

Evaluation of Vertical Bearing Capacity for H section Steel Pile with Soil cement Ground Improvement

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ABSTRACT

In recent years, works to improve existing structures and strengthen their seismic resistance have increased. Pile construction in narrow spaces is constrained by the site and process. Furthermore, noise and industrial waste need to be considered with regard to their effects on the surrounding environment. Therefore, a construction method of H section steel pile construction combined with soil cement ground improvement using a mechanical agitator was developed. This method is characterized by having no need to drill up to a fixed depth as in the pre boring pile construction method. Instead, soil is agitated along with the cement milk at the original position. In this study, static compression load tests on the soil-cement composite pile that were constructed with the mechanical agitator ground improvement method were carried out to evaluate the vertical bearing capacity. Furthermore, it was evaluated the performance of vertical bearing capacity on the H-section steel piles with soil-cement ground improvement to compare the evaluation method as shown in the design specifications in Japan.

Keywords: soil-cement composite pile, shaft friction, end bearing capacity

1 INTRODUCTION

There are several pile construction methods with relatively small construction machinery that are suitable for construction in narrow urban spaces and areas with low overhead clearance. The Top drill Boring Hole (TBH) method, which has a machine height of 4.5m, is often used. However, there are many cases where even these construction machines are interfered with by architectural limitations and existing structures. In particular, piles near railway tracks or on rail platforms are currently constructed after temporary construction is carried out to ensure construction space. The Boring Hole (BH) pile method can handle narrow spaces and low overhead clearances better than the TBH method. However, because the BH pile method is a direct circulation method, mud cakes easily form on the hole walls, and slime tends to accumulate at the pile tip. This lowers the bearing capacity of the piles, so subsidence is more likely to occur. Such challenges related to the

construction method, bearing capacity and settlement need to be resolved for pile construction in narrow urban spaces.

Pile construction in narrow urban spaces and for existing structures to strengthen the seismic resistance is subjected to constraints on the construction site and process. Especially, this pile is subjected to the lack of bearing capacity due to the increase of superstructure weight by strengthening the superstructure. Furthermore, noise and industrial waste need to be considered with regard to their effects on the surrounding environment. Therefore, a method for H section steel pile construction combined with soil cement ground improvement was developed that uses a compact mechanical agitator for pile foundations of lightweight structures. The construction machine is a mechanical agitator with an attached vibrating mechanism and improved drilling capacity. This developed machine can be used to realize pile construction in narrow spaces where construction is



Fig. 1. Construction machine of H-section steel pile.



Fig. 2. Pile tip shape of H section steel pile.

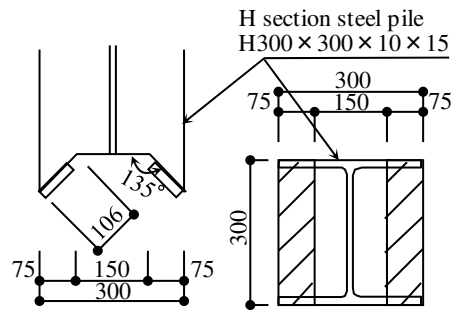


Fig. 3. Scale of pile tip shape of H section steel pile.

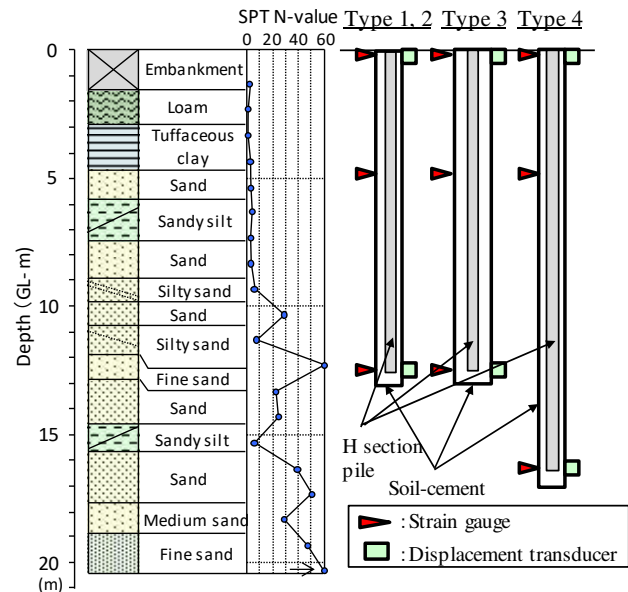


Fig. 4. Soil profile and test piles.

usually difficult. This method is characterized by having no need to drill up to a fixed depth as in the pre boring pile construction method. Instead, soil is agitated along with the cement milk at the original position. This greatly reduces the spoil generated by pile construction. In this method, the drilling rod of the developed machine is sent down to the bearing stratum; after agitating and mixing, the pile is composed of segmental steel pipes that are connected with bolts on flanges.

In this study, static compression load tests on the H-section steel piles with soil-cement ground improvement that were constructed with mechanical agitator ground improvement method were carried out to evaluate the vertical bearing capacity. Furthermore, it was evaluated the performance of vertical bearing capacity on the H-section steel piles with soil-cement ground improvement to compare the evaluation method as shown in the design specifications in Japan.

2 OVERVIEW OF H-SECTION STEEL PILE WITH SOIL CEMENT GROUND IMPROVEMENT

In this construction method, strength of the soil cement is in the ranges of $1000 \sim 5000 \text{ kN/m}^2$. The H section steel piles were used to be fabricated from JIS standard steel piles to ensure a low cost and certain level

of quality. The typical construction process with this method is described as follows;

- 1) Excavate to the bearing stratum, carry out agitation and mixing, and lay the soil cement as the ground improvement structure. During this time, carry out drilling so that the rod will reach a predetermined depth.
- 2) Build H section steel pile joints in the ground improvement structure, which is in loose and poorly lithified soil.
- 3) After the pile construction is completed, fix the pile head before the soil-cement hardens.

The above construction can be carried out using only the developed construction machine shown in Fig. 1. The planar dimensions of the construction machine are extremely compact: a 1.55m width and 2.32m length. In addition, the construction machine is 3.0m tall, including the leader. Thus, construction is possible even with low overhead clearances. The machine has a vibration mechanism to improve the agitation and mixing capability. The results of construction test showed that even sand with an N value of about 40–50 can be agitated and mixed (Kitade et al., 2012).

In order to increase the end bearing capacity, two

Table 1. Specifications of test piles.

	Pile diameter (mm)	Pile length (m)	Strength of soile-cement (kN/m^2)
Type 1	600	14.0	1000
Type 2	600	14.0	3000
Type 3	800	14.0	1000
Type 4	600	17.0	1000

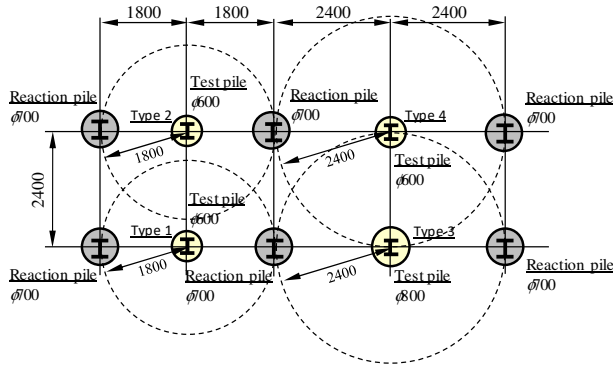


Fig. 5. Arrangement of test piles and reaction piles.

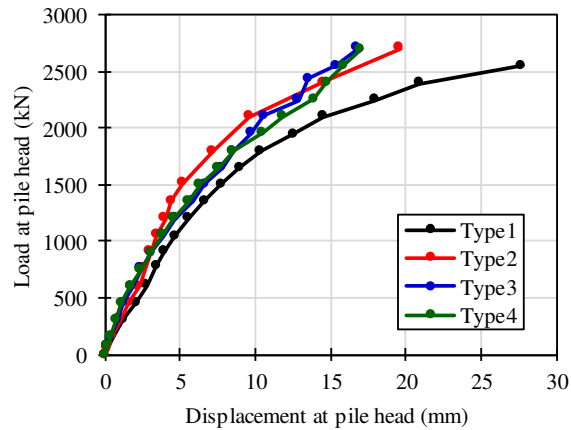


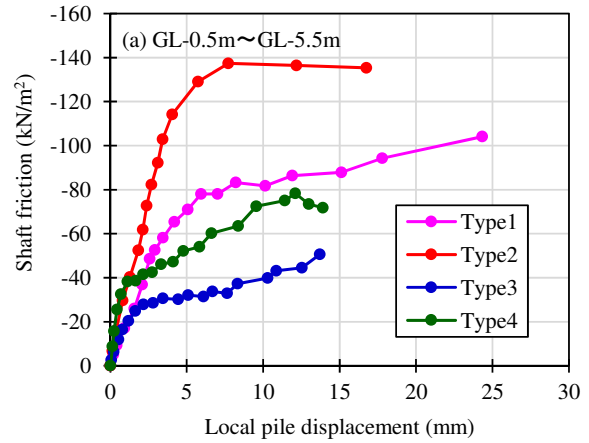
Fig. 6. Relationships between load and displacement at pile head.

plates were attached to the tip of the H section steel pile. Fig. 2 and Fig. 3 shows the tip shape of the H section steel pile. As shown in Fig. 2 and Fig. 3, two plates were attached to the tip of the H section steel with an inclination of 135deg. from the horizontal direction.

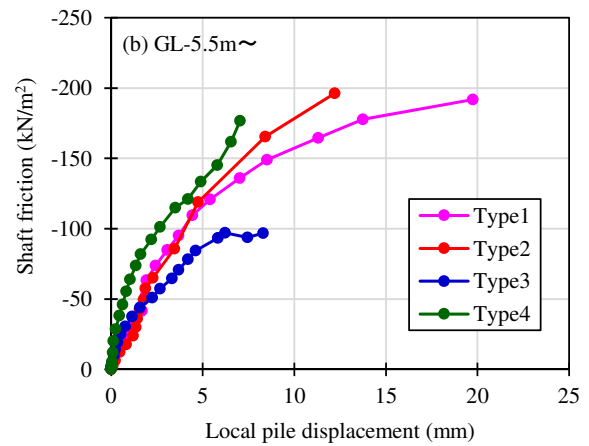
3 FULL-SCALE LOAD TEST

The soil profile and test piles indicates in Fig. 4. The test ground was composed of loam and tuffaceous clay up to about GL -5.0 m and sandy silt and medium sand, fine sand below that. Four piles were constructed for the static load test with the soil cement diameter, pile length, and soil cement strength as parameters.

Table 1 presents the specifications of the test piles. The bearing stratum was adopted to be $N=20$ and 40 from the results of ground investigation; the test piles were embedded in the bearing stratum. The test piles were pre-drilling soil-cement column diameter of 600mm and 800mm, H section steel shape of H300×300×10×15. The target strength of the pre-drilled



(a) Clayey soil: GL-0.5m~GL-5.5m.



(b) Sandy soil: GL-5.5m~.

Fig. 7. Relationships between shaft friction and local pile displacement.

soil cement as the improved ground structure was 1000kN/m^2 with the test pile of Type 1, 3, 4 and 3000kN/m^2 with the test pile of Type 2. In the core strength test carried out after the load test, the average strengths with the all of the test piles were over the target strength, respectively. The arrangement of test piles and reaction piles presents in Fig. 5. Four test piles and six reaction piles were constructed. Similar to the test piles, six reaction piles were also constructed as the H section steel pile with soil cement by the same construction method as the test piles. The distance between the test piles and the reaction piles were set based on the influence range as described in the Japanese Geotechnical Society (“Methods for vertical load test of piles”) (2001), the distance are $3D=1800, 2400$ (mm). Here, D means the pile diameter such as soil cement diameter.

The static load test was carried out based on the standards of the Japanese Geotechnical Society (“Methods for vertical load test of piles”) (2001). A stepwise multi cycle loading system was employed with a new load holding period of 30min, hysteretic load holding duration of 2min, and zero load holding duration

of 15min. The measured parameters were the pile head load, pile head and pile tip displacements, and strain of the H section steel. The pile tip displacement was measured with the pipe-in pipe method (i.e. double steel tube method). In order to evaluate the shaft friction of each stratum and the end bearing capacity, the strain were measured at the tip of pile and the boundary of each stratum, top of pile.

4 RESULTS OF FULL-SCALE LOAD TESTS

4.1 Compression load tests

Figure 6 shows the relationships between the load and displacement at the pile head. The maximum loads were 2500kN for Type 1 and 2700kN for Type 2~Type 4. For all of the piles, the curve was steep from the initial of loading; and all of the piles possessed a large initial stiffness. The gradient of the curve then changed with the loading and reached the maximum load. For the test piles of Type 2~Type 4, a larger N value for the bearing stratum, a larger pile diameter and a longer pile length meant a higher stiffness.

The axial force was calculated by considering only the H section steel. The strain of the H section steel obtained from the load test was multiplied with the Young's modulus and cross-sectional area of the H section steel. The relationships between the shaft friction and local pile displacement which was obtained by dividing this axial force difference by the circumferential area are shown in Fig. 7. The improved diameter of the soil cement (i.e. outer diameter of soil cement column) was used when calculating the circumferential area of the pile. Figure 7(a) shows that a maximum shaft friction of 50 ~ 140kN/m² was reached in clayey soil stratum. In comparison, the average value for the unconfined compressive strength of the corresponding section of the ground was 57kN/m². Thus, it can be concluded that the shaft friction was more than the undrained shear strength of the ground (=28kN/m²). In the sandy ground stratum, it is observed that the maximum shear strength is 100~200kN/m². Therefore, it is said that the shaft friction of the corresponding section shows the large value.

The end bearing capacity was calculated by dividing the axial force reaching the pile tip by the envelope area of the H-section steel ($B \times H$) as shown in Fig. 8. The relationships between the end bearing capacity and displacement at pile tip indicates in Fig. 9. The reference displacement of pile tip is 10% of the diameter of the equivalent circle area which is equal to the envelope area of H-section steel pile when the end bearing capacity is evaluated. However, the maximum displacement at pile tip does not reach the reference displacement in this load test. Thus, the end bearing capacity is evaluated at the maximum displacement at pile tip. The end capacity of 3000~6600kN/m² is examined in this load test. The trend indicates that the end bearing capacity is gradually increasing because the displacement at pile tip is small

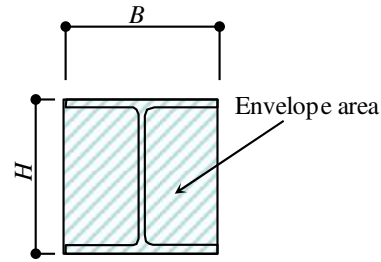


Fig. 8. Pile tip area (Envelope area).

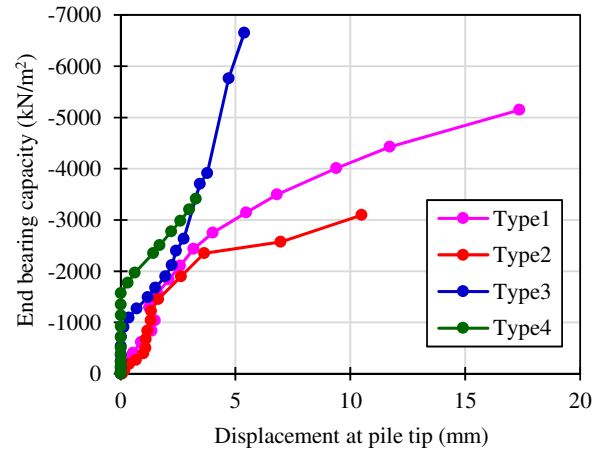


Fig. 9. Relationships between end bearing capacity and displacement at pile tip.

and does not reach the reference displacement to evaluate the end bearing capacity. In addition, the end bearing capacity of the test pile Type 3 indicates the largest value of four test piles. This means that the large end bearing capacity is mobilized due to the large diameter of the pile.

4.2 Comparison of design specifications

The end bearing capacity which was obtained from the developed H-section steel piles with soil-cement ground improvement is compared to the calculated end bearing capacity as shown in the design specification of Japan. In this study, the calculated value is estimated by the Design Standards for Railway Structures and Commentary (Railway Technical Research Institute, 2012) because the developed soil-cement composite pile is applied to the railway structure. The estimation equations of bearing capacity for the steel pipe soil-cement pile and cast in-situ pile are used in this study. The estimation equations are described as follows;

1) Steel pipe soil-cement pile

Shaft friction for sandy soil:

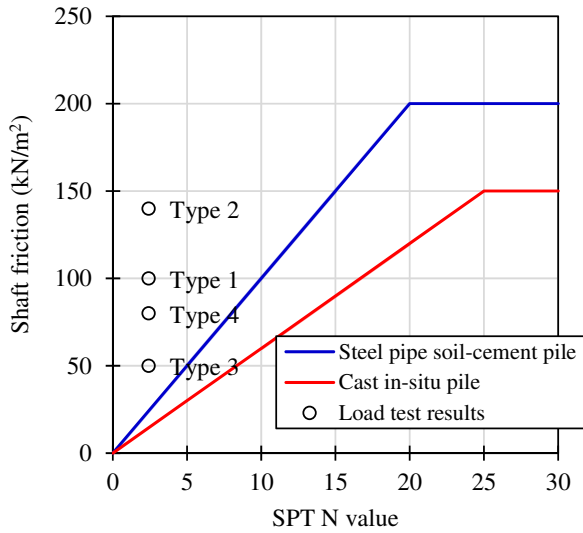
$$\gamma_{fk} = 7N \leq 200(\text{kN/m}^2) \quad (1)$$

Shaft friction for clayey soil:

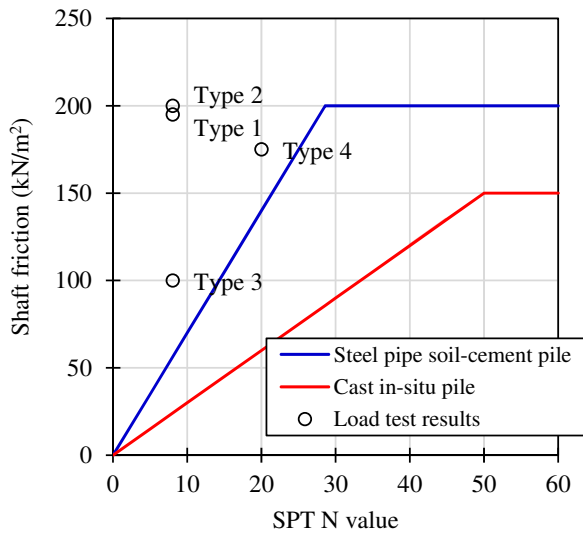
$$\gamma_{fk} = 10N \leq 200(\text{kN/m}^2) \quad (2)$$

End bearing capacity for sandy soil:

$$q_{tk} = 150N \leq 10000(\text{kN/m}^2) \quad (3)$$



(a) Clayey soil



(b) Sandy soil

Fig. 10. Relationships between shaft friction and SPT N value.

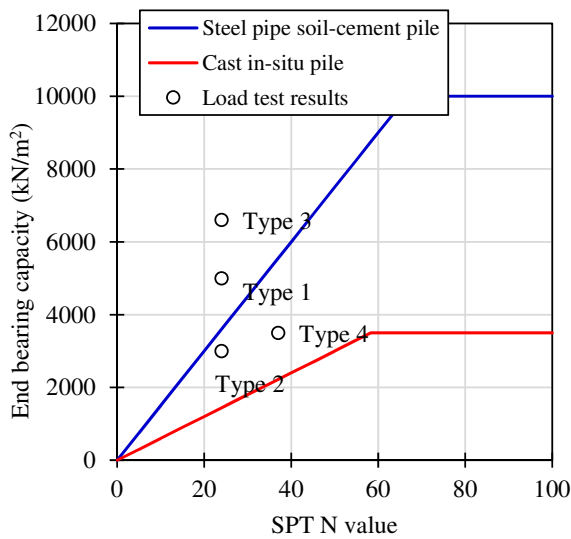


Fig. 11. Relationships between end bearing capacity and displacement at pile tip.

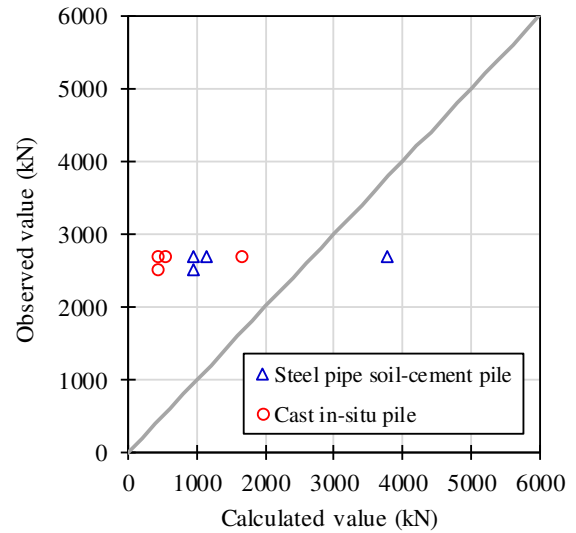


Fig. 12. Relationships between observed bearing capacity and calculated bearing capacity.

2) Cast in-situ pile

Shaft friction for sandy soil:

$$\gamma_{fk} = 3N \leq 150(\text{kN/m}^2) \quad (4)$$

Shaft friction for clayey soil:

$$\gamma_{fk} = 6N \leq 150(\text{kN/m}^2) \quad (5)$$

End bearing capacity for sandy soil:

$$q_{tk} = 60N \leq 3500(\text{kN/m}^2) \quad (6)$$

Where,

N : SPT (Standard Penetration Test) N value

The relationships between shaft friction and SPT N value for clayey soil and sandy soil indicate in Fig. 10. The estimated values from Eqs. (1), (2), (4) and (5) are also plotted in Fig. 10. According to Fig. 10(a), the shaft friction which is obtained from the load test is larger than the estimated value from the design specification. It is said that the developed H-section steel piles with soil-cement ground improvement has the enough shaft friction for the clayey soil. From Fig. 10(b), compared to the shaft friction from the load test and that from the design specification, the shaft friction of load test shows the large value. Therefore, it is also said that the shaft friction of the developed H-section steel piles with soil-cement ground improvement has the enough shaft friction for the sandy soil.

The relationships between end bearing capacity and SPT N value for sandy soil are plotted in Fig. 11. The estimated values from Eqs. (3) and (6) are also plotted in Fig. 11. It is seen that the end bearing capacity of Type 1 and Type 3 from the load test is larger than that of the estimated value. However, the end bearing capacity of Type 2 and Type 4 from the load tests is lower than that of estimated value for the steel pipe soil-cement pile although the end bearing capacity of load test shows the large value for the cast in-situ pile. This means that the

end bearing capacity does not mobilize because the displacement at the pile tip is too small.

5 CONCLUSIONS

The static compression load tests on the H-section steel piles with soil-cement ground improvement that were constructed with the mechanical agitator ground improvement method were carried out to evaluate the vertical bearing capacity in this study. Furthermore, it was evaluated the performance of vertical bearing capacity on the developed soil-cement composite pile to compare the evaluation method as shown in the design specifications in Japan. The following findings were obtained from this study.

1) According to the compression load test, both the shaft friction and the end bearing capacity has the enough performance on the vertical bearing capacity.

2) It is concluded that the shaft friction of the load test is larger than the estimated shaft friction which is calculated by the design specification in Japan.

3) Compared to the end bearing capacity which is obtained from the load test and that of estimated value from the design specification in Japan, the end bearing capacity of the load test shows the large value. However, the partial results is lower than the estimated value. This

means that the end bearing capacity is gradually increasing because the displacement at the pile tip is too small.

4) There are some research issues to address in the future. More vertical load tests to examine the vertical bearing behavior will be carried out. Moreover, it is needed to confirm the performance of pile body such as the bond strength and the effect of reinforcing pile tip. We will tackle the research issues described as the above sentence in the future.

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