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Research on Pressed Pile Test and Finite Element Analysis of Large-diameter Steel Pipe Pile of Zhanjiang Port

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***Abstract*—**In order to study pressed pile test and ultimate bearing capacity character of large-diameter steel pipe pile, based on two high-piled wharfs of Zhanjiang Port, pressed pile test and numerical simulation of three large-diameter steel pipe piles are analyzed in this paper. Anchored pile method is used to pressed pile test, and the curves of Q-s and ultimate bearing capacity are attained. Then the three piles are numerically simulated by ABAQUS, and results of numerical simulation and those of field test are comparatively analyzed. The results show that settlement value of numerical simulation is larger than that of field test in the process of loading, the difference value is widening with the increasing of load, and the ultimate difference value of settlement is 20% to 30%.

***Keywords*—**Large-diameter steel pipe pile, field test, finite element analysis, comparative analysis.

I. Introduction

BECAUSE of its superior whole performance, strong bearing capability and simple pile sinking technology, large-diameter steel pipe pile is widely used in the port structures. Since the end of the last century, many scholars have made thorough study of large-diameter steel pipe pile. Xie Shi-bo (1997) [1] researched the influences of the surrounding soil of large-diameter steel pipe pile in the process of piling, found that effective stress is decreased with the cracks in pile side soil, and pointed out the pile-soil interaction need to be considered. Wang Hong etc.(2004) [2] researched the bearing capacity of large-diameter steel pipe pile, bearing capacity and axial stiffness of large-diameter steel pipe pile are analyzed based on load transmission calculation, proposed some advices in the process of calculation. Liu Run etc. (2005) [3] analyzed soil plugging effect and piling process, presented judgments of soil plugging effect by static equilibrium method, established a simplified interaction model of soil plugs. Zhu Zhao-qing etc. (2010) [4] researched horizontal bearing capacity of large-diameter steel pipe piles, horizontal bearing capacity and displacement of vertical pile and inclined pile are analyzed by using unidirectional round robin load method. Yoshiaki etc. (2010) [5] made an experimental research on behaviors of large-diameter steel pipe pile under vertical load, the test based on the coastal road project in the port of Tokyo, found that small displacement resulted in bigger end bearing, big displacement resulted in bigger side friction, and it need to consider the impact of the soil plugs in the analysis of the end bearing capacity. Zhang Ming-yuan etc. (2006) [6] analyzed vertical bearing capacity by using numerical simulation method based on FLAC3D. The result shown the super-long large-diameter steel pipe piles were typical friction piles, side friction of piles was complex with the increasing of depth, and was close with property of soils.

It can be seen from the above studies, researches on large-diameter steel pipe pile were concentrated on its ultimate vertical bearing capacity and its settlement character, this is due to geological conditions of harbor engineering are very complex, analysis of pile capacity and settlement characteristics are significant to engineering safety. Common methods of bearing capacity detection of piles are pressed pile test method and high strain method, the pressed pile test method is the most direct and reliable method to determine axial bearing capacity and settlement character of single pile.

There are many pile types in harbor engineering, it is difficult to conduct pressed pile test for each pile type because of the costs, but it could solve the problem by using numerical simulation. However, it need to consider the interaction of pile and soil, initial soil stress balance etc. in the analysis of numerical simulation, and the results of numerical simulation are difficult to apply in practical engineering.

Thus in order to research pressed pile test and bearing capacity character of large-diameter steel pipe pile, this paper study from two aspects of field test and numerical simulation. Firstly, based on Baoman container terminal engineering and new oil terminal in Zhanjiang Port, pressed pile tests of three piles, named S1, S2 and T1 respectively, are conducted, and bearing capacity and Q-s curves are attained. Then established finite element modeling of test piles by ABAQUS, Initial stress balance of soil, stresses of piles, settlement performance are analyzed. And comparative analysis of tests and numerical simulations are conducted.

II. Analysis of Field Test

In the project site, three steel pipe piles are tested, there are a pile named T1 of new oil terminal and two piles named S1 and

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S2 of Baoman container terminal. Basic parameters of the three piles are shown in Table I.

TABLE I
BASIC PARAMETERS OF TEST PILES

Name	Type	Diameter/thickness(mm)	Length(m)
T1	steel pipe pile	1400/20	63.0
S1	steel pipe pile	1400/20	48.8
S2	steel pipe pile	1400/20	44.4

Fig. 1 The test site

Reaction force system of the test is steel frame, which including anchor piles and horizontal beams, loading step by step using jacks placed on the top of the piles. Observing system is consisting of reference piles and reference beams, and four dial indicators are installed in which 0.5m lower than the test pile top to measure top settlement of the pile.

Fast load-keeping method is used to test loading. Loading should be step by step, a loading step is 1/10 estimate maximum load, and loading time of each step is 60 minutes.

Reading time of settlement observation in the process of the test is 0min, 5min, 10min, 15min and 30min respectively after the test begin, and read the dial indicator every 30 min afterward until reached the specific time.

When the test meets one of the following conditions, it should terminate loading, and offload step by step.

1) The test load reached the design requirements;

2) In the process of loading, the test pile top deviates from the axis of displacement too large, and endangering test safety.

3) Total settlement exceeding 40mm, and in a load step, settlement of the step is more than five times that of the previous, or drop-down segments of Q-S curves are found.

Q-s curves of the three test piles are shown in Fig.2 ~Fig.4.

It can be seen from Fig.2~Fig.4, drop-down segment of Q-S curves is not found in the test piles, and displacements of top of piles are less than 40mm. The maximum displacement of S1 is 32.21mm, vertical bearing capacity of that is more than 11000kN; the maximum displacement of S2 is 32.30mm, vertical compressive bearing capacity of that is more than 11000kN; the maximum displacement of T1 is 25.25mm, and its vertical compressive bearing capacity is more than 10000kN; all of the piles meet the design requirements.

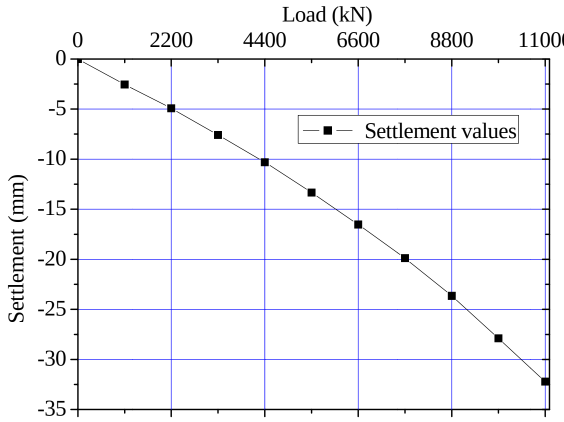


Fig. 2 Q ~ s curves of S1

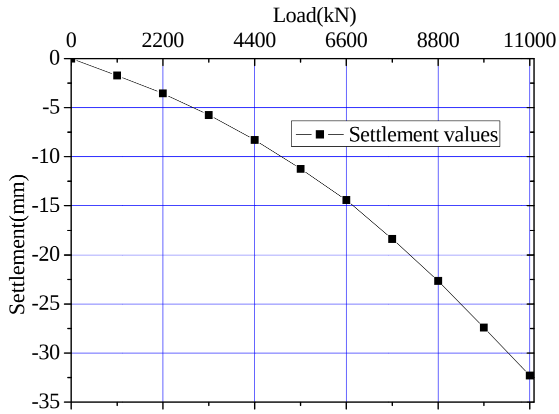


Fig. 3 Q ~ s curves of S2

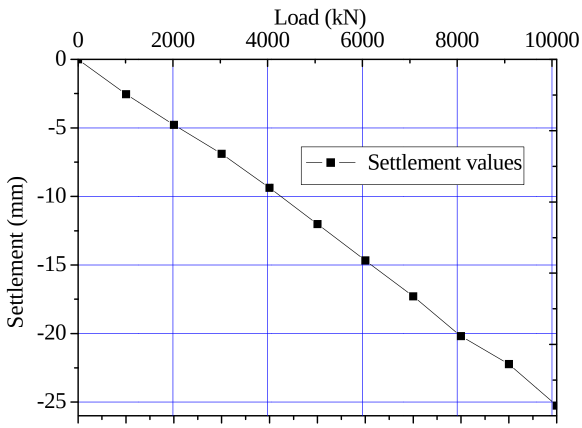


Fig. 4 Q ~ s curves of T1

III. NUMERICAL SIMULATION ANALYSIS

A. Parameters of Piles

Parameters of soil are derived from “Engineering geological exploration report of Baoman container terminal of Zhanjiang Port” and “Engineering geological exploration report of oil terminal of Zhanjiang Port”. Limited to the article length, only main soil parameters of S1 pile are listed in Table II and Fig.5.

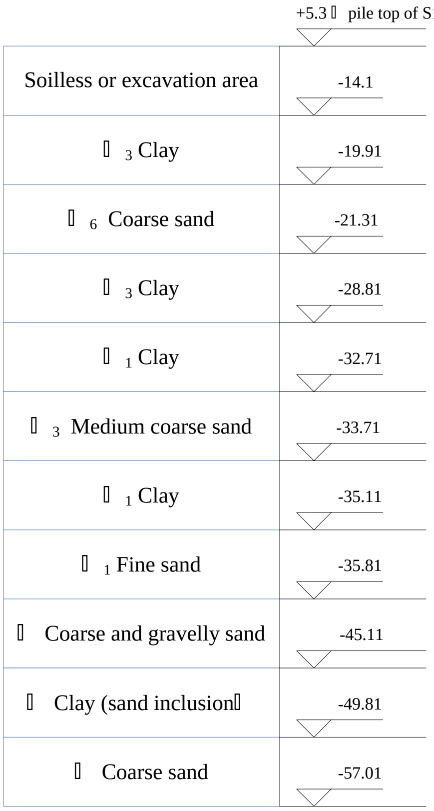


Fig. 5 Soil layers and thicknesses (S1)

TABLE II
MAIN PARAMETERS OF SOIL (S1)

SN.	category	status	compression modulus (MPa)	friction factor	density (g/cm^3)
④$_3$	clay	plastic	6.853	0.25	1.68
④$_6$	coarse sand	medium dense	13.333	0.45	1.95
⑥$_1$	clay	plastic ~ hard plastic	5.962	0.3	1.72
⑥$_3$	medium coarse sand	medium hard soil	15	0.5	1.95
⑦$_1$	fine sand	medium dense ~ dense	7.5	0.47	1.95
⑦	coarse sand	medium hard soil	15	0.5	1.95
⑧	clay (sand including)	plastic ~ hard plastic	5.369	0.3	1.87
⑨	medium coarse sand	dense ~ very dense	18	0.5	2.05

B. Basic Analysis Models

1) Constitutive model of soil

This paper make a hypothesis of deformations of soil are consisting of linear deformation and nonlinear deformation. Linear elastic model is adopted in elastic stage, and Mohr-Coulomb model is adopted in inelastic stage. In coordinate system of $\tau-\sigma$, Mohr-Coulomb yield or failure line is shown in Fig.6.

2) Constitutive model of steel pipe pile

The steel strength grade of pile is Q345, and yield strength is 345MPa. Ideal elastic model is adopted in linear elastic stage, and MISES Criterion is adopted in nonlinear stage. The criterion can be expressed by principal stresses as:

$$(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2=2\sigma_s^2=6K^2 \qquad (1)$$

In equation (1) , is yield strength , K is shear yield strength. MISES yield is meaning that under certain deformation conditions, plastic status emerges when equivalent stress reached a certain value. Stress-strain relationship of steel pipe pile is:

$$\sigma=\begin{cases} E\varepsilon\ , & \text{when } \varepsilon<\varepsilon_s \\ \sigma_s+E'(\varepsilon-\varepsilon_s), & \text{when } \varepsilon<\varepsilon_s \end{cases} \qquad (2)$$

In equation (2), is elastic modulus, is plastic modulus, and is yield stress, basic parameters of steel are shown in Table III.

TABLE III
BASIC PARAMETERS OF STEEL

Strength grade	ρ (kg/m^3)	E (GPa)	ν	σ_s (MPa)	σ_b (MPa)
Q345	7850	210	0.3	345	470

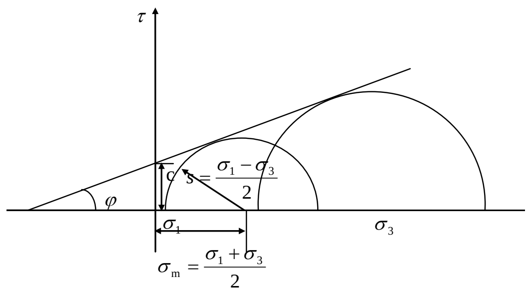


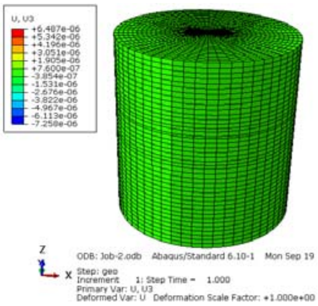
Fig. 6 Mohr-Coulomb Criterion

3) Pile- soil interface model

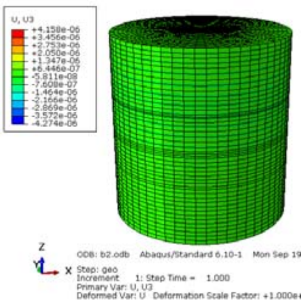
Pile-soil interaction is high nonlinear behavior, it needs to determine analysis model, including contact area, state and behavior. Surface to surface contact is used in this paper, and Coulomb friction model is adopted in the constitutive relationship of interfaces. There are two models in ABAQUS to simulate sliding of pile and soil: small sliding model and finite sliding model. Relative sliding within a certain range is permitted in finite sliding model, is suitable for pile-soil interaction analysis.

C. Analysis of Initial Grand Stress Equilibrium

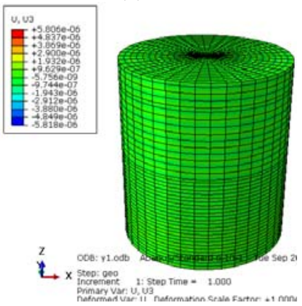
There are two methods can be used to analyze initial grand stress equilibrium in ABAQUS, the first method get equivalent weight stress field by giving coefficient of vertical stress and that of lateral stress. The second method using finite element analysis, attain stress values of Gauss point, then the stresses of gauss point as the initial stresses of elements. The latter is applied in this paper because its efficiency in FEM analysis. And the results of initial grand stress equilibrium of the three piles are shown in Fig. 7.



(a) S1



(b) S2



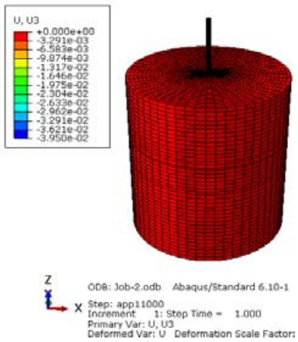
(c) T1

Fig. 7 Results of initial grand stress equilibrium

It can be seen from the results of initial grand stress equilibrium of the three piles, deformations in the direction of gravity are 10-6 to 10-7order of magnitude. It shows ABAQUS could solve the problem of initial grand stress equilibrium.

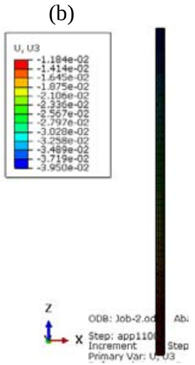
D. Comparative Analysis of FEM Method and Field Test

Using ABAQUS to analyze the piles, loading process of numerical simulation is consistent with that of pressed pile test. The results of numerical simulations are shown in Fig.8, only listing the result of S1 because of article length restriction. And comparison of Q-s curves of tests and that of finite element analysis are shown in Fig. 9~Fig. 11.



(a) Cloud picture of integer displacement

(b)



(b) Cloud picture of pile displacement

Fig. 8 FEM results of S1

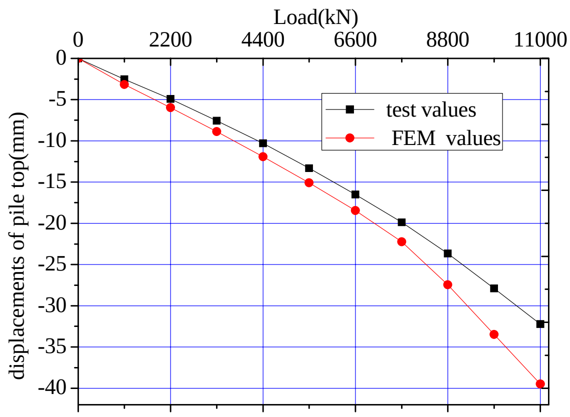


Fig. 9 Comparison of Q-s curves of test and FEM (S1)

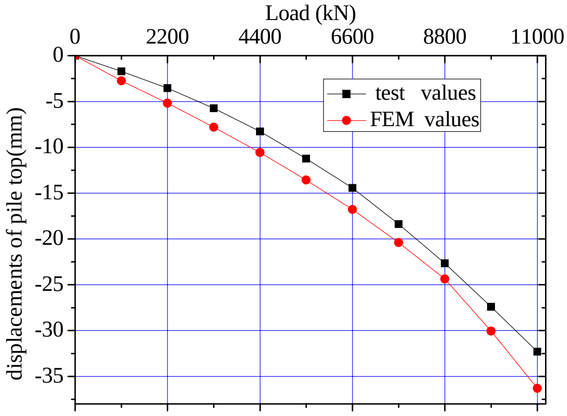


Fig. 10 Comparison of Q-s curves of test and FEM (S2)

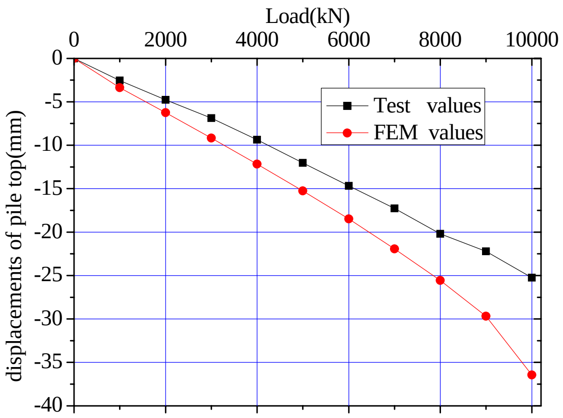


Fig. 11 Comparison of Q-s curves of test and FEM (T1)

It can be seen from the process and the results of FEM analysis, displacements of external soil are small after analyzing of initial grand stress equilibrium, the main displacements of soil is emerged in pile side soil and small area near the pile end. Distribution of piles like an inverted triangle, the maximum displacement is in pile top, and the minimum is in pile end.

From comparison of Q-s curves of test and FEM, displacements of pile top of FEM analysis are 20%~30% larger than those of tests. This is because analysis factors of settlement are very complex, including material nonlinear of pile and soil, Boundary conditions, parameters of soils etc. Furthermore, additional stresses of piling cannot be considered in FEM analysis, compression modulus of numerical simulation are smaller than actual value, Idealization of the soil constitutive model are ignored also. These factors result in displacements of FEM analysis larger than that of pressed pile tests. Calculated displacements of piles are bigger than test values are common in engineering analysis, using adjustment factors to control the differences according to relative codes. Thus it is proper to analyze piling process by ABAQUS, the displacements of numerical simulations should be discounted, and the reduction coefficient is preferable to 0.8 or so.

IV. Conclusion

Field test and numerical simulation of large-diameter pipe piles are conducted in this paper, the following conclusions are attained:

(1) It could attain Q-s curves and ultimate bearing capacity by using anchor pile method in piling test, as long as the loading time and loading condition are strictly controlled in the process of piling.

(2) Analysis of initial grand stress equilibrium is very important in numerical simulation of piling, which is the basis of loading analysis.

(3) Because of additional stress of piling, idealization of the soil constitutive mode and uncertainty of soil parameters etc., the displacements of FEM analysis is larger than that of pressed pile test, the final settlement value of FEM analysis is 20%~30% bigger than that of field test.

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