Experiment on the Negative Friction of Single Pile under Self-weight Consolidation for the Dredger Fill

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Abstract: The objective of this paper is to analyze the negative friction of pile caused by the self-weight consolidation of dredger fill. It is difficult for routine test to meet the time requirement of self-weight consolidation of soil. However, the centrifugal test model adopted the scale-shrink effect and the model satisfied the requirement of pile-soil consolidation in a short time. Thus the self-weight consolidation of the dredger fill at the upper part of the single pole foundation in the soft soil was simulated by the centrifugal model test. The result of the experiment showed that when the self-weight consolidation of dredger fill sustained for 2.5, 20, 50 months, the negative friction was 85.6%, 52.67%, 20.65% of the pile top load. The negative friction disappeared when the self-weight consolidation sustained for 75 months. The relationship between pile-soil settlement and time corresponds with the Hill Model. It is feasible to forecast the pile-soil settlement of the self-weight consolidation of stacking dredger fill through the Hill Model.

1. Introduction

Dredger fill is used to backfill the clay frequently in the harbor engineering when the pile foundation cuts across the clay layer and embeds the hard sand layer, as shown in figure1 (a) [1]. The clay becomes over consolidated under the stress of numerous stacking dredger fill. Degree fill will also consolidate under its self-weight, as shown in figure 1 (b) [2-3].It will cause Negative skin friction (NSF) on the pile as the soil settlement is greater than the pile settlement. NSF causes the drag load and affect the normal use of the pile foundation.

NSF of piles could be analyzed through the theoretical analysis [4-5], laboratory tests [6-9] and site tests [10-11]. Abdrabbo [12] acquired the effect of pile top load and soil layer additional load through three-dimensional nonlinear analysis. Kong [13] acquired the results that when the relative displacement reaches to 2mm, the negative friction account for 75-95 percent of the maximum and the neutral surface becomed steady when the consolidation time was 240 hours through model tests and numerical analysis. Hong [14] discovered that the depth of neutral point of drilled pile equaled to

0.04-0.06H (H was the thickness of clay layer).

It takes a long time to finish the self-weight consolidation for dredger fill [15]. It is difficult for routine tests to meet the time requirement of self-weight consolidation. However, the centrifugal test model adopted the scale-shrink effect and the model satisfied the requirement of pile-soil consolidation in a short time. Therefore, NSF of piles caused by the self-weight consolidation of dredger fill was conducted by centrifugal model tests. The development of lateral friction of piles in dredger fill was analyzed.

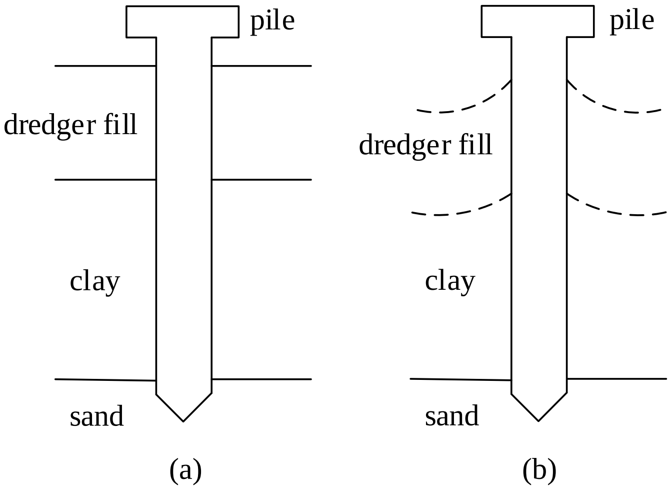


Fig. 1 The schematic diagram of generation of negative friction of pile function.

2. Methods

Tests were conducted at TLJ-150 centrifugal machine in Tongji laboratory. The maximum acceleration was 200g. The effective radius was 3.0m and the peak load was 1.5t.

2.1 Section headings

According to the similarity criterion of geotechnical centrifuge model, the character and the stress state of centrifugal model tests must be identical with prototype. The similarity criterion of centrifugal model is Eq. (1). n is model rate.

$$g_m=n\cdot g_p \quad (1)$$

It shows that if the strength of model narrow n times, the gravitational acceleration（gm）of model must be as n times large as gravitational acceleration of prototype on the condition that the character of model is identical with prototype.

2.2 Experimental model

The length\width\height of the test model is 0.6m\0.4m\0.28m and the length\width\height of the prototype is 45m\30m\21m; the height of model pile is 25 cm and the external diameter is 20mm, 16mm, 14mm. The thickness of aluminum-alloy pipe is 1mm. On the other hand, the length of prototype is 16.25m. The external diameter is 1.5m, 1.2m, 1.05m and the inner diameter is 1.5m, 1.2m, 1.05m; the model boundary is steel plate with 50mm thickness. The soil of the model was sampled from Shanghai Lin-gang and its properties are shown in Table 1. The basic physical and mechanical properties are shown in Table 2:

Table 1 Particles content of degree fill and clay

Grain composition	Dredger fill/%	Silt/%	Silty sand/%
0.25-0.074mm	8.8	31.6	62.9
0.074-0.005mm	79.1	62.6	32.1
<0.005mm	12.1	5.8	5.0

Table 2 Basic physical and mechanical properties of foundation soil

Description	Dredger fill	Clay	Silt	Silty sand
density/g/cm3	1.85	1.74	1.86	1.90
moisture content/%	32.2	43.3	30.4	26.6
void ratio	1.10	1.22	0.86	0.76
proportion/g/cm3	2.71	2.75	2.70	2.69
internal friction angle/°	29	13	33	35
cohesion/kPa	11	14	7	4
compressibility factor	0.24	0.80	0.14	0.09
Plastic limit		21.3		
liquid limit		0.84		

2.3 Measure of test data

The deformation of pile was measured with strain gage and the method is half-bridge. The displacement of soil was measured by LVDT and pre-embed the settlement-pole in the layer, as shown in Fig. 2.

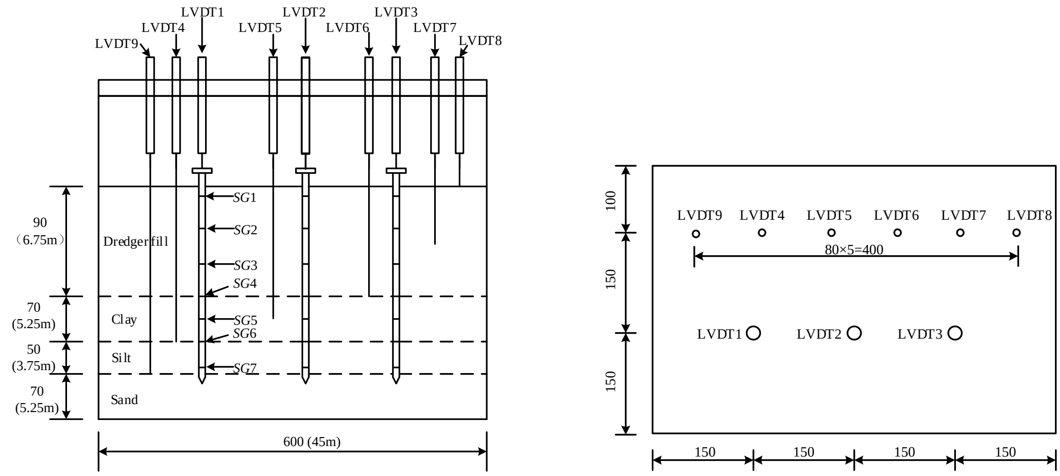


Fig.2 Schematic diagram of model test. (unit:mm)

2.4 Modeling

Working process of the pile-soil test model: (1) calculate the weight of dry soil and water of each layer according to the scale of model box; (2) stir the homogeneous soul and throw it to the model box with uniform velocity. The thickness of each turn shouldn't pass 2 cm. Start the next turn from the opposite direction until it reaches to the design height. (3) sustain for 2 hours and wait for saturation after each layer of soil is finished. (4) bury the settling-pole at the designed location;(5) operate the centrifugal machine for 8 hours with the accelerated velocity of 75g. Close machine when the degree of consolidation of layer reaches to 90%; (6) throw fill the dredger fill with the accelerated velocity of 1g. Repeat the procesure1-4; (7) install the single-pole at the accelerated velocity of 1g. Insert the pole into 1.5D depth of the sand (D is radius of pole). Finally insert the single-pole into the designated spot through the piling equipment with the velocity of 0.5mm/s (8) Install cushion cap and load the design load of experiment. Simultaneously, install the measuring transducer, as shown in Fig. 3.

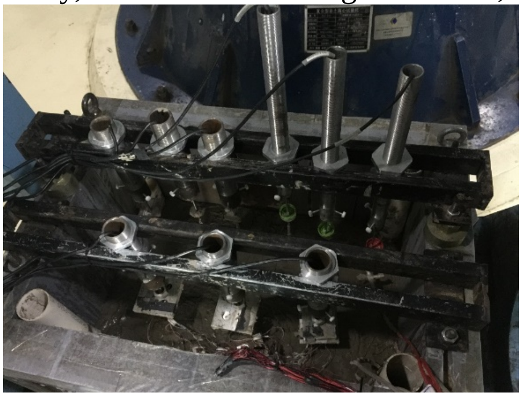


Fig. 3 Pile-soil centrifuge test model

2.5 Experimental scheme

Vertical stress of 157.60 t, 126.08 t, 110.32 t is loaded on the single pile cap with the radium of 1.5 m, 1.2 m, 1.05 m respectively. According to the similarity principle, the weight of 0.374 kg, 0.299 kg, 0.261kg should be loaded on the single pile cap with the radium of 20 mm, 16 mm, 14 mm.

Fix the model on the centrifugal machine and adjust the accelerated velocity as 75g for 8 hours after the single-pile installation is finished. The operation of centrifugal machine: (1) make sure every sensor is normal working and collecting data automatically with the period of 1s (2) The accelerated velocity starts from 0g and come up to 75g after 5 minutes;(3) Steady operation with the accelerated velocity of 75g for 8 hours;(4) Stop the collect data automatically when the centrifugal machine stops.

3. Results

3.1 Consolidation settlement of pole-soil

According to the similarity principle, the consolidation settlement of pole-soil of prototype is shown in the Table 3. The condition of above calculation is that the accelerated velocity of centrifugal machine reach to 75g and dredger fill self-weight consolidates for 8 hours. The Table 3 shows that the sediment of silt is less than the sediment of single-pile and the sediment of dredger fill is larger than the sediment of single-pile.

Table 3 Sediment of pile-soil

Sediment of layer/mm				Sediment of single pile /mm		
layer	thickness/mm	model/mm	prototype/mm	Single-pile	model/mm	petrotype/mm
LVDT8	30	6.548	491.100	radius20	0.641	48.075
LVDT7	30	4.137	310.275	radius16	0.661	49.575
LVDT6	35	2.729	204.675	radius14	0.681	51.075
LVDT5	35	1.351	101.325			
LVDT4	50	0.736	55.225			
LVDT9	70	0.319	23.925			

3.2 Relationship between the consolidation of pile-soil and time

The relationship between sediment of prototype and time through the similarity principle is shown in figure4.

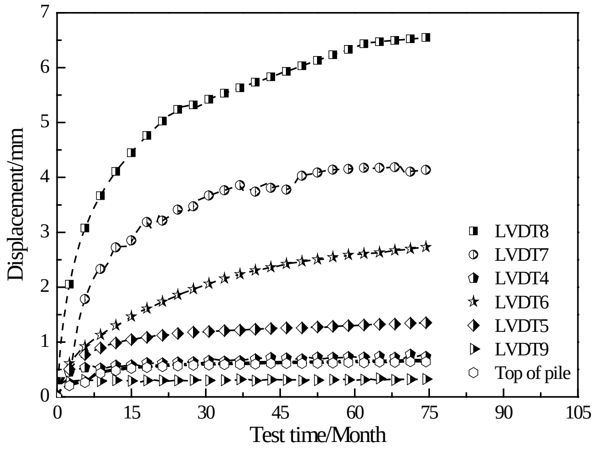


Fig. 4 Relationship between settlement of pile-soil

The result shows that the relationship between sediment of layer, sediment of pile and time is appropriate for Hills model [15]:

$$s_t = s_{tm} \frac{t^{\lambda}}{t^{\lambda} + k^{\lambda}} \tag{2}$$

Where s_t is the displacement of pile and soil at any time, mm; s_{tm} is the maximum settlement value of soil and pile, mm; t is the time of consolidation, h; k and$\lambda$are fitting parameters, the parameters are shown in Table 4.

Table 4 Fitting parameters of sediment of pile-soil

Fitting parameters of sediment of layer					Fitting parameters of sediment of pile				
displacement	s_{tm}	λ	k	R^2	Single-pile	s_{tm}	λ	k	R^2
LVDT8	6.548	1.1452	6.6783	0.970	radius14	0.681	1.3411	5.3414	0.982
LVDT7	4.137	1.5333	7.8170	0.982	radius16	0.661	1.2608	5.2349	0.982
LVDT6	2.729	1.4042	11.5658	0.959	radius20	0.641	1.3536	5.3880	0.983
LVDT5	1.351	1.0806	4.4337	0.990					
LVDT4	0.736	0.6970	1.3162	0.868					
LVDT9	0.319	9.5573	0.5357	0.922					

3.3 The relationship between axial force of pile and time

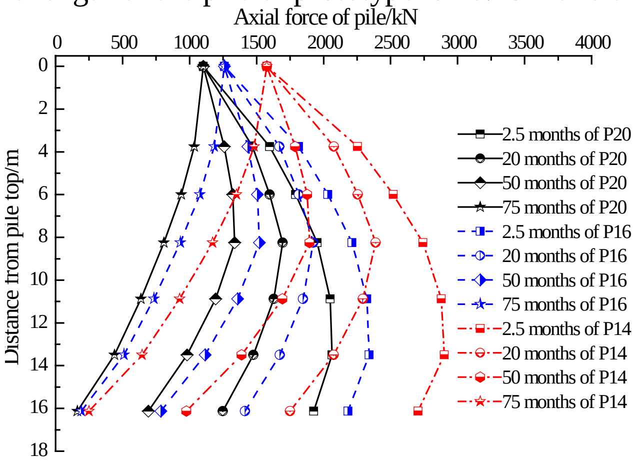
According to the similarity criterion, lateral friction of pile and the axial force of the pile of prototype can be calculated with the Eq. (3) and Eq. (4).

$$P_{ti} = n^2 E_m A_m \varepsilon_{ti} \tag{3}$$

$$q_{ti} = \Delta P_{ti} / S \tag{4}$$

Where P_{ti} is the axial force of I pile, kN; E_m is elasticity modulus of the model pile, GPa; A_m is the sectional area of model pile, mm2; ε_i is measured strain value of I model pile; ΔP_{ti} is the difference of measured axial force of the cross section of I pile, kN; S is lateral surface area of measuring section of the pile of prototype, m^2.

The axial force of pile shaft is shown as Fig. 5 when it load the loading of 1576.0 kN, 1260.8 kN, 1103.2 kN on the hollow pile of radius of 1.5m, 1.2m, 1.05m. The lateral friction is shown in Fig. 6. The length of the pile of prototype is 16.25m and the thickness of dredger fill is 6.75m.



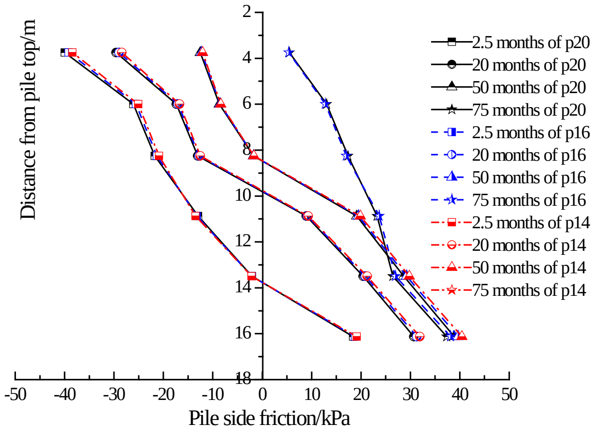


Fig. 5 Relationship between axial force and time   Fig. 6 Relationship between lateral friction and time

The negative friction of pile of prototype caused by the self-weight of dredger fill is shown in figure6. According to Fig. 5-6 and Table 5 we can find that the increasing rate of axial force of pile is 85.56%, 52.57%, 20.65% as the time of consolidation is 2.5moths, 20months, 50months. Negative friction of single-pile is smaller when the consolidation of dredger fill is longer. All of the friction of pile will become positive when the soil consolidate for 75months.

Table 5 Relationship between maximum friction of pile of prototype and time

pile of prototype /m	The maximal negative friction/kN					
	2.5months	rate of increase/%	20 months	rate of increase /%	50months	rate of increase /%
1.05	960.75	87.09%	591.72	53.63%	232.43	21.06%
1.2	1078.58	85.54%	662.73	52.56%	260.33	20.64%
1.5	1324.44	84.03%	811.83	51.51%	318.89	20.23%

4. Conclusion

(1) When the thickness of the dredger fill in soft foundation is 6.75m, the negative friction equals to 85.56%, 52.657%, 20.65% of the pile top load when the time of self-weight consolidation is 2.5months, 20months, 50months.

(2) The negative friction of the pile foundation decrease with the self-weight consolidation of the dredger fill until it disappears.

(3) The relationship between pile-soil consolidation and time conforms to the Eq. (2), It is feasible to forecast the pile-soil settlement value of the self-weight consolidation of stacking dredger fill in soft soil through this formula.

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