Tip resistance characterization of embedded piles with inclined tip plates using dynamic pile tests

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ABSTRACT

Several methods for increasing the tip resistances of embedded piles have been developed with a focus on reducing the cost and period of construction. The embedded piles with different tip plates were installed and the tip resistances of test piles were estimated through dynamic pile tests. The experimental results showed that the tip resistance of the pile with an inclined plate is larger than that of the pile without a tip plate. In addition, the tip resistance increases with an increase in the inclination angle of the tip plate. This study demonstrates that the tip resistance of embedded piles depends on the shape of the pile tip, and the tip resistance of piles can be maximized by controlling the inclination angle of the tip plate.

Keywords: dynamic pile test; embedded piles; inclination angle; inclined tip plate; tip resistance

1 INTRODUCTION

Embedded pile method is commonly used in urban areas because of its low noise and vibration. The procedure of embedded pile method is as follows: boring the ground; locating the precast pile into the prebored hole; injecting cement paste grouting; and finishing with blows (Cho, 2010).

The skin friction of an embedded pile is significantly dependent on the ground condition and construction process. Thus, the end bearing capacity should be sufficient to satisfy the design criteria. Many studies have aimed to increase the tip resistances of embedded piles at a reduced cost and period of construction.

Seo (2016) developed a pile with an inclined plate as shown in Fig. 1 to maximize the tip resistance of embedded pile. According to that study, the tip resistance of the pile with an inclined plate was larger than that of the pile without a tip plate. However, the study did not attribute the change in tip resistance to any specific factors.

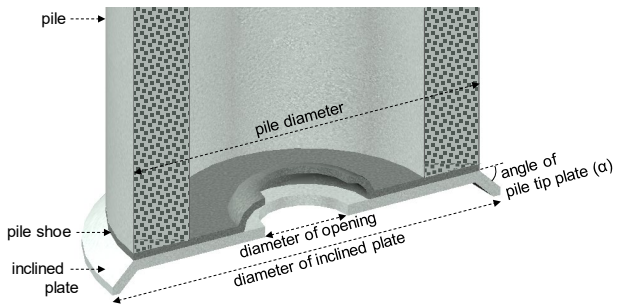

Fig. 1. Concept picture of the pile with inclined plate.

In this study, three different types of test piles were constructed to estimate tip resistance. Dynamic pile tests were carried out while embedded piles were being constructed for the estimation of the tip resistance. Finally, the results were analyzed to examine the effect of the inclination angle of the tip plate.

2 FIELD TESTS

2.1 Test setup

Pretensioned high spun concrete (PHC) piles with 45° and 60° inclined plates and a pile without a tip plate were constructed in the field. The diameter and length of the test piles are 500 mm and 12 m, respectively. The outer diameter of the tip plates is 560 mm, which is longer than that of the PHC piles by 60 mm. According to the site characterization, the N values near the pile tip ranged from 50/4 to 50/2. The summary of the field test is shown in Table 1. Dynamic pile tests were conducted while the test piles were being constructed according to ASTM D4945 (2008).

Table 1. Summary of the field test.

Pile diameter	500 mm
Length of pile	12 m
Type of pile tips	without tip plate, with 45° inclined plate, with 60° inclined plate
Diameter of plate	560 mm
N value around pile tip	50/4 ~ 50/2

2.2 Test results

The typical force and velocity waveforms measured at the pile head are plotted in Fig. 2. The results of the piles: without a tip plate, with a 45° inclined plate, and with a 60° inclined plate are shown in Figs. 2(a), 2(b), and 2(c), respectively. As shown in the Fig. 2, the force

and velocity waveforms match at the initial part of the graph because of the proportionality. However, the two waveforms become separated when soil resistance is applied. The reflected waves from the pile toe arrive back at the measuring point at the time of 2L/c = 1. Note that the extent of separation at the point of pile toe refers to the sum of tip resistance and skin friction. The results indicate that the total resistance of the pile with an inclined plate is expected to be larger than that of the pile without a tip plate.

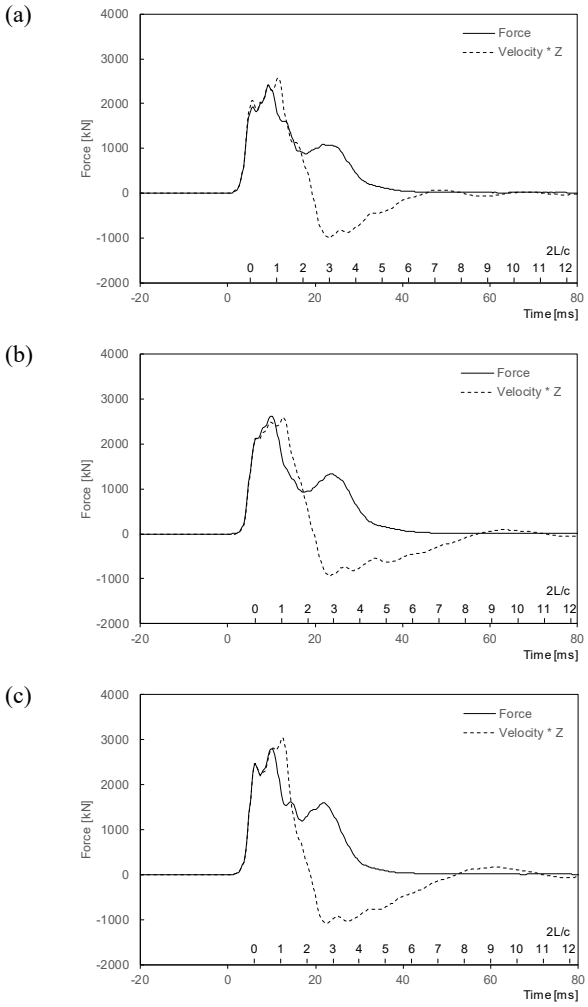

Fig. 2. Force and velocity waveforms measured at the piles: (a) without a tip plate; (b) with a 45° inclined plate; (c) with a 60° inclined plate. Z denotes the impedance of pile.

Force and velocity waveforms measured during dynamic pile tests were analyzed using CAse Pile Wave Analysis Program (CAPWAP), which produces the total resistance versus head settlement, as well as tip resistance versus toe settlement, as shown in Fig. 3. As shown in Fig. 3(a), the head settlement of the pile with an inclined plate is smaller than that of the pile without a tip plate under the fixed head load. In addition, as the inclination angle increases, the settlement decreases. Thus, the total resistance is expected to increase with increases in the inclination angle. Fig. 3(b) shows that the toe settlement of the pile without a tip plate is smaller than that of the pile with an inclined tip plate. The tip resistance is also expected to be larger when the inclination angle is larger.

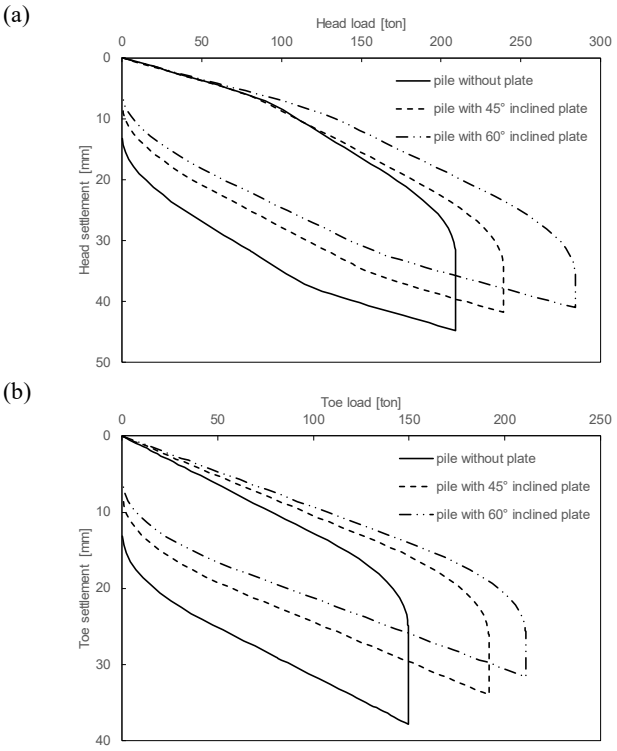

Fig. 3. Load and settlement curves; (a) at pile heads; (b) at pile toes.

The total resistance and tip resistance are estimated using the load and settlement curves shown in Fig. 3. The maximum load at pile head as shown in Fig. 3(a), is the total resistance. Similarly, the tip resistance is determined by the maximum load value in Fig. 3(b). The total and tip resistances are summarized in Table 2 and Table 3, respectively. As shown in Table 2, the total resistance of the pile without a tip plate is 209.3 ton, whereas that of the pile with a 45° inclined plate is 239.2 ton, and that of the pile with a 60° inclined plate is 284.1 ton. The total resistances of the piles with inclined plates are higher than that of the pile without a tip plate. In addition, the total resistances increase with increases in the inclination angle of the tip plates. The increments in the total resistances of the pile with 45° and 60° inclined plate are 14.3 % and 35.7 %, respectively. The tip resistance of the pile without a tip plate, and those of the piles with 45° and 60° inclined plates are 149.7 ton, 191.7 ton, and 211.2 ton, respectively. The tip resistances of the pile with 45° and 60° inclined plates increase by 28.1 % and 41.1 % compared to the pile without a tip plate.

Table 2. Estimated total resistances by dynamic pile tests.

	Total resistance [ton]	Increment [%]

without plate	209.3	-
with 45° inclined plate	239.2	14.3
with 60° inclined plate	284.1	35.7

Table 3. Estimated tip resistances by dynamic pile tests.

	Tip resistance [ton]	Increment [%]
without plate	149.7	-
with 45° inclined plate	191.7	28.1
with 60° inclined plate	211.2	41.1

3 ANALYSES

In this study, the test piles were constructed under the same condition with only the pile tip shape varied. Thus, variations in the total resistance and the tip resistance can be attributed due to the pile tip shape. First, the projected area of the pile with an inclined plate is larger than the pile toe area of the pile without a tip plate. The area of the tip plate is larger than the pile toe area by 25.4 %, assuming that the pile toe had closed end. The unit tip resistances, which are the ratios of the tip resistances to the projected areas, are summarized in Table 4. As the unit tip resistance is the normalized tip resistance by the toe area, the area effect is removed. The unit tip resistance of the pile without a tip plate is 762.4 ton/m^2, whereas that of the pile with a 45° inclined plate is 778.3 ton/m^2, and that of the pile with a 60° inclined plate is 857.5 ton/m^2. The unit tip resistance of the pile with a 45° inclined plate is slightly larger than that of the pile without a tip plate, but that of the pile with a 60° inclined plate is larger by 12.5 %.

Table 4. Calculated unit tip resistances.

	Unit tip resistance [ton/m^2]	Increment [%]
without plate	762.4	-
with 45° inclined plate	778.3	2.1
with 60° inclined plate	857.5	12.5

Second, while the embedded piles were being constructed, pre-boring produced slime (Lee et al., 1995), which is made up of disturbed soil particles. Thus, the slime should be effectively removed. The pile with an inclined plate is expected to be of appropriate shape to get rid of the slime as the inclined plate attached to the pile is shaped like an upturned funnel. The funneled tip is expected to collect the slime more easily than the flat toe. Therefore, the pile with an inclined tip plate easily penetrates through the slime; this effect is greater when the inclination angle is larger.

4 SUMMARIES AND CONCLUSIONS

The pile with an inclined plate is developed in order to increase the tip resistances of the embedded piles. In this study, the pile without a tip plate, that with a 45° inclined plate, and that with a 60° inclined plate were constructed and the dynamic pile tests were conducted. The total and tip resistances of the test piles were evaluated by analyzing the force and velocity waveforms using CAPWAP. The main observations of the study are as follows.

(1) The total resistances of the piles with inclined plates are higher than that of the pile without tip plate. The total resistance of the pile with a 45° inclined plate and that of the pile with a 60° inclined plate are higher than that of the pile without a tip plate by 14.3 % and 35.7 %, respectively.

(2) The tip resistance is higher in the pile with an inclined plate than in the pile without a tip plate. In addition, the tip resistance is higher when the inclination angle is larger. The pile with a 45° inclined plate and the pile with a 60° inclined plate have higher tip resistances of 28.1 % and 41.1 %, respectively. The tip resistances increase with increases in the inclination angle.

(3) The unit tip resistance of the pile without a tip plate is 762.4 ton/m^2, that of the pile with a 45° inclined plate is 778.3 ton/m^2, and that of the pile with a 60° inclined plate is 857.5 ton/m^2. The unit tip resistance of the pile with a 45° inclined plate and that of the pile with a 60° inclined plate increase by 2.1 % and 12.5 %, respectively.

(4) The toe areas of the piles with inclined plates are larger than that of the pile without a tip plate by 25.4 %. The diameter of the inclined plate is 56 cm whereas that of the pile is 50 cm; this larger toe area is expected to produce a higher tip resistance. In addition, the inclined plate easily collects the slime because the shape is like an upturned funnel. Therefore, the pile with inclined plate has a higher tip resistance because the slime is more removed compared to the pile with a flat toe.

5 ACKNOWLEDGEMENTS

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