Seismic Performance Analysis of Asymmetric High-Rise Connecting Structure under Frequent Earthquakes

Chen Bihua, Huang Xianhai

***Abstract*—The seismic response of high unsymmetrical connected structure is more complex, and its vibration response is related to the input of the earthquake and its own structure. Therefore, this paper taken a non-symmetrical high-rise connected structure as the research object, and used the general finite element software SAP2000 to establish analytical model. The mode decomposition response spectrum method and elastic time-history method were used to analyze the response of the engineering background model under the frequent earthquake.The results show that the corridor has a great influence on the seismic response of the whole structure, and the design of the corridor will reduce the drift of the partial floors. The internal force of corridor and substrate will be different under the action of different directions earthquake, and it should be considered separately in the structural design. At the same time, the results of the seismic response obtained by the two methods are in accordance with the requirements of the code. However, the seismic response of the complex connected structure is related to the input of earthquakes, and the time-history analysis results should be used to guide the design.**

***Key Words*—asymmetry; connecting structure; frequent earthquakes; response spectra; time -history analysis**

I. Introduction

Structural seismic response refers to the structural vibration displacement, velocity, acceleration and structural internal forces caused by earthquakes [1].The seismic response of high-rise conjoined structures is more complex, and its vibration response is not only related to seismic action, but also related to the stiffness and mass distribution of the structure itself, structural damping and other parameters.In order to ensure the safety of the structure during the design reference period of the high-rise structure, it is necessary to ensure that the vibration response of the structure under the action of frequent earthquakes must meet the requirements of the code [2].The seismic response of conjoined structures is particularly complex, and many scholars have studied such structures. Including the mandatory selection of corridor connection methods[3,4], optimization analysis of seismic parameters[5-7], analysis of seismic control measures[8], simulated shaking table test[9,10], etc.

Manuscript received June 18, 2023

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Common seismic response analysis methods include bottom shear method, response spectrum method and time history method. China's code clearly stipulates that for complex high-rise building structures, the response spectrum method must be used for calculation, and the time history method must also be used for supplementary calculations for frequent earthquakes[11]. Therefore, this paper uses the response spectrum method and the time history method to analyze the seismic response of an asymmetric high-rise conjoined structure.

II. Modeling

Taking an office building with a frame shear wall conjoined structure as the background project, Building No. 1 of the project has 28 floors above ground, and Building No. 2 has 22 floors above ground. The schematic diagram of the structure is shown in Fig.1. The cross-sectional dimensions of the frame columns of the two buildings are 800mm×800mm, the frame beams are 400mm×600mm, and the thickness of the shear walls is 300mm. The floor height of the first floor is 4.2m, and the floor height of each floor above the second floor is 3.3m. The corridor adopts steel structure truss, which is located between the 13th and 15th floors. The truss column adopts H500mm×300mm×12mm×20mm, the truss beam adopts H400mm×300mm×10mm×16mm, and the truss diagonal rod adopts □200mm×200mm×20mm.The structural design life of the building is 50 years, and the safety level is two. The anti-seismic fortification degree is 8 degrees, the design basic seismic acceleration is 0.2g, and the site category is Class II.

The three-dimensional space model (Fig.2) was established using SAP2000 finite element software, which included a total of 1751 nodes, 3363 frame elements and 1227 surface elements.

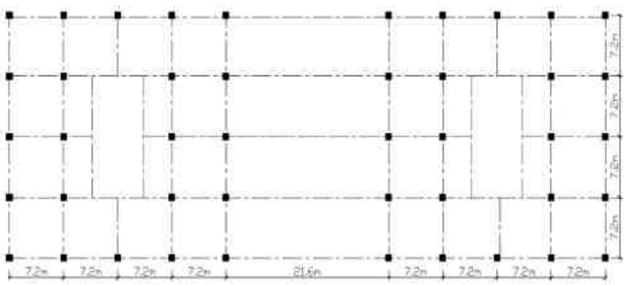


Fig.1 Structural floor plan

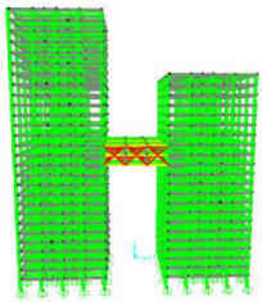


Fig.2 3D finite element model

III. Parameter Setting

3.1 Parameter of Vehicle-Track

According to the "Technical Regulations for Concrete Structures of High-rise Buildings" JGJ3-2010, the design response spectrum curve used is shown in Fig.3. According to the general information of the project, when setting the the parameters of the response spectrum, Tg=0.4s, $\alpha_{\max}=0.16$, γ=0.9, $\eta_2=1.0$, and the mode damping ratio is 0.05.parameters of the response spectrum, Tg=0.4s, $\alpha_{\max}=0.16$, γ=0.9, $\eta_2=1.0$, and the mode damping ratio is 0.05.

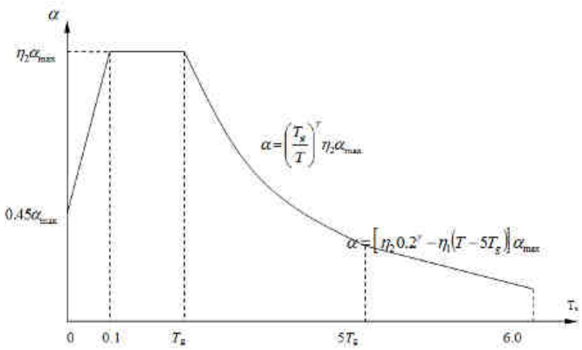


Fig.3 Earthquake influence coefficient curve

In the SAP2000 finite element software, the reaction spectrum curve parameters are set according to the specification requirements, and the response spectrum analysis is performed in the X and Y directions of the numerical model. In order to ensure the calculation accuracy, when calculating the maximum seismic response of the structure according to the mode shape

3.1 Structural deformation

Tab.1 shows the maximum displacement and acceleration peak value of the top layer of the structure. It can be seen from the table that the displacement values of the structure under the action of X-oriented earthquake are greater than the calculation results under the action of Y-direction earthquake. And the maximum displacement of building 1# is greater than that of building 2#, and the acceleration peak of building 2# is greater than that of

superposition method, the first 200 mode shapes are taken and combined, and the mode shape participation coefficient in the two directions is greater than 90%, and the mode shape combination adopts the CQC method. The reaction spectrum analysis is in the form of mode shape damping and the damping ratio is set to 0.05. The calculation results using mode decomposition reaction spectroscopy are shown in Tab.1, Fig.4 and Fig.5.

Fig.4 and Fig.5 plot the variation curves of the story drift ratios. It can be seen from the figure that under the X-direction earthquake, the story drift ratios of the two buildings is greatly affected by the corridor. The story drift ratios at the location of the corridor is small. And the corridor affects the story drift ratios of several adjacent floors. There is a quadratic curve relationship between the ground floor and the corridor, and between the corridor and the top floor, all showing a trend of increasing first and then decreasing. On the floors below the corridor, the story drift ratios of the two buildings are basically synchronized, with little difference. However, the difference of story drift ratios of floors above the corridor increases gradually. On the whole, the story drift ratios of each floor meets the requirement that story drift ratios between floors is not more than 1/800 in the specification. Under the action of Y-oriented earthquake, the story drift ratios is bounded by the floor where the corridor is located, and the overall trend is to increase first and then decrease, and the story drift ratios of building 1# is greater than that of building 2#, and the difference between the story drift ratios between the floors of the two buildings increases with the increase of floor height. At the same time, the story drift ratios between the floors of the two buildings meet the requirements of the code.

to 80 km/h, and the train is marshalled by six vehicle bodies, and in the track structures, 60kg/m grade rail applied for the metro track, 1600 bearing blocks are laid in quota per kilometer, elastic supporting block ballastless track and DTVI2 type fasteners are also selected. The parameters of track and vehicle are shown in table 1 and table 2.

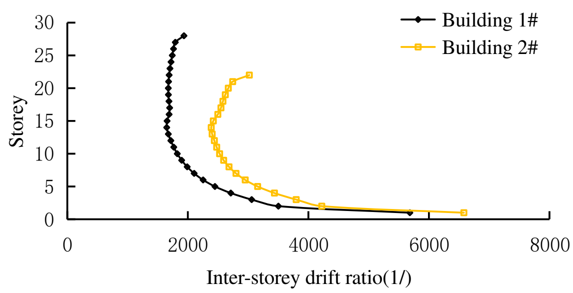


Fig.4 Variation curve of story drift ratios under X-direction earthquake

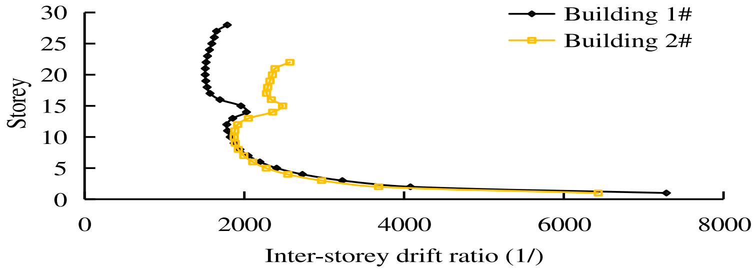


Fig.5 Variation curve of story drift ratios under Y-direction earthquake

Tab.1 Maximum displacement and acceleration of the top floor of the structure

Earthquake response	Building 1#		Building 2#	
	X	Y	X	Y
Maximum displacement of the top layer（mm）	49.35	48.19	31.52	25.88
Maximum acceleration on the top floor（m/s2）	2.54	1.62	2.71	1.74

Tab.2 Internal force of corridor and building base

Internal force	Corridor		Building base	
	Maximum bending moment in mid-span(kN·M)	Maximum shear force of upper beam(kN)	Shear force of the base(10^3kN)	Overturning moment(10^3kN·M)
X	38.11	10.51	12.91	630.60
Y	16.76	4.63	11.90	550.00

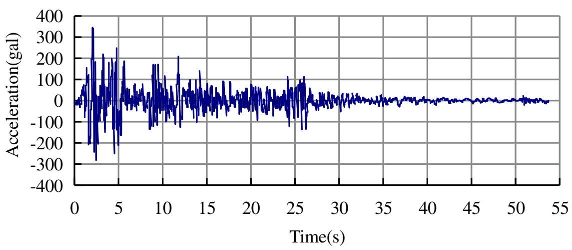
3.2 Internal force of corridor and building base

Tab.2 lists the shear force and overturning moment values of corridor and base under the action of response spectrum. It can be seen from the table that the internal force of the structure under the X-direction earthquake is greater than the calculation results under the Y-direction earthquake, indicating that the structure has a larger X-direction stiffness and a more obvious seismic response.

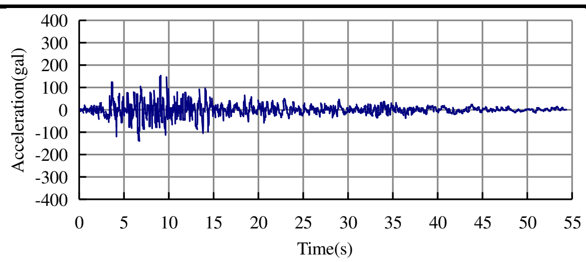
IV. ELASTIC TIME HISTORY ANALYSIS OF CORRIDOR STRUCTURE

4.1 Selection of time history curves

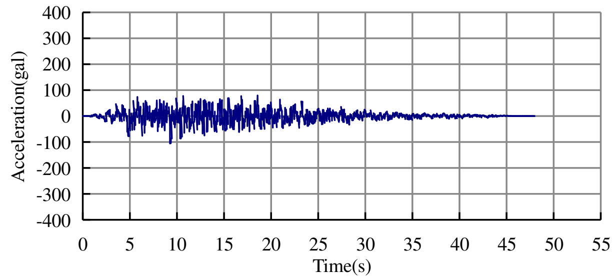
According to the basic information of seismic fortification in the engineering background, El-Centro wave, Taft wave and one artificial wave were selected for time history analysis, and the time history curves of the three waves are shown in Fig.6. According to the requirements, the peak adjustment of the three waves was carried out, and the adjustment coefficients were 0.2048, 0.4584 and 6.667, respectively.



（a）El-Centro wave



（b）Taft wave



（c）artificial wave

Fig. 6 Input time history curve

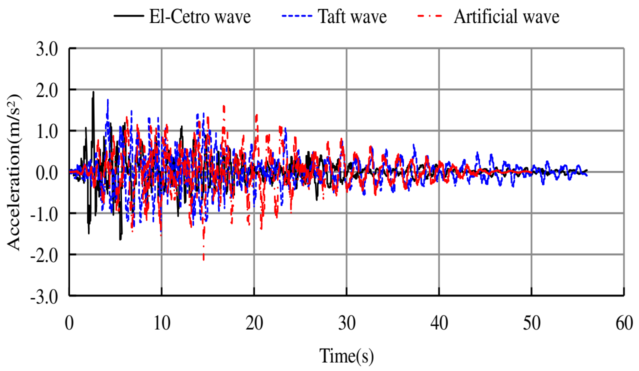
4.2 Structural Deformation

According to the seismic wave input determined in 4.1, the linear elastic time history analysis method was used to analyze the model. Tab.3 lists the maximum displacement and acceleration values of the top floors of the two buildings under different seismic waves. The maximum displacement and maximum acceleration of the top layer in the table are the maximum seismic response values in all nodes at the top level of the structure. It can be seen from the table that the top floor displacement of building 1# is greater than that of building 2#, and the top floor acceleration of building # 2 is greater than that of building 1#, which is determined by the floor height of the two buildings. At the same time, artificial waves have a greater impact on the 1# building; El-Centro has a greater influence on the Y direction of building 2#, and artificial waves have a greater influence on the X direction of building 2#.

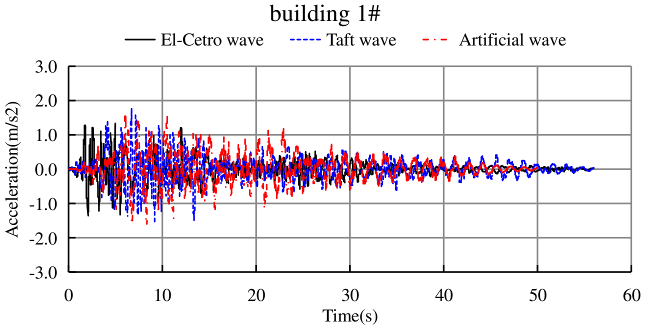
Tab.3 Maximum displacement and acceleration of the top floor of the structure

Seismic waves		Building 1#		Building 2#	
		Maximum displacement of top layer（mm）	Maximum acceleration on the top floor（m/s^2）	Maximum displacement of top layer（mm）	Maximum acceleration on the top floor（m/s^2）
El-Centro	X	43.33	2.05	27.12	2.88
	Y	37.82	1.71	38.11	2.44
Taft	X	55.40	2.94	35.41	4.61
	Y	49.43	1.84	29.83	2.33
Artificial wave	X	56.46	2.18	36.81	2.90
	Y	57.77	1.75	30.75	2.36

Fig.7 and Fig.8 respectively show the acceleration time history curves of the two buildings under the action of X-direction and Y-direction seismic waves. It can be seen from the figure that under the action of different seismic waves, the acceleration peaks appear at different times, and there is a certain phase difference. The peak value appeared first under the action of El-Centro, and the acceleration time-history curves under the action of Taft wave and artificial wave were more similar.

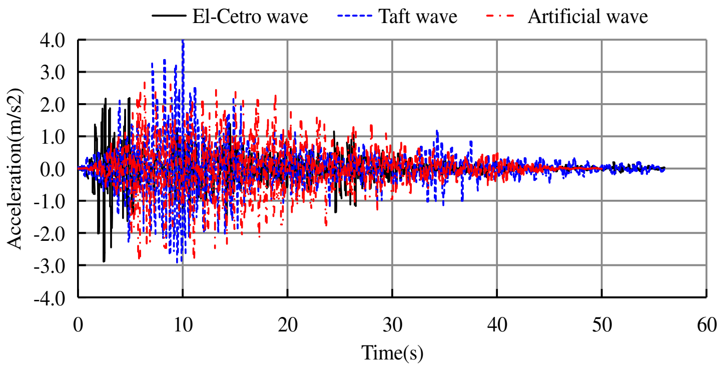


（a）Time-history curve of acceleration on the top floor of building 1#

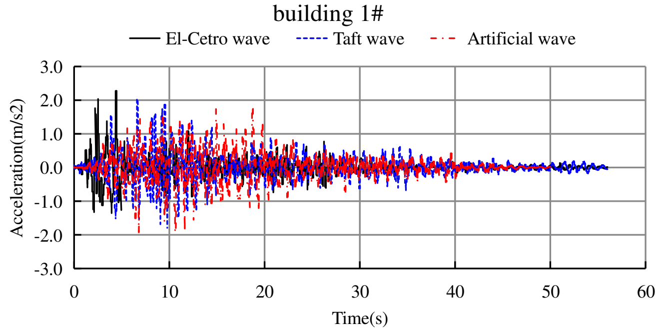


（b）Time-history curve of acceleration on the top floor of building 2#

Fig.7 The time-history curve of top floor acceleration under the action of X-direction seismic wave



（a）Time-history curve of acceleration on the top floor of building 1#

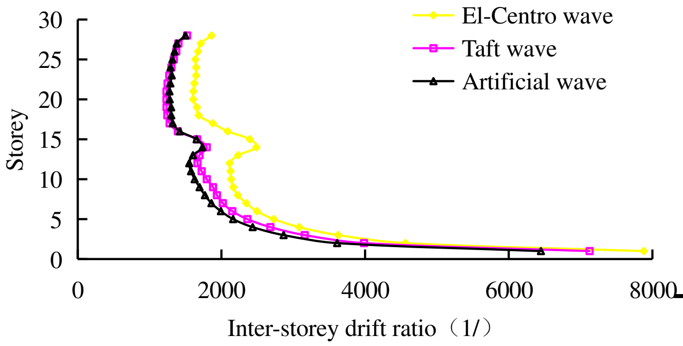


（b）Time-history curve of acceleration on the top floor of building 2#

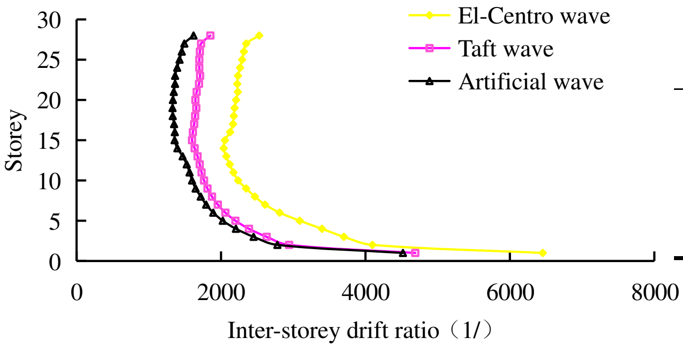
图 8 The time-history curve of top floor acceleration under the action of Y-direction seismic wave

It can be seen from Fig.9 that under the X-direction earthquake, the story drift ratios between the two buildings is greatly affected by the corridor. The story drift ratios of the floor where the corridor is located is small, and the corridor affects several adjacent floors. And it changes in a quadratic curve between the ground floor and the corridor, and between the corridor and the top floor, showing a trend of first increasing and then decreasing.On the floors below the corridor, the story drift ratios between the two buildings are basically the same. On the floors above the corridor, the difference in story drift ratios between floors increases gradually.Compared with the action of the three seismic waves, the story drift ratios under the action of El-Centro wave is relatively small, and the story drift ratios under the action of artificial wave is large. The story drift ratios of all floors is not greater than 1/800. And the impact of the corridor on the building 1# is greater than the impact on the building 2#. In general, the results of time history analysis are similar to those of response spectrum analysis.

Under the action of Y-direction earthquake, the story drift ratios between floors is bounded by the floor where the corridor is located, and the overall trend is to increase first and then decrease. The story drift ratios of building 1# is greater than that of building 2#. The difference in story drift ratios between the two buildings increases with the increase of floor height. The impact of the corridor on the building 1# is greater than that of the building 2#. Compared with the action of the three waves, the story drift ratios between the two buildings is the smallest under the action of El-Centro waves. Under the action of Taft wave, the story drift ratios between the layers of building 1# is large. Under the action of artificial waves, the story drift ratios between the layers of building 2# is large.

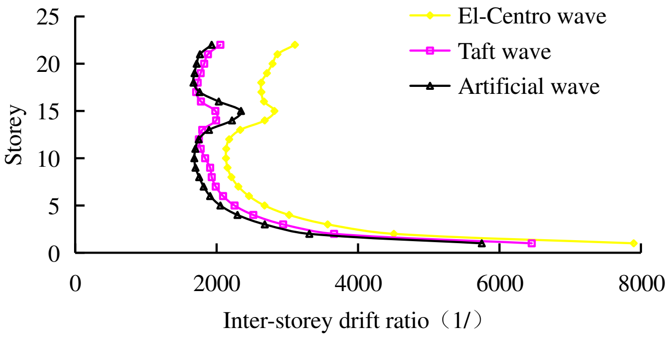


（a） Building 1#

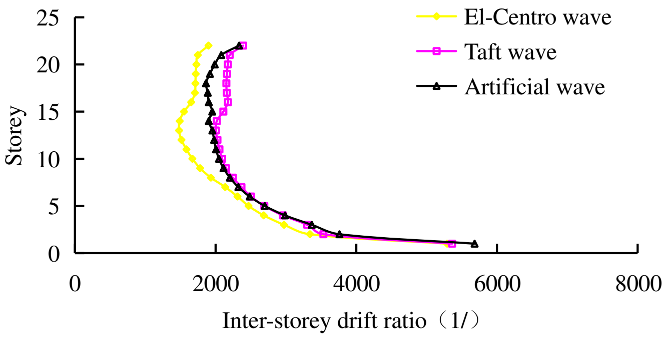


（b） Building 2#

Fig.9 Story drift ratios under the action of X-direction seismic wave



（a） Building 1#



（b） Building 2#

Fig.10 Story drift ratios under the action of Y-direction seismic wave

4.3 Internal force of corridor and building base

Table 4 lists the internal forces of the corridor, the shear force of the building foundation and the overturning moment values under the action of three seismic waves. It can be seen in the table that the internal forces of the corridor under the action of X-oriented earthquake are greater than those under the action of Y-direction earthquake. For the overall structure, the internal force of the substrate under the action of earthquake in the X direction is smaller than the internal force under the action of earthquake in the Y direction, and should be considered separately in the structural design. Compared with the three seismic waves, artificial waves had the greatest influence on the internal forces of the structure.

Tab.4 Internal force of corridor and building base

Seismic waves		Corridor		Building base	
		Maximum bending moment in mid-span(kN·M)	Maximum shear force of upper beam(kN)	Shear force of the base(10^3kN)	Overturning moment(10^3kN·M)
El-Centro	X	31.26	8.61	11.71	534.1
	Y	15.74	4.33	13.00	507.5
Taft	X	39.74	10.95	12.25	645.9
	Y	20.58	5.68	12.56	672.7
Artificial wave	X	45.64	12.61	14.12	699.3
	Y	22.18	6.13	15.34	712.9

5 Comparison of Response Spectrum and Elastic Time History Analysis Results

When calculating the seismic response by elastic time history analysis, the ratio of the bottom shear force of the structure under the action of each seismic wave to the result of the response spectrum method should not be less than 65%. The ratio of the average shear force at the bottom of the structure under the action of multiple seismic waves to the result of the response spectrum method should not be less than 80% [12]. Therefore, Table 5 lists the internal forces of the corridor and the shear values at the bottom of the structure under the action of three seismic waves and response spectra. From the comparison results, the ratio of the average value of the three wave time history analysis results to the response spectrum results is greater than 80%, and the single wave results are not less than 65% of the response spectrum results, which verifies that the three seismic waves used in the time history analysis meet the specification requirements. It can be used for further structural parameter analysis.

Tab. 5 Comparison of time history analysis and response spectrum analysis results

Seismic waves		Corridor		Building base	
		Maximum bending moment in mid-span(kN·M)	Maximum shear force of upper beam(kN)	Shear force of the base(10^3kN)	Overturning moment(10^3kN·M)
El-Centro	X	31.26	8.61	11.71	534.1
	Y	15.74	4.33	13.00	507.5
Taft	X	39.74	10.95	12.25	645.9
	Y	20.58	5.68	12.56	672.7
Artificial wave	X	45.64	12.61	14.12	699.3
	Y	22.18	6.13	15.34	712.9
average value	X	38.88	10.72	12.69	626.43
	Y	19.50	5.38	13.63	631.03
response spectrum	X	38.11	10.51	12.91	630.60
	Y	16.76	4.63	11.90	550.00
Average value/Response Spectrum（%）	X	102.02	102.03	98.32	99.34
	Y	116.35	116.20	114.57	114.73

CONCLUSION

In this paper, SAP2000 is used to establish the finite element model, and the mode decomposition reaction spectrum method and elastic time history analysis method are used to analyze the engineering background model, and the following conclusions are obtained:

(1) Under frequent earthquakes, the displacement response of the top floor of the high-rise building in the asymmetric connected structure is relatively large, and the acceleration response of the top floor of the low-rise building is relatively large.

(2) The corridor has a great influence on the seismic response of the whole structure, and the setting of the corridor will reduce the story drift ratios between the local floors. Both the response spectrum and time history analysis results show that the story drift ratios of each floor of the corridor structure meet the code requirements.

(3) The internal force of the corridor under the X-direction earthquake is greater than that under the Y-direction earthquake; but the internal force of the basement is relatively small, which should be considered separately in the structural design.

(4) The seismic response comparison results obtained by the two analysis methods meet the requirements of the code, but since the seismic response law of complex conjoined structures is related to the seismic input, the time history analysis results should be used to guide the design.

ACKNOWLEDGMENTS

The authors acknowledge the Science and Technology Program of Fujian Province Housing Department (2022-K-170).

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