OSCILLATOR TESTS OF PILE FOUNDATION IN DISSIPATION PROCESS OF EXCESS PORE WATER PRESSURE AFTER LIQUFACTION

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SUMMARY

This paper presents the results on oscillator tests in dissipation of excess pore water pressures, after the near-to full-scale shaking table excitations of a pile foundation and soil utilizing the big shear box (about 6m in height, 11.6m in length and 3.1m in width). The objective of the tests is to clarify relationship between soil subgrade reactions and excess pore water pressures after liquefaction. From seismic design viewpoint of piles in liquefied soils, the reactions are one of the most important factors. The oscillator, whose eccentric moment was set 100kg□cm constant, was installed on footing of pile foundation. The oscillator was operated several times at several stages of excess pore water pressure dissipation. The model of pile foundation is made of steel and is 40cm, 10cm and 5.82m in width, thickness and length, respectively. Excitations were carried out by a sweep up and sweep down method at a frequency range from 3 Hz to 16 Hz, and their excitation duration time was 50 seconds. Accelerations were determined during the oscillator tests, and excess pore water pressures were continuously measured after the shaking table excitation. The concluding remarks are summarized as follows; The stiffness of soil and the coefficient of the horizontal subgrade reaction are recovered with dissipation progress of excess pore water pressures. At higher excess pore water ratios, the resonant frequencies of foundation are low and their damping ratios large. At lower excess pore water ratios, the frequencies are high and their damping ratio become small. The impedance of pile foundations and the subgrade reaction coefficient of soil are evaluated from the oscillator tests.

INTRODUCTION

The research was conducted under a series of a activity related to a project of the Construction Technology, Research and Development(Ministry of Construction) titled "Development of technology for earthquake disaster prevention in large metropolitan areas”[Ministry of Construction, 1997]. In the project, the shaking table tests utilizing big shear box to understand the behavior of the pile foundation in the liquefaction process is executed. The result of the shaking table tests is reported in a companion paper titled “Dynamic Behavior of Pile Foundations In Liquefaction Process – Shaking Table Tests Utilizing Big Shear Box” (Abstract Reference No: 1883/5/ A) [Mizuno T. et al. , 2000].

This paper presents the oscillator test result in dissipation process of excess pore water pressure after liquefaction by the shaking table test. The objective of the oscillator tests is to clarify relationship between soil subgrade reactions and excess pore water pressures after liquefaction. From seismic design viewpoint of piles in liquefied soils, the reactions are one of the most important factors.

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SHAKING TABLE TESTS AND TEST SPECIMEN

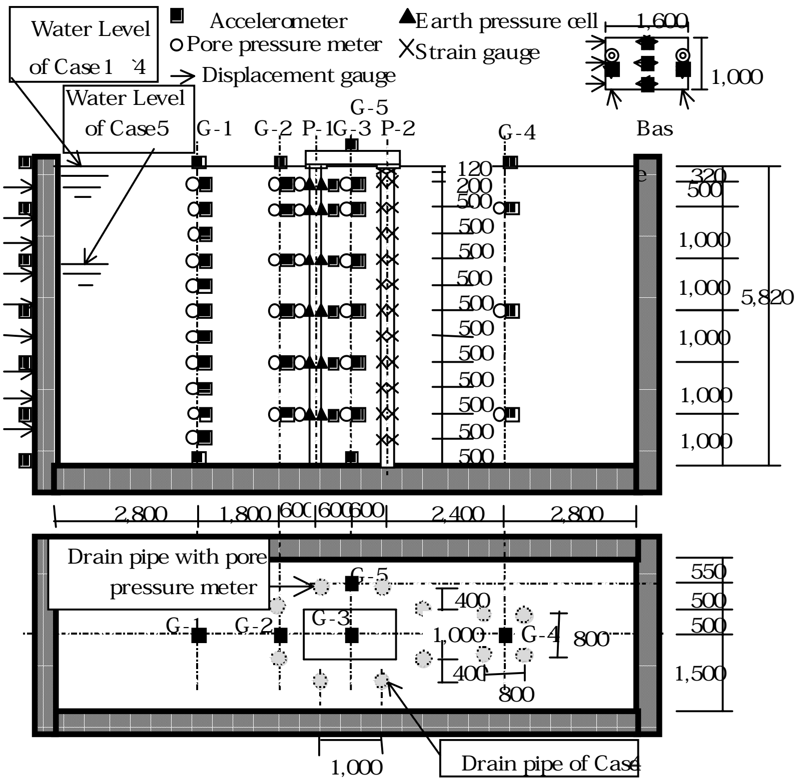

Fig.1 outline of test specimen and measurement

Table 1 Test Series and Objects

Test Case & Test Ground Condition	Shaking Table Test(O:input)				Static Load (before shake table)	Oscil-later Test	Object
	Ran-dom 30gal	Earthquake wave ,gal (Port island GL-32m,Ns)					
		500	200	re-500			
Case1 Drop of Sand into Water, water level G.L.	$O_{2,5}$	O_3			$O_{1,4}$	O_7 At dissipation	check the liquefaction seismic behavior of ground & foundations
		O_6*350gal,time scale=1/2					
Case2 Produced by boiling, water level G.L.	$O_{2,6}$	O_3		O_7 *600 gal	$O_{1,5}$	O_4 At dissipation	seismic behavior of ground & foundations (compare Case1)
Case3 Reproduced by boiling, water level G.L.	$O_{3,7,9}$	O_4	O_8	O_{10}	$O_{2,6}$	$O_{1,5}$ Before earthquake wave	reappearance of seismic behavior of ground & foundations (compare Case2)
		measured dissipation					
Case4 Reproduced by boiling with drain, water level G.L.	$O_{2,4,6}$	O_3	O_5	O_7	O_1		seismic behavior of ground & foundations under the drain (compare Case3)
		measured dissipation					
Case5 Reproduced by boiling, water level G.L.-1.4m	$O_{2,6,7}$	O_3	O_6	O_8	$O_{1,5}$	O_4 At dissipation	seismic behavior of ground & foundations at low water level (compare Case2,3)
		measured dissipation					

Oindex : Test Order

The details of the shaking table tests is reported in a companion paper titled “Dynamic Behavior of Pile Foundations In Liquefaction Process – Shaking Table Tests Utilizing Big Shear Box” (Abstract Reference No: 1883/5/ A) [Mizuno T. et al. , 2000]. Two types of shaking table tests were carried out; The one is random noise (white noise) excitation for grasping dynamic soil properties, and another for clarifying dynamic behavior of pile foundation in liquefaction process. The oscillator tests reported later were carried out after liquefaction of virgin soil due to earthquake excitation in case1 of Table 1, namely Oscillator test O_7. The test soil of case 1 were made by dropping sand into water at constant height from water surface. For earthquake excitation, the acceleration waveform of NS component at the depth GL-32m in Port Island, Kobe during 1995 Hyogoken Nanbu earthquake, and its maximum acceleration were adjusted 500 gals.

Fig.1 shows a test setup. The size of the shear box used to experiment is 11.6m, 3.1m in depth, and 6m in height in length (direction of the vibration) in the inside measurement size. The pile foundation model is a steel material of 40cm in width and 10cm in thickness. In the boundary condition of the pile foundation model, the pile tip is a hinge and the pile head is rotation-fixed. The accelerometers and the excess pore water pressure meters were located in measurement line (G-1~G-5) in the soil ground, and the accelerometer, the excess pore water pressure meter and the earth pressure cell (both sides in the direction of the vibration) were located on pile (P-1). The strain gauges were glued on the surface of pile (P-1, P-2) for the bending moment measurement. The accelerometers and the displacement gauges were set on the foundation and at some of the shear box layers, respectively. Kasumigaura sand was used for the test soil model. Table 2 shows soil properties and Fig. 2 presents equivalent shear modulus and damping. A uniformity coefficient is about 3. Fig. 3 shows strain dependency of equivalent shear stiffness and equivalent damping factor base on the dynamic biaxial test(a confining pressure : 0.5kgf/cm^2).

Table 2 Soil Properties

Test item	Result
density (g/cm^3)	2.718
gravel fraction (%)	0.8
sand fraction (%)	94.8
silt fraction (%)	3.5
day fraction (%)	0.9
uniformity coefficient	3.01
D50 (mm)	0.311
natural water content	5.71

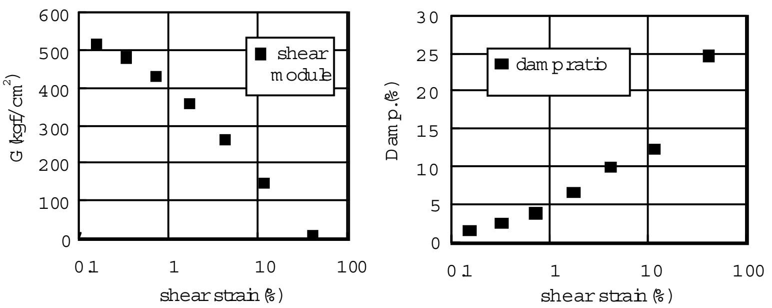

Fig.2 Equivalent Shear Modules & Damping

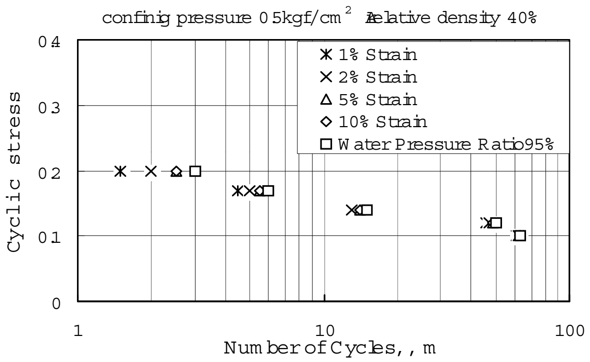

Fig.3 Liquefaction Resistance of Kasumigaura sand Shear Modules & Damping

Fig. 4 is spectrum ratio of Fourier spectrum at soil surface to that at the soil bottom, derived from random excitation (maximum acceleration 30 gals) before earthquake excitation. The predominant frequency (fundamental frequency) of the ground is 5.35Hz. The vibration mode at the predominant frequency of the ground is shown in fig. 5. The solid line in the figure shows the fundamental natural mode, under the assumption that the shear rigidity distribution of the soil is constant in the direction of depth.

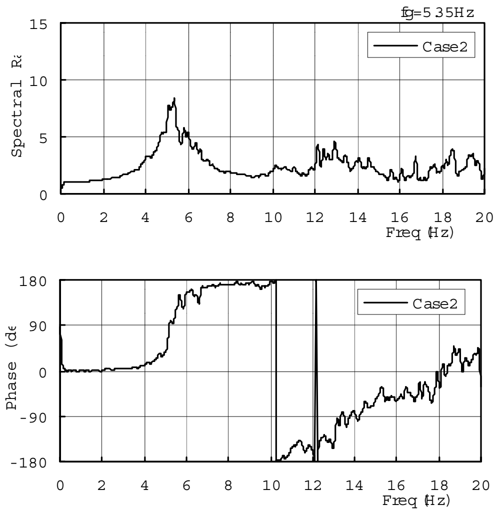

Fig.4 Spectral Ratio due to Random Wave(30gals)

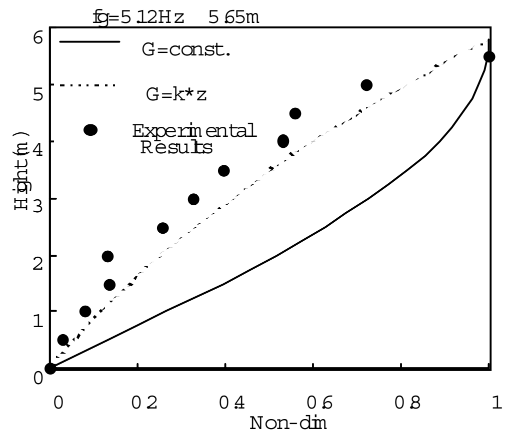

Fig.5 Vibration Mode

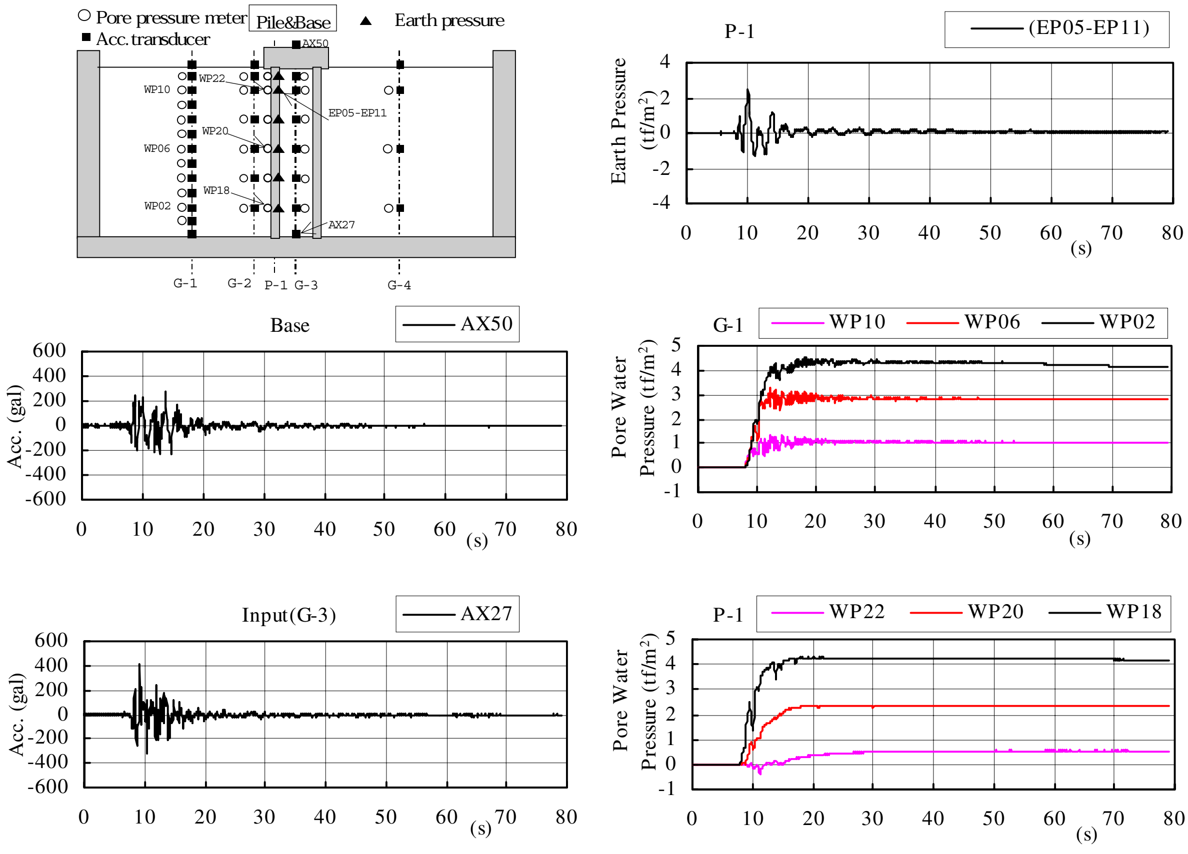

Fig.6 Time History of Earthquake Excitation

The dotted line shows the fundamental natural mode, under assumption that shear rigidity distribution of the soil is proportional to the overburden pressure. The fundamental natural mode derived from the random excitation of shaking table tests corresponds to the dotted line in figure well. Fig. 6 shows accelerations, excess pore water pressures and earth pressure of some measurement points in 500gals earthquake excitation of shaking table tests.

OSCILLATOR TEST OF PILE FOUNDATION

In order to determine relationships between the subgrade reaction of the soil and the excess pore water pressure, an oscillator (an eccentric moment is l00kg.cm) was installed on the footing of the pile foundation. After 500 gals earthquake excitation, a series of oscillator tests was conducted at several stages of dissipated process of the soil deposit. A excitation by the oscillator is a sweep excitation with increase or decrease of frequency between 3 Hz and 16 Hz during 50 seconds. Following presented results are those of sweep up excitations in dissipation process.

Responses of Footing and Pile

The time history of excess pore water pressure in the dissipation process after earthquake excitation are shown in Fig. 7. The broken lines means the duration at early stages in dissipation process that the excess pore water pressures were not measured just after 500 gals earthquake excitation. The excess pore water pressure is zero before the earthquake excitation. Symbols T1 to T6 means several stages in dissipation process. Though excess pore water pressures increase a little during the oscillation test, the influence on the whole dissipation process is very small.

The distributions of excess pore water pressures at the several stages are drawn in Fig. 8. In the figure, the distribution of the maximum of excess pore water pressures during earthquake excitation is plotted. The dissipation of excess pore water pressures starts in the deeper layer, and the dissipated layers move to shallow layers gradually with time

Resonant curves of the foundation displacement at the stages T1 to T6 are illustrated in Fig. 9. With the progress of dissipation process, the resonant frequencies become high, and the amplitudes at the resonant frequencies become small. When the dissipation progresses to a certain extent, the resonance of the soil deposit (about 5 Hz)

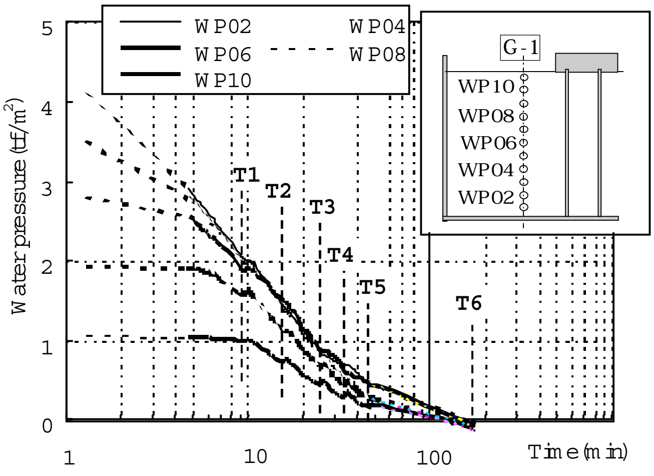

Fig.7 Pore Water Pressure in Dissipation process after Earthquake Excitation

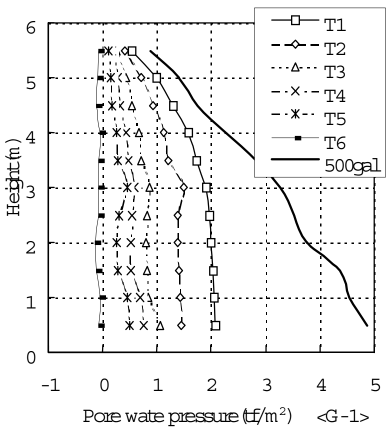

Fig.8 Distribution of Pore Water Pressure at several stages

appears again by getting the shear stiffness of the soil. Fig.10 shows relationship between the resonance frequency and the average excess pore water pressure ratio of pile (p-1). The excess pore water pressure ratio divides by the effective overburden pressure and obtains measured excess pore water pressure value. The average excess pore water pressure ratio averages excess pore water pressure ratio of each measurement point.

The relationship between the resonance frequency and the average excess pore water pressure ratio of pile (p-1) is linear.
The distribution of the pile bending moments at the resonant frequencies of each stage is shown in Fig. 11. The maximum of pile bending moments occurs at the pile head in all tests. The second maximum points of bending moments are 2.5 to 4 merters from soil bottom and become more shallow with the progress of the dissipation.

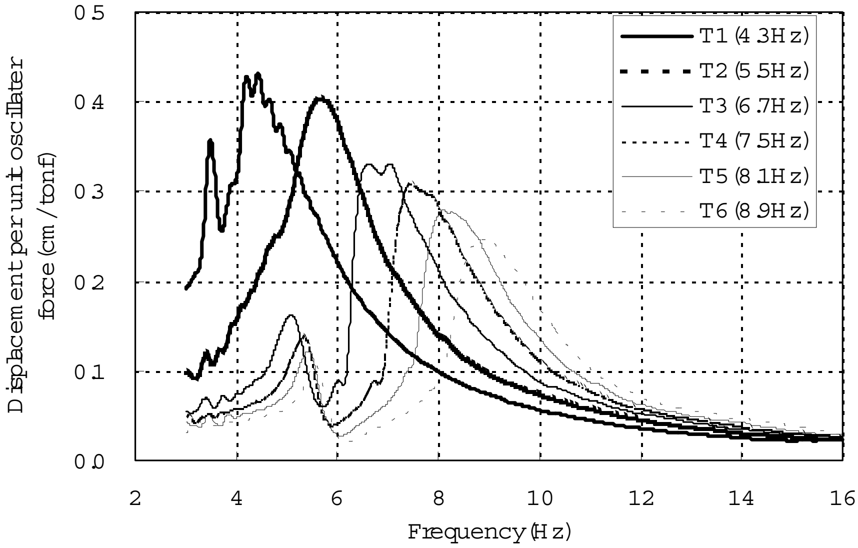

Fig.9 Resonant Curves of Footing Displacement

Subgrade Reaction During Dissipation
The subgrade reactions and coefficients of subgrade reaction to piles are evaluated from the data of bending moments of piles. The distribution of earth pressures to the pile at the resonant frequencies at each stage is presented in Fig. 12. The earth pressure transducers were installed at the both sides perpendicular to the excitation direction. The earth pressures are obtained from values of outer and inner transducers (difference between two). The depth at the maximum earth pressures moves to shallow depth with the progress of the

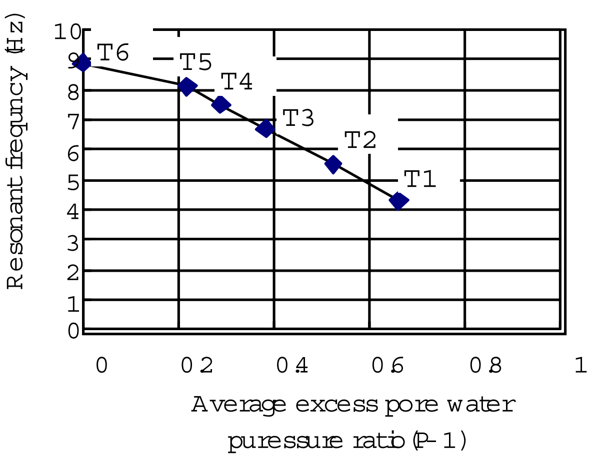

Fig.10 Relationship between resonance frequency and average excess pore water pressure ratio (Pile1)

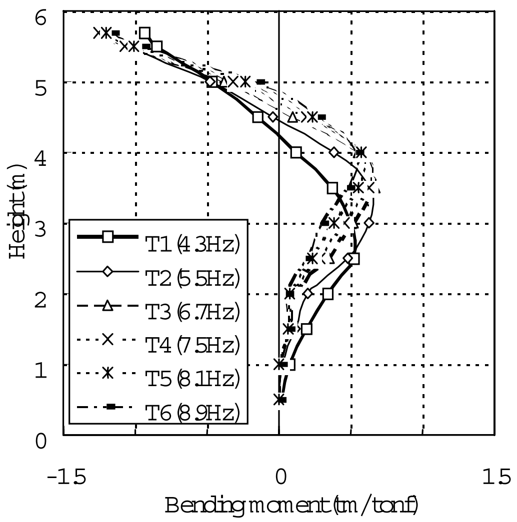

Fig.11 Distribution of Bending Moment at several stages(Pile2)

dissipation. The change of depth at the maximum bending moments and the maximum earth pressures in the soil means the reappearance of soil stiffness with dissipation. The distribution of bending moments is approximately expressed by a polynomial equation. The subgrade reactions do not act to the piles in the depth where the settlement of ground surface occurs during dissipation. The subgrade reactions are obtained to be differentiated twice with respect to a time t. The displacements are obtained by integrating twice with respect to a time. Boundary condition of the relative displacement at the pile tip is assumed zero, and that at pile head is assumed to be equal to the displacement of the footing measured in the experiment. The coefficient of the subgrade reaction is defined as a division of the subgrade reaction by the displacement and the pile width.

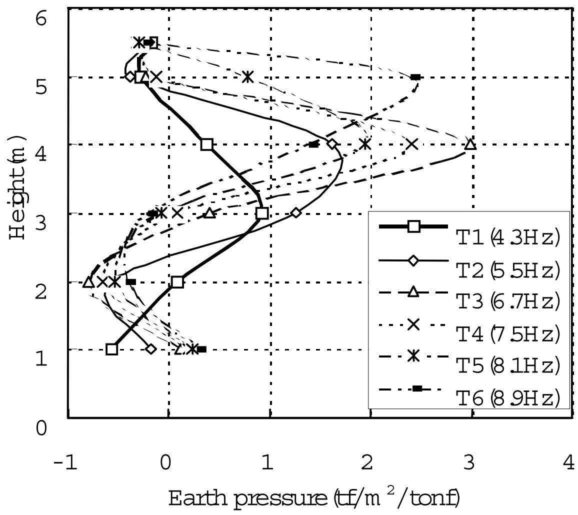

Fig.12 Distribution of Earth Pressure at several stages(Pile1)

The distributions of the pile displacements and the subgrade reactions obtained from the pile bending moments are shown in Fig. 13. In the figure, the mark of T6 from T1 shows the distribution of displacement obtained from the measured acceleration and the distribution of subgrade reaction derived from the measured earth pressures. The approximate polynomial equations are compatible to the distribution of

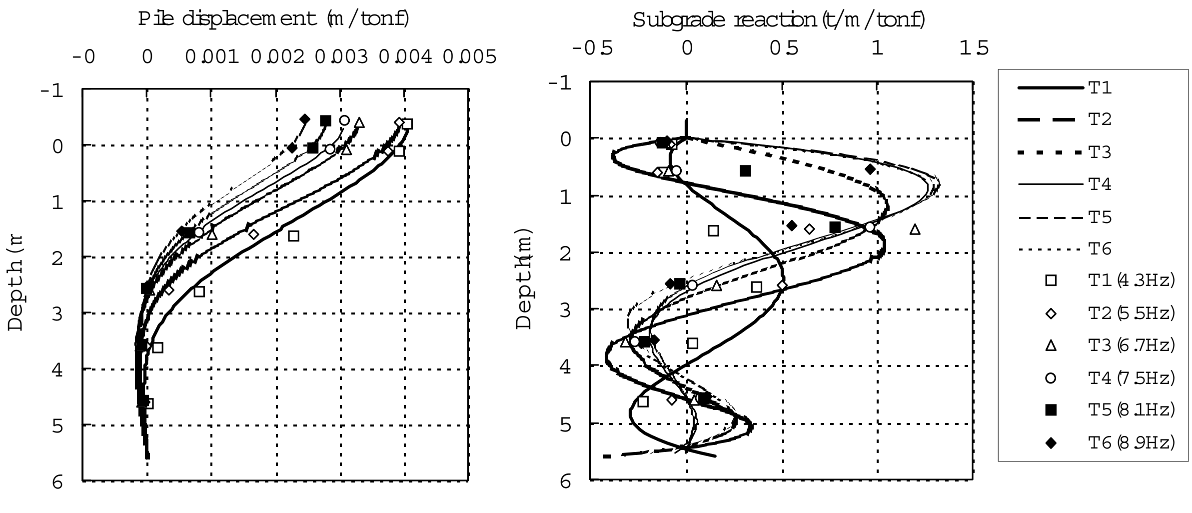

Fig.13 Pile Displacement, Subgrade Reaction obtained by Polynomial Approximation

measured data except a little difference of values.

The coefficients of the subgrade reactions is drawn in Fig. 14. The coefficient of subgrade reactions with nearly zero displacement is omitted in the graph. In early dissipation stage, the coefficients are large in the relatively deep layers. With reproducing shear modulus of soil, the depth at the maximum of the coefficients is gradually shallow.

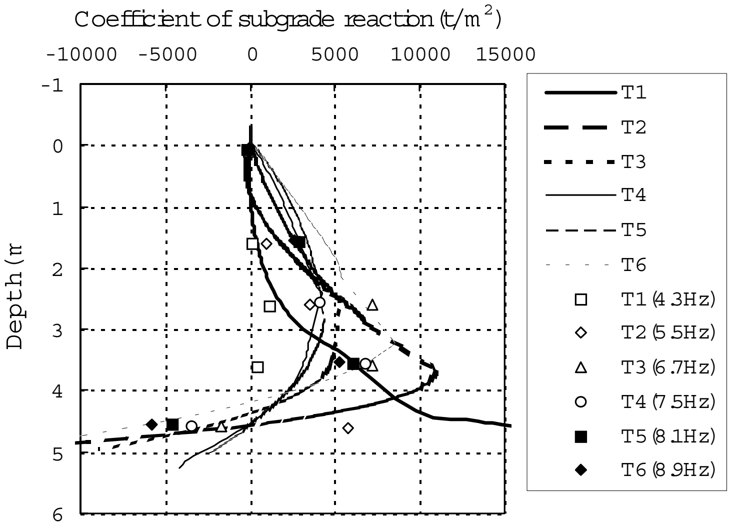

Fig.14 Pile Coefficient of Subgrade Reaction obtained by Polynomial Approximation

CONCLUSIONS

This report describes the results on oscillator tests in dissipation of excess pore water pressures, after the near-to full-scale shaking table excitations of a pile foundation and soil utilizing the big shear box. The objective of the tests is to clarify relationship between soil subgrade reactions and excess pore water pressures in dissipation process after liquefaction.

The concluding remarks are summarized as follows; The stiffness of soil and the coefficient of the horizontal subgrade reaction are recovered with dissipation progress of excess pore water pressures. At higher excess pore water ratios, the resonant frequencies of foundation are low and their damping ratios large. At lower excess pore water ratios, the frequencies are high and their damping ratio become small. The impedance of pile foundations and the subgrade reaction coefficient of soil are evaluated from the oscillator tests

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