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ABSTRACT

The limited strong earthquake database on structure and pile performance obstructs obtaining further progress in soil-pile-structure interaction problem. Model test in laboratory is one of the best ways to expand the database of structure and pile performance during earthquake. In this paper, the problem of pile-soil-pier-structure interaction is investigated by shake table test approach, and on the development of the sandy box for SPSSI test is firstly introduced. Through free field test, the validation of the model container was evaluated by comparisons of soil acceleration records with those numerically calculated by SHAKE91. Secondly, four specimen to simulate friction pile response were employed: single column pile pier, one column pier model with 2×2 piles, two-column piers model with 2×2 piles and two-column piers model with 3×2 piles. The characteristic behaviors of single pier and two piers were comparatively experimented and analyzed under the same condition of pile groups and input motion.

INTRODUCTION

Tests study on soil-pile-structure interaction (SPSI) is helpful to understand the characteristics of structure and pile response under seismic loading. Some experiments and field measurements achievement have been made in recent years in order to increase our understanding of seismic soil-pile-structure interaction and provide parameters for analytical methods. However, the lack of well-documented database of pile performance from actual earthquakes still obstructs further progress in calibration on analytical methods developed for seismic soil-pile-superstructure interaction problems. Model test in laboratory is one of the best ways to expand the database of structure and pile performance during earthquake, which has the advantage of low cost, repeatablity and having controllable condition over field measurement method. Thus, dynamic centrifuge and shake table tests are becoming popular ways to study the behavior of pile-supported structure in different soil type [2,3,4,5,6]. Numerous cases of pile foundation and pile-supported structure damage during Loma Prieta earthquake, 1989, and Kobe earthquake, Japan, 1995, motivates a number of researcher groups in the circles of earthquake engineering and geotechnical engineering to perform scale model physical testing, and model test in laboratory attracts considerable attentions [7].

In this paper, a series of shaking table tests was carried out for investigating earthquake response of pier column with different pile groups, and free field model test had also been conducted. Four SPSSI specimens tests: single column pile pier, one column pier with 2×2 piles, two-column piers with 2×2 piles and two-column piers with 3×2 piles, had been performed. The characteristic behaviors of pier and friction pile response were obtained.

This paper highlights of the shaking table tests on model piles in loose sand and the major finds from the tests.

MODEL DESIGN

Some conditions and factors should be considered in conducting soil-pile-structure interaction on shake table test. Those are as follows:

① Dimensions of shake table and its bearing capacity, it restricts the weight and height of the designed model.

② Determination in materials of model and its similitude law.

③ Boundary condition definition of model soil.

Comparability of test model to prototype of structure was mainly considered, in order to understand the characteristic of soil-pile-structure dynamic interaction through model test.

Realistic modeling of the dynamic response of pile-soil system is an important issue in analysis of highway bridges. Pier and pile model performed in this paper was abstracted from the prototype of inner ring viaducts in Shanghai. The four specimens with the dimensions of piers and piles are shown in table 1, and it will be further described in following paper.

Table 1 Dimensions of model piers, Pile in details

	Single Column		Single pier with 2×2 Piles		Twin Piers with 2×2 Piles		Twin Piers with 3×2 Piles	
	Prototype (m)	Model (mm)	Prototype (m)	Model (mm)	Prototype (m)	Model (mm)	Prototype (m)	Model (mm)
Pier in Height	16	800	16	1000	16	1000	16	1000
Section of Pier	1.8	ϕ90	1.6×1.2	95×75	1.2×1.0	75×62	1.2×1.0	75×62
Length of Pile	24	1200	24.0	1500	24.0	1500	24.0	1500
Section of Pile	1.8	ϕ90	ϕ1.0	ϕ62	ϕ1. 0	ϕ62	0.45×0.45	30×30

A rigid pile head mass with a weight of 50 kg was clamped to the head of the pile to simulated the effect of the superstructure. Accelerometer and strain gauges were placed at various points along the outside of the pile to measure peak bending strains. The rigid container bolted to the table, two 40 cm thick styrofoam pads were placed at each end of the container to prevent wave reflection from the sides of the box perpendicular to the direction of base excited motion.

Details on the construction of the sandy box can be found in reference 1. It was prepared with a plan inner size of 3.3 by 0.8 meters and a height of 4.0 meters. The box contained dry sand with an initial average void ratio of 0.70, known as 'Fujian' standard sand in China. The depth of the sand deposit is 3.5 m and the sand was densified with vibrations induced from the shake table before each model test. The computed shear wave velocity of sand ranged from 100m/s to 150 m/s before and after shaking. The shaking table tests were conducted in March, 1999.

Tests of following five group model cases had been performed:

1) Free-field tests (Case 1). Figure 1 shows a schematic view of the cross section of the free field test model system and the layout of various instrumentation devices. The free field test was aimed at: a)estimating the characteristics of the model ground by the measured data of its response, b)observing the nonlinearities associated with the inelastic behavior of the model sand, and c)examining the availability of the model box for simulating approximately the infinite extension of the ground in the direction of shaking. The accelerometers measure horizontal surface accelerations in the direction of shaking. Three accelerometers were placed on the surface of the sand, and one was placed at the bottom of soil container to measure input accelerations. Another two accelerometers were place in the middle height of the soil.

2) Tests of single column pier (Case 2). This model is simplest pile-soil-structure system. The objective of this model test is to simulate pile pier without any platform, and pile shaft was supported by lateral soil. The similitude ratio of pier was 1:20.

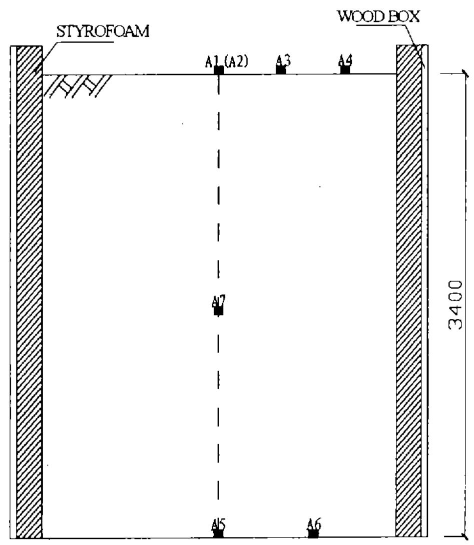


Fig. 1 Layout of single column pier and distribution of

3) Tests of single column pier with 2×2 piles as shown in figure 2 (Case 3). It consists of one pier and four piles. the platform was at pile cap. Dimensions of pile section can be found in table 1. The similitude ratio of pier was 1:16. Fig. 2 shows the schematic elevation of the tested piles and single pier column structure system.

4) Tests of twin-column piers with 2×2 piles (Case 4). The layout of this model is shown in fig.3. Dimensions of pile section are the same as that of model case 3. But the section of piers was different from that of case 3. The objective of this model was to compare the characteristic of pile response with that of case 3 model, meanwhile, to observe the response of

pier under input motion of shaking table.

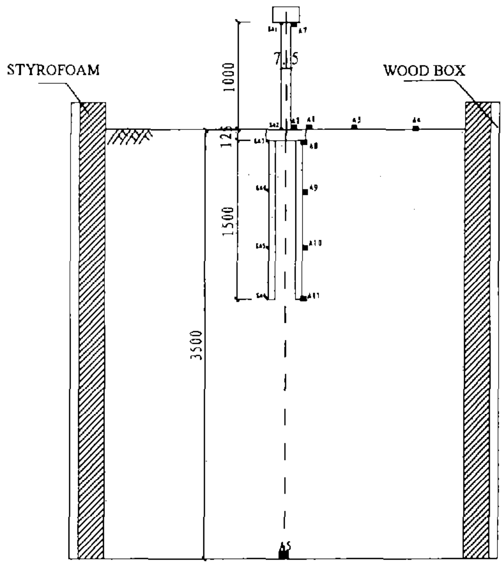


Fig. 2 Layout of single column pier and distribution of instrumentation device

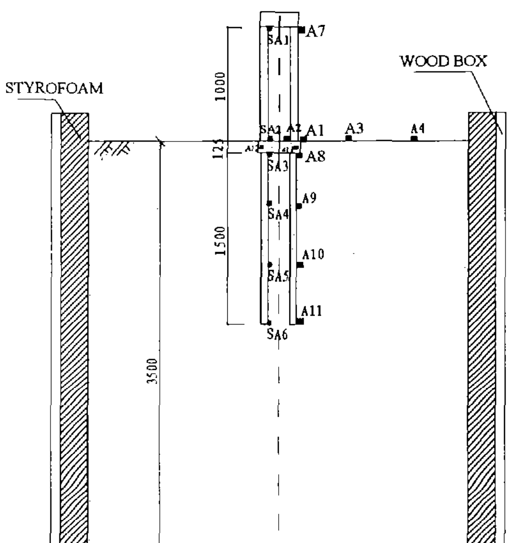
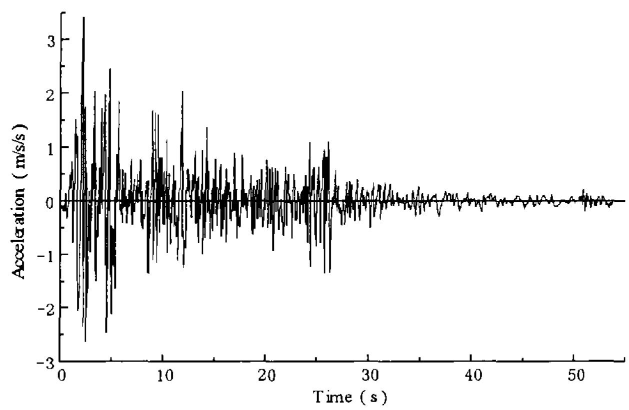


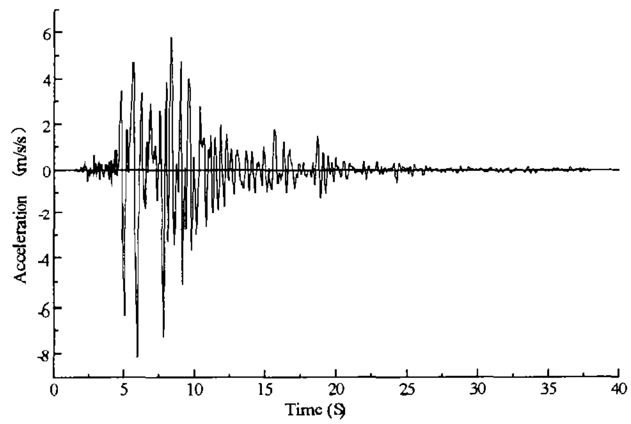
Fig. 3 Layout of single column pier and distribution of

5) Tests of twin-column piers with 3×2 piles (Case 5). Three piles with two rows were arranged in the direction of shaking. Dimension of piles is less than that of case 3. The precast pile was simulated in Case 5. But dimension of pier is the same as that of case 4. The similitude ratio of pier was 1:16.

Two kinds of actual acceleration records were selected for the soil-pile model tests study. They consisted of well-known El Centro south 00 east in Emperial earthquake, and the JMA record north 00 east component from the Kobe earthquake. The acceleration time histories for these two records are depicted in fig. 4. EL Centro record has a wide frequent range in acceleration response spectrum. On the contrary, the Kobe record has a flying effect in acceleration response spectrum. Two records have a time step of 0.02 second. In accordance with the similitude relations, the time steps of those two records were compressed by the square root of scaling ratio. The maximum acceleration of waves were scaled to 0.10g, 0.15g 0.20g, 0.30g, 0.40, 0.50g, respectively. Input acceleration motions were used for unidirectional shaking.



a) El Centro earthquake record in 1940 (N-S component)



b) Kobe earthquake record in 1995 (JMA, N-S component)
Fig.4 The accelerograms for simulated input motion

TEST RESULTS

A preliminary analysis had been completed on the data obtained from above five test models.

Results of case 1

The variation of the amplification factor (β) along with peak acceleration of the input motion measured at the bottom of box (a_g) is shown in figure 5. The amplification factor is defined as the ratio of the peak acceleration at measured point relative to input motion of a_g. It can be found from figure 5 that the response at A1 and A3 differs very small in free field test for a given a_g. It indicates that the availability of the model ground at the middle of soil surface for simulating the infinite extension in the shaking direction. With a_g increasing, the response acceleration decreases sharply. This implies the nonliearilities associated with the inelastic soil behavior.

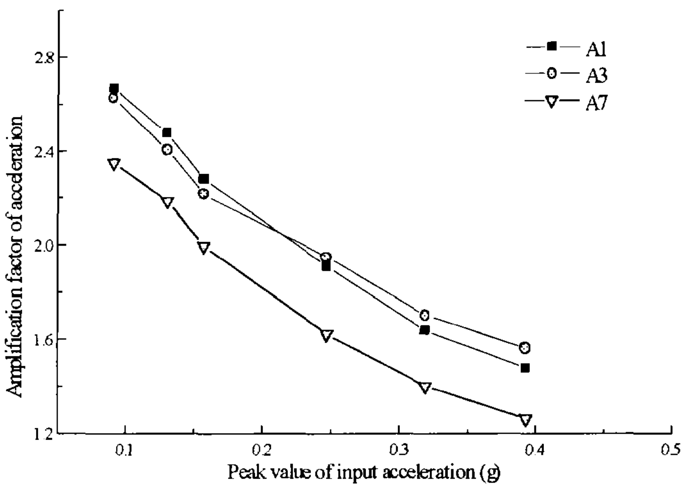


Fig.5 Acceleration amplification factor under different levels of input loading

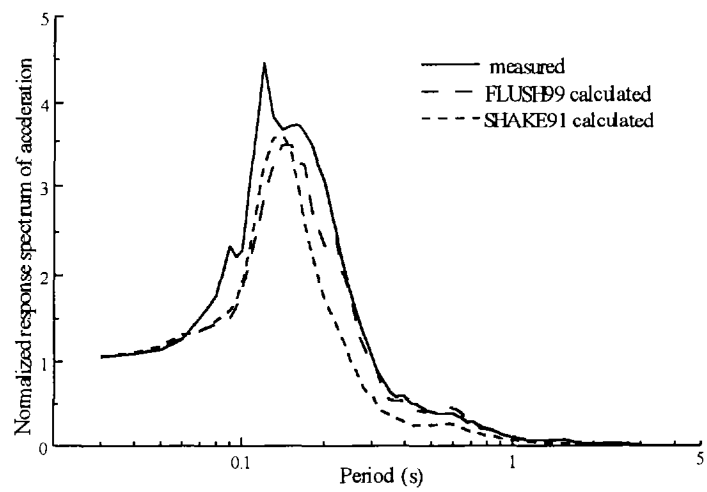


Fig. 6 Comparison of Normalized RSA between measured and theoretical calculated

Figure 6 illustrates the comparisons of observed and theoretical calculated acceleration response spectrum of A1 at the surface of soil under the simulated 0.30g peak value of El Centro wave, all of which were 5% damped normalized acceleration response spectrum (ARS). The dashed line ARS was calculated by two dimensions finite element analysis FLUSH99 [1], moreover, the dotted line was numerically analyzed by SHAKE91 program [8].

From comparison of ARS of A1 between experimental and computed results shows that not only the peak values but also the ARS from the tests and calculations agree well, the response of free field soil is reasonably reproducc by sandy box.

Meanwhile, fig. 7 shows a good agreement between the observed (soild line) and computed acceleration time history (dotted line) at the surface of soil. The dotted line was calculated by SHAKE91

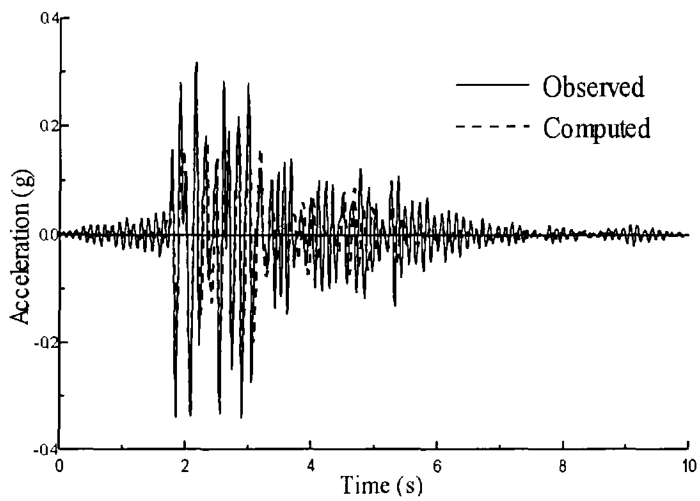


Fig. 7 Comparison of measured and calculated acceleration time history

Those agreements of observed and computed acceleration response spectrum and time history at given point of soil surface indicates that the designed container effectively simulated free field condition and successfully responded in free field mode.

Results of case 2

From the single column pile pier tests it can be found that the amplification factors (β) at surface point versus input a_g obviously decreases with increasing level of input motion a_g. Figure 8 shows a gap between pier shaft and soil formed after test completed, which implies that single pile pier is easier to formulate gap on soil pile surface because it insufficient of lateral support force between soil and pile. This kind of damage phenomena could also been found in historical earthquake case.

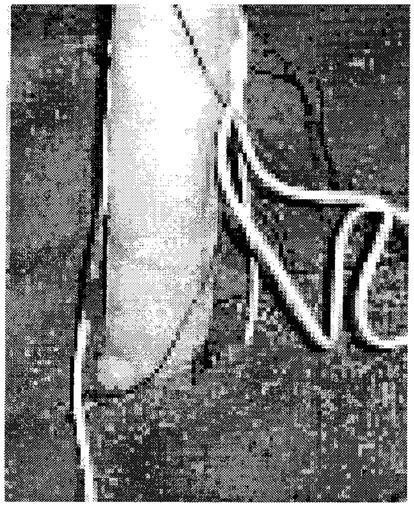


Fig. 8 Formed gap on soil-pile surface of pile pier model

Results of case 3

Figure 9 illustrates the comparison of the amplitude value of pile strain at different location with increasing level of input Kobe earthquake record. It indicates that the amplitude value of strain sharply decreases in the direction of pile shaft downwards. The pile cap location was the maximum place of amplitude value of strain under any level of simulated earthquake load.

It was found that some crack appears in pile shaft near the location of pile top and pile-cap connection place after model test finished.

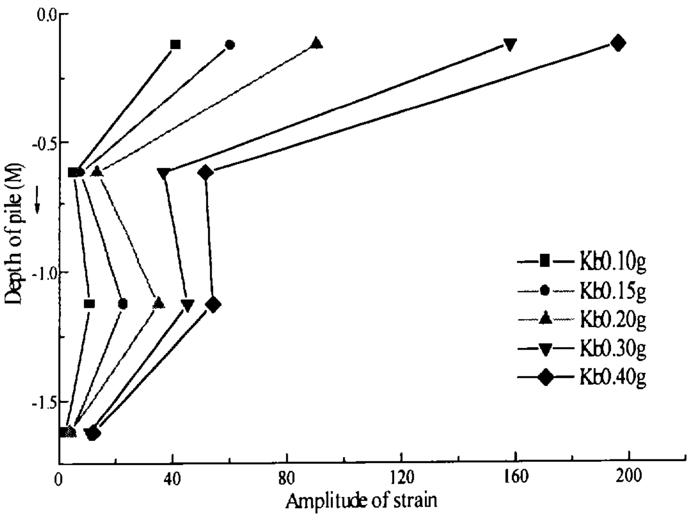


Fig. 9 Amplitude strain at different place of pile shaft to single pier with 2×2 piles model

Results of case 4

Figure 10 summaries response curves of amplitude strain at different place along depth of pile. It can be noticed that the effect of pile strain value under bend moments is significant at pile cap connection. Amplitude strain value increases with increasing level of simulated input motion. Meanwhile, from the figure 10 it can be seen that for the studied structure and the input motion the amplitude strain of pile sharply decrease along the depth of pile. It is almost equal to zero at the foot of pile.

Comparing figure 10 with figure 9, it is concluded that amplitude strain in case 4 is considerably larger than that of case 3 (with single pier) under the same level of simulated motion. Dimension of piles and platform in case 4 model are the same as that of case 3 model, They are almost the same except the size of piers. It means the amplitude strain of pile with twin piers is obviously larger than that of pile with single column pier at the same location. It is well known that lateral resisting stiffness of twin pier is better than that of single pier. It leads to the bend moment difference of friction piles between case 3 and case 4 model. Consequently, it indicates that two piers model has disadvantageous over single pier toward pile seismic behavior from comparison of those two figures.

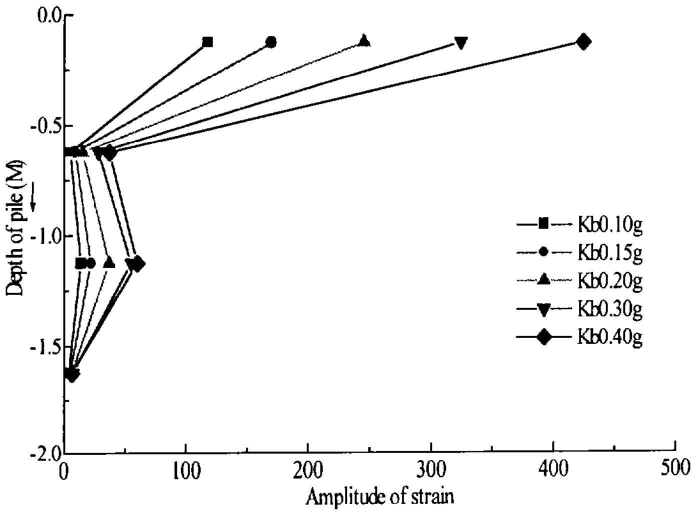


Fig. 10 Amplitude strain at different place of pile shaft to twin piers with 2×2 piles model

Results of case 5

Figure 11 shows that the distributions of amplitude strain at different place of pile under various peak values. Tests were carried out under scaled El Centro input motion. The maximum strain took place at pile cap location, and considerably decreases along the depth of pile. Strain was lower under a relatively low level of input motion with 0.10 g peak value of acceleration.

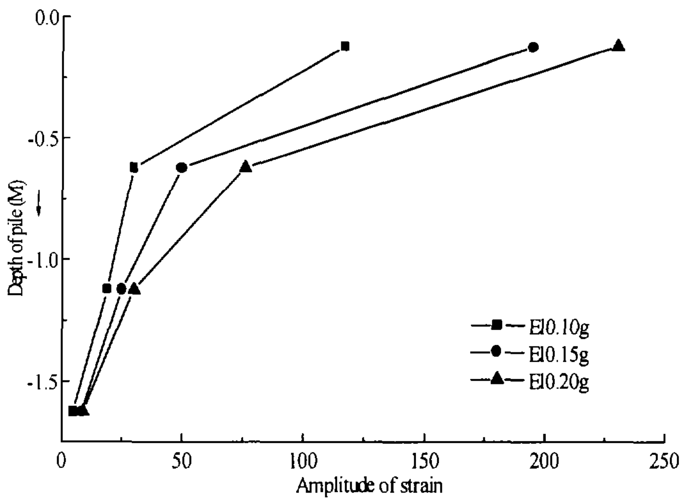


Fig. 11 Amplitude strains at different place of pile shaft to twin piers with 3×2 piles model

CONCLUSIONS

Model shake table tests research on soil-pile-pier-structure system have been accomplished, which includes free field model, single column pile pier model, one column pier model with 2×2 piles, two-column piers model with 2×2 piles and two-column piers model with 3×2 piles. The experimental procedures adopted in the program worked very well, and data resulting from tests can provide useful information on pile behavior during simulated earthquake loading.

The main achievements are described as follows:

1) A sandy box for studying SPSSI shake table test was designed, and the response of free field soil is reasonably reproduce by shake table tests. The simulations of the model free-field response were fairly accurate to analytical results with SHAKE91. Thus, the model soil container system can be judged to have adequately reproduced free field site response.

2) The characteristics of pier and friction pile response are induced through four specimens test; Strains near to pile-cap is the largest one and strain at the bottom of pile equals almost to zero; Strain in pile shaft sharply decreases along the pile depth.

3) Through model test in shake table laboratory, it is concluded that single column pile pier is disadvantageous of aseismic behavior, because pier without pile groups and platform is insufficient of lateral binding force.

4) Single column pier with the same pile groups is advantageous over two column piers toward pile seismic behavior through comparisons in pile bending strain under the action of seismic loading

The experiment and preliminary analysis presented in this paper have not given all data results that we had achieved. The theoretical analysis of soil-pile-structure interaction will been given in ongoing papers.

ACKNOWLEDGMENT

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