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Effect of super-structure frequency on the seismic behavior of pile-raft foundation using physical modeling

Mohammad Hassan Baziar[a,*], Fahime Rafiee[a], Alireza Saeedi Azizkandi[a], Chung Jung Lee[b]

[a] School of Civil Engineering, Iran University of Science and Technology, Tehran, Iran
[b] Department of Civil Engineering, National Central University, Taoyuan, Chungli, Taiwan

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ABSTRACT

This paper presents the results of two physical test series, including shaking table and centrifuge modeling, on two super-structures with different frequencies and supported by piled raft foundations in a dry sand bed. While the height and weight of two super-structures were kept constant, the axial force and bending moment of piles, as well as horizontal displacement of super-structures were recorded during seismic loadings. The input seismic loadings were given different amplitudes and frequencies. The shaking table and the centrifuge test results indicated that the super-structure frequency strongly affected the pile-raft system responses. Based on the centrifuge test results, the super-structure had larger horizontal displacement, when the excitation frequency was close to system frequency with low base acceleration (0.14 g), while subsequently, axial force and bending moment of piles increased. In high input base acceleration (0.4 g), excitation frequency dominated the super-structure response, and larger responses occurred at smaller (1 Hz) input excitation frequency.

1. Introduction

A building, which is designed to rest on the piled raft foundation, is often analyzed according to its super-structure and foundation independently. The internal forces of each column (axial forces, bending moments and torsions) are calculated through structural analysis based on specifications of the super-structure alone (such as mass, height, stiffness and natural frequency), and the associated reactions are applied to the foundation. Therefore, the piled raft foundation system is designed based on forces that are calculated according to the properties of the super-structure. While the super-structure is attached to the foundation and the soil, the natural frequency of the whole system depends on the super-structure, piled raft foundation and soil properties.

Building codes are made to estimate structure frequency based on their types. For instance, in ASCE [1], the approximate fundamental period of a super-structure, T_a, is determined from: $T_a = C_t.\ (h_n)^x$, where h_n is the structural height and the coefficients C_t and x are based on the lateral resistance method, exerted in the structure (refer to ASCE 7–10). In other words, two steel buildings of the same height (for example, 32 m), but different frames: moment-resisting frames and the buckling-restrained braced frames, have different natural periods, as expressed in the following:

Moment − resisting frame:
$C_t = 0.0724,\ x = 0.8 \Rightarrow T_a = 1.16Hz$

Buckling − restrained braced frame:
$C_t = 0.0731,\ x = 0.75 \Rightarrow T_a = 0.98Hz$

As indicated above, two buildings of the same height, yet different lateral resisting systems result in a rough 20% difference in natural frequencies.

As noted previously and also presented by the codes, the two parameters of height and weight of the super-structure and the structure stiffness affect the natural frequency of the super-structure. Accordingly, the above mentioned two buildings may act differently with their foundations and cause different forces and bending moments along the pile foundation.

The aim of this research is to investigate the interactions between super-structure frequency and axial force and bending moment of the piled raft foundation produced by seismic shaking. For this purpose, two physical models, including shaking table and centrifuge test, were conducted to analyze the super-structure frequency effects on the axial force and bending moment of the piled raft foundation.

2. Previous works

Piled raft systems have attracted attention of design engineers due

* Corresponding author.
E-mail address: baziar@iust.ac.ir (M.H. Baziar).

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Table 1
Physical properties of the Firoozkuh Sand.

Sand	G_s	D_{50}	C_u	e_{min}	e_{max}	Dr (%)	Mass density, ρ (gr/cm^3)	Young Modulus, Es (MPa)	Friction angle, ϕ (deg)
Firoozkuh	2.658	0.3	1.54	0.60	0.94	60	1.55	32	33

Table 2
Model specifications for 1 g shaking table tests.

	Properties	Model
Pile	Material	Aluminum
	Diameter	5 (cm)
	Length	70 (cm)
	Number	4
Raft	Material	Aluminum
	Width × Length	50 (cm) × 50 (cm)
	Thickness	10 (cm)
Lumped Mass	Material	Steel
	Mass	27.3 (kg)
	Width × Length	0.2 (m) × 0.2 (m)
	Thickness	0.1 (m)
Column	Material	Steel
	Length	0.5 (m)
Solid Column	Diameter	0.05 (m)
	Frequency	7 (Hz)
Hollow Column	Out Diameter	0.05 (m)
	In Diameter	0.0486 (m)
	Frequency	4 (Hz)

to the contribution of raft for transferring load to the ground. Experimental and numerical investigations have been conducted to study both load sharing between piles and raft and pile behavior under static loading [2–5] and seismic loading [6–9]. The seismic design procedure of the piled raft system is complex due to kinematic interaction among the raft, piles and soil and non-linear behavior of soil under strong earthquake action [10]. The design procedure becomes even more complicated if the interaction between super-structure and piled raft system is also considered.

Only in the recent years, the effects of super-structure on seismic behavior of piled raft system has been the focus of a few researchers.

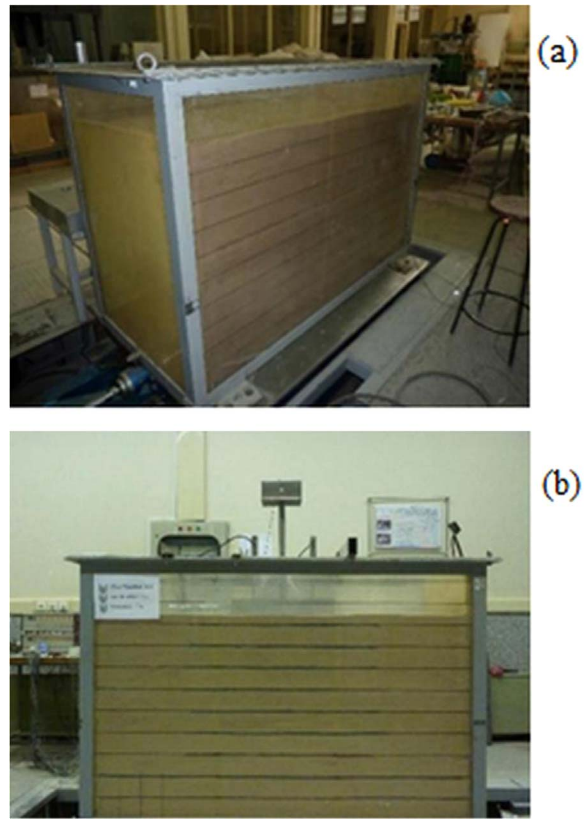

Fig. 2. The physical model on UT shaking table: (a) piled raft (side view) (b) piled raft with structure (side view).

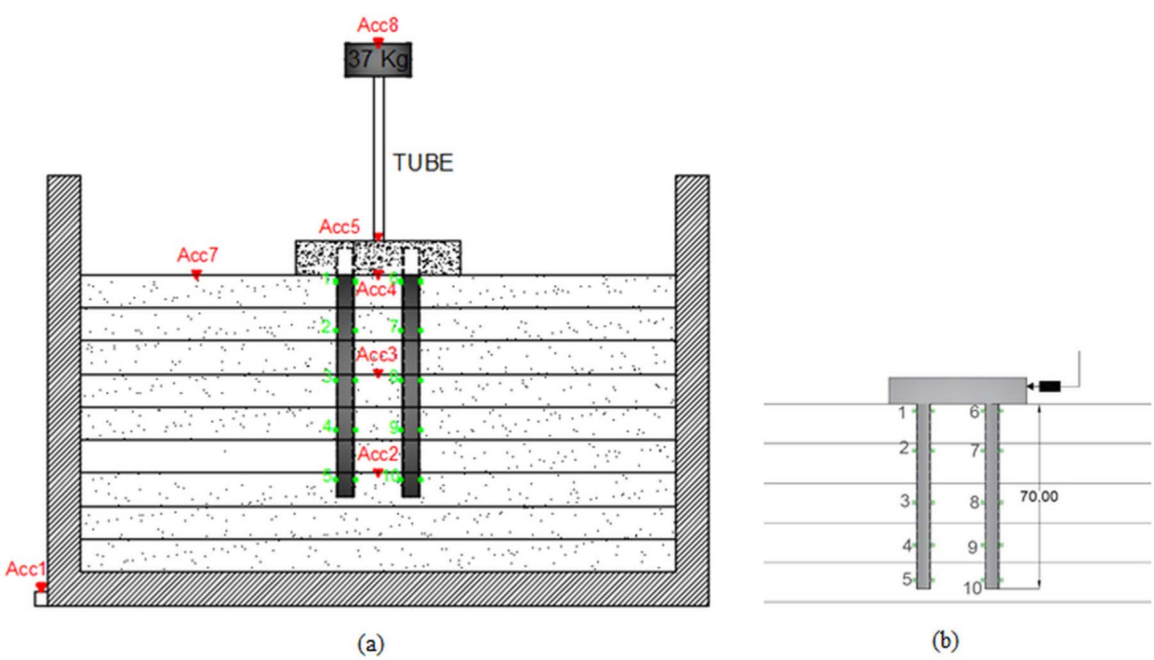

Fig. 1. Schematic diagram of the model, LVDT sensors and strain gauges (a) in the box and (b) along the piles.