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Suggestion on the Value of the Peak Acceleration for Vertical Ground Motion Design in High-intensity Area

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Abstract

Based on design seismic grouping and venue category, make recommendations to the value of the peak acceleration for vertical ground motion design in high-intensity area. Over 10000 sets of three-component seismic data were collected for screening analysing and matching, to perfect the Code for Seismic Design of Buildings (GB50011-2010) (2016 edition)'s stipulation that vertical-to-horizontal (PGAV/PGAH) ratio is 65%. Compared with the code, which defines the ratios according to seismic precautionary intensity, paper added two factors, site and design seismic grouping, to make the value more accurate.

Keywords

Vertical ground motion;peak acceleration for design;site;value suggestion.

1. Introduction

The latest edition of the *Code for Seismic Design of Buildings (GB50011-2010) (2016 edition)* in China stipulates that "for high-rise buildings with long-span structures at 8 and 9 degrees and long cantilever structures at 9 degrees, the vertical seismic action should be calculated" [1] and vertical-to-horizontal (PGA_V/PGA_H) ratios is 65%. With the construction of seismic stations and the increase of seismic data, some earthquake damages show that the vertical seismic action sometimes mainly leads to the final damage of the structure[2], and in many cases, the peak acceleration for vertical ground motion is greater than 65% of the peak acceleration for horizontal ground motion[3,4]. There have even been cases where the peak acceleration of vertical ground motion exceeds that of horizontal ground motion[5,6].

It can be seen that our understanding of vertical ground motion still needs to be deepened, and further discussion on the characteristics of vertical ground motion has profound practical and engineering significance. This paper will discuss the relationship between vertical ground motion and intensity and give suggestions on the value of peak acceleration for vertical ground motion design based on intensity.

2. Data sources and screening

In this paper, a total of 10,283 sets of three-component seismic data were collected through the Institute of Engineering Mechanics of China Earthquake Administration, U.S. Geological Survey (USGS), COSMOS Virtual Data Center (COSMOS VDC), Pacific Earthquake Engineering Research Center (PEER) NGA database, California Integrated Seismic Network (CISN), European Strong-

Motion Database, National Research Institute for Earth Science and Disaster Prevention in Japan, GeoNet Program of New Zealand, Central Meteorological Bureau of Taiwan, and other websites, with a time span of nearly 15 years, covering the following countries and regions: China, the United States, Japan, New Zealand, Europe, Taiwan, China, India, etc.

Since this paper mainly studies the peak acceleration of vertical ground motion, and *Code for Seismic Design of Buildings (GB50011-2010) (2016 edition)* 5.1.1.4 stipulates that "for high-rise buildings with large-span structures at 8 and 9 degrees and long cantilever at 9 degrees, the vertical seismic action should be calculated [1]". At the same time, when the epicentral distance is too large, the records of the stations themselves will be biased[7], and the vertical ground motion attenuates rapidly with the increase of the epicentral distance, so only a total of 6188 sets of three-component seismic data with magnitude M ≥ 5 and epicentral distance R ≤ 300 km were selected in this paper.

Four sets of data with magnitudes M=5, 6, 7, 8 were selected, and the four sets of data were preliminarily fitted with statistical MATLAB software to obtain the attenuation relationship of the peak ratio k with the epicentral distance R under different earthquake magnitudes as follows (Fig. 1):

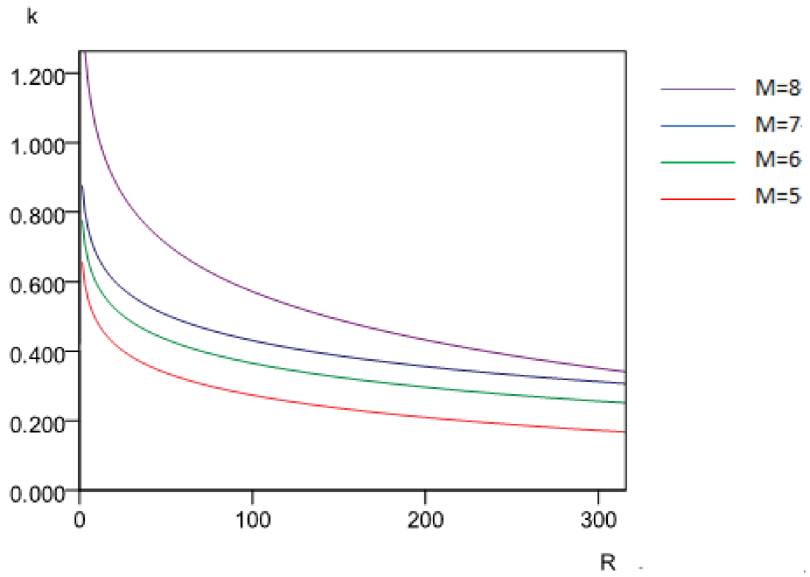

Fig. 1 k-R curves of different earthquake magnitude

It can be found from the figure that for each magnitude of the k-R relationship curve: when the epicentral distance R is greater than 200 km, the ratio k of PGA_V to PGA_H tends to be flat with the change of the epicentral distance R, and hardly changes. Therefore, this paper selected the epicentral distance R≤200 km as the screening condition, and the total number of screened data is 2038 groups.

In order to ensure the reliability of the analysis, it is necessary to eliminate outliers[8]. Using the 3σ principle [9,10] as the screening criteria, the data were screened by MATLAB Software, and a total of 2034 groups of data were used for the analysis in this paper after screening.

3. Discussion on the relationship between the ratio of peak acceleration and intensity

This paper introduced the research results of Hu Yuxian [11], used Hu Yuxian's intensity attenuation model to obtain the seismic intensity corresponding to each set of data, and discussed the relationship between the intensity and the peak ratio considering site factors[12].

In his classic book Earthquake Engineering [13], Hu Yuxian obtained the relationship between the intensity I, the magnitude M, and the epicentral distance R by mean of the regression analysis as follows:

$$I=0.92+1.63M-3.49\log R \quad (1)$$

In this paper, the design seismic grouping is determined by the first degree than the epicentral intensity for near earthquakes and two degrees lower for distant earthquakes, where the classical formula for epicentral intensity is introduced [13].

$$M=0.66I_0+0.98 \quad (2)$$

Combined with the relationship model between intensity and magnitude, epicentral distance, and site design earthquake grouping [14], MATLAB software is used to analyze and map [15]. Fig. 2 can be obtained as follows:

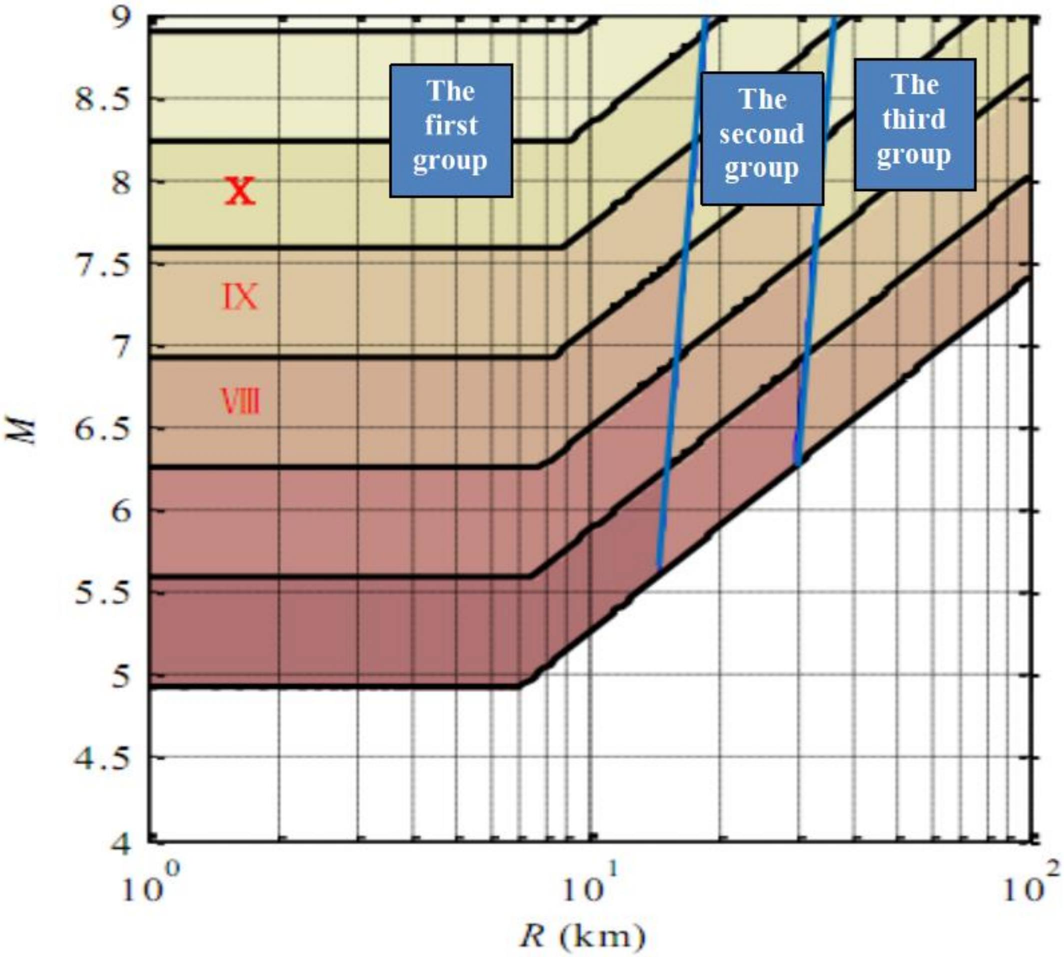

Fig. 2 Equal intensity zoning map

Since the current *Code for Seismic Design of Buildings* in China stipulates that vertical seismic action should be considered in the area of 8 and 9 degrees, the data at the intersection of the 8 and 9 degrees and the design earthquake grouping in the graph are taken out, as shown in Table 1.

Table 1 PGA_V/PGA_H of different characteristic periods when I=8, 9

Intensity	Design seismic grouping	Venue category	Characteristic period (s)	Peak ratio
8	The first group	I	0.25	0.521
		II	0.35	0.535
		III	0.45	0.55

Intensity	Design seismic grouping	Venue category	Characteristic period (s)	Peak ratio
		Ⅳ	0.65	0.58
	The second group	I	0.3	0.606
		II	0.4	0.623
		III	0.55	0.648
		Ⅳ	0.75	0.684
	The third group	I	0.35	0.664
		II	0.45	0.682
		III	0.65	0.719
		Ⅳ	0.9	0.769
	The first group	I	0.25	0.574
		II	0.35	0.589
		III	0.45	0.605
		Ⅳ	0.65	0.638
9	The second group	I	0.3	0.729
		II	0.4	0.749
		III	0.55	0.78
		Ⅳ	0.75	0.822
	The third group	I	0.35	0.811
		II	0.45	0.833
		III	0.65	0.879
		Ⅳ	0.9	0.939

Table 1 compares the peak accelerations corresponding to Category I, Category II, Category III, and Category IV sites when the design earthquakes in the high-intensity area (intensity of 8 degrees and 9 degrees) are grouped into the first, second, and third groups, and the intensity is 8 degrees. When the design earthquakes are grouped in the first and second groups of Category I, Category II, and Category III sites, the peak ratios are all less than 0.65 in the *Code for Seismic Design of Buildings (GB50011-2010) (2016 Edition)*; the intensity is still 8 degrees, but the design earthquake is grouped into the second group of Category IV sites, especially when the design earthquake is grouped into the third group, the peak ratio of 0.65 is obviously smaller; the peak ratio is less than 0.65 when the seismic intensity is 9 degrees and the design seismic grouping is in the first group; while for other design seismic groupings with the intensity of 9 degrees, the peak ratio of 0.65 is too small.

The following rules can be obtained from the table:

The peak ratio increases when the site category is from Class I to Class IV;

The relationship between peak ratio and intensity is closely related to site category and design grouping.

4. Conclusion

In this paper, MATLAB software is used for analysis. Based on the collected 10283 sets of three-component seismic data, the following conclusions can be drawn:

In general, the peak ratio is positively correlated with intensity and negatively correlated with epicentral distance;

The relationship between peak ratio and intensity is closely related to site category and design grouping;

As *Code For Seismic Design of Buildings* defines the ratios according to seismic precautionary intensity is not so accurate, two factors, site and design seismic grouping, is suggested to add to make the value more accurate.

Combined with the design seismic grouping and site category, the recommended design values for peak vertical ground motion acceleration and peak horizontal ground motion acceleration in the high-intensity zone are proposed, as shown in Table 2.

Table 2. Values of PGAV/PGAH for seismic design based on earthquake intensity

Intensity	Design seismic grouping	Venue category			
		I	II	III	IV
8	The first group	0.57	0.59	0.61	0.64
	The second Group	0.66	0.68	0.70	0.75
	The third group	0.73	0.75	0.80	0.85
9	The first group	0.63	0.65	0.66	0.70
	The second Group	0.80	0.83	0.86	0.90
	The third group	0.89	0.92	0.97	1

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