Statistical Analysis on the Characteristics of Normalized Response Spectra of Ground Motion Records from Wenchuan Earthquake

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SUMMARY:
With 191 groups of acceleration records from the main shock of Wenchuan earthquake, the effects of site condition and fault distance (D) on the normalized response spectra of acceleration, such as predominant period(T_p), peak value and the shape of the spectrum, were analyzed. The normalized response spectra of acceleration from Wenchuan earthquake were compared with seismic design spectra of Chinese code. From the analysis, the following conclusions can be gotten: (1) when D<50km or 50≤D<200km, there is no obvious difference between the shapes of normalized response spectra of acceleration; (2) when D>200km, T_p increases and the value of normalized response spectrum of acceleration decreases in short period but increases in long period; (3) T_p calculated from the records increases with the increasing of D, and T_p calculated from the records of vertical component is smaller than those of horizontal component, but close with the increasing of D; (4)site condition is important for the shape of normalized response spectrum of acceleration, while the site turning soft, T_p calculated from the records becomes long and the value of normalized response spectrum decreases at short period range and increases at long period range; (5) for site class Ⅱ, design spectra of Chinese code is unsafe for some buildings on certain site under large magnitude earthquake.

Keywords: Wenchuan Earthquake; normalized response spectrum; predominant period

1. INSTRUCTIONS

Response spectrum, definite as the peak response of linear single-degree-of-freedom system to earthquake motion, is the research hot spot of earthquake engineering and the foundation of seismic design. Previous researches on the response spectrum were base on foreign ground motion records, which can not reflect the characteristics of frequency and attenuation in China. A large number of high quality digital strong motion records were got from Wenchuan Earthquake. It is the first one in China Mainland. Thus, ground motion records from Wenchuan Earthquake can better reflect characteristics of frequency and attenuation in China. Researches on spectrum characteristics of these records will provide more scientific basis for the seismic response analysis of engineering structure and correction of our seismic design spectra.

In common, the source characteristics, the dissemination way and the local site conditions influence the characteristics of ground motion response spectrum(Hu, 1988). The site condition among the three factors was paid more attention first, so the site condition was considered in many countries' seismic design code. Then, the source characteristics and the dissemination way also were got the earthquake engineering researchers' attentions with the development of strong earthquake observation technology and the accumulation of strong earthquake observation data. Kuribayashi et al.(1972) pointed out that response spectra in the long period is bigger at large magnitude or epicenter distance. Zhou(1984) analyzed influence factors to shape of normalized response spectrum of acceleration based on Japanese strong ground motion records, and indicated that the shape of normalized response spectrum is depended on magnitude and site condition more than epicenter distance. Zhou(2006) searched the relationship between T_p and site condition, magnitude and epicenter, discovered that the vertical Tp increased with the epicenter distance and magnitude and almost had nothing to sit condition. Researches of Li(2004), He(2006) and Dong(2008) showed that focal mechanism has influence to the spectrum characteristics near-fault ground. The paper analyzed the influence of site condition and fault displacement to response spectrum characteristics based on ground motion records from Wenchuan earthquake.

2. RECORDS FROM WENCHUAN EARTHQUAKE

At 14:28 on May 12, 2008 (Beijing time), an Ms=8.0 earthquake struck Southwest China. The earthquake epicenter was located at latitude 31.021°N, longitude 103.367°E, Wenchuan, Sichuan Province. Field investigations and an earthquake source inversion study showed that the devastating earthquake ruptured unilaterally from southwest to northeast with a rupture length at the ground surface of about 240 km along the Beichuan-Yingxiu fault and 72 km along the Guanxian-Jiangyou fault(Chen,2008; Liu, 2009).The paper selected 191 groups, 573 components, ground acceleration records from Wenchuan main shock, analyzed the influence of site condition and fault distance to response spectrum characteristics. The distribution of records selected from Wenchuan earthquake is shown in Table 1.1.

Table1.1. Distribution of records from Wenchuan Earthquake

site classification	Fault distance / km			
	0~50	50~200	200~400	>400
Ⅰ	4	6	9	0
Ⅱ	18	39	55	36
Ⅲ	0	1	1	22

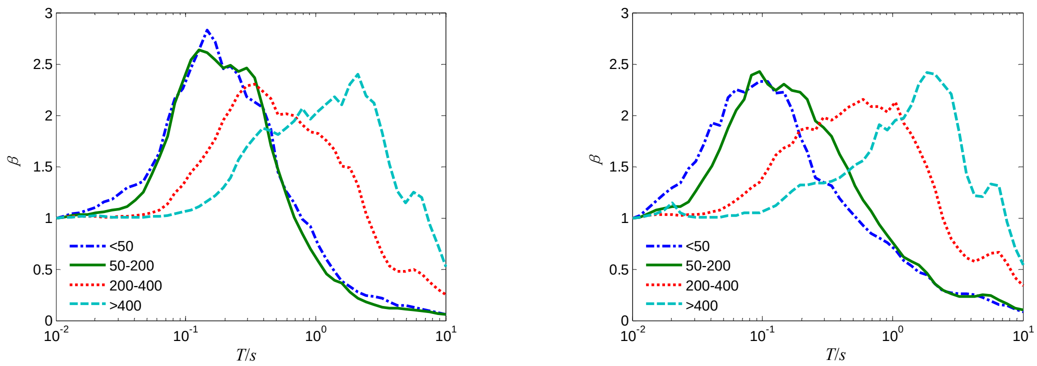
3. CHARACTERISTICS OF NORMALIZED RESPONSE SPECTRUM

The studies in this paper were based on the normalized response spectrum. The normalized response spectrum can be calculated as response spectrum divided by peak acceleration of the ground motion. The average of normalized response spectrum reflects the characteristics of response spectrum shape better than the average of response spectrum for the influence of peak acceleration of ground motions. The design spectra of Chinese seismic code (earthquake influence coefficient curve) are depended on average normalized response spectra of acceleration.

3.1 Influence of fault distance

As shown in Table 1.1, ground motion records on site class Ⅰ are so little that statistical results have no representative within 50km from the fault. So, the section just selects the records on site class Ⅱ to study.

Figure 3.1(a) and (b) are the average normalized acceleration response spectra (β curves) of horizontal and vertical components with different ranges of fault distance (D). From the figure 3.1, it is seen that shapes of β curves are different. The shape of curve 1(D<50km) is similar with curve 2(50km≤D<200) in horizontal direction and different in vertical direction. When D>200km, the shapes of β curves in both direction have large change with fault distance increases. While D increasing, the predominant period becomes long and the value of β decreases at short period range and increases at long period range. The peak value of β curves decrease firstly and then increase with D increase. In comparison with the horizontal β curves, the vertical β curves have more significant regularity. The peak values and predominant periods of horizontal β curves are larger than the vertical when D<100km and become close with D increases. Because the vertical ground motion contains more high frequency component than the horizontal near the fault(Bozorgina, 1993).

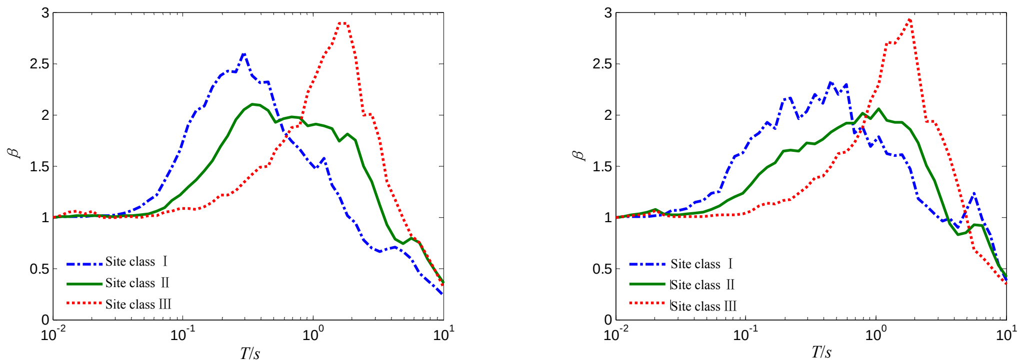


(a) Horizontal direction (b) Vertical direction

Figure 3.1. Normalized response spectra of different fault distances

3.2 Influence of site condition

Ground motion records with *D*<200km is few on site class Ⅲ, so the section just selects the records with D>200km to study the influence of site condition. Figure 3.2(a) and (b) are the average normalized acceleration response spectra of horizontal and vertical components with different site conditions. Figure 3.2 shows that the influence of site condition to the shapes of β curves is significant. While the site turning soft, the predominant period becomes long and the value of β decreases at short period range and increases at long period range. They are consistent with the former statistical results.



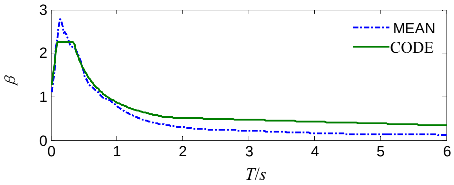
(a) Horizontal direction (b) Vertical direction

Figure 3.2. Normalized response spectra of different site conditions

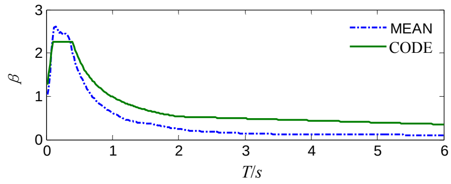
3.3 Comparison with seismic design spectrum of code

According to the Code for Seismic Design of Buildings, most of building sites belongs to the class Ⅱ in our country. And ground motion records on site class Ⅱ from Wenchuan earthquake are the most abundant. So, records on site class Ⅱ are selected to compare with the seismic design spectrum. Divided the records into 3 groups with fault distance ranges as D≤50km, 50km<*D*≤200km and 200km<*D*≤400km. Their average normalized acceleration response spectra compare with the seismic design spectra of 3 groups, design earthquake group first, second and third, in Chinese Code for Seismic Design of Buildings respectively. The results were shown in figure 3.3.

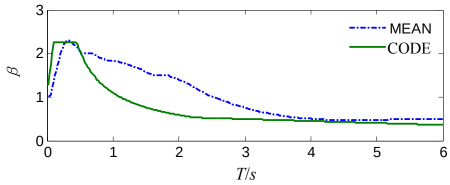
From the figure 3.3, it is known that when *D*≤200km, the average normalized acceleration response spectra are larger than seismic design spectra at short period range *T*<0.4s and smaller at long period range. When *D*>200km, the average normalized acceleration response spectra are larger than seismic design spectra at the period range 0.5s<*T*<3s and smaller at short or long period range. Thus, seismic design spectra in our Code for Seismic Design of Buildings are unsafe on class site Ⅱ for large magnitude earthquake. The seismic design spectra at short period range *T*<0.4s for the site belong to group first or second and at period range 0.5s<*T*<3s for the site belong to group third classified by the code are necessary to increase.



(a) $D\leq$50km



(b) 50km< $D\leq$200km



(c) 200km< $D\leq$400km

Figure 3.3. Comparison with seismic design spectra of code

4. CONCLUSIONS

Influences of site condition and fault distance to the normalized acceleration response spectra had been analyzed base on 191 groups strong ground motion records from Wenchuan main shock. And the paper compared the average normalized acceleration response spectra with the seismic design spectra on site class Ⅱ, pointed out that the seismic design spectra are unsafe for some buildings on certain site under large magnitude earthquake. The results as follows:

(1) while D increasing, the predominant period becomes long and the value of β decreases at short period range and increases at long period range. The peak value of β curves decrease firstly and then increase with D increase. The peak values and predominant periods of horizontal β curves are larger than the vertical when D<100km and become close with D increases.

(2) site condition is important for the shape of normalized response spectrum of acceleration, while the site turning soft, predominant periods calculated from the records become long and the value of normalized response spectra decreases at short period range and increases at long period range.

(3) when $D\leq$200km, the average normalized acceleration response spectra are larger than seismic design spectra at short period range T<0.4s and smaller at long period range. When D>200km, the average normalized acceleration response spectra are larger than seismic design spectra at the period range 0.5s<T<3s and smaller at short or long period range. Thus, seismic design spectra in our Code for Seismic Design of Buildings are unsafe on class site Ⅱ for large magnitude earthquake.

It's necessary to explain that the conclusions above are based on the strong motion records from Wenchuan earthquake. The results have limitations for the influence of some factors such as source characteristics, magnitude and so on. But the paper will provide reference for the seismic response analysis of engineering structure and correction of seismic design spectra in code.

AKCNOWLEDGEMENT

The work is supported by Basic Research Foundation of Institute of Engineering Mechanics, China Earthquake Administration under Grant No. 2011B02.

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