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Discussion on the Relationship Between the Ratio of Ground Motion Peak Acceleration and the Site & Magnitude

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Abstract

Discussion on the relationship between the ratio of ground motion peak acceleration and the site & magnitude, we come to these conclusions as following: 1. When the magnitude and epicentral distance are the same, the peak ratio increases with the increase of the natural period of the site; 2. The larger the magnitude is, the faster the attenuation of the site's natural period will be with the epicentral distance; 3. The larger the magnitude is, the more the peak ratio is affected by the natural period of the site; 4. The vertical-to-horizontal (PGAV/PGAH) ratio is positively correlated with magnitude and negatively correlated with epicentral distance.

Keywords

Vertical ground motion;peak acceleration;site;magnitude.

1. Introduction

Studies have shown that the three major natural disasters that humans encounter in the 21st century are: earthquakes, tsunamis, and typhoons, of which earthquakes are the most frequent, have the greatest impact on humans, and cause the most losses[1]. In the beginning, due to the limited understanding of ground motion and the lack of seismic data, people paid insufficient attention to vertical ground motion and thought that the effect of vertical ground motion could be treated as the expansion of gravity. However, with the deepening of post-disaster investigation and the deepening of people's understanding of ground motion, it is not enough to regard vertical seismic action as the expansion of gravitational action[2,3]. Further discussion on the characteristics of vertical ground motion is of profound practical and engineering significance. This paper mainly discusses the relationship between the ratio k of the vertical ground motion peak acceleration to the horizontal peak value (hereinafter referred to as the ratio k of PGA_V and PGA_H) and the site and magnitude.

2. Data Sources and Screening

2.1. Data sources and distribution

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

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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 [4]". In this regard, only a total of 6188 sets of three-component seismic data with magnitude M ≥ 5 were selected in this paper. In the meantime, when the epicentral distance is too large, the records of the stations themselves will deviate [5]. Moreover, with the increase of the epicentral distance, the vertical ground motion attenuates rapidly[6]. Therefore, this paper selected the three-component seismic data with the epicentral distance R≤300 kilometers, and the total number of screened data is 6188 groups.

2.2. Data screening

In this paper, the ratio k between the peak vertical ground vibration acceleration and the peak horizontal acceleration is obtained through the peak acceleration in three directions, and it is found that some data are obviously unreasonable and belong to anomalous values, which should be eliminated[7,8].

Using MATLAB for analysis and trial calculation, the statistical samples collected in this paper may obey lognormal distribution, normal distribution, and t distribution. In this paper, the statistical software SPSS[9] was used to perform Q-Q plot tests for lognormal, t-distribution, and standard normal distributions for the five groups of data, and finally, it was found that these five groups of data most closely converged to the lognormal distribution. Taking the 3σ principle [10] as the screening standard, the mean and variance of the data before and after screening are compared as follows:

Table 1 Mean μ and variance σ of sample data before and after screening

Magnitude (M)	μ		σ	
	Before screening	After screening	Before screening	After screening
5	0.443	0.441	0.050	0.046
6	0.489	0.479	0.071	0.048
7	0.484	0.480	0.041	0.035
8	0.500	0.503	0.347	0.033
9	0.498	0.498	0.0283	0.0283

The distribution of data after screening is obviously not as scattered as before screening, and it is also more concentrated than before screening, which is more conducive to the upcoming analysis work.

3. Statistical Analysis on the Ratio of Peak Acceleration

3.1. Discussion on the relationship between the ratio of peak acceleration and the site

The peak acceleration is a function of magnitude, epicentral distance, and site relationship. Referring to the formula in the literature [11], the following equation is proposed to express the attenuation law of the peak acceleration ratio:

$$\log(k) = a + bM + c\log(R+30) + dT \quad (1)$$

where k is the ratio of PGA_V to PGA_H, M is the magnitude, R is the epicentral distance (km), and T is the natural period of the site (s).

Using the existing seismic data, regression analysis is performed on various parameters to obtain the fitted equation as follows:

$$\log(k)=0.126M-0.283\log(R+30)+0.116T-0.715 \quad (2)$$

The correlation between the equation and the sample data is very good, as shown in Fig. 1, where red represents the line connecting the observed values and blue indicates the fitted curve with a correlation coefficient of 0.969, which shows a more reliable fitting result.

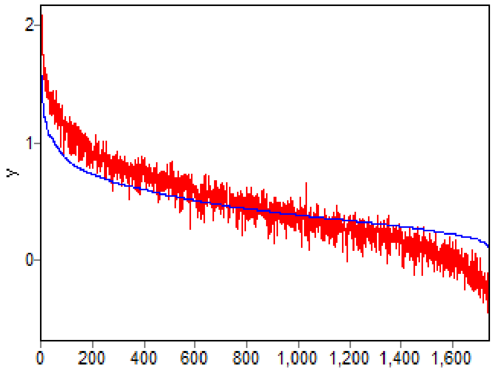
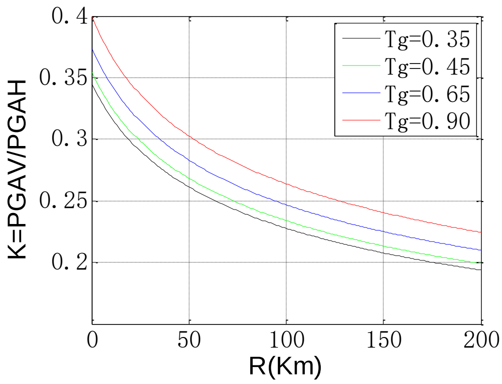
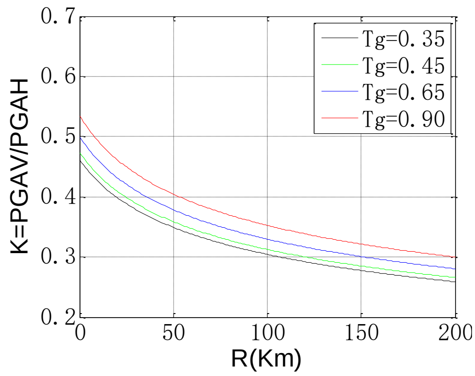


Fig. 1 Samples and curves of PGA_V/PGA_H

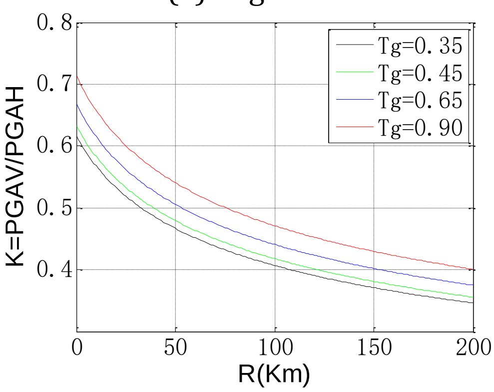
The magnitudes are 5, 6, 7, 8, and 9; the natural period of the site is 0.35, 0.45, 0.65, and 0.90 (corresponding to the Class II field of China's seismic code, the first and third groups of the design group, and the first and third groups of the design group in the Class IV site respectively). Fig. 2 shows the variation law of the peak ratio with the epicentral distance for different natural periods of the site at each magnitude.



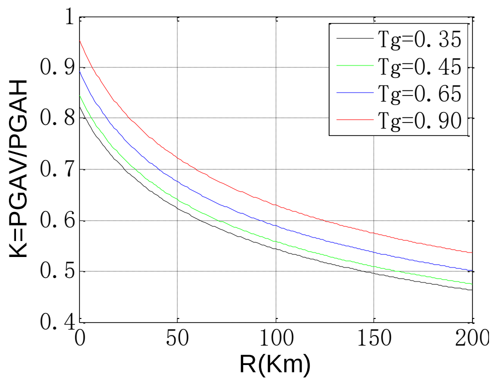
(a)Magnitude M=5



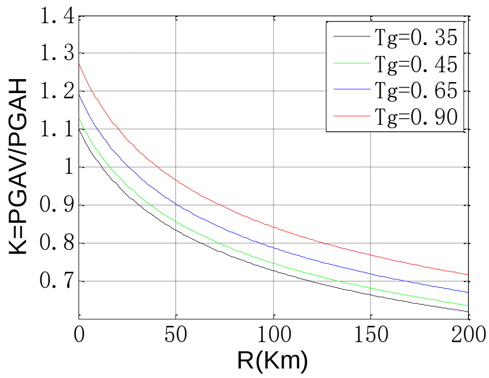
(b) Magnitude M=6



(c) Magnitude M=7



(d) Magnitude M=8



(e) Magnitude M=9

Fig. 2 k-R curves of different earthquake magnitude and side condition

From the above figure, it can be noted that when the magnitude and epicentral distance are the same, the peak ratio increases with the increase of the natural period of the site; the larger the magnitude is, the faster the attenuation of the natural period pair of the site will be with the epicentral distance; the larger the magnitude is, the greater the impact of the peak ratio on the natural cycle of the site will be.

Since the code takes no account of the effect of the site, the application of the code needs to consider the factor of simplicity. For the sake of comparison, in the next discussion of the relationship between peak ratio and earthquake magnitude and intensity, this paper will be conducted in two aspects, considering the site factor and without considering the site factor[12].

3.2. Discussion on the relationship between the ratio of peak acceleration and magnitude

3.2.1. Without considering site factors

In order to obtain the relationship between the ratio of PGA_V and PGA_H and the magnitude as accurately as possible, more than 2,000 sets of previously screened data were grouped according to the epicentral distance: 0km~10km, 10km~20km, 20km~30km, 30km~50km, 50km~100km, 100km~200km, which were divided into 6 groups[13]. There are 215 groups of data from 0 km to 10 km, 383 groups of data from 10 km to 20 km, 307 groups of data from 20 km to 30 km, 492 groups of data from 30 km to 50 km, 612 groups of data from 50 km to 100 km, and 299 groups of data from 100 km to 200 km.

Similarly, the statistical software SPSS was used to perform linear fitting, quadratic fitting, cubic fitting, logarithmic fitting, and exponential fitting [14] on the above 6 sets of seismic data. The fitting degree is the best and the correlation is the highest when the exponential fit is used, and its sig=0, i.e., the probability of significance test by the regression equation is 0, which is less than the significance level of 0.05, and the test passed. To this end, the relationship can be considered significant, and the exponential relationship of the ratio of magnitude to peak acceleration holds.

The fitting curve of the relationship between the magnitude M and the peak acceleration ratio k is shown in Fig. 3.

For the convenience of observation, the observation points in Fig. 3 are hidden, and the data fitting curves of six areas with epicentral distances R ranging from 0 km to 10 km, 10 km to 20 km, 20 km to 30 km, 30 km to 50 km, 50 km to 100 km, and 100 km to 200 km are placed in the same coordinate chart (Fig. 4).

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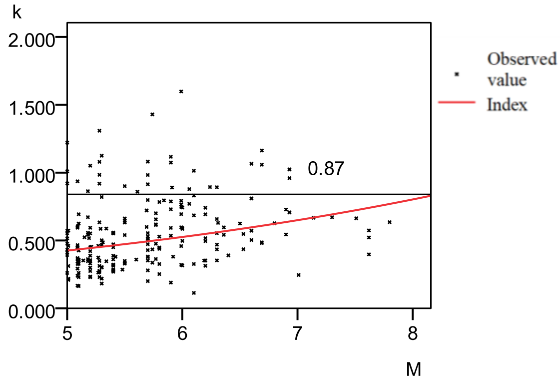
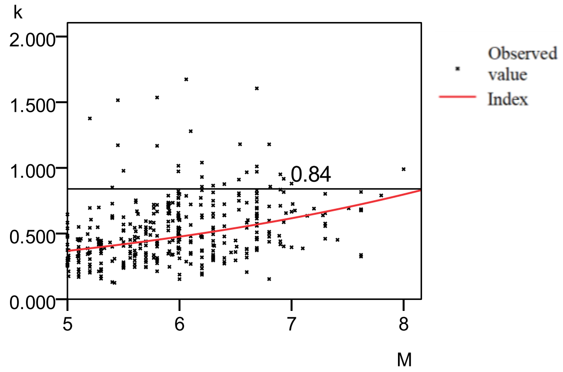
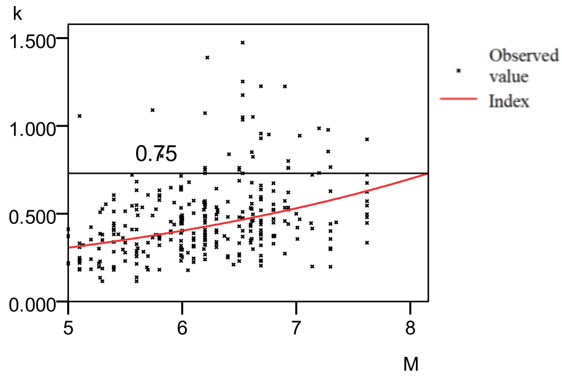
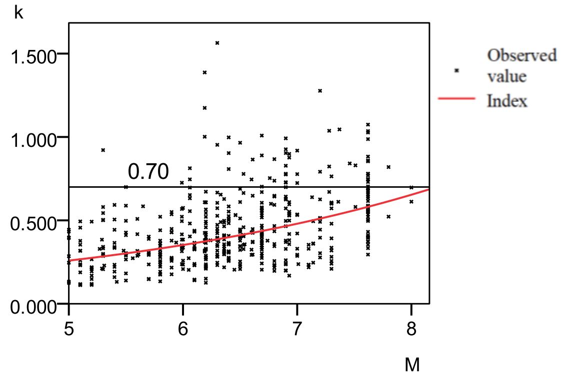


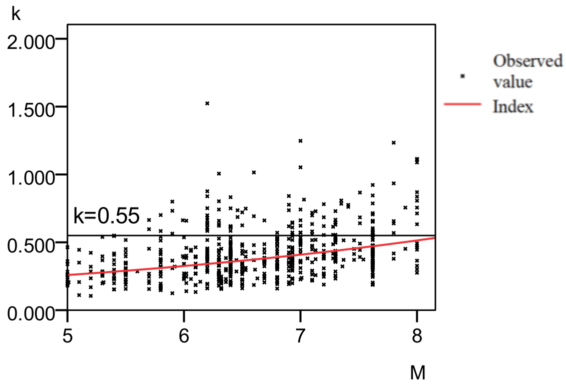


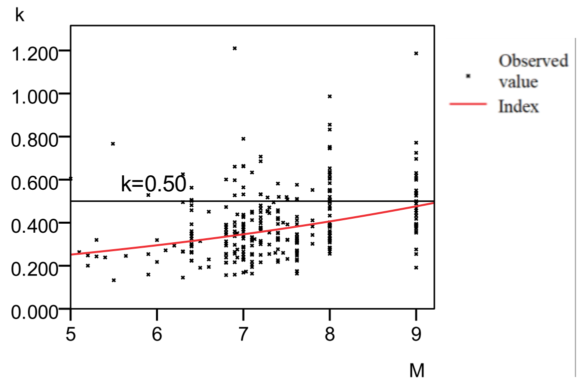
(a) The epicentral distance R≤10km (b) The epicentral distance 10km＜R≤20km





(c) The epicentral distance is 20km<R≤30km (d) The epicentral distance is 30km<R≤50km





(e) The epicentral distance is 50km<R≤100km (f) The epicentral distance is 100km<R≤200km

Fig. 3 k-M curves of different epicentral distance

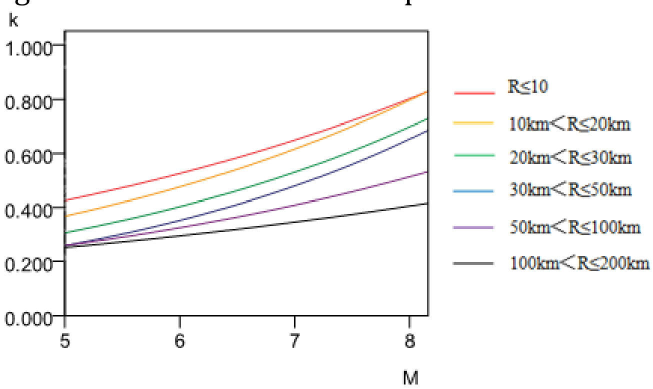
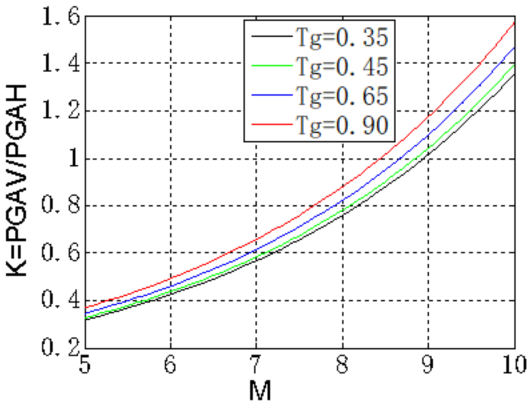


Fig. 4 k-M curves

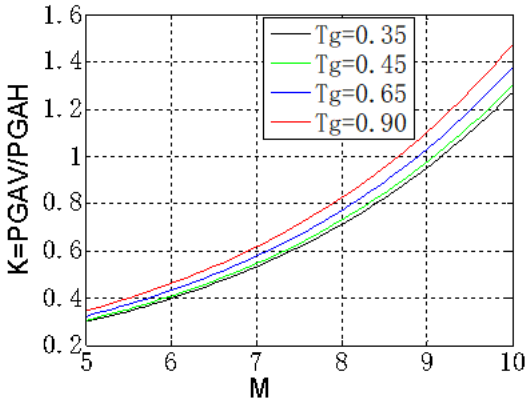
From Fig. 3 and Fig. 4, it can be seen that when the epicentral distance is 0 km~10 km, 10 km~20 km, 20 km~30 km, 30 km~50 km, 50 km~100 km, 100 km~200 km in these six areas, there is a rule as follows: the peak ratio increases with the increase of the earthquake magnitude; meanwhile, it can be seen that the peak ratio decreases with the increase of the epicentral distance. In addition, in the near-field area, the vertical effect of the earthquake is quite intense, which should be given sufficient attention in the seismic design of the structure; while when the epicentral distance is greater than 50km, the peak ratio is still small even though the magnitude reaches 8 or even 9 because the vertical seismic effect decays rapidly with the epicentral distance.

3.2.2. Considering site factors

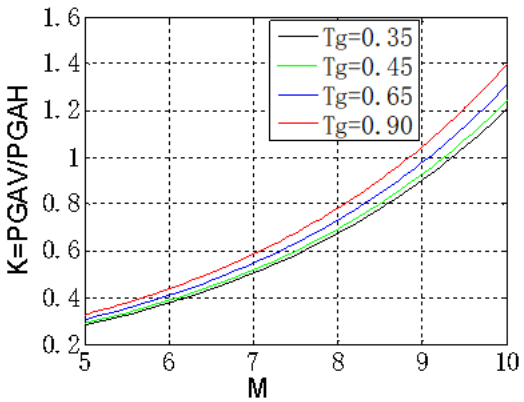
Using the model of the relationship between the peak ratio and the magnitude, epicentral distance, and site obtained by fitting in Section 3.1 (Equation 2), the epicentral distances are taken as 10 km, 20 km, 30 km, 50 km, 100 km, and 200 km respectively[15]; the natural period of the site is 0.35 s, 0.45 s, 0.65 s, 0.90 s, and the relationship between the epicentral distance and the peak ratio is obtained as shown in Fig. 5.



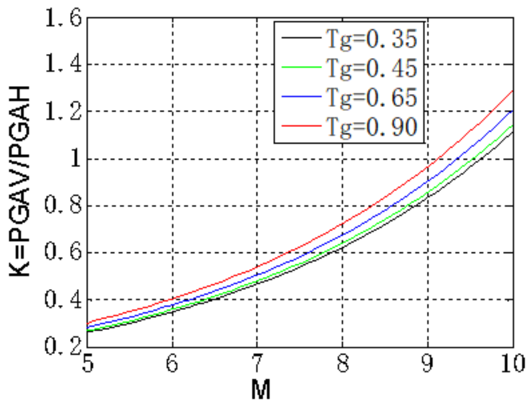
(a) The epicentral distance R≤10km



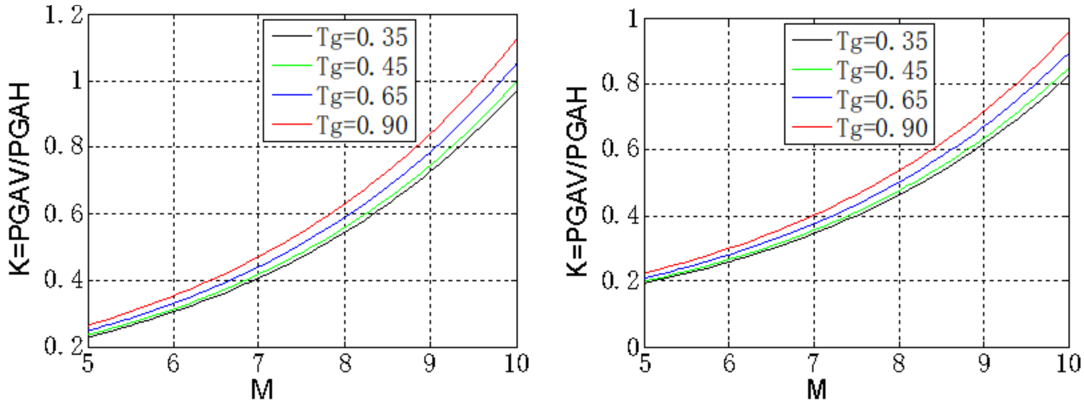
(b) The epicentral distance 10km＜R≤20km



(c) The epicentral distance is 20km<R≤30km



(d) The epicentral distance is 30km<R≤50km



(c) The epicentral distance is 50km<R≤100km (d) The epicentral distance is 100km<R≤200km

Fig. 5 k-M curves of different epicentral distance and side condition

Analyzing Fig. 5, it can be obtained that the ratio of peak acceleration increases with the increase of magnitude for the same epicentral distance and the same site conditions; for the same epicentral distance, the characteristic period increases from 0.35 to 0.9, and the growth rate of peak ratio increases with the increase of magnitude in order; the smaller the epicentral distance is, the faster the rate of peak ratio increases will be with the magnitude; for the same epicentral distance and the same site conditions, the rate of peak ratio increases from magnitude 5 to 7 and more rapidly from magnitude 7 to 9.

4. Conclusion

In this paper, by analyzing the relationship between the ratio of the vertical ground motion peak acceleration and the horizontal ground motion peak acceleration, the epicentral distance and magnitude, and discussing the characteristics of the peak acceleration ratio, the following conclusions can be drawn:

When the magnitude and epicentral distance are the same, the peak ratio increases with the increase of the natural period of the site;

The larger the magnitude is, the faster the attenuation of the site's natural period will be with the epicentral distance;

The larger the magnitude is, the more the peak ratio is affected by the natural period of the site;

The peak ratio is positively correlated with magnitude and negatively correlated with epicentral distance.

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