Determination of Design Earthquakes based on the Dynamic Properties of Structures

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SUMMARY:
To decrease the level of unacceptable seismic risks, the practical and efficient approach is to determine design ground motion for the structures reasonably by seismic hazard analysis. In this paper, a method of determining design ground motion based on the dynamic properties of structures was proposed. Then its practicability and applicability were discussed by an example that two structures with different periods were constructed in Dalian. We suggest that the dominant potential seismic source be determined according to the dynamic properties (e.g. expected period) of the structures. And then we utilized the contribution functions of some dominant sources, and attenuation law to determine design earthquake magnitude and epicentral distance. According to these results, design ground motion parameters could be determined reasonably.

Keywords: seismic hazard analysis; design earthquake; dynamic property; potential seismic source

1. INTRODUCTION

With the fast development of science and technology in China, lots of critical engineering structures have been constructed all over the country. It's inevitable that some of them may be constructed in the regions where earthquakes frequently occur. Once these critical engineering structures are destroyed, they will bring serious secondary disasters and inestimable economic loss. Whereas the tremendous economic losses and deaths of people, as well as the enormous effects on the harmonious and continuous development of society in the past earthquakes home and abroad, both government and society should pay more attention to improving the level of prediction and increasing the seismic safety of the critical structures. To mitigate the seismic hazard, one of the most efficient approaches is to determine design ground motion for these critical structures reasonably by seismic hazard analysis. What's more important is how to determine ground motion reasonably. The conventional methods to design ground motion are often considering the consistency of peak values or response spectra. They cannot reflect the synthetical effects of magnitude, distance and site condition. By much research work, the author indicate that the design ground motion not only reflects the effect of the most dominant potential seismic sources on the site, but also reflects the dynamic properties of the structures, i.e. the predominant period of the ground motion close to the vibration period of structures. In this paper, the latter was discussed in detail. The purpose is to establish the connection between the design ground motion and exact structures.

A method of determining design ground motion based on the dynamic properties of engineering structures is proposed in this paper and its practicability and applicability are discussed by an example that two structures with different periods are constructed in Dalian, China.

2. DETERMINATION OF DESIGN GROUND MOTION

The contribution of potential seismic source in different magnitude intervals is specifically related to probability distribution function of magnitude and spatial probability distribution function at given intensity of ground motion. The former reflects the possibility of earthquake occurrence while the latter reflects the effect of earthquake of given intensity on the site. The probability distribution function of magnitude $P_l(m_j)$ is written as

$$P_l\left(m_j\right) = \frac{v\left(m_j\right) f_{l,m_j}}{\sum_{j=1}^{N_m} v\left(m_j\right) f_{l,m_j}} \tag{1}$$

where $f_{l,m}$: spatial distribution function of magnitude interval m_j within potential seismic source l; $v(m_j)$: average annual occurrence rate of magnitude interval m_j within the seismic belt.

$$v\left(m_j\right) = \frac{2v\exp\left[-\beta\left(m_j - M_0\right)\right]}{1-\exp\left[-\beta\left(M_{uz} - M_0\right)\right]} \mathrm{sh}\left(\frac{1}{2}\beta\Delta m\right) \tag{2}$$

Based on given intensity of ground motion y and magnitude m_j, spatial distribution function $P_s(m_j|Y\geq y)$ is given by

$$P_s\left(m_j \mid Y \geq y\right) = \frac{N_{m_j}}{\sum_{j=1}^{n} N_{m_j}} \tag{3}$$

where n: number of magnitude intervals in which ground motion acceleration at the site is bigger or equal to given y; N_{mj}: total number of element in which ground motion acceleration at the site is bigger or equal to given y when magnitude is in the magnitude interval j.

In general, the smaller the magnitude is, the bigger the occurrence probability and the smaller the spatial probability are, vice versa. Therefore, the probability distribution of contribution given by earthquakes with different magnitudes should be obtained by normalizing the results of the probability distribution of magnitude multiplied by spatial probability distribution.

$$P_l\left(m_j \mid Y \geq y\right) = \frac{1}{Q} \frac{N_{m_j}}{\sum_{j=1}^{n} N_{m_j}} P_l\left(m_j\right) \tag{4}$$

where Q: normalized coefficient. Then the magnitude interval with largest contribution is obtained. Therefore, the design earthquake magnitude is determined.

The magnitude and epicentral distance are not in-dependent of each other. After design earthquake magnitude is determined, the epicentral distance will be obtained according to attenuation law.

In this paper, we select the expected periods of structures as the characteristic parameters to determine the design ground motion related to the structures. Assuming that the natural periods of first q modes of project as $T_i(i=1,2,\ldots q)$ and the relevant mode participation coefficients γ_i, the expected period of the engineering project is computed as

$$\overline{T} = \sum_{i=1}^{q} w_i T_i \; ; \quad w_i = \gamma_i / \sum_{i=1}^{q} \gamma_i \tag{5}$$

3. EXAMPLE

First, the ground motion parameters of sites with different levels of seismic hazard were obtained by probabilistic seismic hazard analysis (PSHA). Then, we determined the dominant potential seismic sources according to the dynamic property (e.g. expected period) of the structures. And we utilize the contribution functions of some dominant sources, and attenuation law to determine design earthquake magnitude and epicentral distance.

Dalian is located in the northeast of North China seismic belt where the frequency and intensity are both higher. Figure 1 showed the sketch map of potential seismic sources in the research region. The results of seismic hazard analysis in Dalian are shown in Table 1 and Fig. 2.

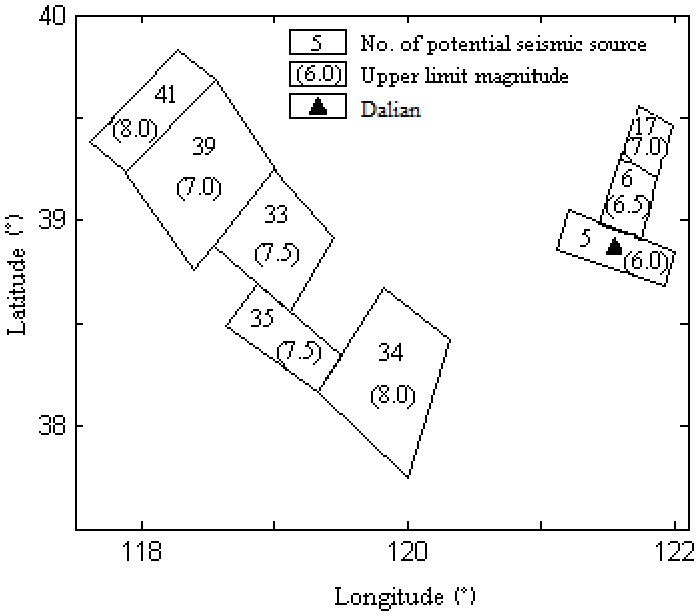

Figure 1. The sketch map of potential seismic sources in the research region

Table 1 Results of seismic hazard analysis in Dalian

Probability of exceedance in 50 years /(%)	Peak horizontal acceleration, a_A /(cm/s^2)
63	24.9
10	118.8
2	241.3

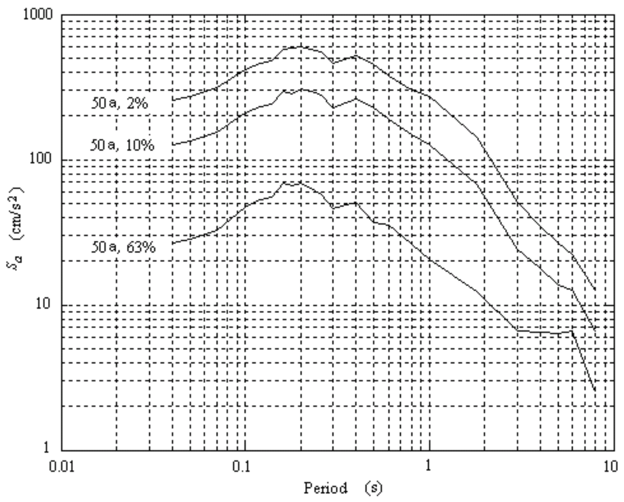

Figure 2. Acceleration spectrum of Dalian

In this paper, we chose two structures with different periods to illustrate the determination of the design ground motion based on the dynamic properties of structures. Firstly, we took the higher structure as example to compute the expected period. The natural periods T of first 10 vibration modes were 7.05364 s, 4.91414 s, 0.21619 s, 0.09783 s, 0.09058 s, 0.05136 s, 0.04456 s, 0.03418 s, 0.02011 s, 0.01554 s. According to the relevant mode participation coefficients γ_i, the expected period of the higher structure was computed by Eq. (6), $\overline{T}$ =1.8 s. In the same way, the expected period of the shorter structure was 0.1 s.

Then, the contribution curves of the major potential seismic sources to Dalian at T=1.8 s and T=0.1 s were obtained by PSHA (see Figs. 3 and 4). The bold line in the figures stood for the total annual probability of exceedance.

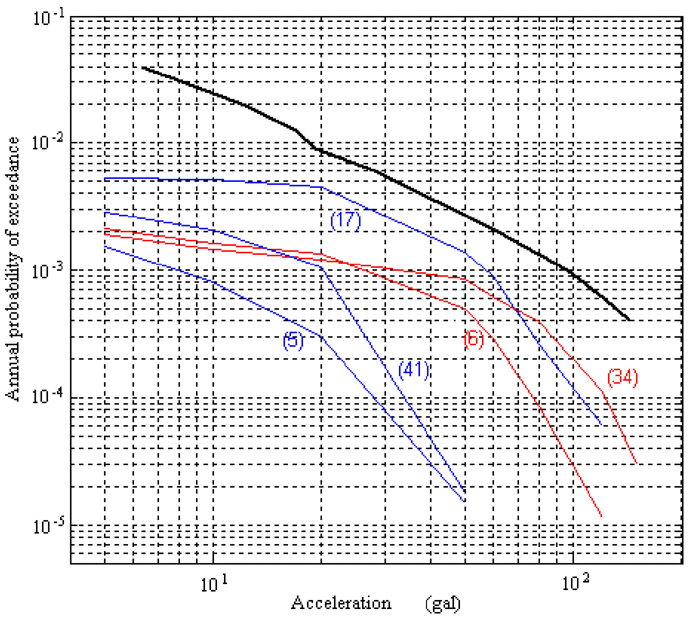

Figure 3. Contribution curve of the major potential seismic sources to Dalian at T=1.8 s

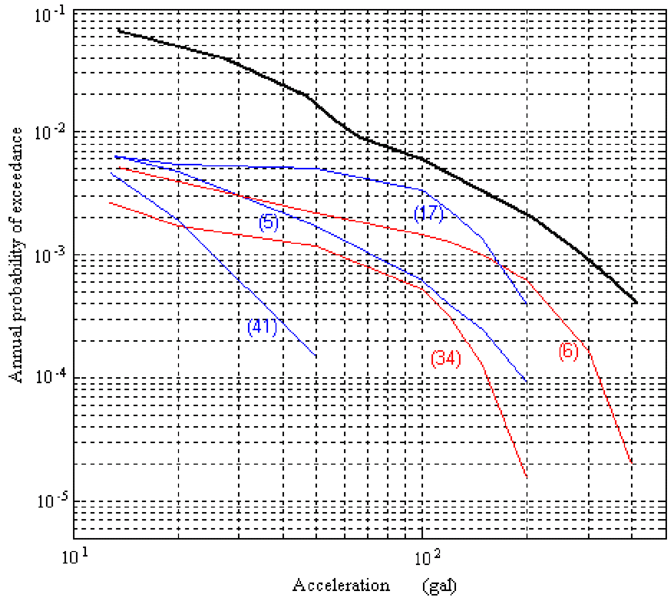

Figure 4. Contribution curve of the major potential seismic sources to Dalian at T=0.1 s

In Fig. 3, we could see that at T=1.8 s, the effects of No. 17 potential source on Dalian were the most dominant when the probabilities of exceedance in 50 years were 63% and 10%; while No. 34 potential source was the most dominant when 2%. We also could find that in Fig. 4, at T=0.1 s, No. 17 was the most dominant potential sources when the probabilities of exceedance in 50 years were 63% and 10% while No. 6 was the most dominant when 2%. Then the probability distribution functions of magnitude were obtained by Eqs. (1) and (2) and the probability distribution of contribution given by earthquakes with different magnitudes was obtained by normalizing the results of the probability distribution of magnitude multiplied by spatial probability distribution using Eqs. (3) and (4), (see Figs. 5 and 6). After the design earthquake magnitudes were determined, the epicentral distances were obtained according to the attenuation law. The results were shown in Table 2.

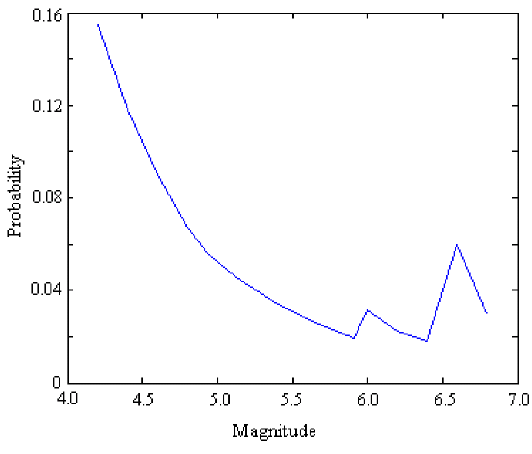

Figure5. Probability distribution of magnitude in No.17 potential seismic source

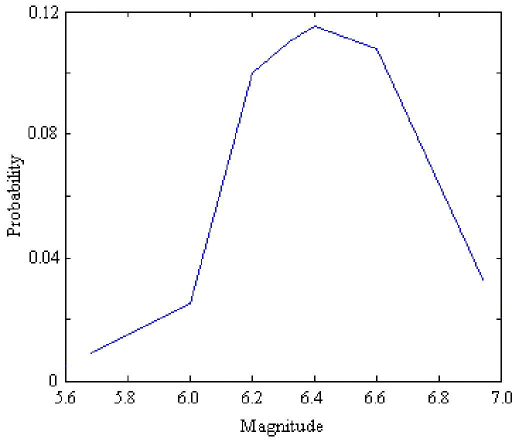

Figure 6. Probability distribution of contribution given by earthquakes with different magnitudes in Dalian based on 63% probability of exceedance in 50 years (1.8 s)

Table 2. Comparison of design earthquakes in Dalian at T=0.1 s and T=1.8 s

Probability of exceedance in 50 years	T=0.1 s			T=1.8 s		
	Dominant potential source	Magnitude	Epicentral distance	Dominant potential source	Magnitude	Epicentral distance
63%	17	6.2	60 km	17	6.4	66 km
10%	17	6.6	36 km	17	6.7	35 km
2%	6	6.5	18 km	34	7.8	92 km

It could be concluded through Table 2 that the effects of different structures at the same sites suffered from the same earthquake were different. The structures with long periods were more sensitive to the ground motion caused by far and large earthquakes while structures with short periods were sensitive to near and small earthquakes. Therefore, the design earthquakes should be determined based on the dynamic properties of the structures and site condition. The design earthquakes under different levels of seismic hazard may be come from different potential seismic sources.

4. CONCLUSIONS

In this paper, the conception of design earthquakes related to structures was proposed based on the determination of design ground motion by dynamic properties of structures. The effects of different structures at the same sites suffered from the same earthquake were researched. We found that the structures with long periods were more sensitive to the ground motion caused by far and large earthquakes while structures with short periods were sensitive to near and small earthquakes. Therefore, different design ground motions should be determined according to the dynamic properties of structures with different periods at the same site and then they could be used in the seismic design of structures.

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