Study of Shaking Table Test of Rigid-subrigid Pile Composite Foundation under Sandy Field Condition

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Abstract. To study the seismic response of rigid-subrigid pile composite foundation, shaking table test was conducted under sandy field condition. The experimental results show that the acceleration response strength of the pile top is greater than that of the pile bottom, and is smaller with the increase of buried depth; seismic wave types will have an impact on the acceleration amplification effect; from pile bottom to pile top, the peak value of Fourier spectrum increases gradually, and the frequency distribution of Fourier spectrum in frequency domain does not change. The frequency range of the peak value of Fourier spectrum under three kinds of seismic waves is different; with the peak acceleration of the input excitation increase, the strain peak of pile body changes more and more significantly along the length direction, and the strain peak of rigid pile appears abnormal , which is the weak part of seismic resistance.

Keywords: Sandy Field; Rigid-Subrigid Pile; Composite Foundation; Shaking Table Test.

1. Introduction

Rigid-subrigid pile composite foundation is a new and efficient foundation treatment technology [1], which is based on in-depth study of the working mechanism, cushion effect, load transfer characteristics, stress analysis, deformation and bearing capacity of composite foundation at home and abroad, and widely used in engineering practice. As an advanced design method, CM composite pile foundation has good application prospects, and it will become a research hotspot in the field of civil engineering in China.

In recent years, rigid-subrigid pile composite foundation has been discussed in theoretical analysis, experimental research and engineering measurement, and some achievements have been achieved. It has also been applied in engineering design, but mainly in static research, the research on dynamic response of rigid-sub-rigid pile composite foundation is seriously lagging behind. Shaking table is used to carry out the research, model test is an effective means to study the dynamic characteristics of buildings under seismic loads. This seismic simulation method has been widely used abroad[5]-[7]. At present, it is also developing gradually in China[8]-[11].

In view of this, the shaking table test of rigid-sub-rigid pile composite foundation under sandy soil condition has been completed in this paper. The acceleration time history, acceleration amplification effect, Fourier spectrum and pile strain of rigid-subrigid pile composite foundation under different seismic wave types and different excitation peaks have been analyzed. The purpose of this paper is to
study the dynamic response of rigid-subrigid pile composite foundation under sandy soil conditions, and to provide reference for seismic analysis and design of rigid-subrigid pile composite foundation.

2. Overview of the test

The test was carried out in the seismic center of Guangzhou University, the size of the shaking table is 3m*3m*1.2m. It is a welded steel honeycomb structure with a mesh size of 40cm*40cm. The whole outer surface is enveloped with steel plates to improve its flexural and torsional stiffness. The shape of the whole mesa is slightly tapered to reduce its weight and increase its bending stiffness. The test adopts a circular laminated shear model box, which is composed of 12-story steel frames, each frame can move horizontally, the diameter of the model box is 2m and the height is 1.44m, as shown in Fig. 1.

Table 1. Loading condition

| Input Seismic Wave Type, Direction | Peak acceleration |
|-----------------------------------|-------------------|
| E1centro, Tianjin and Taft waves X | 0.1g              |
| E1centro, Tianjin and Taft waves X | 0.2g              |
| E1centro, Tianjin and Taft waves X | 0.4g              |
| E1centro, Tianjin and Taft waves X | 0.6g              |
| E1centro, Tianjin and Taft waves X | 0.8g              |

Guangzhou local sand was selected for the test, with a porosity ratio of 0.406 and a density of 1.71 g/cm³. The thickness of gravel sand cushion is 50mm and the ratio of sand to gravel is 3:7. Hollow PMMA with modulus of about 3.0 Gpa and density of about 1190 kg/m³ is to be used to make rigid piles. The length of rigid piles is 800mm, the outer diameter is 35 mm and the inner diameter is 30mm. The length of sub-rigid piles is 400mm, the outer diameter is 45mm, the inner diameter is 39mm, and the net distance between piles is 100mm.

The test piles are arranged in 4*4, as is shown in Figure 2. Strain gauges are arranged along the length direction of piles No.1, No.2, No.3 and No.4, with intervals of 200 mm. Among them, pile No.1 and pile No.3 are sub-rigid piles, and piles No.2 and No.4 are rigid piles. Acceleration sensors are arranged at the top, 2/3 from the top, 1/3 from the top and the bottom of piles of No.2 and No.4 rigid piles. Acceleration sensors are arranged at the top and the bottom of piles of No.1 and No.3 subrigid piles. Acceleration sensors are placed at the bottom of the test box to monitor the output acceleration.

As is shown in Table 1 of the test loading conditions, each group of excitations is swept in three directions with 0.05g white noise.
3. Analysis of test results

(a) 0.1g, E1centro wave of pile No.2

(b) 0.1g, Tianjin wave of pile No.2

(c) 0.1g, Taft wave of pile No.2

(d) 0.1g, E1centro wave of pile No.3

(e) 0.1g, Tianjin wave of pile No.3

(f) 0.1g, Taft wave of pile No.3

Fig.2 Layout diagram of test pile

Fig.3 Taft wave of pile
In order to comprehensively analyze the dynamic response of rigid-sub-rigid pile composite foundation under sandy soil site conditions. In this section, the acceleration time history, acceleration amplification effect, Fourier spectrum and strain are analyzed and studied.

3.1. Time history analysis of acceleration
In this paper, the acceleration time history curves of pile No.2 and pile No.3 under the input of 0.1g Elcentro wave, Tianjin wave and Taft wave are given, as shown in Figure 3. The results show that under the action of 0.1g excitation peak value of three kinds of seismic waves, the acceleration response strengths of No.2 rigid pile and No.3 subrigid pile decrease gradually with the increase of buried depth, and the measured acceleration peak values of pile top are larger than the measured acceleration peak values of pile bottom. Among them, under the action of Elcentro wave, the measured acceleration peak values of pile top of No.2 rigid pile and No.3 sub-rigid pile are 1.36 times and 1.39 times of the measured acceleration peak values of pile bottom respectively; under the action of Tianjin wave, the measured acceleration peak values of pile top of No.2 rigid pile and No.3 sub-rigid pile are 1.44 times and 1. Under the action of Taft wave, the measured acceleration peak values of pile top of No.2 rigid pile and No.3 sub-rigid pile are 1.32 times and 1.18 times of the measured acceleration peak values of pile bottom.

![Fig.4 Acceleration amplification factor of the No.2 pile](image)

3.2. Analysis of acceleration amplification effect
Acceleration amplification factor is defined for more accurate analysis of seismic amplification effect of rigid-sub-rigid pile composite foundation in sandy soil. Acceleration amplification factor is the ratio of the measured peak acceleration at any measuring point to the input peak acceleration.

An accelerometer for monitoring acceleration response is arranged in the test site to measure the acceleration response of rigid-subrigid pile composite foundation under different seismic excitation in dry sand site. The accelerometer is arranged at the bottom of the box to measure the acceleration response of the platform. The acceleration response of this point is used as the test model. The input ground motion acceleration response of type I. Figure 4 shows the variation curve of the acceleration amplification factor of pile No.2 with different earthquake ground motion amplitudes under three kinds of seismic wave input.

From this figure, we can see that under the action of three kinds of seismic waves, the variation trend of pile acceleration amplification coefficient is the same. When the excitation peak value is 0.1g and 0.2g, the acceleration amplification coefficient of pile body is basically greater than 1. The maximum acceleration amplification coefficient is located at the top of pile. The acceleration amplification coefficient of pile body decreases gradually with the increase of embedded depth, and the acceleration amplification coefficient of pile body under 0.1g excitation peak value is slightly larger than that under 0.2g excitation peak value. When the excitation peak value is 0.4g, 0.6g and 0.8g, the maximum acceleration amplification coefficient is located at the bottom of the pile, and the acceleration amplification coefficient is less than 1. The acceleration amplification coefficient of the pile decreases first and then increases with the increase of buried depth. It may be that with the increase of excitation peak value, the inherent dynamic characteristics of the site have changed.

Comparing the acceleration responses of three kinds of seismic waves, it is found that the frequency characteristics of three kinds of loaded seismic waves are different, which results in the difference of
acceleration response of the same measuring point under three kinds of seismic waves. The acceleration amplification coefficient of pile under Tianjin wave is larger than that under E1centro wave and Taft wave. The magnification factor of pile acceleration under E1centro wave and Taft wave has little difference.

3.3. Analysis of acceleration spectrum

The length of rigid pile and sub-rigid pile in rigid-subrigid pile composite foundation is different, so they must have different frequency response. In order to study its change rule in frequency domain, the acceleration time history curve of the measured point is transformed by Fourier transform, and then the

![Graphs showing Fourier spectra for No.2 and No.3 piles under different seismic waves.](image-url)

**Fig.5** Acceleration Fourier spectrum of the No.2 pile and the No.3 pile
change characteristics of acceleration spectrum are analyzed. The Fourier spectrum curves of pile No. 2 and pile No. 3 are given in Fig. 5, it shows that the Fourier spectra of pile No. 2 and pile No. 3 increase with the peak value of input excitation, and the corresponding amplitudes of each frequency of the three seismic waves increase gradually. However, the frequency distribution characteristics of the three seismic waves do not change with the increase of peak value of input excitation, that is, the shape of Fourier spectra does not change with the increase of peak value of input excitation. From the bottom of pile to the top of pile, the peak value of Fourier spectrum increases gradually, but only the amplitude is enlarged, and the frequency distribution of Fourier spectrum in the frequency domain does not change. The main frequency bands of the three seismic waves are as follows: the peak value of Fourier spectrum of Elcentro wave is mainly concentrated in the frequency domain of 4-7Hz and 13-18Hz; the peak value of Fourier spectrum of Tianjin wave is mainly concentrated in the frequency domain of 13-15Hz; and the peak value of Fourier spectrum of Taft wave is mainly concentrated in the frequency domain of 4-7Hz and 8-15Hz.

3.4. Strain analysis

Fig. 6 shows the peak strain of piles No. 2 and No. 3 along the pile length. From Figure 6, we can see that the peak strain of rigid and subrigid piles increases with the increase of the peak excitation of input seismic wave. Under different excitation peaks, the variation trend of peak strain along the length direction of pile body is different with the increase of buried depth of No. 2 rigid pile and No. 3 sub-rigid pile. When the excitation peak value of No. 2 rigid pile and No. 3 sub-rigid pile is 0.1g and 0.2g, the minimum value of strain peak value lies at the top of pile, and the variation of strain peak value along the length direction of pile body is small. When the excitation peak value of No. 2 rigid pile body is 0.4g, 0.6g and 0.8g, the distribution of strain peak value along the length direction is abnormal, showing "W" and 60 cm away from the top of pile. It may be that with the increase of excitation peak value, the sudden change of site stiffness results in obvious stress concentration of pile body. When the excitation peak value is 0.4g, 0.6g and 0.8g, the peak strain distribution along the length direction is slightly more significant than that under the excitation peak value is 0.1g and 0.2g, and the peak strain is larger in the middle part of the pile.
4. Conclusion
In this paper, the dynamic response characteristics of rigid-subrigid pile composite foundation in dry sand site are discussed by shaking table test. The following conclusions are drawn:

(1) The acceleration response strength of pile top is greater than that of pile bottom, and the acceleration response strength of pile body becomes smaller with the increase of buried depth.

(2) Under the action of three kinds of seismic waves, the variation trend of pile acceleration amplification coefficient is consistent, and the pile acceleration amplification effect decreases gradually with the increase of buried depth. Seismic wave type will affect the amplification effect. The acceleration amplification effect under Tianjin wave is greater than that under pile under Elcentro wave and Taft wave. There is little difference between the acceleration amplification effect under Elcentro wave and Taft wave.

(3) From pile bottom to pile top, the peak value of Fourier spectrum increases gradually, and the frequency distribution of Fourier spectrum in frequency domain does not change. The frequency range of the peak value of Fourier spectrum under three kinds of seismic waves is different.

(4) With the increase of excitation peak value, the distribution of strain peak value along the length direction of pile body becomes more and more significant. The distribution of peak strain of rigid piles along the length direction of piles is abnormal, which is the weak part of earthquake resistance.

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