depth and p-y curve of soil at different depth. Then through LPILE software calculation to get the load-displacement curve of single pile and the pile body internal force distribution.

LPILE calculation value accords well with those of experimental value, the average error is 13% ~17%, on the condition of the pile horizontal displacement is less than 10 mm at the top of the pile, the error is controlled within 15%. Revised p-y curve considers the good effect of soil above the scouring pit at the bottom, the maximum error of the horizontal bearing capacity calculation value and experimental value is about 3.6%~6.0%, the maximum horizontal displacement of pile head error is about 13.9%~23.5%, the maximum moment error is about 2.9%~4.4%, the maximum moment point position error is about 3.3%~ 7.7%, these results can provide some references for engineering design.

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