DYNAMIC BEHAVIOR OF BRIDGE FOUNDATION DURING LIQUEFACTION BY SHAKING TABLE TEST

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1. INTRODUCTION

Many extensive damages to piles and other structures in areas of liquefaction has been observed in 1995 Hyogken-nambu earthquake. Some of them are failures of piles near the bottom of liquefied layer was caused by kinematic force from its lateral movement, some cases are pile failures near the pile head was likely influenced by inertial force from superstructure and others are failures caused by both kinematic and inertial force. Therefore, this research aims to study the behavior of soil-pile foundation and their effect on superstructure performance to liquefaction. 1-G shaking table test with scaling 1:60 was conducted in this study. 2-D numerical modeling was also applied by an effective stress analysis that was employed on a multi-spring model.

2. SHAKING TABLE TEST

Physical model

The prototype of model is tower-steel pipe pile foundation MP4 of a new project. The pier of physical model consists of four steel columns that rigid together by steel plate at the top with its weight of 60 kg. Each column has cross section in tubular shape of 2.27 cm diameter and 0.19 cm thickness. The foundation is a caisson made of acrylic material with dimension of 49 cm width, 60.8 cm length and 83.4cm height. The cap at the top of foundation is an acrylic plate with 60.8 cm length, 49 cm width and 98 cm thickness. The ground in the models consisted of a 48.8 cm liquefiable sand layer with a relative density of 50 % overlying a 74.3 cm non-liquefiable layer with a relative density of 90 % using Soma-sand No. 5 (D_{50} = 0.3 mm) and the rubble layer used Grade 6 crushed stone with a particle size of 13-20 mm..

Instrument and arrangement

The accelerometers and pore pressure transducers were arranged in area of near field and far field of ground at various depths of liquefied layer and non-liquefied layer. There were two horizontal laser displacement transducers and accelerometers at the top and the bottom of pier and two vertical displacement transducers were at the bottom of pier. The strain gauges were installed along the foundation to record bending strains. Detail of physical model, the instruments and their arrangement are shown in **Fig. 1**.

Base excitation

The model was shaken with base harmonic acceleration with a constant frequency of 10 Hz in horizontal direction. It was increased amplitude step by step from 50 gal, 75 gal, 100 gal, 200 gal, 300 gal, 400 gal and 500 gal. Duration of excitation was 30 s for each case.

3. CALCULATION MODEL

The nonlinear dynamic analysis was conducted by FLIP program. The boundary at the bottom of model was fixed in the vertical and horizontal direction and lateral boundary was fixed in the horizontal direction. The piles, pier columns and acrylic plate at the top of pier were modeled as elastic beam elements. The steel footing plate and the acrylic cap of piles were modeled as elastic strain plane elements. In the effective stress analysis, the soil was considered as strain plain elements using a multi-spring model. The numerical integration was done by Wilson-θ method with θ=1.4. Rayleigh damping with parameters α=0 and β =0.002 was adopted to ensure numerical stability of the analysis.

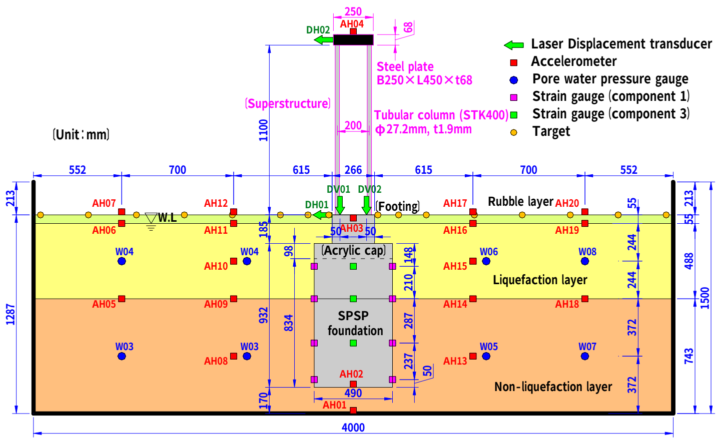

Fig-1 Physical model and instrument arrangements

Table-1 List of soil parameters

	Parameter	Symbol	Liquefaction layer	Non-Liquefaction layer	Rubble layer
Parameters for deformation characteristics	Wet unit weight	ρ (t/m3)	1.96	2.05	1.37
	Initial shear modulus	G_{ma} (Kpa)	3,866	21,788	2,99
	Initial bulk modulus	K_{ma} (Kpa)	10,083	56,819	7,8
	Standard confining pressure	σ_{ma}' (kPa)	2.27	6.85	0.28
	Poisson's ratio	ν	0.33	0.33	0.33
	Internal friction angle	ϕ_f (degree)	36.55	42.8	41.6
	Hysteretic damping ratio	h_{max}	0.24	0.24	0.24
Parameters for dilatancy characteristics	Phase transformation angle	ϕ_p(degree)	28	-	-
		w_1	8.2	-	-
		p_1	0.45	-	-
		p_2	1.07	-	-
		c_1	4.48	-	-
		S_1	0.005	-	-

Keywords: Bridge foundation, Shaking table test, Effective stress analysis, Liquefaction.
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4. RESULTS AND DISSCUSIONS

Liquefaction of ground

The **Fig-2** illustrates the result of the pore water pressure and acceleration responses of ground when liquefaction occurred. There was a good agreement between the experimental result and analysis result. Based on the measured coordination data of points on the surface of ground and the dissipation of pore water pressure of W2, W4, W6 and W8 point, the movement of liquefaction soil layer was in the direction from W2 to W8. Along with that, the excess pore water pressure generated faster following this direction. Therefore, the generation rate of pore water pressure in near field and far field depends on the movement direction of liquefaction layer. In case of 100gal when the EPWP ratio was small the amplitude of horizontal acceleration almost did not change during excitation time. However, in case of 300gal when EPWP ratio was large acceleration amplitude reduced gradually.

Behavior of superstructure and foundation

The **Fig-3** shows the displacement and acceleration response of superstructure and foundation in cases of 100gal and 300gal. There was a good agreement between experiment and analysis result. To express the behavior of foundation and effect of superstructure on foundation, the influence factor δ was calculated as follows:

$$\delta = abs\left(\frac{Response\ of\ superstructure - Response\ at\ the\ top\ of\ foundation}{Response\ of\ superstructure}\right)$$

The result of influence factor in **Fig-4** shows that the factor from 50 gal to 200 gal was large and from 200 gal to 500 gal, the factor was small and almost was not change in case of acceleration. It means that in cases from 50 gal to 200 gal the effect of superstructure on foundation was significant and the inertial force took advantage. Conversely, in cases from 200 gal to 500 gal the response of superstructure and foundation is almost same. The response of foundation almost depends on the kinematic force.

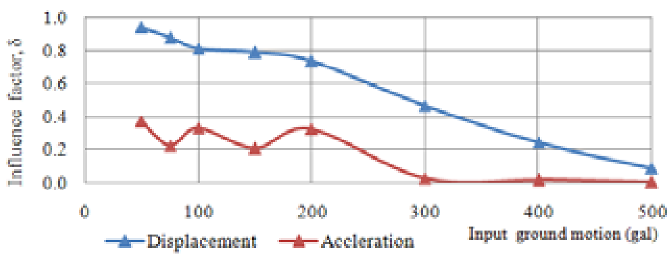

Fig-4 Influence factor of displacement and acceleration

5. CONCLUSIONS

The main findings are as following:

1. There is a good agreement between the experiment result and the analysis result.
2. In this study, from 50 gal to 200 gal input ground motion the effect of superstructure on the behavior of foundation significantly. From 200 gal to 500 gal, the effect of superstructure is not so much significant on foundation.

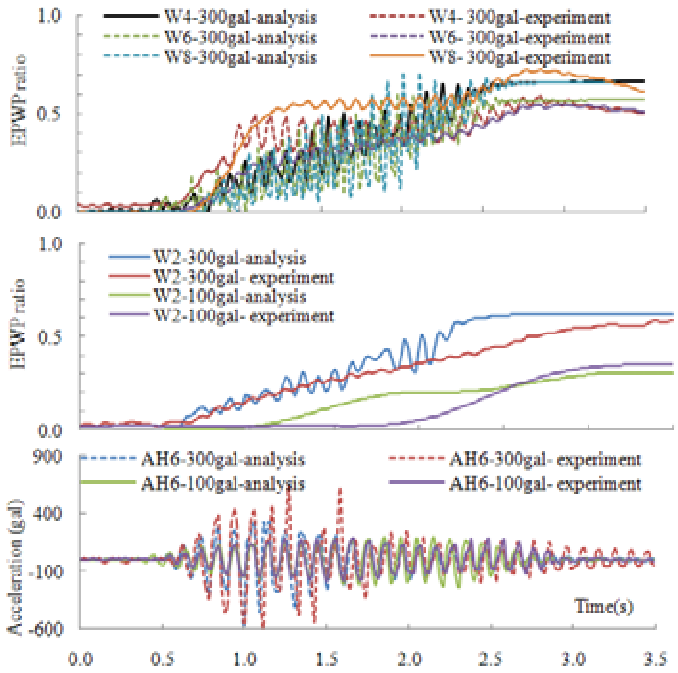

Fig-2 EPWP ratio and acceleration response of ground

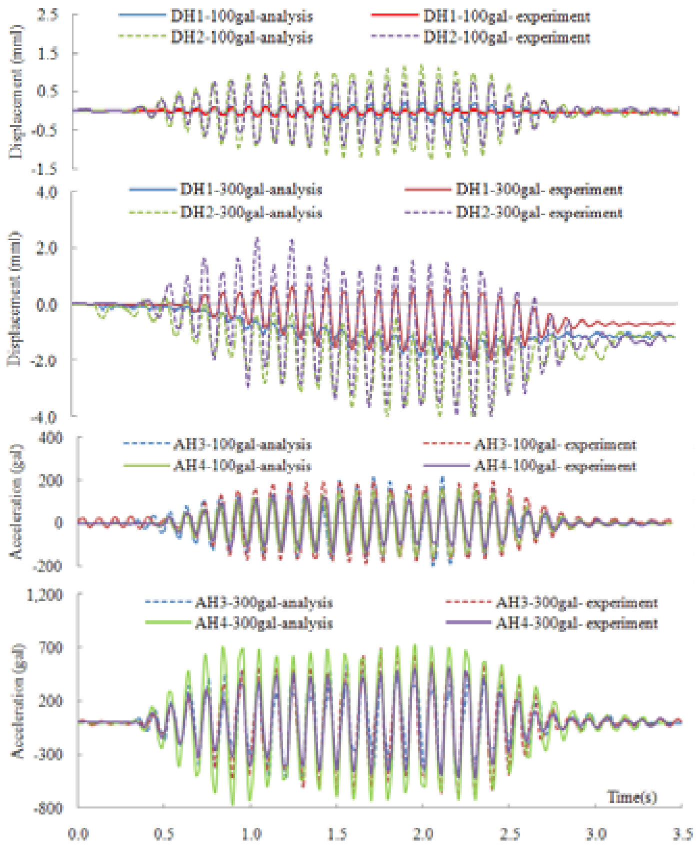

Fig-3 Responses of superstructure and foundation

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