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Procedia Environmental Sciences 12 (2012) 1055 – 1062

Procedia Environmental Sciences

2011 International Conference on Environmental Science and Engineering (ICESE 2011)

Settlement Characteristics of Pile Composite Foundation under Staged Loading

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Abstract

The settlement characteristics of pile composite foundation in soft soils were analyzed by staged loading tests. The results showed that the settlement of pile composite foundation, under different loads, comprised two stages: in the first stage, the pile composite foundation settled quickly. Ninety percent of the total settlement under a certain load occurred in this stage. The remaining 10% of the settlement finished slowly in the second stage. The relationship of settlement with time was fitted by an empirical formulation.

*Keywords :*Ppile composite foundation, staged loading, settlement characteristics

1. Introduction

Calculation and prediction of settlement of composite foundation are important issues for composite foundation design and research. The settlement of composite foundation is a compositive and complex process due to many factors [1-3]. The available calculation methods for the settlement of composite foundation are limited compared with that of bearing capacity of composite foundation,and the development of research on this lags behind the need of engineering practice[4].The settlement of composite foundation increases monotonically with time. The curve of settlement against time is normally in a “S” shape [5-7] derived analytical solutions for the deformation of the piles and the surrounding reinforced soils. A two dimension finite element method (FEM) was adopted to investigate the deformation of composite foundation under embankment [8].

*This work was supported by the National Natural Science Foundation of China, Project No.41002093, National Key Technologies R&D Program, Project No. 2008BAJ08B14-06, Shanghai Leading Academic Discipline Project, Project No.B308, the Program for Young Excellent Talents, Tongji University.

 doi:10.1016/j.proenv.2012.01.387

Another way of predicting the settlement of composite foundation is to use fitting curves based on experimental data. The existing curves are exponential curves and hyperbola curves. The prediction from exponential curves is normally larger than the actual value in the early settling stage of composite. And for hyperbola curves, the prediction is lower than the observed data. So, it is important to derive a more precise model to describe the settlement of composite foundation, based on observed data.

2.Properties of soft soil

Site investigation showed that the ground was covered by a 0.4 m to 1.5 m of top fill, overlying a 20 m to 24 m of soft saturated marine clay with sand underlain. The properties of the soft soils are shown in Table 1.

Table 1 Properties of Soft Soil

Water content (%)	Pore ratio	Liquid limit (%)	Plastic limit (%)	Modulus of compressibility (MPa)	Cohesion (kPa)
65.96	1.72	48.96	34.13	1.98	5.82

3.Test plan

Loading tests were carried out on single pile and four piles composite foundation (see Fig.1and Fig.2).The cement mixing piles were built by wetting spraying method. The length of the pile was 15.5 m, and the diameter of the pile was 0.5 m. The 2x2 group piles were arranged in square, with a pile to pile spacing of 1.5 m. The designed bearing capacity of the single pile and group piles was 110 kPa.

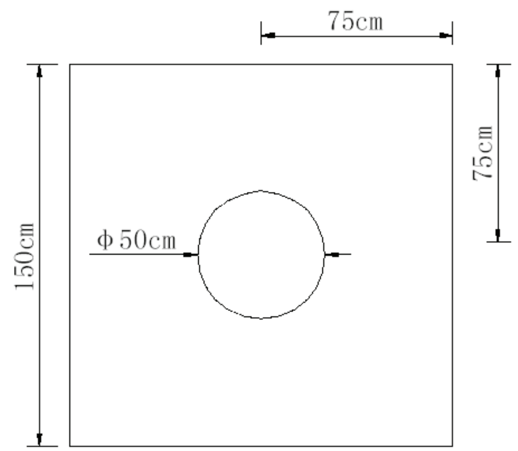


Fig.1 Plan sketch of composite foundation for single pile

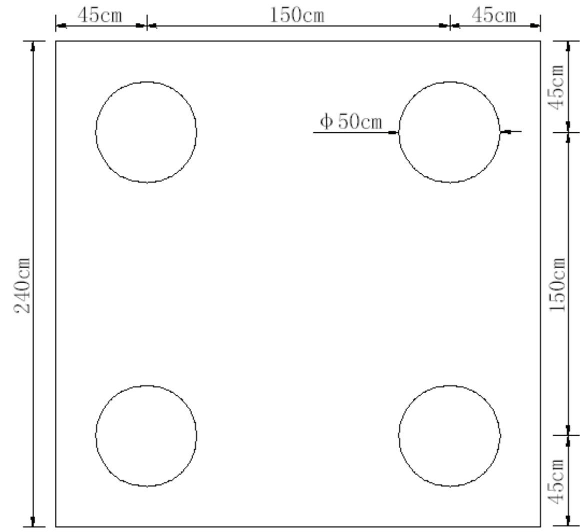
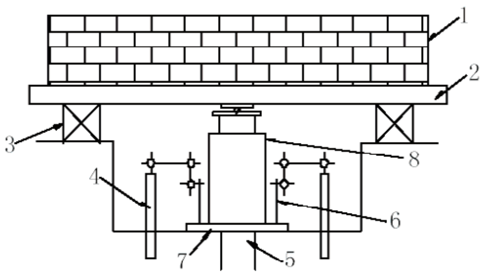


Fig.2 Plan sketch of composite foundation for four piles

The loading tests were conducted as per requirement of Chinese Standard, JGJ79-2002. A sketch of the loading system was shown in Fig. 3. A bearing plate was installed on the pile head on which loading was applied via an oil jack with dead load as reaction force. A 50 cm thick medium dense sand layer was placed between the bearing plate and the ground soil. Four displacement gauges were installed symmetrically on reference piles 2 meters away from the test piles. The average reading was used to determine the settlement. Loadings were applied in eight stages to 200 kPa, with 25 kPa in each stage. When the settlement of composite foundation becomes stable, e.g. less than 0.1 mm in one hour in the tests, the next loading was applied. It was observed that the settlement stabilizes within 2 hours time of each loading in the tests.



1-stack weight 2-stack weight platform 3-wood beam 4-reference pile 5-test pile 6-dial indicators 7-load-bearing plate 8-oil jack

Fig.3 Sketch of loading test

The loading test stops on condition that:

(1) The settlement of composite foundation increases rapidly, with soil been extruded or obvious heaves observed around bearing plate, or (2) the maximum load applied reaches two times of the designed bearing capacity the foundation.

4.Analysis of test results

4.1.The relationship between settlement and time for single pile and four piles composite foundation

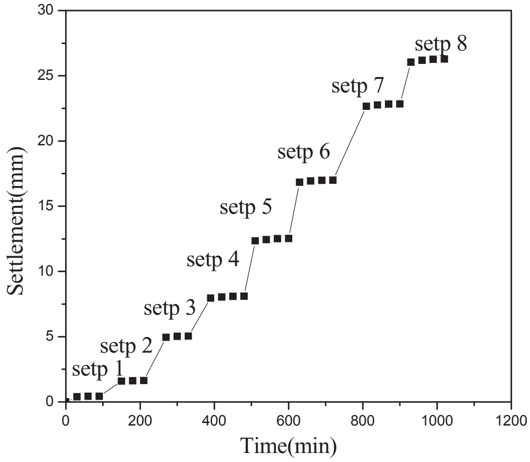


Fig.4 Curve of between settlement and time for single pile

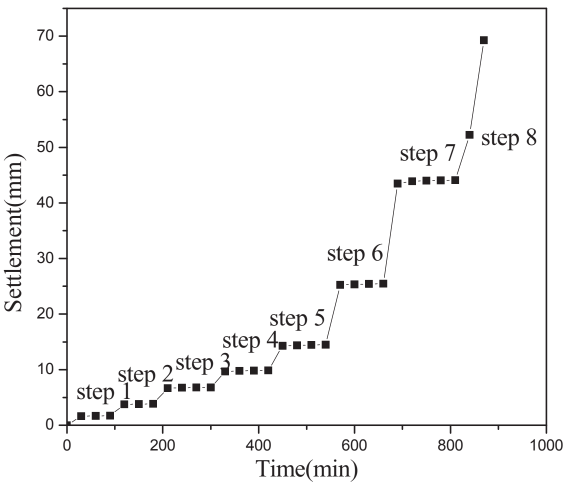


Fig.5 Curve of between settlement and time for four piles

The settlement of single pile and four piles composite foundation under each loading stage are shown in Fig.4 and Fig.5. The figures show that, the settlement of the single pile composite foundation increases slowly during the first two loads, and increases almost linearly after that. But the rate of settlement increases a little bit when the loading is over 50 kPa. For the group-pile composite foundation, the settlement increases gently before a sharp increase when the 6th loading was applied. A rapid settlement of the foundation was observed when the loading was increased to 200 kPa, as shown in step 8 in Fig 5. This might suggest the failure of the composite foundation. On the contrary, no rapid settlement was observed for the single pile composite foundation. This might be due to the size effect of the bearing plate and the higher strength of the top soil. The loading on the group-pile composite foundation may result in a deeper influence zone due to the larger size of the bearing plate, which may cause the failure in the deeper soils.

4.2.Settlement curve fitting of composite foundation

For the convenience of analysis, the settlement of composite foundation at certain time under each load is normalized. A settlement ratio was introduced to represent the ratio of the settlement at certain time under a certain grade of load to the total settlement under such load. The ratio is zero at the beginning of load, and close to 1 when settlement becomes relatively stable, e.g. after 2 hours in this research. The development of settlement ratio with time under eight grade loads is plotted in Fig.6 (for single pile) and Fig.7 (for group piles).

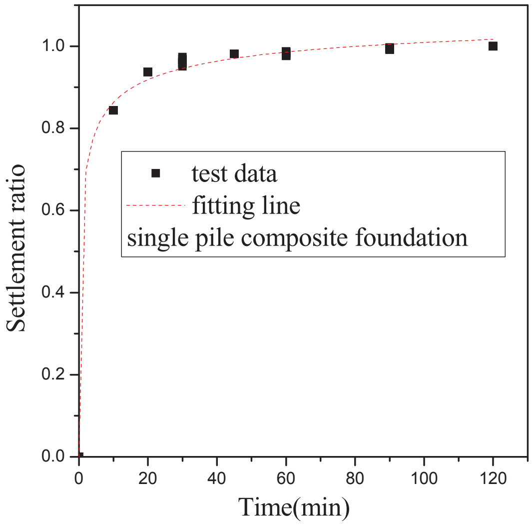


Fig.6 Curve of between settlement ratio and time for single pile

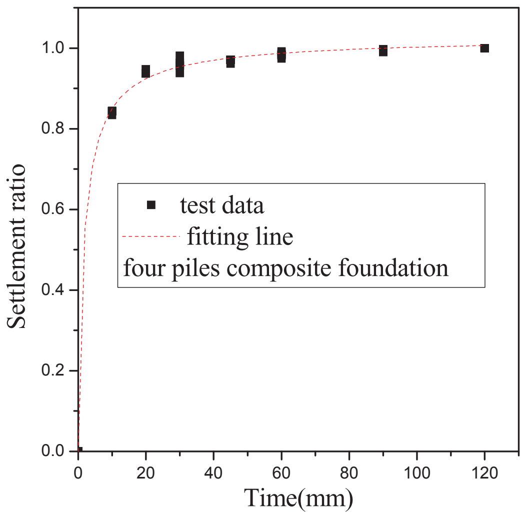


Fig.7 Curve of between settlement ratio and time for four piles

Fig.6 and Fig.7 show that the settlement ratio curves under eight loads almost overlap. This means that, the increment ratios under different loads remain approximately the same after the same duration of loading. It can also be seen that, the settlement of composite foundation, under different loads, comprises two stages: in the first stage, the composite foundation settle quickly. Ninety percent of the total settlement under a certain load occurred in this stage. The remaining 10% of the settlement finished slowly in the second stage, which takes within 1.5 hours.

An empirical formulation was obtained by fitting method to describe the variation of settlement ratio with time:

$$s_t / s_0 = \frac{t^n}{m^n + t^n} \tag{1}$$

Where S_t is settlement at time t, in unit of minutes, S_0 is the finally settlement under the grade load, t is loading time (min), m and n are fitting parameters. The fitting parameters of fitting curves in Fig.6 and Fig.7 are shown in Table 2.

TABLE 2 FITTING PARAMETERS

Type of foundation	m	n	R^2
Single pile composite foundation	0.64587	0.45666	0.91093
Four piles composite foundation	1.73576	0.88659	0.96302

Rewriting (1), the settlement can be expressed with (2):

$$s_t = s_0 \frac{t^n}{m^n + t^n} \tag{2}$$

To verify the equation, the settlement of single pile and group piles under other loading conditions are predicted with (2). The results are plotted in Fig. 8 and Fig. 9. The Fig. 8 and Fig. 9 showed that, there is a little difference, mostly with in 10% (see Table 3), between the predicted data and the measured values. So a coefficient k is introduced into (2):

$$s_t = k s_0 \frac{t^n}{m^n + t^n} \tag{3}$$

For single pile composite foundation, k=1.11, for four piles composite foundation, k=1.03. In practice, the parameter m and n in (3) can be obtained by fitting the test result.

TABLE 3 SETTLEMENT ERROR UNDER DIFFERENT TIME

Pile	Load (kPa)	Settlement Error under different time（%）							
		30 min		60 min		90 min		120 min	
		A	B	A	B	A	B	A	B
single	75	2.75	12.12	0.16	9.93	0.91	9.05	1.65	8.43
	125	1.42	13.61	0.77	11.93	1.18	11.76	2.14	10.95
	175	3.69	19.82	0.13	16.94	1.38	15.75	2.83	14.50
four	75	0.27	3.18	0.42	2.51	0.66	2.27	0.65	2.28

	125	0.30	3.20	0.70	2.24	0.64	2.29	0.64	2.28
	175	0.53	3.43	0.20	3.10	0.31	2.62	0.64	2.29

A: corrected computed data, B: computed data

The aforementioned settlement of single pile and group piles are reanalyzed with (3). The results are compared with those from (2) and measured data in Fig.8 ~Fig.9, and Table 3. The results showed that, the predictions with (3) are well consistent with the test datum. Though the function obtained from fitting curve method is not rigorous, the method of using settlement ratio as a measurement to predict the settlement of piles is shown to be promising.

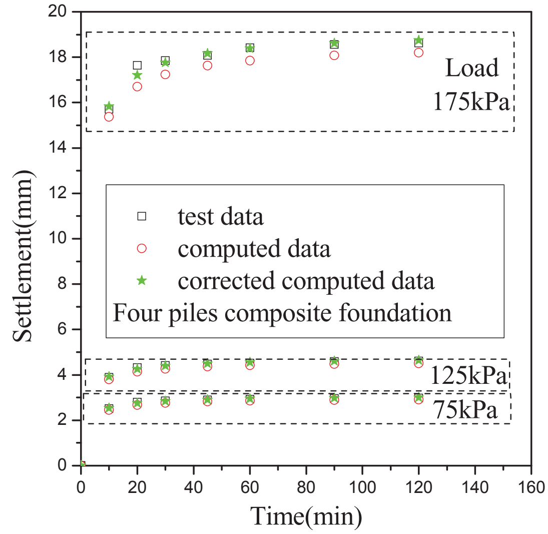


Fig.8 Curve of between settlement and time for four piles

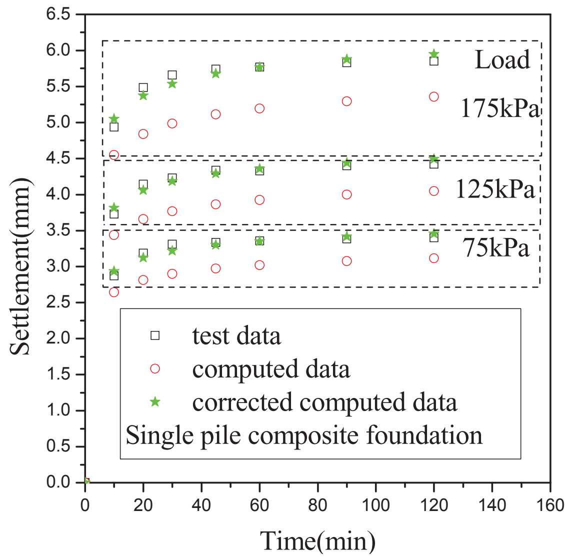


Fig.9 Curve of between settlement and time for single pile

5.Conclusions

Based on a series of in situ loading tests carried out a single pile and four-pile foundation, the following conclusions were made:

(1) The development of settlement with time for single pile and four piles composite foundation follows the same trend. The settlement curve under loading is well divided into two stages: quick and slow settlement stage. Most settlement was finished during the early stage of the loading.

(2) Settlement ratio was introduced to describe the settlement rate of piles during loading. A function was derived for settlement ratio based on fitting curve method.

(3) An empirical function was derived to describe the settlement process of composite foundation. The formula can be used to predict the settlement of composite foundation in load test.

6.Acknowledgements

This investigation was supported by the National Natural Science Foundation of China, Project No.41002093, National Key Technologies R&D Program, Project No.2008 BAJ08B14-06, Shanghai Leading Academic Discipline Project, Project No.B308, Kwang-Hua Fund for College of Civil Engineering, Tongji University and the Program for Young Excellent Talents, Tongji University. The authors are deeply indebted to the five financial supporters.

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