Piling Tests and Induced Surface Settlement of Rotating Static Pressure Steel Pipe Pile in Shanghai Soft Soil

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ABSTRACT

This paper presents a series of piling tests of rotating static pressure steel pipe pile including the pile length design in Shanghai soft clay. The construction technology was examined by extensive field data of surface settlement during the construction. It was found that the vertical displacements of the surrounding soil were well controlled with a maximum value of 5 mm. The static pressure rotary method can be applied in various geological and environmental conditions, especially in the case of river embankment, short distance protection piles, complex strata and low clearance. This construction method can prove to be the valuable reference for mitigating risks of construction to adjacent structures in similar soft soil geotechnical engineering project.

Key words: *Rotating static pressure, steel pipe pile, soft soil disturbance*

1. Introduction

With the rapid development of infrastructure facilities, particularly in Shanghai, during the past two decades, more and more underground structures and metro stations accompanied with excavations are increasingly carried out in congested urban areas. The soft soil in Shanghai is classified as very soft soil with high water content, low strength and low permeability. In such circumstances, the deformation control and the prediction of the effects of excavations on surrounding and structures, and necessary protection countermeasures to mitigate any adverse situation, are of great concern. The traditional construction technology for foundation pit support in Shanghai mainly includes: bored pile + pile water-stop curtain sprayed with high pressure; open caisson; diaphragm wall + water-seal drapery; SMW process pile; and some other less used construction technologies. In the very sensitive areas for environment and surrounding buildings, the aforementioned technology may not meet the requirements of the foundation pit engineering. In this paper, based on first use of rotating static pressure steel pipe pile technology in China, a series of piling tests including the design for pile length were conducted, and the short construction duration and low impact on environment are described.

2. Outline of the project

2.1. Place

The test location was the Jinze warehouse of Shanghai Urban Construction Municipal Engineering (Group), Qingping Road 9623 in Shanghai.

2.2. Background and objectives of the project

The soil deformation characteristics and the environmental impact induced by the equipment in Shanghai soft soil were expected to gain by the piling tests.

3. Structural type and piling method

3.1. Site condition

No existing structures can be found around the test location.

3.2. Ground condition

Design methodology of this test was mainly based on parameters evaluated from field and laboratory testing of soil through vertical core drilling. Different in-situ and laboratory testing was carried out to get a realistic value of the geotechnical properties of the soil encountered. Details of Standard Penetration Test (SPT) of soil profile in the location are presented in **Fig. 1**.

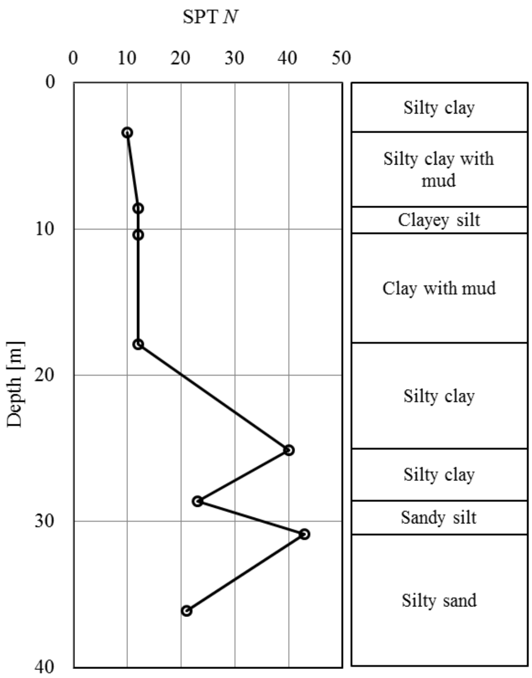


Fig. 1 SPT results of soil profile

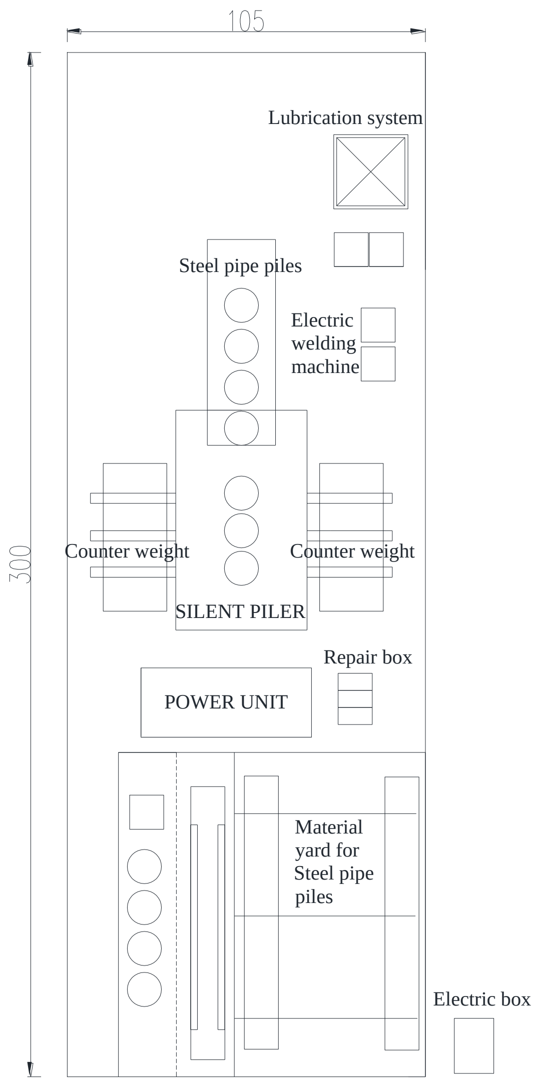
3.3. Piling method

The static piling methods include standard press-in, press-in with water jetting, press-in with augering and rotary cutting press-in. The adopted method here was rotary press-in with water lubrication.

4. Press-in piling

4.1. Layout

Fig. 2 shows the layout of the piling work.



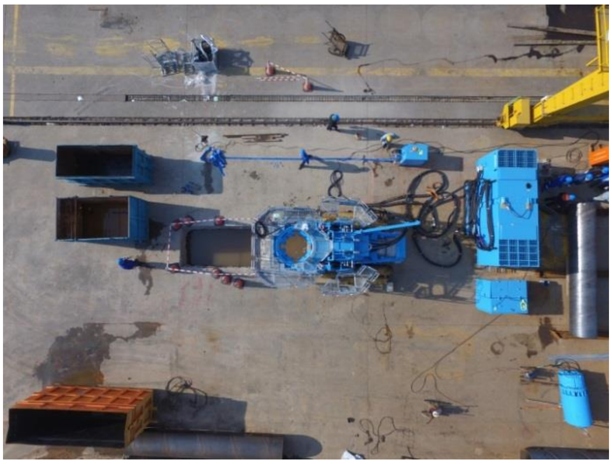


Fig. 2 Layout of the piling work

4.2. Piling data and the design for the pile length

The tests were performed on 4 steel pipe piles, with the diameter of 1m, thickness of 14 mm, pile spacing of 1.2 m, and four lengths of 6 m, 10 m, 10 m and 36 m.

The maximum rotating force is 100 kN·m, and the maximum pulling force is 400 kN·m. The calculation process for design is as follows.

In the standard projects, when steel pipe pile is initially pressed, the counterforce is usually provided by the completed steel plate piles. The present tests optimized the process, being the maximum counterforce gradually provided through progressive length of steel pipe pile.

According to the article 5.3.7 in Chinese Standard, Technical Code for Building Pile Foundation (JGJ 94-2008), the following **Eq. (1)** was used for determining the vertical ultimate bearing capacity of steel pipe pile by the empirical relationship between the physical parameters of soil and the parameters of pile bearing capacity.

$$Q_{\mathrm{uk}} = Q_{\mathrm{sk}} + Q_{\mathrm{pk}} = u\sum q_{\mathrm{sik}} l_i + \lambda_{\mathrm{p}} q_{\mathrm{sk}} A_{\mathrm{p}} \tag{1}$$

If $h_{\mathrm{b}} / d < 5$, $\lambda_{\mathrm{p}} = 0.16 h_{\mathrm{b}} / d$;

If $h_{\mathrm{b}} / d \geq 5$, $\lambda_{\mathrm{p}} = 0.8$.

Where q_{sik} is the standard value of ultimate side resistance of pile for the *i* layer soil, the same value as the precast concrete pile;

q_{sk} is the standard value of ultimate tip resistance of pile, the same value as the precast concrete pile;

λ_{p} is the coefficient of plugging effect of pile tip, $\lambda_{\mathrm{p}} = 1$ for the closed steel pile;

h_{b} is the penetration depth of pile tip into the bearing stratum;

d is the outer diameter of steel pipe pile.

The counter weight of base for counterforce was calculated by

$$W_1 = 2\left(Q_{\mathrm{uk}} - W_2 - Q_{\mathrm{uki}}\right) \tag{2}$$

where W_1 is the counter weight of base with the safety factor of 2; Q_{uk} is the side resistance of pile that is in construction; W_2 is the weight of equipment; Q_{uki} is the side resistance of completed pile.

The counter weight of base and the length of pile can be determined by the above formulas without considering the influence of lubrication system, see **Fig. 3** and **Table 1** for more details.

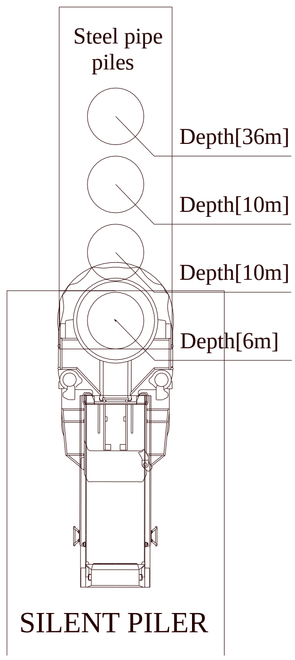


Fig. 3 Depth design of the steel pipe piles

Table 1. Frictional resistances of the test piles and counter weight of base

Soil name	f_S of the precast pile /kPa	Layer thickness/m	6m pile	10m pile	36m pile
Silty clay	15	3.4	3.4	3.4	3.4
Silty clay with mud	15(≤6m)	5.2	1.4	5.2	5.2
Clayey silt	30	1.8	1.2	1.8	1.8
Clay with mud	25	7.44			7.44
Silty clay	40	7.2			7.2
Silty clay	70	3.5			3.5
Sandy silt	100	2.3			2.3
Silty sand	110	5.16			5.16
Q_{sk} /kN			361.1	631.1	4169.92
Q_{pk} /kN			102.5	156.7	331.58
Weight of SILENT PILER/Tons			32.5	32.5	32.5
The friction force of completed pile/kN				361.1	4397.16
Required counter weight (Safety factor = 2)/Tons			27.8	20.4	

According to the geological survey report, the pile length of the test pile was determined through the above calculation, and the drag reduction effect of the water lubrication system was not considered. The length of the first test pile is 6 m, the required counter weight of base is 27.8 Tons; The length of the second test pile is 10 m, the required counter weight of base is 20 Tons; The length of the third test pile is 10 m, the required counter weight of base is 20 Tons. Since the counter-force provided by the first three completed steel pipe piles is much larger than the maximum static pressure of the equipment, the largest length of the fourth pile is set to be 36 m.

4.3. Construction flowcharting

The general construction flowcharting of the tests is shown in **Fig. 4**.

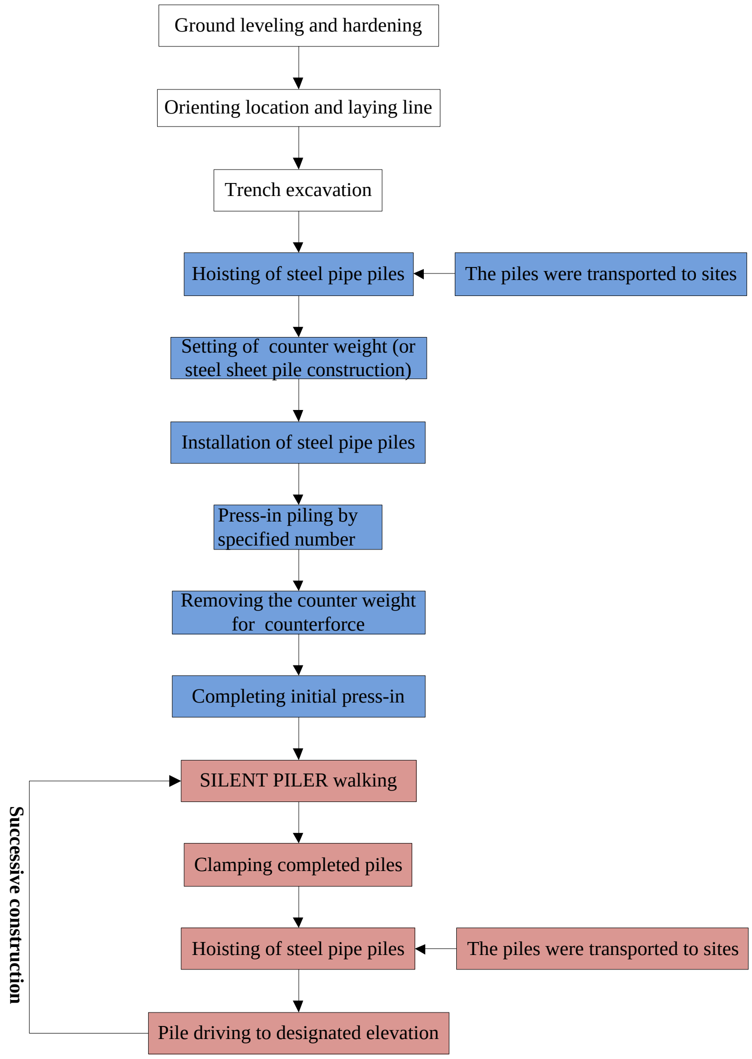


Fig. 4 Construction flowcharting of the tests

4.4. Productivity

The time or efficiency for working procedures is shown in **Table 2**. It can be found that the rotating static pressure steel pipe pile technology can effectively improve construction speed and reduce construction cost. However, if the welding efficiency of the steel pipe can be improved, the construction duration of single pile will be effectively improved.

4.5. Encountered difficulties

A difficulty was encountered during the piling process. Because the first three piles were short, when the fourth steel pipe pile was rotated and pressed into the field, the equipment of SILENT PILER twisted around. When it happened, we reinserted the steel pipe pile, or adjusted the plane position and the pushing speed of the steel pipe pile, so that the chuck of the press-in equipment was axially fixed relatively.

Table 2. Information for construction productivity

Working procedures	Hoisting of steel pipe pile	Press-in	Abutting joint	Welding	Velocity of press-in	SILENT PILER walking
Time or efficiency	15min	1.5m/min	15min	1h	1.5m/min	15min

5. Surface settlement data during piling

As shown in **Fig. 5**, five settlement monitoring points with specified distances were arranged on both sides of the 36 m pile during piling.

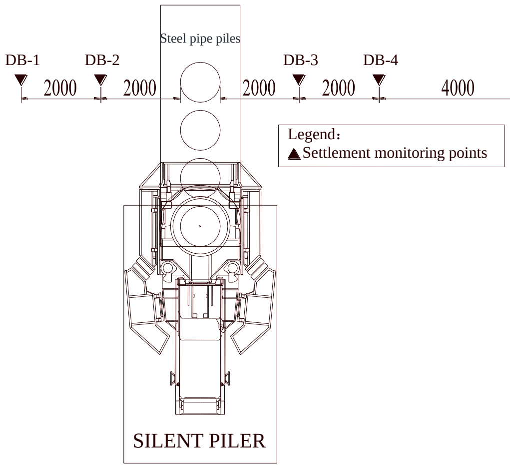


Fig. 5 Layout of the settlement monitoring points during piling

Fig. 6 presents the change of surface settlement curves with time. It can be seen from the figure that the maximum surface settlement was 5 mm without obvious subsidence or uplift during the construction of static pressure steel pipe pile with SILENT PILER (F401). Considering the acceptable measurement errors, the disturbance of steel pipe pile construction on surrounding soil is small, and it may be applied in the densely built areas with strict settlement requirements.

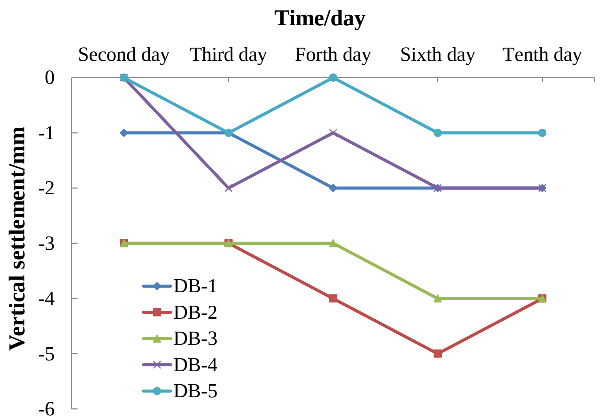


Fig. 6 The change of surface settlement curves with time

6. Concluding remarks

From the above piling work, the following conclusions can be drawn:

(1) In soft soil areas, the construction of rotating static pressure steel pipe pile has a small influence on the surrounding environment, and also can fulfill the requirement of low noise and vibration. The steel pipe pile can be removed by "pulling" type machine, to achieve resource recycling.

(2) If the welding efficiency of the steel pipe can be improved, the construction duration of single pile will be effectively improved.

7. Acknowledgements

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References

Chinese Standard. Technical Code for Building Pile Foundations (JGJ 94-2008).