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Frequency based analysis of Piled-Raft foundation during an earthquake: Centrifuge Modeling and Numerical Investigations

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1. Introduction

Soil liquefaction has resulted in the damage of many pile-supported structures during the past earthquakes. A number of such case studies of pile-related failure has been documented during the 1995 Kobe earthquake [1-3]. Pile foundations are subjected to lateral kinematic and inertial loading generated during an earthquake shaking event. The kinematic interactions may be significant depending on the extend of lateral soil deformations under strong earthquakes and might be a dominating factor post-shaking leading to the collapse of a pile-supported structure.

2. Novelty of the present Research

Though most of the past research is focused on the performance of pile foundation in liquefied soils during an earthquake, there has been no research, carried out on the performance of piled-raft foundation in liquefied soil under large deformations. Kinematic interactions would be different depending whether the soil-pile interaction takes place in plain horizontal (cyclic deformations) or sloped liquefiable deposits (large monotonic permanent lateral displacements) as shown in Fig. 1.

where, k is the initial stiffness of the soil model and β is the degree of reduction in stiffness due to liquefaction and subsequent non-linear behavior.

(a) Before earthquake induced soil liquefaction,

$K_1 = K_2$ because β is 0

(b) After earthquake induced soil liquefaction,

Because of the build-up of excess pore pressure and due to the fact that large lateral monotonic displacements are induced in the sloping ground, whereas which are cyclic in nature in a normal plain ground, the resulting kinematic interactions would be different among both the cases. Hence, $\beta_1 \neq \beta_2 \neq 0$ resulting in $K_1 \neq K_2$.

However, such uniform soil deposits are not usually encountered in a real-in-situ conditions, a more complicated case arises for a soil deposit comprising of multiple soil layers having distinct stiffness. This is described in Fig. 2 (a) and 2 (b). In this case, the soil stiffness's are different among the soil layers before the occurrence of liquefaction. It is evident from the case histories that significant lateral forces are generated at the interface between soil layers having contrasting stiffness [3]. Note that reduction in stiffness due to the generation of excess pore pressure is different depending on the initial strength of corresponding layer.

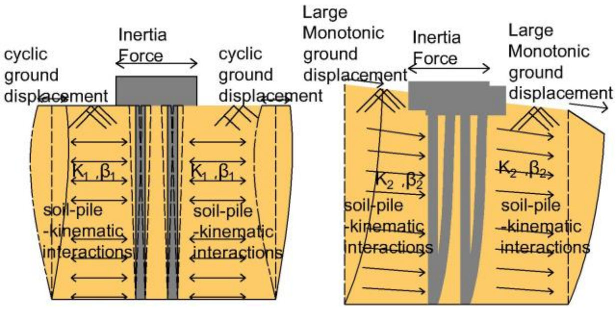

Fig.1. Soil-pile model for a uniform loose sand (a)Plain Model (b)Sloped ground

3. Development of the Novel Dynamic Centrifuge Models

Dynamic centrifuge models were developed at the Disaster Prevention Research Institute (Kyoto University). The beam-type centrifuge has an effective radius of 2.5 m (payload capacity of 24 g-ton) with a maximum reachable centrifugal acceleration of 50G for dynamic tests and 200G for static tests. The models were developed to study the soil-pile kinematic interactions, soil-pile-raft interactions and soil-pile-raft-superstructure interactions. The adopted superstructure is a MDOF structure.

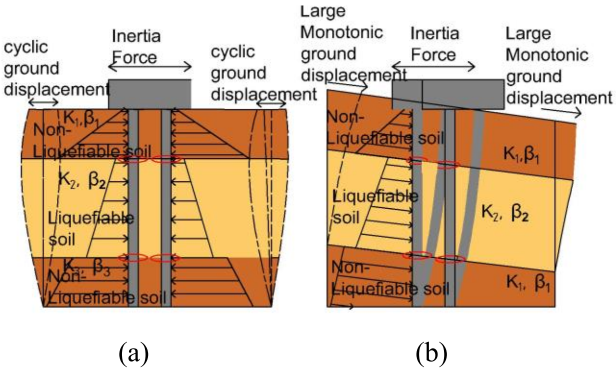

Fig.2. Soil-pile model for a 3-layered soil model (a)Plain Model (b)Sloped ground

In order to represent in-situ dynamic stresses and strains prevailing in the free field, a laminar box comprising of 20 aluminum made rings having comparatively smaller stiffness as compared to the stiffness of the liquefied soil is used for the present research work. The laminar box mounted on the shake table before the spin-up is shown in Fig. 3

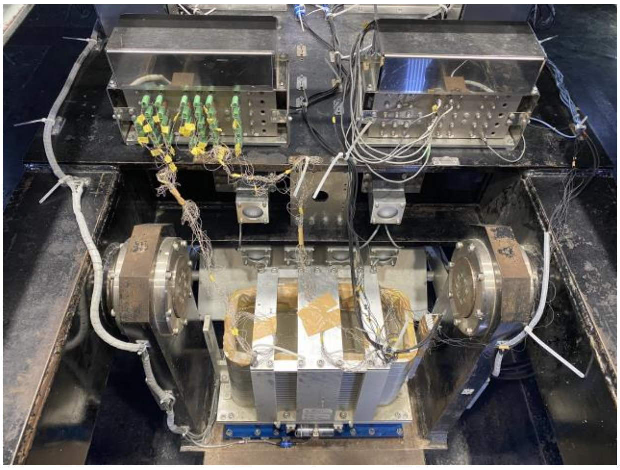

Fig.3. Soil-Model with the sensors mounted on the shake-table in geotechnical centrifuge

4. Earthquake Suite selection

All the models were subjected to a suite of four horizontal earthquake motions. The four motions were selected in order to study the soil-pile-structure response for a vast range of excitation frequencies and the energy associated with the earthquake. Fig. 4 shows the spectral response at the shake-table for the 4 motions.

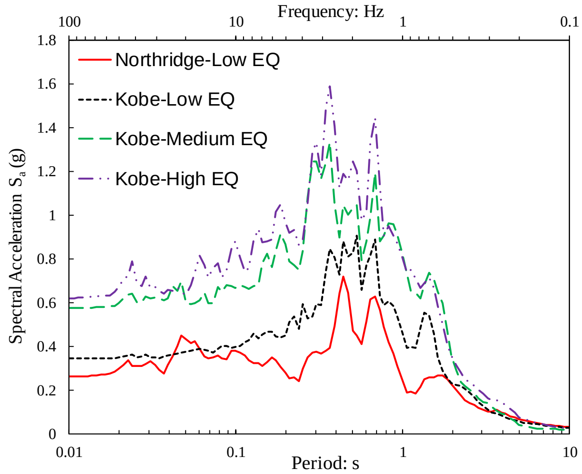

Fig.4. Spectral Response of the selected earthquakes

5. Results and Discussions

The results are presented in terms of excess pore pressure generated during an earthquake, frequency based analysis in terms of spectral response and time-domain (continuous window) frequency wavelets. A failure mechanism is discussed for the soil-pile-structure system based on the dynamic centrifuge tests. Moreover, an attempt has been made to study the coupling behavior under kinematic and inertial interactions.

References

1. Tokimatsu, K., Mizuno, H., and Kakurai, M. (1996): Building damage associated with geotechnical problems, *Soils and Foundations,* 219-234.

2. Karube, D., and Kimura, M. (1996): Damage to foundations of railway structures, *Soils and Foundations,* 201-210.

3. Tokimatsu, K., and Asaka, Y. (1998): Effects of liquefaction-induced ground displacements on pile performance in the 1995 Hyogoken-Nambu earthquake, *Soils and Foundations,* 163-177.