Experimental study on axial and lateral bearing capacities of non-welded composite piles based on pile load test results

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ABSTRACT
In the presented paper, the axial and lateral behaviors of non-welded composite piles were investigated based on pile load test results. Recently, a composite pile composed of steel pipe and PHC pile was introduced into the market in Korea. A steel pile is placed in the upper part to support lateral loads and a PHC pile is placed in the lower part to resist axial load mainly. A mechanical joint is applied at the interface of the two different materials. This could be more favoured to conventional welding method in terms of cost and time in construction. Dynamic load tests and lateral load tests are performed to evaluate the axial and lateral behaviors of composite pile, respectively. The performance of the composite piles were thought to be satisfactory compared to that of steel pipe and PHC piles with a long history of successful applications. Additionally a new design chart was suggested for the design of non-welded composite pile.

Keywords: Composite pile, non-welded, load test, axial behavior, lateral behavior

1 INTRODUCTION

Recently, the number of large-scaled civil engineering works and skyscraper construction sites has escalated and so has demand for piles that can provide high bearing capacity against axial and lateral loads.

Soil conditions and loads applied to superstructures determine the length of piles used in civil and architectural foundation works. The length tends to be shorter in sites where the soil exhibits high strength and the depth of the support layer is relatively shallow. In contrast, the length tends to be longer in marine environments or in reclaimed sites with weaker soil strength and much deeper support layer.

The majority of the commercially manufactured piles in the market are each limited to approximately 15m maximum in length, due to productivity and transportability concerns. For a site deeper than 15m, therefore, piles should be connected for extension, and the most commonly used method is welding. The technique entails procedural requirements regarding weather conditions, wind-speed, and temperature. The workmanship is also one of the main cause to affect the quality of welding, and subsequently that of the entire piling-installation work. Other shortcomings of the welding approach include a rise in costs and a longer construction period because ultrasonic tests are required upon completion of welding as part of quality tests and detecting significant flaws may be identified at the joints.

In recent years, a growing number of local and international construction sites have been looking into the cheaper, faster and safer alternatives to the conventional pile-connecting method, the most prominent of which being non-welded joint, with aggressive research and development under way (Park et al., 2011; Shin et al., 2014; Shin et al., 2014).

The non-welded pile-connecting method, uses a three-piece side connecting panel and 12 bolts fitting of both the upper pile end and the lower pile top. In such mechanisms, the bending moments and shear stresses from the superstructures are transmitted through the upper pile bottom to the side connecting panel at the joint, which continue to travel down to the lower pile head. However, there are few case histories and research data available for the non-welded pile joint of a composite pile, which necessitates verification through field pile load tests and numerical analysis.

In this study, we analyzed behavior characteristics of non-welding composite piles (NCP) composed of steel pipe piles on top of PHC (pretensioned high spun concrete) piles with applying mechanical joint at the interface of the two different materials of piles. In order to evaluate the axial and lateral behaviors, dynamic load tests and lateral pile load tests are conducted.

2 LOAD TEST DATA

2.1 Site conditions for axial load test

According to the results from our borehole tests and cone penetration tests at the load test site, a silty sand layer was reclaimed on the site up to 1.3~2.3m below the surface, a soft cohesive soil layer (SPT N-value less than 5) existed 18.9~23.5m thick below the landfill layer, and weathered rock layer existed from GL-30.0~31.0m (Figures 1 and 2).

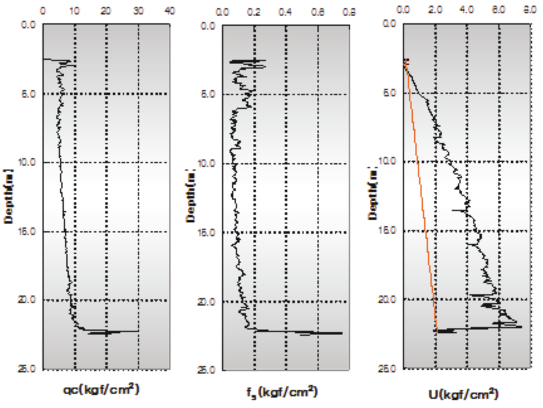

Figure 1 SPT N values of boring holes.

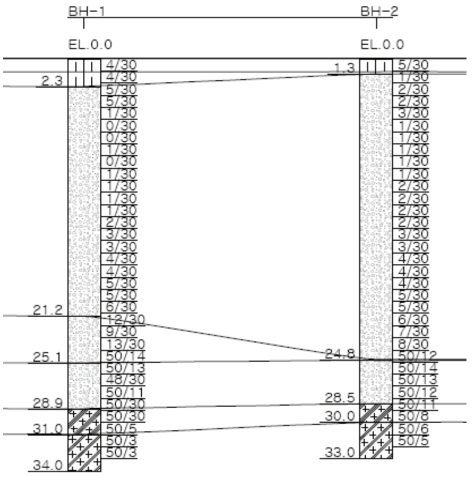

Figure 2 SPT N values of boreholes.

2.2 Site conditions for lateral load test

Field load tests were performed in two sites (Site-A, Site-B) in order to examine the lateral behavior of the NCP and evaluate the stress-transfer effects and structural stability of the joint. For the five composite piles, dynamic load tests were performed by using a PDA (pile driving analyzer). Of the five piles, one was also submitted to axial load tests and three other piles to lateral pile load tests.

The geotechnical investigations were performed in the two pile load testing sites to help examine the soil conditions. Based on the results of the investigations, Table 1 shows the soil profile of each site.

Table 1 Soil conditions at the pile load tests.

Site-A			
Depth(m)	**Soil layer**	**Classification**	**N-value**
0.0~3.9	Fill	Sandy gravel	7~9
3.9~5.1	Residual	Sand	3
5.1~24.8	Residual	Silty clay	2~3
24.8~25.9	WR	Sandy gravel	50/4
25.9~27.0	Soft rock	Rock	RQD:27%

The top-down profile of the soil consisted of the reclaimed layer, the deposits of sand and silty clay, the weathered rock, and the bedrock.

2.3 Load test conditions

We carried out dynamic pile load tests on large-sized (pile diameter =1,000mm) composite piles and PHC piles to analyze (1) drivability of the piles, (2) calculate the axial bearing capacities, and (3) assess the structural safety of mechanical joints.

Each pile had an upper portion made of a steel pipe, 1,000mm in external diameter and 16mm in thickness, and a lower portion comprised of a PHC pile, 1,000mm in external diameter and 140mm in thickness, which were connected by the non-welded pile connecting method.

Dynamic pile load tests used a hydraulic hammer (160kN) and manipulated the stroke between 0.5m and 1.5m.

A total of three medium size (pile diameter = 500mm) non-welded composite piles were used in the lateral pile load tests. Each pile had an upper portion made of a steel pipe, 500mm in external diameter and 12mm in thickness, and a lower portion comprised of a PHC pile, 500mm in external diameter and 80mm in thickness, which were connected by the non-welded pile connecting method.

Table 2 provides the information on the types of the piles used, diameter, and thickness used for axial and lateral load tests.

Table 2 The types and amount of pile load tests.

Pile load Test	Pile No.	Diameter of pile	Thickness of pile
Dynamic	Pile-1	ϕ1000	Steel 16t PHC 140t
	Pile-2		
	Pile-3		
Lateral	Pile-4	ϕ500	Steel 12t PHC 80t
	Pile-5		
	Pile-6		

3 LOAD TEST RESULTS

3.1 Dynamic load test results

Fifteen dynamic pile load tests on large-sized composite piles and PHC piles were performed by using a pile driving analyzer (PDA). For the dynamic pile load tests, we used a 160kN hydraulic hammer and DH 658 pile driver. Bearing capacities and drivabilities of piles and structural safeties of the mechanical joints were assessed and evaluated by dynamic load tests. We implemented the internal excavation construction method (auger device put into pile's inner hole and under-reaming at the bottom of pile) to compare and examine differences between bearing capacities of each construction methods. Dynamic pile load tests were conducted on 3 test piles applying the following conditions summarized in table 2.

3.2 Driveability analysis results

As Pile-1 and Pile-2 were bored piles using the internal excavation construction method, pile driving was carried out at the final process for dynamic load test using PDA. On the other hand, Pile-3 was a driven pile and dynamic load test was performed during pile construction. In order to analyze the difference of bearing capacity according to construction methods, we calculated bearing capacities for the same depth and energy level. Piles built by the internal excavation construction method provided similar values of bearing capacity with driven pile case. The shaft resistance of a pile, therefore, constructed by internal excavation method was seem to be mobilized sufficiently.

Table 3 shows dynamic load test results.

Table 3 Dynamic load test results.

Pile No.	Embedded Depth (GL-m)	Hammer stroke	CSX* (MPa)	CSB* (MPa)	EMX* (kN.m)	RMX* (kN)
Pile-1	32.0	0.7	16.6	6.6	113.3	4,510
	33.0	2.0	33.8	0.0	314.3	4,150
Pile-2	27.5	1.0	1.9	1.1	103.4	4,100
		1.5	2.6	1.4	153.6	4,540
	28.5	0.7	18.9	7.5	98.6	4,130
		1.0	20.0	8.1	117.4	4,520
	29.0	0.5	2.2	1.7	92.7	4,530
		1.0	2.5	2.0	118.6	5,180
		1.5	3.2	2.6	184.2	5,960
Pile-3	32.5	0.5	1.4	1.1	50.4	3,990
		1.0	1.8	1.4	76.5	4,170
		1.5	2.7	1.8	143.0	4,470
	37.5	0.7	2.7	1.7	98.5	9,460
		1.0	3.2	2.5	143.8	10,280
		1.5	3.8	3.6	198.3	11,030

*CSX: Maximum compression stress on gauge
*CSB: Maximum compression stress on bottom
*EMX: Maximum energy
*RMX: Optimal bearing capacity by the case method

3.3 Calculation of allowable bearing capacity from dynamic load test

To calculate allowable bearing capacity through dynamic pile load tests, the Davisson's method (Davisson, 1972) which safety factor of 2.0 is applied to was used to determine yield limit of the total bearing capacity obtained from CAPWAP analysis (Iskander and Stachula, 2002) and the method that safety factor of 2.5 is applied to total bearing capacity obtained from CAPWAP analysis was used (Korean Geotechnical Society, 2008). Pile-1 and Pile-2 constructed by the internal excavation method were bored into the bottom of weathered soil layer and they have allowable bearing capacity of 1,620~3,061kN. However, Pile-3 was driven and socketed into 6.0m of the weathered rock, and calculated the maximum allowable bearing capacity of it reached to 5,660kN. Since these are the results from the EOID (end of initial driving) tests, we believe that much larger allowable bearing capacity may be calculated if the setup effect is mobilized over time on the soft cohesive soil ground. In order to consider how much bearing capacity would increase due to the setup effect, we conducted a restrike test on Pile-1. However use of a drop hammer in a restrike test led to somewhat deteriorated accuracy in comparison with bearing capacity calculated by using a hydraulic hammer.

Table 4 provides calculation results from dynamic load test.

Table 4 Allowable bearing capacity from dynamic load test.

Pile No.	Skin Friction (kN)	End Bearing Capacity (kN)	Total Bearing Capacity (kN)	Allowable Bearing Capacity	
				CAPWAP (S.F=2.5)	Davisson (S.F=2.0)
Pile-1	1,040	3,410	4,450	1,780	2,225
	2,902	3,220	6,122	2,449	3,061
Pile-2	880	3,170	4,050	1,620	2,025
	900	3,630	4,530	1,812	2,265
	900	3,270	4,170	1,660	2,085
	970	3,560	4,530	1,812	2,265
	910	3,639	4,549	1,820	2,275
	1,010	4,190	5,200	2,080	2,600
	1,120	4,980	6,100	2,440	3,050
Pile-3	670	3,260	3,930	1,572	1,965
	730	3,460	4,190	1,676	2,095
	780	3,700	4,480	1,792	2,240
	4,390	5,270	9,660	3,864	4,830
	4,560	5,960	10,520	4,208	5,260
	4,890	6,430	11,320	4,528	5,660

3.4 *Lateral load test results*

At the maximum 300kN lateral pile load, the total pile head displacements of all three test piles were 21.82~31.89mm, while the residual displacements were found to be 5.61~9.74mm. Converting the figures to make comparisons with the displacement criterion of 15.0mm, which is known as the serviceability criteria in Korea (MLTM, 2008) led to the load value of 157.6~223.9kN.

And at the maximum 350kN lateral pile load, the total displacement was 54.53mm, while the residual displacement was found to be 25.77mm. Converting the numbers to make comparisons with the dis-placement criterion of 15.0mm led to the load value of 177.3kN. These load value, which is evaluated as the allowable lateral bearing capacities of NCP's, are larger than the design lateral bearing capacity calculated to 120kN of 500mm diameter steel pile.

Results of the LPILE program (Ensoft, 2004) and the field lateral load tests were compared for the three NCP's. In case of the Pile-4, the displacement was found almost identical at the load point for the lateral load of 100kN. Under lateral loading of 200kN, displacement of 12.1mm took place during the field pile load tests while the number from the LPILE analysis was 14.1mm at the load point.

For the pile-5, displacement of 21.2mm took place during the field pile load tests against lateral load of 200kN, while the number from the LPILE analysis was 14.4mm at the load point. Comparing the data for Pile-4 and Pile-5, the displacement was presumably due to the differences in pile behavior that are associated with specific location of the non-welded joint. The steel portion of Pile-4 was 12.0m in length whereas that of Pile-5 was 6.0m.

For the pile-6, displacement of 11.6mm took place during the field pile load tests while the number from the LPILE analysis was 14.4mm at the load point under lateral loading of 200kN.

The shear stresses caused by the external lateral load at the depth of non-welded joint are calculated to solve the joint stability problem. The non-welded joints are located

GL-3.9~10.0m for the pile-4, 5, and 6. At the non-welded joint, the shear stresses are calculated to 3.4~214.3kN for the lateral load 100~350kN respectively (Figures 3 and 4).

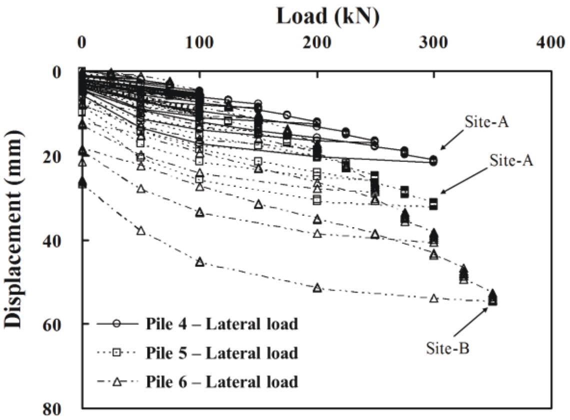

Figure 3 Load-settlement relation of lateral load tests.

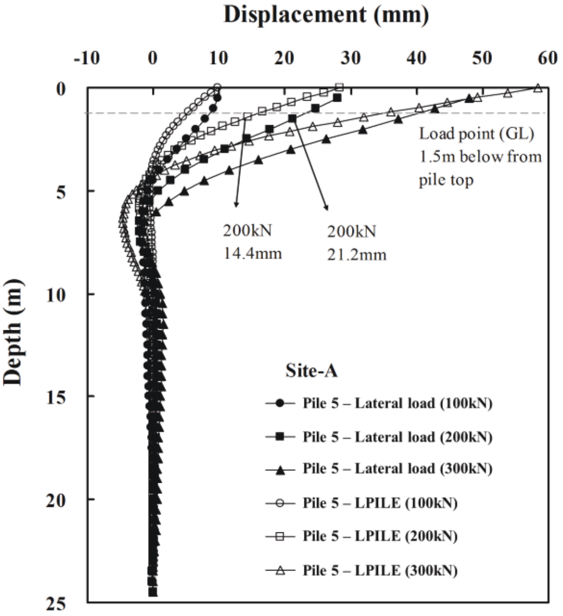

Figure 4 Depth-displacement relation of lateral load tests and comparison with LPILE results at pile-5.

4 CONCLUSION

In this study, we performed the dynamic and lateral pile load tests to evaluate the axial and lateral behaviors of non-welding composite piles composed of steel pipe piles on top of PHC piles.

Based on results from the dynamic pile load tests, drivability was verified as successful without any damage of the piles. From the analysis of differences in bearing capacity by large-sized pile construction method, piles constructed by the internal excavation construction method provided similar values of bearing capacity with driven pile case.

Piles located at the lower end of the weathering soil (Pile-1, 2) showed allowable bearing capacity of up to 3,061kN. Piles socketed into 6.0m of the lower part of the weathered rocks (Pile-3) showed the maximum allowable bearing capacity of approximately 5,660kN.

From the lateral pile load tests, NCP (pile diameter=500mm) showed higher lateral bearing capacities (157~224kN) comparing the design value (120kN) of the same diameter steel pile.

Therefore, it is notable that axial and lateral behaviors of non-welding composite pile ensured the stability of connection part.

5 ACKNOWLEDGEMENT

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