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Effect of Shear Key on the Pile to Pile-cap Connection of Steel Pipe Piles Subjected to Axial Loads

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ABSTRACT

When a pile-cap is loaded, moments and axial loads are transferred to the pile through the connection between the pile and the pile-cap. There is an uncertainly in the magnitude of the loads that the connection experiences due to the inability to effectively monitor the applied force field during the loading period. Although the standard drawing for the pile to pile cap connections is essential and it exists, many pile to pile-cap connection methods have been developed in Korea. It is worrisome that the developers usually omit some of the elements or procedures for pile to pile-cap connection systems to reduce the cost and processing time. As the rapid growth of pile to pile-cap connection field takes place, this trend may result in fraudulent construction practices. Omitting shear keys for the pile to pile-cap connection is one of the critical issues associated with such activities. This study examines the effect of presence of shear keys on the pile to pile-cap connection for steel pipe piles subjected to various axial loads. Full scale tests were conducted. It was found that the presence of the shear keys has a very significant effect on their axial capacity. The load bearing capacity of the specimens with shear keys was about 10 times higher than that of the specimens without shear keys.

1. INTRODUCTION

Many alarming earthquakes have occurred globally over the last two decades. This trend has resulted in an increased demand for performance verification for bridge structures during seismic events. Many research projects have focused on assessing the degree of structural damage especially for the upper structure of the bridges. However, the number of research activities on the pile foundation systems and their response to earthquakes especially for a pile to pile-cap connection remains low. When a pile-cap is loaded, moments and axial loads are transferred to the pile through connection between the pile and pile-cap. There is an uncertainty in magnitude the loads that the connection experiences due to the inability to effectively monitor the applied force field that the connection experiences during loading period.

Although the standard drawing for the pile to pile cap connection is essential and it exists, many pile to pile cap connection methods have been developed in Korea. Until the end of 2014, number of patent registrations were 69 (Fig. 1) and the number of new construction technologies permitted by the Korean government were 8. These new methods were developed to reduce the construction cost and the processing time. It is observed that developers usually omit some elements or procedures on pile to pile-cap connection systems to reduce the cost and time even more. As the rapid growth of pile to pile-cap connection field takes place, this misleading trend may result in development of fraudulent construction practices. Omitting shear keys on pile to pile-cap connection is one of the critical issues associated with such activities. In this study, full scale tests were conducted in order to investigate the effect of existence of shear keys on the load bearing capacity of the pile to pile-cap connection for steel pipe piles subject to various axial loads, .

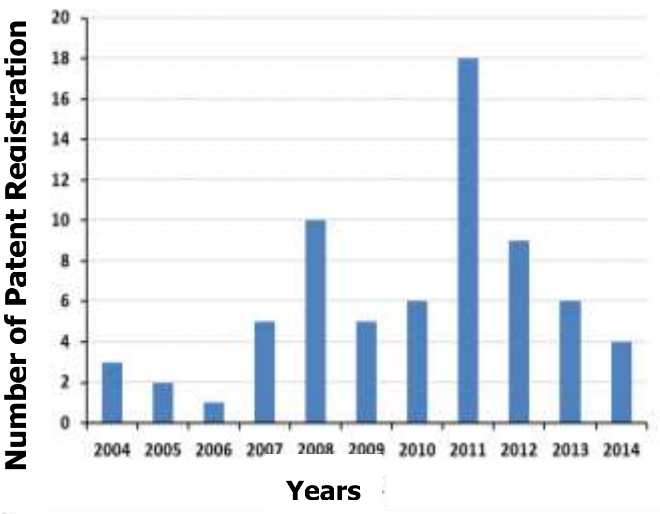


Fig. 1. Number of patent registrations for pile to pile-cap connection

2. TEST PLAN

According to the standard specifications for road bridge construction for pile to pile-cap connection (2008), shear keys on steel pipe piles should be welded to ensure the fixity of the pile and the embedded concrete inside of the piles. Some methods created along with the recent developments in pile to pile-cap connection field in Korea omit shear keys for the convenience of manufacturing. To assert the importance of shear keys for the pile to pile-cap connection, full scale specimens were prepared as summarized in Table 1. The detailed information for this test is available in (Nam et al., 2014).

The specimens were fabricated as shown in Fig. 2-4. Shear keys were welded on the inside of the steel pipe pile for P-1 and T-1 specimens as shown in Fig. 5. P-2 was not welded to any shear key as shown in Fig. 6 in order to compare shear key's effect on the behavior of the pile to pile-cap connection. After welding shear keys, concrete was poured into the steel pipe piles and cured for 28 days. The target compressive strength of the concrete was 27 MPa. Instrumentations including strain gauges, rebar, and concrete were installed to the specimen and their locations are shown in Fig. 2-4.

In order to investigate the effect of existence of shear keys without the pile cap under the axial loading conditions, axial loading was applied on P-1 and P-2 as shown in Fig. 7. Moreover, a pile cap was applied to T-1, as shown in Fig. 8, to identify the effect of existence of shear keys and pile cap under the axial loading conditions. The loading ratio of these tests was standardized as 1.0 mm/min.

Table 1. Test plan

Test No.	Pile Dimension (mm)	Pile Cap	Shear Key	Pile Cap Dimension (mm)
	Diameter × Length			Diameter × Length
P-1	508 × 1270	X	O	
P-2	508 × 1270	X	X	
T-3	508 × 1270	O	O	2.0 × 2.0 × 1.3

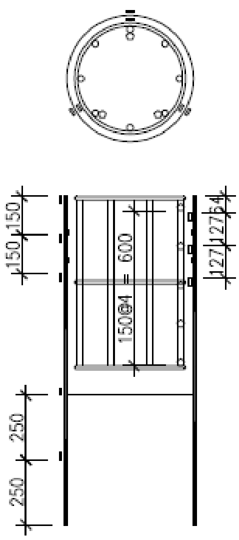


Fig. 2. Drawing of P-1

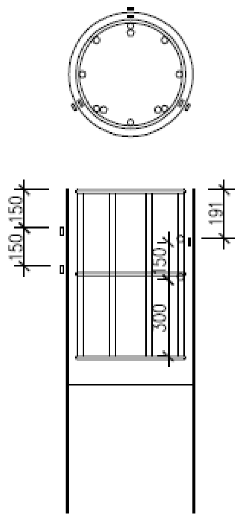


Fig. 3. Drawing of P-2

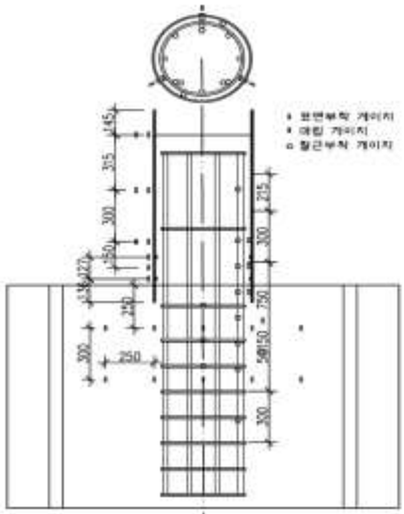


Fig. 4. Drawing of T-1


Fig. 5. Shear keys on pile


Fig. 6. Pile without shear key

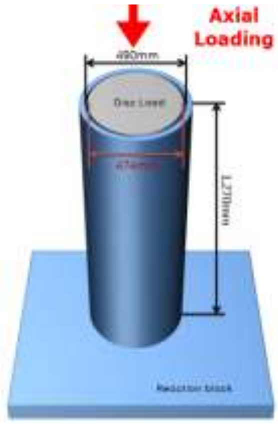


Fig. 7. Schematic of P-1 and P-2

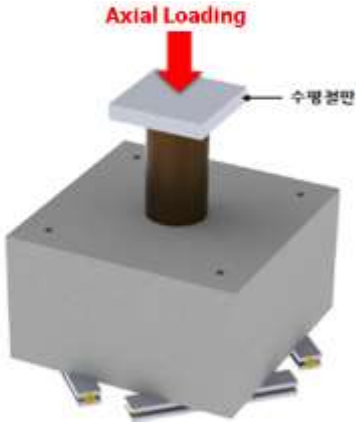


Fig. 8. Schematic of T-1

3. TEST RESULTS

Test results for P-1, P-2, and T-1 are shown in Fig. 9. Maximum axial loads for P-1 and T-1 having shear keys were approximately 3500 kN. Deformation of the in-filled concrete for P-1 and T-1 was not occurred until 3200 kN was reached, which turns out that most axial loads were carried by shear keys. Over 3200 kN, the large deformation of the both specimens were observed as shown in Fig. 10 (a) and (b). The deformation in the steel pile was identified as the dilation caused by the interaction between shear and normal forces due to shear keys as shown in Fig. 11, which was investigated in (Nam et al., 2014). There was no indication for the clear failure of the in-filled concrete except shear failures on grooves made by shear keys as shown in Fig. 10 (a).

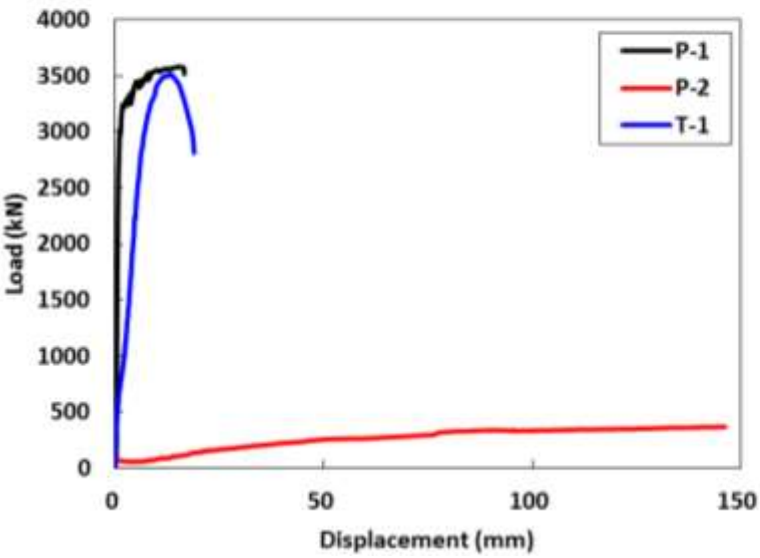
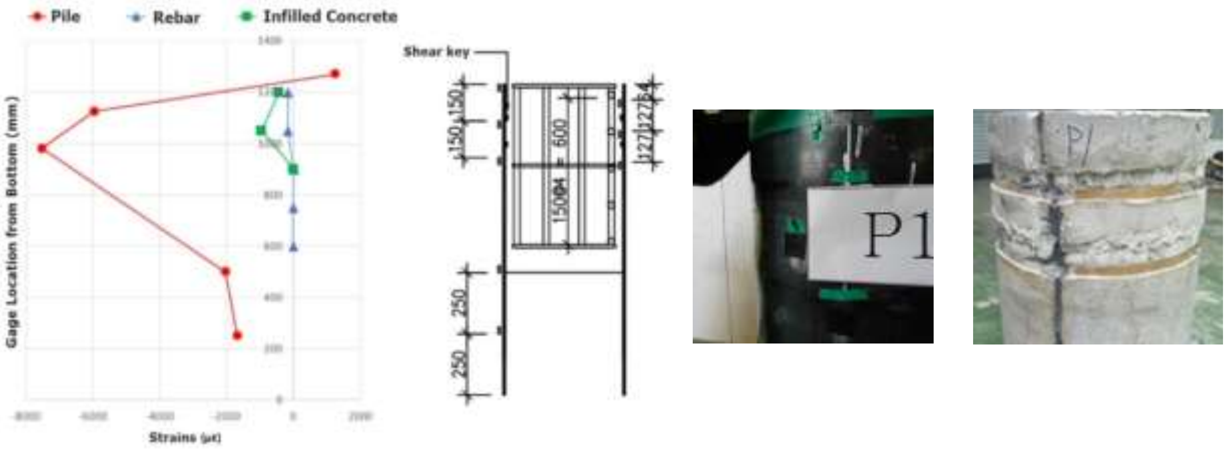


Fig. 9. Test results for P-1, P-2, and T-1



(a) Strains on the element of pile to pile-cap connection (b) Deformation on pile (c) Infilled concrete after testing

Fig. 10. Effect of shear keys subject to axial loading for P-1

The test result of P-2 having no shear key was shown in Fig. 9. Maximum applied axial load was 382 kN, which was only 10% of the maximum load applied for P-1 and T-1. No deformation was observed on the pile to the point at which maximum load was applied. Following this, about 140 mm displacement was occurred by the slip between the infilled concrete and the pile. Soon after the axial loads applied on the P-2 specimen, a chemical adhesion was applied on the interface between the infilled concrete and the pile until 75 kN was reached. After detaching of the chemical adhesion, a frictional force was acting on the interface between the infilled concrete and the pile.

Based on the test results, the presence of the shear keys subjected to the axial loading conditions had an important impact on their capacity. The load capacity of the specimens with shear keys was about 10 times higher than the load capacity of the specimens without shear keys.

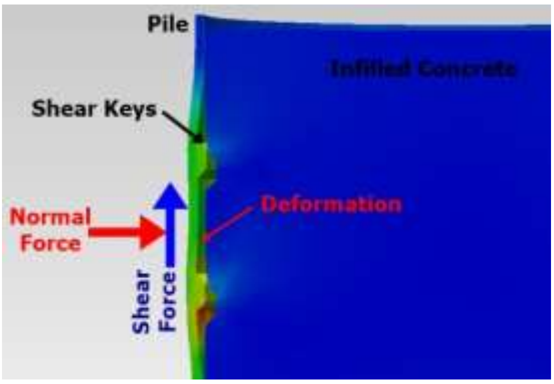


Fig. 11. Deformation developed by shear keys (Nam et al., 2014)

4. CONCLUSIONS

Tests with full scale specimens were conducted to reveal the importance of shear keys for the pile to pile-cap connection. For axial loading conditions, the presence of the shear keys had an important impact on their capacity. The loading capacity of the specimens with shear keys was about 10 times higher than the loading capacity of the specimens without shear keys. Under the applied axial force, the deformation of the steel pile with shear keys was identified as the dilation caused by the interaction between shear force and normal force due to shear keys. Based on the test results, the shear key can be accepted as a key element for the pile to pile-cap connection.

REFERENCES

Korean Society of civil Engineers (2008), "Bridge design standards specification," Korean Society of civil Engineers (in Korean).

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