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A Vertical Bearing Capacity Experimental Analysis of Prestressed Concrete Piles Based on Material Constitutive Relation of Piles and Soil

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Abstract. The purpose of the paper is to research the vertical bearing capacity and settlement idiosyncracies of prestressed concrete piles. In-situ experiments, which was carried out by anchor-pile beam counterforce device, and numerical analysis methods was adopted as research methods on 3 tested piles. Mohr-Coulomb model was employed as the constitutive model of soil mass and isotropic elastic damage model as the constitutive model of piles to analyze its yield functions. Furthermore, the basic idea of modelling large deformation problems was analyzed based on Finite Difference Method (FDM). The comparison results was obtained in the paper and it suggested that the simulated data is highly identical with the experimental ones. Load-settlement curve basically presents a quadratic function form.

1 Introduction

Prestressed Concrete (PC) piles, which are made of high-grade concrete generally no less than C50, is characterized by its high property of bearing capacity, pounding resistance, crack resistance and etc., thereby it has been widely applied in civil engineering projects. Whereas, its force mechanism significantly influenced by the soil plug effect in the construction procedure. This effect is so non-negligible that existing load transfer theory based on end-closed piles cannot be directly utilized on PC piles. Currently, its load transfer mechanism and load-settlement relation under vertical load remains uncomprehensive. It is necessary to further the research in this aspect.

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This article conducted research on piles' subsidence rule under vertical load by FDM and in-situ experiments. And the Mohr-Coulomb model, which is able to describe shear failure, was employed as the model of soil mass. Slow maintain load method was adopted in field test and its data was compared with numerical analysis data. The results showed that computation results was consistent with the experimental results. The feasibility of applying this numerical method to predict PC piles' settlement trends was verified.

2 In-situ Experiments

2.1 Geological Features and Piles Parameters

The workyard was relatively flat and its average elevation was 35m from yellow sea height datum of China. Engineering geologic investigations suggested that its soil possessed good load bearing conditions. Hydrogeological condition of the field was pretty simple, groundwater system was relatively scarce. Its engineering geologic conditions was middle-complicated type. Lithology of stratum is formed by quaternary debris. And its Holocene series was constituted by sludge, middle Pleistocene series by mild clay and sand gravel, Cretaceous series by silty mudstone. Sand gravel could be selected as bearing stratum of building foundation thereby and applied piles partly. The pile tips need be penetrated into deep stratum to maintain foundation stability.

Tested piles was 19 m long and its outside diameter was 500 mm. Thickness of the pipe wall was 100 mm. Pile type followed the standard type of *Prestressed Concrete Pipe Piles (03SG409), China.* The designed strength of core concrete was C60. Longitudinal bars was 14 SBPDL1275/1420 through prestressed bars, which diameter was 12.6 mm. Its tension control stress was 994 MPa. Spiral stirrup of piles was HPB235 cold-drawn low-carbon wire, which diameter was 5 mm. The stirrup was densely placed at pile tops and tips, its spacing was 50 mm. At the rest part it was 100mm.

Loading System

In consideration of capital and device restriction, the experiment employed 3 working piles as experimental subjects to fulfill the in-situ vertical bearing capacity tests. And all of them employed Anchor-pile beam counterforce device, which applied 500t property jacks. The project locates at Renmin South Road, Changsha. To measure the pile top settlement in the process of loading, dial gauge was installed at the top as in Fig.1. The initial load of Pile 1# and 2# was 600 kN, and its stages of loads were 300 kN. The initial load of 3# pile was 1200 kN, and its stages of loads were 600 kN. And the 3# piles was loaded until its settlement exceeded the allowable value. After the experiment, Q-s curves of every tested pile was obtained.

The experiment operation was conducted in accordance with relevant clauses of *Checking Technique Code of Architectural Stake Ground(JGJ106-2003),China*. According to the slow maintain load method, the first load was 2 times of load stages. Then, the parameters was measured every 5 minutes. After that, it was measured every 15 minutes. 1 hour later, the gap was enlarged to 30 minutes. When the settlement less than 0.1 mm in 1 hours and for 2 times during the period, it can be considered entering into stable status, and next load stage could be proceeded.

2.2 Analysis of Constitutive Relation of Materials

Meanwhile, simulation analysis of pile-soil interaction is conducted by Three-dimension Fast Lagrange Analysis Continua in the research. The Mohr-Coulomb

Model Theory, which is considered as an isotropic elasticity constitutive relation model, is applied as the theoretical basis of constitutive model of soil.

Coverage of Simulation and Boundary Conditions

The model is 35m deep from the pile top and 5 times wider than pile diameter from axis of pile to its x and y direction, positively and negatively. It is the displacement that mainly applied as the boundary condition in the model. Displacement at 4 sides and bottom is constrained while the ground is a free boundary. The pile part was modeled by real conditions.

Modelling of Soil Mass

Mohr-Coulomb Model is often used to describe shear failure of soil and rock mass. Its failure envelope corresponding with Mohr-Coulomb strength criterion (shear yield function) and tension failure criterion (tension yield function).

Yield Function

According to type (3), the failure criterion is described on σ_1, σ_3 plane (Fig.1). The failure envelope from A point to B point can be achieved by Mohr-Coulomb yield function:

$$f^s = \sigma_1 - \sigma_3 N_\phi - 2c\sqrt{N_\phi} \tag{1}$$

The tension failure function from B point to C point is as follows:

$$f^t = \sigma^t - \sigma_3 \tag{2}$$

In the type (6):

ϕ -internal friction angle;

c -cohension;

σ^t -strength of tension.

$$N_\phi = \frac{1+\sin\phi}{1-\sin\phi} \tag{3}$$

It should be noticed that only the maximum and minimum principle stress is functional in the shear yield function, middle principle stress has no effect. For material which internal friction angle $\phi \neq 0$, its strength of extension cannot exceed $\sigma^t_{\max}$, the equation is as follows：

$$\sigma^{t}_{\max} = \frac{c}{\tan\phi} \tag{4}$$

Modelling of Piles

Isotropic elastic model provides the simplest description for mechanical behavior of material. It fits the homogenous, isotropic and continuous materials that only present linear stress-strain relation and present no hysteresis effect after unload.

In the condition of plane strain state, model increment expression of stress-strain can be conducted from the Hook's Law as followed:

$$\Delta\sigma_{11} = \alpha_1\Delta e_{11} + \alpha_2\Delta e_{22} \tag{5}$$

$$\Delta\sigma_{22} = \alpha_2\Delta e_{11} + \alpha_1\Delta e_{22}$$

$$\Delta\sigma_{12} = 2G\Delta e_{12}$$

$$(\Delta\sigma_{12} = \Delta\sigma_{21}) \tag{6}$$

$$\Delta\sigma_{33} = \alpha_2(\Delta e_{11} + \Delta e_{22})$$

In the condition of plane stress state, model increment expression of stress-strain is as followed:

$$\Delta\sigma_{11} = \beta_1\Delta e_{11} + \beta_2\Delta e_{22}$$

$$\Delta\sigma_{22} = \beta_2\Delta e_{11} + \beta_1\Delta e_{22}$$

$$\Delta\sigma_{12} = 2G\Delta e_{12}$$

$$(\Delta\sigma_{12} = \Delta\sigma_{21})$$

$$\Delta\sigma_{33} = 0$$

2.3 Analysis of Experiment Results

In accordance with data of in-situ experiments and numerical analysis, the authors compared the relation concluded from two methods and the comparison is as followed:

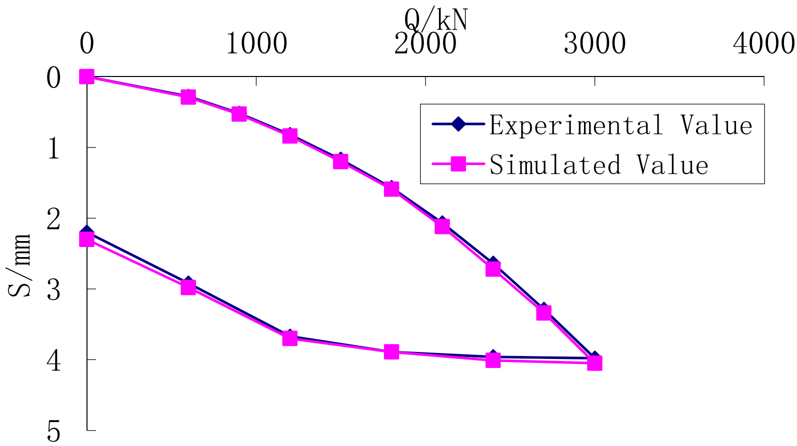

Fig.1 Comparison of Pile 1# top settlement relation with load.

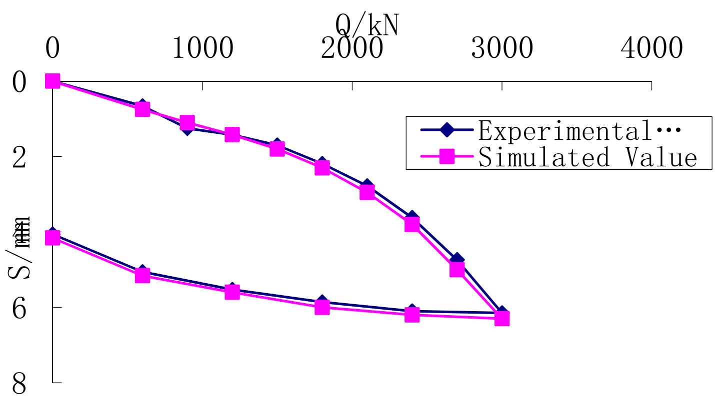

Fig.2 Comparison of Pile 2# top settlement relation with load.

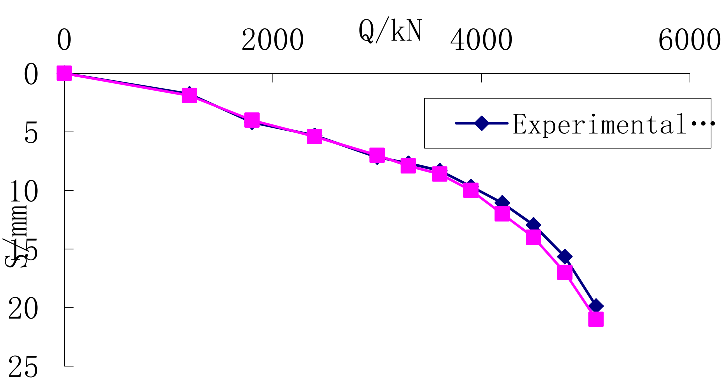

Fig.3 Comparison of Pile 3# top settlement relation with load.

From the results of 1# and 2# pile, Q-s relations of two piles presented a slow-varying tendency and no obvious inflection point appeared. Whereas, the increase range of settlement significantly enhanced after loads excessed 1500kN. When the loads added up to 3000Kn, the settlement of pile top remained less than 7mm, which was far below the specified value of *Code of Foundation Design for Buildings(gb50007-2002),China* and *Technical Code for Building Pile Foundation(JGJ94-94),China.* Therefore, it was reasonable to come to the conclusion that 3000kN is less than the tested piles' ultimate bearing capacity.

From the results of 3# pile, its settlement increases were comparatively higher when loads excessed 3600 kN. Furthermore, its deviation level between calculated settlement and real settlement and ratio between deviation value and real settlement significantly raised. Yet, the ratio still remained less than 10%.

From the results of above-mentioned tested piles, it could be noticed that calculated settlement slightly higher than real settlement. Among them, 1# pile and 2# pile fitted relatively ideal, comparison result of 3# pile basically coincided. But, with the increase of load level, the deviation between real value and calculated value mildly deviated and its ultimate bearing capacity was 5100 kN.

3 Conclusion

(1) By conducting in-situ vertical bearing capacity experiments of 3 tested piles, load-settlement relation under the circumstance of design load and ultimate bearing load were obtained. The settlement type of PC piles in the field was one of slow-vary type which have no distinct inflection point. Therefore, it is favorable to choose settlement as the main index to evaluate ultimate bearing capacity of piles.

(2)Based on Finite Difference Method, the numerical analysis result under large deformation condition is achieved by applying FLAC3D software and Mohr-Coulomb constitutive model to modeling mechanical behavior of soil mass. The result showed data conducted from experiments and numerical analysis are almost similar on the basis of comparison while the simulated is lightly higher than the experimented one, which suggested that the numerical method is relatively conservative in the respect of predicting pile-top settlement.

(3)Within the limit load, the Q-s function curve of concrete tube piles roughly presents a quadratic function form and no apparent inflection point appeared. Therefore, it is suggested to apply quadratic function when subsequent researchers need match this relation mathematically.

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