Testing of pile to pile-cap connection on steel pipe piles subject to axial and uplift loads

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ABSTRACT

Earthquakes have occurred globally over the last two decades, which have resulted in an increased expectation of acceptable performance for bridge structures during seismic events. Many research projects have been performed to assess the degree of structural damage especially upper structure of bridges. However, a few researches are available on the pile foundation systems and their response to earthquakes especially for a pile to pile-cap connection. When a pile-cap is loaded, moment and axial loads are transferred to the pile through the pile to pile-cap connection. There is uncertainly with regards the portion of the loads the connection experiences due to the inability to effectively monitor the forces the connection experiences during loadings. In order to investigate behavior of the pile to pile-cap connection for steel pipe piles subject to axial and uplift loads, full scale tests were conducted, and their key factors were considered from test results.

Keywords: pile to pile cap connection, steel pipe piles, shear keys, infilled concrete

1 INTRODUCTION

Earthquakes have occurred globally over the last two decades, which have resulted in an increased expectation of acceptable performance for bridge structures during seismic events. Many research projects have been performed to assess the degree of structural damage especially upper structure of bridges. However, a few researches are available on the pile foundation systems and their response to earthquakes especially for a pile to pile-cap connection. When a pile-cap is loaded, moment and axial loads are transferred to the pile through the pile to pile-cap connection. There is uncertainly with regards the portion of the loads the connection experiences due to the inability to effectively monitor the forces the connection experiences during loadings. In order to investigate behavior of the pile to pile-cap connection for steel pipe piles subject to axial and uplift loads, full scale tests were conducted, and their key factors were considered from test results.

2. TEST PLAN

In specification for road bridges (2008) on pile to pile-cap connection, shear keys on steel pile piles should be welded for the fixity of the pile and the embedded concrete inside of piles. Since recent developments of pile to pile-cap connection methods have been are evolving day by day in Korea, some methods omit shear keys for the convenience of manufacturing. To figure the importance of shear keys for the pile to pile-cap connection, full scale specimens were prepared as summarized in table 1. The detail information for this test is available in Nam et al. (2014).

Table 1. Test plan

| Test No. | Dimension (mm) | Loading Condition | Shear Key |
|----------|----------------|-------------------|-----------|
| P-1      | 508 × 1270     | Axial             | O         |
| P-2      | 508 × 1270     | Axial             | X         |
| P-3      | 508 × 1270     | Uplift            | O         |
| P-4      | 508 × 1270     | Uplift            | X         |

The specimens were fabricated as designed in figure 1~4. Shear keys were welded on the inside of the steel pipe pile for P-1 and P-3 specimens as shown in figure 5. P-2 and P-4 specimens were not welded any shear key as shown in figure 6 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 until 28 days. The target compressive strength of the concrete was 27 MPa. Instrumentations including strain gages on pile, rebar, and concrete was installed in the specimen and their locations are in figure 1~4.

In order to investigate the effect of existence of shear keys under the axial loading conditions, axial
loading was applied on P-1 and P-2 as shown in figure 7. Also, an uplift loading was applied to P-3 and P-4 as shown in figure 8 to figure out the effect of existence of shear keys under the uplift loading conditions. The loading ratio of these tests was standardized into 1.0 mm/min.

3. TEST RESULTS

The test result of P-1 was shown in figure 9, and its maximum axial load was 3582 kN. The deformation of the infilled concrete was not occurred until 3000 kN, which means most axial load was carried by shear key. Over 3200 kN, the deformation was continuous increased due to the deformation of the steel pile as shown in figure 10 (a) and (b). The deformation of the steel pile was a dilation caused by interaction between shear force and normal force due to shear keys as shown in figure 11. There was not clear failure on the infilled concrete except shear failures on grooves made by shear keys as shown in figure 10 (a).

The test result of P-2 was shown in figure 12, and its maximum axial load was 382 kN, which was 1/10 less than the P-1’s maximum axial load having shear keys. There was no deformation on the pile, and about 140 mm displacement was occurred by slip between the infilled concrete and the pile. As soon as the axial loads applied on the P-2 specimen, only a chemical adhesion was applied on the interface between the infilled concrete and the pile until 75 kN. After detaching of the chemical adhesion, a friction force was action on the interface between the infilled concrete and the pile.

The test result of P-3 was shown in figure 13, and its maximum uplift force was 1450 kN. Only 3 mm deformations were occurred at the top of infilled concrete until reaching the maximum uplift force, and the test was ended up by rupturing at rebar bolted to hydraulic jack to apply the uplift force to the specimen. If there was no rupturing at rebar, the maximum uplift force might be slightly less than the P-1’s maximum uplift force because of hoop stress developed by the steel pipe pile and Poisson effect of the infilled concrete. The strain of rebar in figure 14 (a) was reached to yield condition but strains of the pile and the infilled concrete were in elastic condition still having capability to carry more uplift loads. Especially, the strain of the infilled concrete was in negative, which shows the Poisson effect due to the uplift force. As shown in figure 14 (b), there was not clear failure on the infilled concrete except shear failures on grooves made by shear keys.

The test result of P-4 was shown in figure 15, and its maximum uplift load was 468 kN, which was 1/3 less than the P-3’s maximum uplift load having shear keys. There was no deformation on the pile, and about 65 mm displacement was occurred by slip between the infilled concrete and the pile. As soon as the uplift loads applied on the P-4 specimen, only a chemical adhesion was applied on the interface between the infilled concrete and the pile until 175 kN. The difference of chemical adhesions of P-2 and P-4 was the condition of surface roughness on steel pile piles. After detaching of the chemical adhesion, a friction force was action on the interface between the infilled concrete and the pile.

For axial loading conditions, the presence or
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For uplift loading conditions, the presence or absence of the shear keys had also an important impact on their capacity. The capacity with shear keys was about 3 times higher than the capacity without shear keys. Based on the test results, the shear key is most important element for the pile to pile-cap connection.

Fig. 9. Test results for P-1

(a) Strains on element of pile to pile-cap connection

(b) Deformation on pile

(c) Infilled concrete

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

Fig. 11. Deformation developed by shear keys

Fig. 12. Test results for P-2

Fig. 13. Test results for P-3

(a) Strains on element of pile to pile-cap connection

(b) Infilled concrete

Fig. 14. Effect of shear keys subject to uplift loading for P-3

Fig. 15. Test results for P-4

Fig. 1. Effect of shear keys subject to uplift loading for P-3
4. CONCLUSIONS

To figure the importance of shear keys for the pile to pile-cap connection, full scale specimens were conducted and the conclusions are drawn as follows,

1) For axial loading conditions, the presence or absence of the shear keys had an important impact on their capacity. The capacity with shear keys was about 10 times higher than the capacity without shear keys.

2) For uplift loading conditions, the presence or absence of the shear keys had also an important impact on their capacity. The capacity with shear keys was about 3 times higher than the capacity without shear keys. Based on the test results, the shear key is most important element for the pile to pile-cap connection.

3) Under axial or uplift force, the deformation of the steel pile with shear keys was the dilation caused by interaction between shear force and normal force due to shear keys.

4) If there was no rupturing at rebar, the maximum uplift force might be slightly less than the maximum uplift force because of hoop stress developed by the steel pipe pile and Poisson effect of the infilled concrete. The Poisson effect could perceive through the negative strain in the infilled concrete under uplift loading.

5) The difference of chemical adhesions of P-2 and P-4 was the condition of surface roughness on steel pile piles. After detaching of the chemical adhesion, a friction force was action on the interface between the infilled concrete and the pile.

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