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Numerical Analysis on Adjacent Highrise and Multistoried Buildings-Pile-Soil Dynamic Interaction

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Abstract. In this paper, the general finite element analysis program ANSYS is adopted to analyze the 3D finite element model of adjacent highrise and multistoried buildings-pile-soil dynamic interaction system. In the model, the soil parameters are based on the characteristics of Shanghai soft soil, and the adjacent upper structures are two frame structures, which had 12 stories and 5 stories respectively. Through comparing the simulation results of this particular dynamic cross interaction system with those of single structure and two identical structures, some useful conclusions were obtained.

Introduction

With the development of population and urbanization, the distance between the adjacent buildings was becoming closer and closer. Under the earthquake, there exists Dynamic Cross Interaction (DCI) among the buildings through the underlying soil. It is a very important research subject to consider DCI of the two adjacent buildings, even of the multiple buildings in a certain area. Because there had lots of highrise buildings adjacent with the multistoried buildings, the study on DCI system of adjacent highrise and multistoried buildings has important theoretical and practical significances.

Since the 1970s, a good many experiments and computational simulations on DCI systems have been done, lots of which gave consideration to different adjacent structures. In the research program on DCI launched by The Nuclear Power Engineering Corporation (NUPEC), full scale field tests of three interactional systems including a single reactor building, two adjacent identical reactor building and a reactor building adjacent to a turbine building, were done respectively [1]. Natio et al. mainly employed 2-D FEM and 3-D FEM-BEM to conduct numerical simulations of the above-mentioned field tests [2]. Xu et al. developed 3-D full scale models of two adjacent identical reactor buildings and a reactor building adjacent to a turbine building with SASSI2000, and the stochastic of soil properties was taken into consideration in this process [3]. More recently, a lot of works have been done on analyzing the influence of large groups of buildings and on the seismic response of the overall system using experimental and numerical methods [4, 5].

In the studies on DCI, numerical simulation is one of the most significant research means. In this paper, the general finite element analysis program ANSYS was adopted to analyze the 3D finite element model of adjacent highrise and multistoried buildings-pile-soil dynamic interaction system.

Modeling Method

In this paper, ANSYS program was employed to develop a 3-D model of a DCI system consists of a highrise building and an adjacent multistoried building, which referred to engineering practice. Then, the calculation and analysis of the dynamic responses of the model was conducted. In addition, the models which consist of two identical buildings or one single building were also developed. The symmetry of the buildings was used in the modeling. The overview of the models and its establishment are described in detail as follows.

Overview of the Models. The highrise building is a cast-in-place reinforced concrete frame structure, and the column arrangement is shown in Fig.1. The superstructure has 12 stories and the storey is 3.6 m in height. The cross-section dimensions of the columns and beams are 600 mm×600mm and 300mm×600mm respectively, and the cast-in-place floor slabs have a thickness of 120 mm. The main bar adopted in the structure is HRB335 deformed bar, and the concrete used here is C30. Pile-raft foundation is employed as the foundation; the layout of the piles is shown in Fig.2. The raft has a thickness of 1000 mm, and the square piles is 41 m long with a cross-section of 450mm×450mm. The multistoried building has 5 stories, and the number of stories is the only difference with the highrise building described above. The soil distribution adopted in the models can be referred to the soil nearby Shimen Yi Road, Shanghai (see [6]).

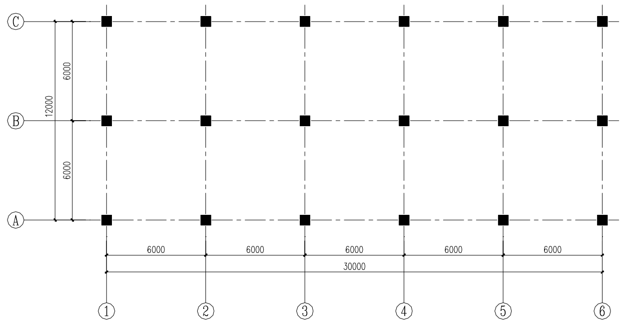


Fig.1 Column arrangement of the building

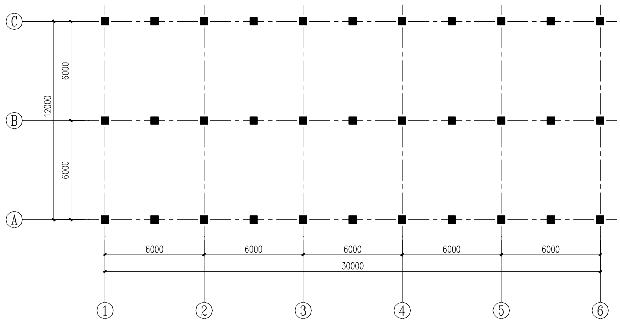


Fig.2 Pile arrangement of the building

Dynamic Constitutive Model of the Soil. The precision of the results given by a numerical simulation mostly depends on the selections of soil model and calculation parameters. An equivalent linear model of soil was adopted in the models. Through a comparison of several dynamic constitutive models, the Davidenkov model was selected, which can be described as:

$$\frac{G}{G_{\max}} = 1 - \left[\frac{\left(|\gamma| / \gamma_r\right)^{2B}}{1 + \left(|\gamma| / \gamma_r\right)^{2B}} \right]^A \quad (1)$$

$$\frac{D}{D_{\max}} = \left(1 - \frac{G}{G_{\max}}\right)^{\beta} \quad (2)$$

Where G_{max} and D_{max} are the maximum dynamic shear modulus and damping ratio respectively; A and B are fitting parameters; β is the shape factor of the $D\sim\gamma$ curve, and can be taken as 1.0 for Shanghai soft soil; γ_r is the reference shear strain which can be taken as $\gamma_r'(0.01\sigma_m')^{1/3}$. G_{max} can be calculated from the statistical relationships about the soil of Quaternary system in Shanghai, which was put forward by Zheng [7]. The other parameters can be taken from Table 1.

Table 1. The parameters of the Davidenkov model

Categories	A	B	D_{max}	$\gamma_r'(10^{-3})$
Clay soil	1.62	0.42	0.30	0.6
Silty soil	1.12	0.44	0.25	0.8
Sandy soil	1.10	0.48	0.25	1.0
Medium-coarse sand	1.10	0.48	0.25	1.2

Damping Model. In DCI systems, the soil damping ratio is usually larger than that of the concrete superstructure. So, it is necessary to input the damping ratios in the ANSTS program dividually.

In the models, the β-damping was adopted in modeling with ANSYS. So different damping ratios can be input for different materials. In this paper, the damping ratio of the superstructure was taken as 0.05. The initial damping ratio of soil was also taken as 0.05, which was then iteratively determined from the $D\sim\gamma_d$ curves.

The Viscous-Spring Artificial Boundary. Viscous-spring boundary is one of the commonly used artificial boundaries. Due to its clear concept and easy implementation, the viscous-spring artificial boundary is widely used, though it is only of first order accuracy. Deeks [8] derived viscous-spring artificial boundary condition under the assumption that the 2-D scattered wave is one kind of cylindrical wave. The viscous-spring artificial boundary condition derived by Deeks was adopted here and was implemented in the ANSYS program.

In ANSYS, the viscous-spring artificial boundary was implemented through the using of spring-damper elements. Boundary units in three directions was applied on each node. For the spring-damper element in ANSYS is based on the concepts of concentrated damper and concentrated spring, the damping coefficient and stiffness coefficient of every unit should be multiplied by the dominating area of the node which the unit is applied on.

Meshing. When meshing the model, the influence of wave motion should be paid full attention. It is difficult for the high-frequency component of the wave motion to be transmitted if the element is too large. A study reported by Gupta et al. [9] showed that, in the case of a shear wave transmitted vertically, the maximum height of the element h_{max} can be taken as $(1/5\sim1/8)v_s/f_{max}$,where v_s is the velocity of the shear wave and f_{max} is the highest wave frequency intercepted. The limitation of meshing size in the plane is not as strict as that in the height direction, and the size in the plane is commonly chosen as 3 to 5 times h_{max}.

Calculating Size of the Soil. When calculating the DCI, the key points to make sure that the developed model can reasonably simulate the engineering case are reasonable calculating size of the soil and correct artificial boundary. Li [10] studied the soil-structure interaction system and gave some conclusions on the enactment of calculating size of the soil. According to the conclusions, the longitudinal (y-direction) boundary was taken as 5 times the longitudinal size of the building, and the ends of the longitudinal boundary was set to be free boundary. As the seismic wave is along x-direction, the lateral boundary was determined through a comparison among several models with different lateral boundaries respectively. Ultimately, the lateral boundary was chosen as 18 times the lateral size of the building, with the artificial boundary to be viscous-spring artificial boundary.

The Dynamic Responses

After establishing 3-D models of the buildings with ANSYS, the El Centro wave was taken as the x-direction excitation to study the dynamic responses. The model consists of a highrise building and an adjacent multistoried building is shown in Fig.3. The analysis results of the model shown in Fig.3 was compared with the results of other models including two adjacent highrise buildings, two adjacent multistoried buildings, one single highrise building and one single multistoried buildings.

The Comparison of Acceleration Response. Fig.4 shows the peak accelerations of the highrise building which is adjacent to a multistoried building, the peak accelerations of the highrise building which is adjacent to a highrise building and that of a single highrise building. From Fig.4, we can see that the peak accelerations of the highrise building which is adjacent to a multistoried building are greater that in the other two conditions. The phenomenon means that the adjacent multistoried building makes the peak accelerations of the highrise building increase obviously.

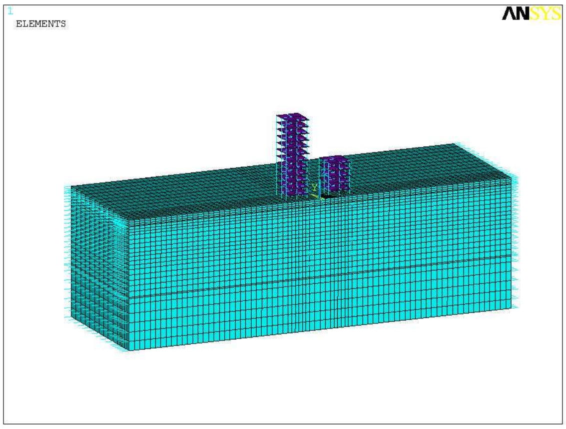


Fig.3 The model of adjacent highrise and multistoried buildings

Fig.5 shows the peak accelerations of the multistoried building which is adjacent to a highrise building, the peak accelerations of the multistoried building adjacent to a multistoried building and that of a single multistoried building. We can learn from Fig.5 that the peak accelerations of the multistoried building which is adjacent to a highrise building are lightly smaller than that in the other two conditions, but the decreasing range is no more than 5%. So, the influence of the adjacent highrise building on the peak accelerations of the multistoried building is slight.

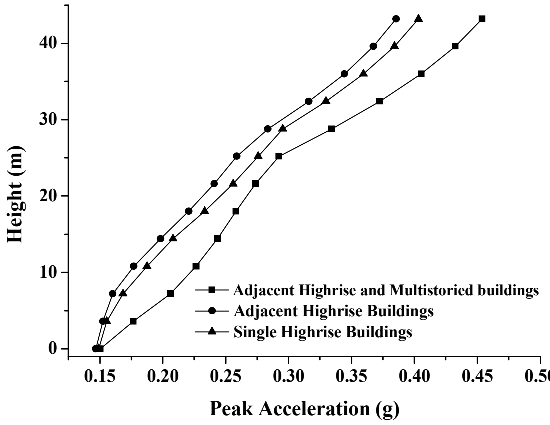


Fig.4.Peak acceleration of the highrise building

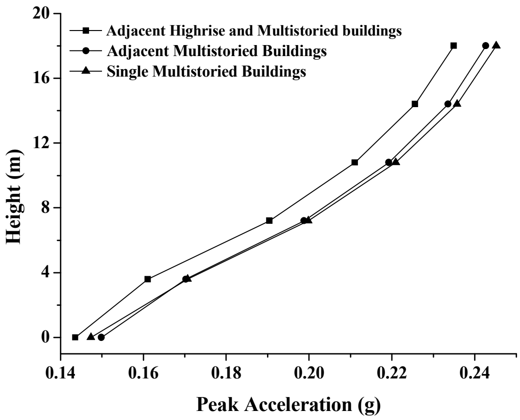
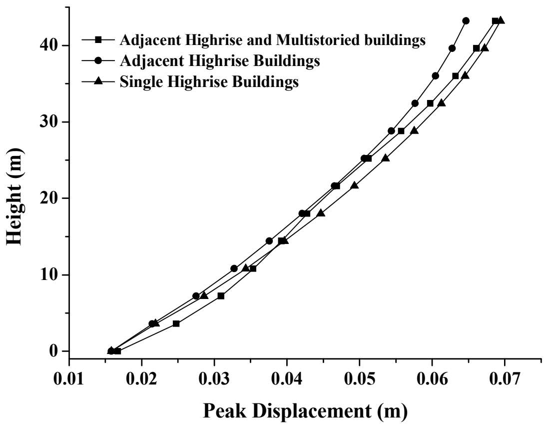


Fig.5.Peak acceleration of the multistoried building

Comparisons of the Peak Displacement Response. Fig.6 shows the peak displacement responses of the highrise buildings. As is shown in the figure, the peak displacement response of the highrise building adjacent to a multistoried one is obvious different from that of a single highrise building in the lower part, with the peak displacement of the foundation and the first two floor enhanced by 6%, 13% and 8% respectively. In the case of adjacent highrise buildings, the displacement of the upper part is affected obviously and tends to decrease.

The peak displacement responses of the multistoried buildings in three conditions are shown in Fig.7. From the figure, we can see that the peak displacements of the multistoried building decrease by a range of about 6% compared to that of one single building. On the other hand, the peak displacement response of the multistoried building is almost the same with that of one single building. The conclusion can be drawn as that, the adjacent highrise building could cause the peak displacements of the multistoried building to decrease to some extent.

Comparisons of the Composition of the Top Floor Displacements. Table.2 and Table.3 show the composition of the top floor displacement of the highrise buildings and the multistoried ones. As is shown in the tables, rocking takes an increased proportion in the top floor displacement both for the highrise building and the multistoried building, if they are adjacent to each other. It is well known that the rocking part reflects the influence to structure by the vertical disturbance of soil. So we can infer that, when a highrise building is adjacent to a multistoried one, the vertical disturbance of the soil under the structures will increase compared with the disturbance in the condition of two adjacent identical buildings or one single structure.



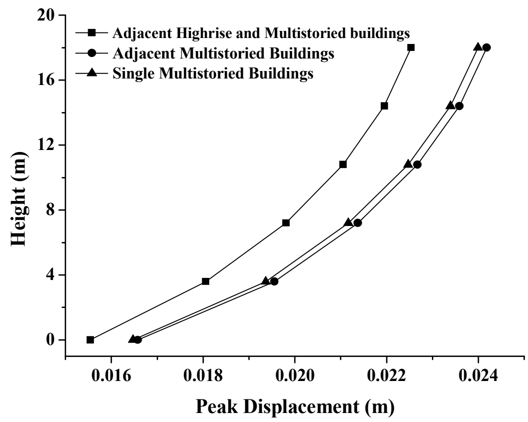


Fig.6.Peak displacements of the highrise building Fig.7.Peak displacements of the multistoried building

Table.2. The composition of the top floor displacement of the highrise buildings (unit: m)

Type	Total	Rocking		Translation		Elastic deformation	
	u	$H\theta$	Ratio	u_g	Ratio	u_e	Ratio
Adjacent Highrise and Multistoried buildings	0.0687	0.0148	21.6%	0.0167	24.3%	0.0372	54.1%
Adjacent Highrise Buildings	0.0647	0.0104	16.1%	0.0158	24.4%	0.0385	59.5%
Single Highrise Buildings	0.0694	0.0118	17.0%	0.0158	22.8%	0.0418	60.2%

Table.3. The composition of the top floor displacement of the multistoried buildings (unit: m)

Type	Total	Rocking		Translation		Elastic deformation	
	u	$H\theta$	Ratio	u_g	Ratio	u_e	Ratio
Adjacent Highrise and Multistoried buildings	0.0225	0.0014	6.2%	0.0155	68.9%	0.0056	24.9%
Adjacent Multistoried Buildings	0.0242	0.0007	2.9%	0.0166	68.6%	0.0069	28.5%
Single Multistoried Buildings	0.0240	0.0008	3.3%	0.0165	68.8%	0.0067	27.9%

Conclusions

In this paper, the general finite element analysis program ANSYS is adopted to analyze the 3D finite element model of adjacent highrise and multistoried buildings-pile-soil dynamic interaction system. From the analysis and comparison the following conclusions are obtained.

(1) Under the El Centro wave, when adjacent to a multistoried building, the peak accelerations of the highrise building on soft-soil foundation will increase compared with that of a single highrise building. Due to the effect of the adjacent multistoried building, the peak displacements of the lower part of the highrise building will increase. On the other hand, peak accelerations and peak displacements of the adjacent multistoried will slightly decrease.

(2) Compared with the condition of adjacent highrise buildings, the DCI effect on the highrise building adjacent to a multistoried building is more obvious.

(3) Under earthquake, rocking part of the top floor displacementof both the highrise building and the adjacent multistoried building will be much larger than which in the condition of two adjacent identical buildings or one single building. The phenomenon indicates a more intense disturbance in the soil below the structures.

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