Numerical Investigation of Dynamic Centrifuge Tests on Disconnected Piled Raft Foundation

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ABSTRACT: To accurately evaluate the soil–structure interaction behavior of disconnected piled raft foundation (DPRF), both physical and numerical modelling are required due to the inherent uncertainty and complicated engineering characteristics of soil. Centrifuge model tests are widely recognized as an efficient experimental method for simulating real geotechnical phenomena, as it can replicate in-situ confined stress conditions more effectively than other methods such as 1g shaking table tests. However, dynamic centrifuge modelling also has inherent limitations as a form of physical modelling. To complement the results of dynamic centrifuge model test of DPRF, FEM-based numerical simulations using LS-DYNA were performed. The results from numerical analysis and centrifuge tests were compared in terms of natural frequency, peak ground acceleration (PGA), settlement, and bending moment. The findings suggest that, considering the strengths and limitations of each method, both dynamic centrifuge testing and numerical simulations should be used complementarily for the reliable evaluation of DPRF's dynamic behavior.

1 INTRODUCTION

Disconnected piled raft foundation (DPRF) is a design approach that mobilizes yielding behavior and controls the residual deformation of the soil–foundation system during earthquakes by installing disconnected piles beneath a shallow foundation. The dynamic behavior of DPRF was examined through centrifuge model tests (Ko et al., 2019), and it provided reasonable findings. These tests measured the dynamic behavior of the DPRF by applying input motions in a sequence of gradually increasing intensity. However, the influence of such staged excitations is usually ignored due to time and cost constraints. It may lead to overestimate or underestimate the seismic performance of the DPRF during earthquakes.

To identify the effects of staged dynamic excitation on the DPRF during the centrifuge test, numerical analyses were performed. The centrifuge model of the DPRF was numerically modelled, and the dynamic behavior was evaluated by applying gradually increasing staged input motions.

By comparing both the centrifuge test and numerical analysis results, the validity of the numerical model was verified. The dynamic characteristics of the DPRF and the effects of dynamic excitations were evaluated.

2 NUMERICAL MODELING

A three-dimensional general-purpose finite element program, LS-DYNA, was used for the time-history analyses. This program is an explicit dynamic code that operates in the time domain and incorporates both structural and soil non-linearity, and it is widely used for solving dynamic soil–structure interaction (SSI) problems. All finite element models of DPRF in this study were modelled at prototype scale based on the virtual prototype used for centrifuge tests (Ko et al., 2019).

2.1 Superstructure modelling

The dynamic behavior of the structure is predominantly governed by its frequency characteristics. The target frequency of the FE model was set to 1.2 Hz, consistent with the fundamental frequency of the prototype and the model scale of the DPRF centrifuge tests. The superstructure was modeled as an SDOF column with a height of 9 m and a lumped mass, considering the mass participation ratio. For computational efficiency, one-dimensional beam elements were used, and the base of the SDOF column was fully fixed. Modal analysis confirmed a fundamental frequency of approximately 1.24 Hz, which is close to the target value.

2.2 Soil domain modelling

The soil profile consists of 24 m of dry silica sand overlain by a 1 m gravel LTP layer. The mechanical properties of dry silica sand were determined from a previous study (Kim et al., 2015), and representative gravel properties were used for the LTP layer. The shear wave velocities of sand and gravel were assumed to be 180 m/s. Modulus-reduction curves for dry sand and gravel were adopted from the literature for cohesionless soils.

The soil elements consist of 8-node solid elements, and *MAT_HYSTERETIC_SOIL was used as the soil constitutive model. This model captures hysteretic soil behavior under cyclic loading, where energy dissipation is represented by the area enclosed by the shear stress–strain hysteresis loop (Bolisetti et al., 2020).

The pile group consists of 3 by 3 friction piles with a length of 20 m, and the raft dimensions are 7.5 m × 7.5 m × 2 m (length × width × thickness). The LTP layer was inserted between the soil layer and the raft. Non-reflecting boundary conditions were assigned at the base soil to represent an infinite half-space condition and prevent wave reflections. The numerical model of the DPRF and the soil domain used in this study is shown in Fig. 1.

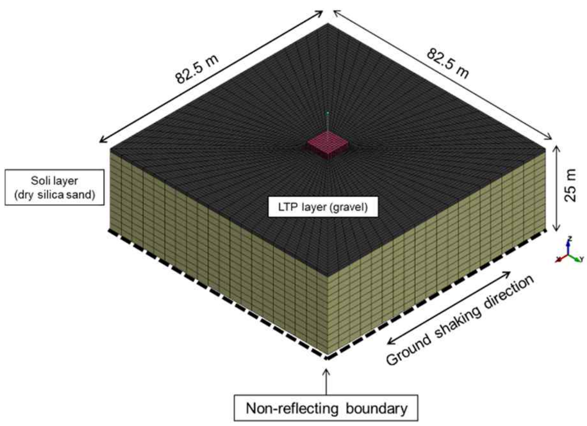

Figure 1. Numerical model of DPRF in LS-DYNA.

3 DYNAMIC ANALYSIS

Two earthquake records, Ofunato and Hachinohe, were used as input motions for the time-history analyses. The analyses were performed after the kinetic energy of the FE model reached a static equilibrium state. Each input motion was applied under two conditions: an original level and staged levels with gradually increasing intensity to investigate excitation effects. In this work, only the results from the Hachinohe earthquake in the FE model are presented.

Figure 2 shows the difference in acceleration time histories at the top of the SDOF column between the original and staged inputs. The peak acceleration for the staged input motion slightly increases compared to the original input motions. The results are approximately 20 percent smaller than the peak acceleration of 1.8 g reported in the centrifuge tests. These tendencies suggest that staged input motions may reduce shear strength as the intensity increases to the original level during centrifuge tests.

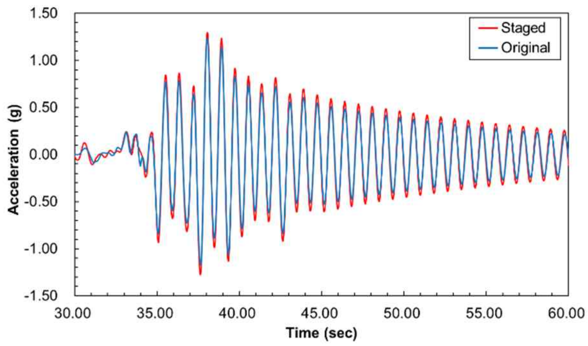

Figure 2. Comparison of acceleration time-histories between original and staged input motions.

4 CONCLUSIONS

In this simulation, staged input motions produce higher responses than original-level inputs, suggesting possible shear strength reduction under staged dynamic excitation. Staged inputs may therefore be useful for capturing conservative responses or cumulative degradation effects, whereas original-level inputs may be sufficient for simplified or time-efficient analyses. Accordingly, the choice between staged and original input motions should be made based on the objectives of the analysis.

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