Evaluation of seismic behavior of disconnected pile foundation via dynamic centrifuge tests

Évaluation du comportement sismique des bases de tas déconnectées par des essais de centrifugation dynamiques

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ABSTRACT: Recently the several strong seismic records have been reported that caused structural damage. In order to reduce the damage caused by a severe earthquake, a disconnected pile foundation separating the lower supporting pile and the pile cap has been proposed as the improved foundation concept. In this research, the dynamic centrifuge tests of various foundation-structure systems were carried out to evaluate the seismic behavior of the disconnected pile foundation compared with other foundation types. Shallow foundation and connected pile foundation was used as a comparative model, and the test specimen consisted of a soil, a foundation, and a single degree of freedom structure model. As a result, in the case of the disconnected pile foundation, the rocking behavior of pile cap decreased the seismic load, and the supporting pile decreased the settlement amount. This shows the potential to achieve economical and safe earthquake design using the disconnected pile foundation.

1 INTRODUCTION. FIRST LEVEL HEADING

In recent decades, strong earthquakes with accelerations exceeding the design load occurred worldwide, such as the the Tohoku Earthquake (2011), caused great damage to society and the economy. In the current seismic design method, the nonlinear behavior of the structure is reflected in the design, but it is forbidden on the foundation like the full mobilization of the strength of the soil foundation system. However, in order to prevent serious damage of the superstructure in the event of a strong earthquake it is suitable to enable the nonlinear behavior of the foundation in seismic design.

In nonlinear soil-foundation-structure interactions (SFSI) including sliding and rocking of the foundation, recent research is based on the "rocking foundation" that utilizes the rotational behavior of the shallow foundation (Kim et al. 2015; Gazetas 2015). The concept of rocking foundation is to reduce structural damage during an unexpected strong earthquake. However, the shallow foundation has a serious disadvantage to the large sedimentation of the system. Therefore, it is necessary to compensate for ground subsidence problems of shallow foundation system during strong earthquakes.

On the other hand, the pile foundation is widely used at construction sites and has the advantage of decreasing settlement and increasing bearing capacity to support the system. The interface between the pile and the pile cap is mostly connected to the pile foundation. Then the horizontal shearing force and the overturning moment are large, and there is a problem that a large seismic load is generated at the time of the strong earthquake.

By solving the problems of large settlement of shallow foundation and large seismic load of pile foundation, a disconnected pile foundation which releases the connection between the pile and the pile cap emerges as an innovative alternative. In order to utilize the disconnected pile foundation design concept, it is necessary to understand the seismic behavior of the disconnected pile foundaiton.

In this paper, the seismic behavior of the disconnected pile foundation was investigated by conditions such as the foundation types, the connection of the pile foundation, the stiffness of the interposed layer. The dynamic centrifuge tests for various foundation and structure systems were performed. From the experimental results, the seismic load of the super structure and the settlement of the ground were compared based on the foundation conditions at the time of the initial strong earthquake.

2 CENTRIFUGE TEST SETUP

Using a KAIST beam-type centrifuge, all tests were carried out at the 50 g centrifugal acceleration field reported here. The centrifuge test specimens consisted of a single-degree-of-freedom (SDOF) structure model, a foundation, and subsoil deposits in a model container. For manufacturing the SDOF model, two thin steel plate and a lumped mass were used. The natural period of the structure is about 0.6 sec in the prototype scale. Four types of foundation were selected in these tests; shallow foundation, connected pile foundation and the two disconnected pile foundation with different material of the interposed layer. Except for the connected pile foundation in which the pile and the mat were connected using bolts, three foundation types can easily move horizontally and vertically. The size of the mat (shallow foundation) is 9 cm, 9 cm, and 3 cm for width, length, height in model scale, which corresponds to 4.5 m, 4.5 m, and 1.5 m in the prototype scale. The model pile is 10 mm in outer diameter and has 1 mm thickness. A total of nine piles for each foundation type were used in uniform square arrangement of 3 by 3. The mat and pile foundation is made of aluminum. In case of the disconnected pile foundation model, the backfill material in the interposed layer between the piles and the pile cap can affect the amount of settlement. So, the backfill material was changed with loose sand, small stiff gravels.

The schematic diagram for the centrifuge tests are depicted in Figure 1. For the input motion, the recorded Hachinohe earthquake motion of about 0.3g was applied to the bottom of model container.

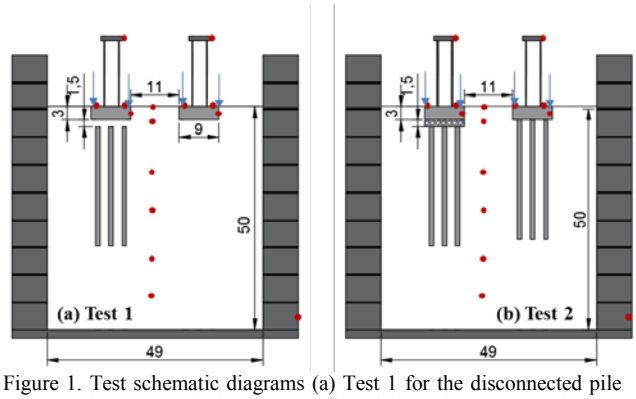

Figure 1. Test schematic diagrams (a) Test 1 for the disconnected pile with sand layer and the shallow foundation (b). Test 2 for the disconnected pile with gravel layer and the connected pile foundation

3 CENTRIFUGET TEST RESULT

3.1 *Seismic load of SDOF structure*

In Figure 2, the net displacement of the SDOF structure on each foundation was compared with the calculated structural displacement based on the fixed base condition using the rcorded free-field motion of soil surface. The difference between flexible and fixed based motion indicates that the influence of SFSI depends on the foundation type. In the case of disconnected pile and shallow foundation (SF, PF-DSS, PF-DSG), the peak of the structural displacement was smaller than 0.15 m, but the peak of the connected pile foundation was as large as the fixed based motion. This result shows that the foundation movement ,in particular the rocking behavior, reduce the structural seismic load on the foundation. It is a similar phenomena as previous work about rocking foundation and disconnected pile foundation (Kim et al., 2015, Allmond et al., 2014).

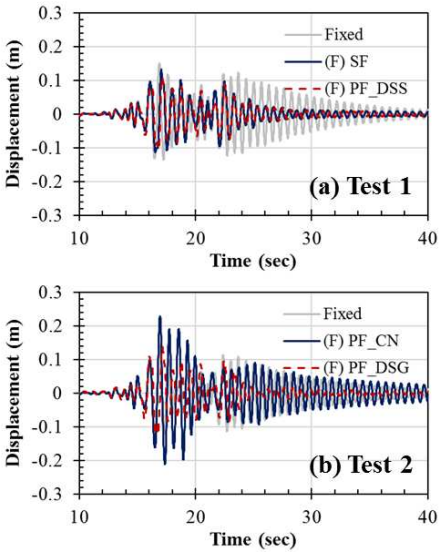

Figure 2. Displacement time history of the fixed and flexible motion for the initial strong earthquake (a) Test 1 (b) Test 2

3.2 *Overturning Moment and Rotation angle*

An overturning moment acting on the bottom of the foundation was calculated from the displacement of the structure and the foundation. Figure 3 shows the hysteresis loop of the foundation rotation angle and overturning moment. When foundation rocking is allowed, the hysteresis loop shows nonlinear behavior with reduced rocking stiffness and increased energy dissipation characteristics. Furthermore, there is no overturning moment greater than about 3000 kNm which is the ultimate moment capacity. However, in the case of connected pile foundation, the overturning moment increases to 7000 kNm and linear behavior is depicted despite strong earthquake input motion.

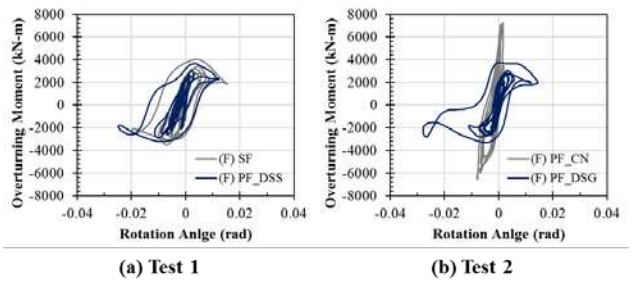

Figure 3. Overturning moment and rotation angle relationship for the initial strong earthquake (a) Test 1 (b) Test 2

3.3 *Foundation settlement and Rotation angle*

The settlement of the foundation is one of the important factor to use the disconnected pile foundation system. The total amount of ground subsidence includes settlement due to subsoil densification and settlement due to foundation rocking. Figure 4 shows the variation of settlement based on the rotation angle of the foundation. Even if the pile was connected to the pile cap, a small settlement occurred due to soil densification. And the largest permanent settlement that exceeds 1% of the foundation width was generated in the case of a shallow foundation. Then, a small settlements were occured in the disconnected pile foundation. These show the potential of the disconnected pile foundation as the improved design method. Furthermore, less settlement of PF-DSG shows that the stiff interposed layer of gravel is more capable for reducing the settlement.

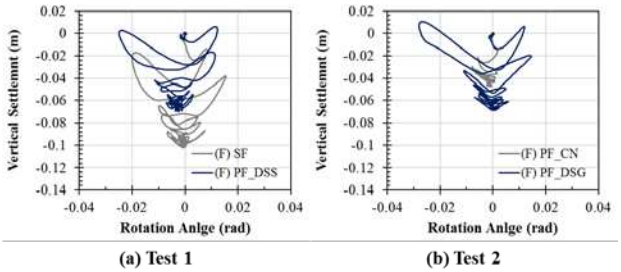

Figure 4 Settlements and rotation angle of foundation for the initial strong earthquake (a) Test 1 (b) Test 2

4 CONCLUSION

A series of dynamic centrifuge model tests were conducted to evaluate the seismic behavior of the disconnected pile foundation. The results provide some important observations and conclusions. In comparison between the fixed and flexible based motion, the seismic load decreases if the foundation rocking is permitted like a disconnected pile or a shallow foundation. And the relationship between the overturning moment and the rotation angle was investigated in the viewpoint of the rocking behavior and the ultimate moment capacity. In addition, the small settlement of disconnected pile foundation during strong earthquake show the capability of disconnected pile foundation as improved design method with small seismic load

3 ACKNOWLEDGEMENTS

The experiments were carried out in KOCED Geo-Centrifuge Facility using KREONET. And this work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF-2015R1A2A1A15054531).

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