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Analysis on the Contribution of Retaining Wall Structure to the Vertical Bearing Capacity of Circular Cross-Section Hand-Dug Cast-In-Place Piles

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Abstract

To investigate the contribution of the retaining wall structure to the vertical bearing capacity of circular cross-section hand-dug cast-in-place piles, a three-dimensional pile-soil spatial model was established using the finite element software ANSYS for numerical simulation. A comprehensive analysis was then conducted combined with monitored data from practical engineering cases. The results indicate that, under the conditions of the case project, the contribution rate of the retaining wall structure to the vertical bearing capacity of piles is approximately 15%–30%.

Keywords

Hand-dug cast-in-place pile, retaining wall structure, numerical simulation, case analysis.

1. Introduction

To ensure the safety of construction workers and achieve successful hole forming, the retaining wall support structure is particularly critical during the construction of hand-dug cast-in-place piles. At present, the supporting theory for large-diameter hand-dug cast-in-place piles is still insufficient, and there are no corresponding national codes. In practical engineering design, technicians usually treat the retaining wall only as a temporary supporting structure without fully considering its vertical bearing effect. In fact, the retaining wall enlarges the pile-soil contact area, increases the ultimate shaft resistance and end resistance of the pile, and thus improves the vertical bearing capacity of the foundation pile. Therefore, the design practice that neglects the contribution of the retaining wall to the vertical bearing capacity of the pile shaft is conservative.

Based on recent research achievements worldwide and the study by Yu Haijian et al. (using rectangular cross-section hand-dug piles) from Chang'an University, this paper takes a practical project as an example. The finite element software ANSYS is used to simulate the interaction among the pile shaft, retaining wall, and rock-soil medium of circular cross-section hand-dug piles under vertical load. The stress responses of the pile shaft with and without the retaining wall are compared, and the vertical bearing contribution of the retaining wall under the engineering conditions is deduced. Finally, the deduction is verified by field monitoring data, aiming to provide references for the engineering design of hand-dug cast-in-place piles.

2. Project Overview

A residential building in a community is a 34-story reinforced concrete shear wall structure with a total height of 99.40 m and a construction area of 709.91 m^2. It adopts a raft foundation with graded sand and gravel replacement as the bearing stratum. After the completion of the main structure, the maximum inclination rate of the building exceeds the code limit and shows a further increasing trend. The treatment measures are as follows: firstly, hand-dug cast-in-place piles are added under the original raft to reinforce the foundation, which effectively controls the inclination; then, the soil-excavation forced settlement method is used for rectification so that the overall inclination rate of the building meets the code requirements.

The foundation reinforcement was completed on November 11, 2018, with a total of 28 additional piles. The pile shaft is of circular cross-section, with diameters of 1.0 m and 1.1 m, and the corresponding single-pile bearing capacities are 8000 kN and 9000 kN, respectively. The thickness of the retaining wall is 0.25 m. The pile-end bearing stratum is moderately weathered mudstone, with a penetration depth of approximately 1.5 m, and the pile length ranges from 12 m to 18 m. The rectification started on December 11, 2017, and finished on May 25, 2018.

3. Numerical Simulation

3.1. Basic assumptions

The interaction between piles and soil in actual pile foundation working conditions is rather complicated. In this paper, the stress of a single pile under vertical load is simulated using ANSYS with the following simplifications and assumptions:

1) The pile is subjected only to vertical axial uniform load; vertical eccentric load and bending moment are not considered; the tensile performance of concrete is neglected. A 1/4 model is adopted for calculation based on symmetry.

2) The soil around the pile adopts the D-P material model. The pile shaft material is isotropic, uniformly dense, and slightly deformable, with a linear elastic constitutive relation, and material nonlinearity is not considered.

3) Friction exists at the contact surfaces between the pile shaft and soil, pile shaft and retaining wall, and retaining wall and soil, and contact elements are set on these surfaces.

4) The retaining wall is modeled as a whole.

3.2. Model establishment and parameter selection

Pile No.16 and Pile No.27 in the project are selected as research objects. The geometric dimensions of the pile shaft, retaining wall, and soil are as follows: the pile (shaft and retaining wall) is 13 m long, the shaft section diameter is 1 m, and the embedded depth is 13 m; the retaining wall thickness is 0.25 m; the lengths of the soil model in the X, Y, and Z directions are 8 m, 8 m, and 39 m, respectively.

According to the geological survey and design data of the project, the material parameters are selected as follows:

- Pile shaft concrete: Grade C30, elastic modulus 3×10^{10} Pa, Poisson's ratio 0.2, density 2500 kg/m^3;
- Retaining wall concrete: Grade C25, elastic modulus 2.8×10^{10} Pa, Poisson's ratio 0.22, density 2500 kg/m^3;
- Soil: elastic modulus 2.5×10^{8} Pa, Poisson's ratio 0.4, density 2000 kg/m^3, cohesion 19000 Pa, internal friction angle 32°, dilatancy angle 30°.

To accurately simulate the deformation and stress processes of the pile shaft, retaining wall, and soil, the SOLID45 element is used to establish the three-dimensional pile-soil model. Considering the modeling difficulty and accuracy of reinforced concrete, the monolithic model is adopted: it is assumed that concrete and steel bars are well bonded, and both piles and soil are uniform isotropic materials.

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Table 1 Parameters of Contact Elements

Name	Element Type		Parameter
	Target Surface	Contact Surface	
Contact Surface Between Pile Shaft and Retaining Wall	TARGE170	CONTA173	Friction Coefficient mu=0.65 KEYOPT,,9,0 KEYOPT,,12,2
Retaining Wall and Surrounding Soil Mass	TARGE170	CONTA173	Friction Coefficient mu=0.3 KEYOPT,,9,0 KEYOPT,,12,2
Pile Shaft and Surrounding Soil Mass	TARGE170	CONTA173	

3.3. Boundary conditions and loading

Since a 1/4 finite element model is used for the pile-soil system, the boundary conditions are set as:

- Symmetric constraints at X=0.0 and Y=0.0;
- Fixed constraints at X=4.0 and Y=4.0;
- Vertical displacement constraints in the Z direction.

A uniform surface load of 10.16 MPa (equivalent to the single-pile bearing capacity) is applied on the pile top. The load is applied step by step through 15 loading steps, with each step being 1/15 of the maximum test load. The self-weight of the soil is considered.

3.4. Analysis of calculation results

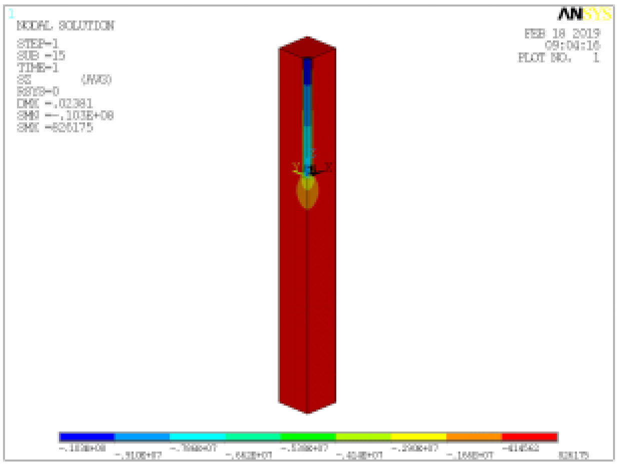

Fig.1 Pile-soil stress contour

Table 2 Stress data of pile shaft and retaining wall (MPa)

Load Step	1	2	3	4	5	6	7	8
Pile Shaft	0.10	0.19	0.33	0.54	0.86	1.33	2.04	2.96
Retaining Wall	0.01	0.02	0.05	0.08	0.14	0.23	0.36	0.53
Load Step	9	10	11	12	13	14	15	/
Pile Shaft	3.89	4.81	5.70	6.60	6.47	8.37	9.10	/
Retaining Wall	0.70	0.87	1.04	1.20	1.36	1.52	1.66	/

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The data in Table 2 and Fig.1 are the stress values at 2 m below the pile top. It can be seen from Table 2 that the total stress variation of the pile shaft is 9.10 MPa, and that of the retaining wall is 1.66 MPa. The converted total forces are 7150 kN and 1630 kN, respectively. Based on the bearing capacity contribution ratio, the contribution of the retaining wall to the vertical bearing capacity of the pile is approximately 18.56%.

4. Field monitoring data

4.1. Monitoring equipment and layout

Pile No.16 and Pile No.27 are selected as monitoring objects. The stress-strain monitoring equipment is a vibrating wire concrete meter. Three concrete meters are uniformly arranged along the pile shaft cross-section at 120° intervals, and the same arrangement is adopted for the retaining wall. The layout is shown in Fig.2, and the on-site installation is shown in Figs.3–5.

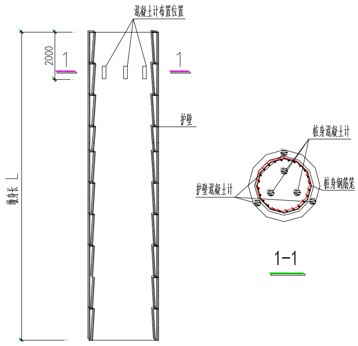

Fig.2 Layout of monitoring equipment

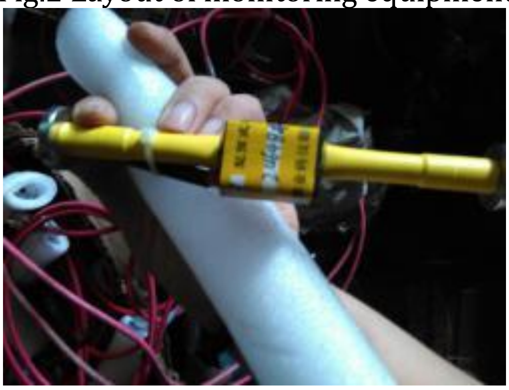

Fig.3 Concrete meter

Fig.4 Protection before concrete meter installation

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Fig.5 On-site installation of monitoring equipment

4.2. Analysis of monitoring results

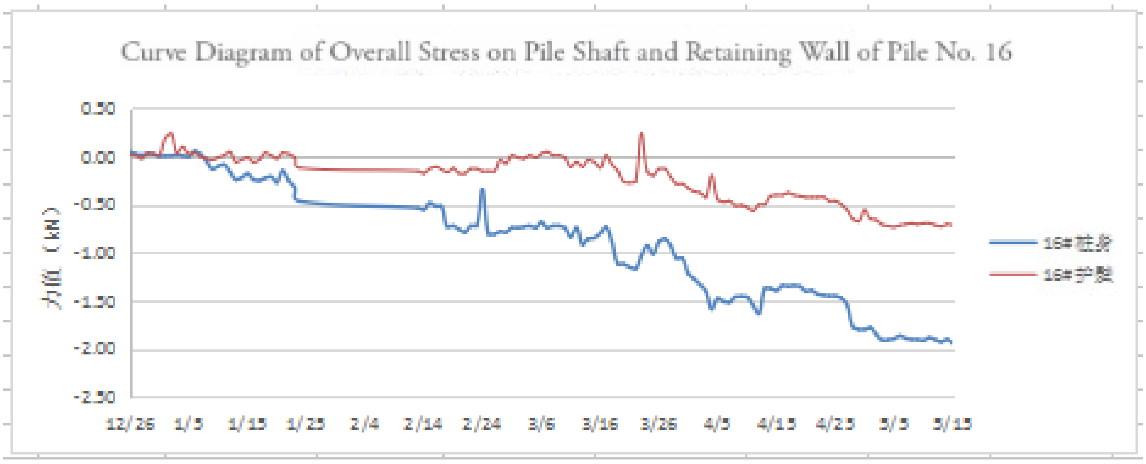

Fig.6 Overall stress curve of pile shaft and retaining wall (Pile No.16)

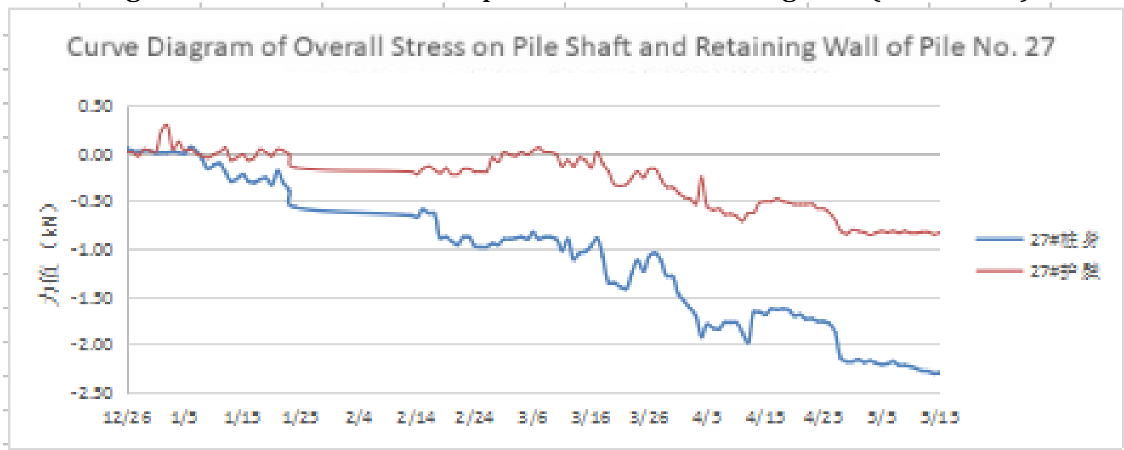

Fig.7 Overall stress curve of pile shaft and retaining wall (Pile No.27)

The curves in Figs.6 and 7 illustrate the variation of the overall force of the pile shaft and retaining wall during the rectification. During the whole rectification process, the stress variation of the shaft of Pile No.16 is 2.54 MPa, and that of the retaining wall is 0.74 MPa; the stress variation of the shaft of Pile No.27 is 3.00 MPa, and that of the retaining wall is 0.73 MPa. According to the bearing capacity contribution ratio, the contribution of the retaining wall to the vertical bearing capacity is about 26.59% for Pile No.16 and 26.13% for Pile No.27. It can be inferred that under the actual engineering conditions, the contribution of the retaining wall structure to the vertical bearing capacity of the pile is about 26%–27%.

Affected by environmental factors such as temperature, the monitoring data of the pile shaft and retaining wall in Figs.6 and 7 fluctuate to a certain extent, but the overall variation trends are basically synchronous, which proves the reliability of the concrete meter monitoring data.

5. Field monitoring data

Under the engineering parameters given in this paper, the comprehensive analysis of the pile-soil model numerical simulation and field monitoring data shows that the contribution of the retaining wall structure to the vertical bearing capacity of the pile is about 15%–30%.

The numerical simulation in this paper focuses on the single-pile bearing capacity and relies on an ideal finite element model. However, most pile-soil environments are more complex in practice. Therefore, it is necessary to develop more identification methods that take environmental disturbances into account.

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