Relationships between CAV and PGA of Wenchuan Earthquake

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Abstract

PGA is an important seismic parameter, which is widely used in seismic design of buildings. CAV (cumulative absolute velocity) can be used to indicate the destruction and non-destruction of buildings caused by ground motion, and is the optimal threshold parameter to indicate the potential damage of ground motion. Therefore, it is very important to study the correlation between CAV and PGA for calibrating the validity of these two ground motion parameters and conversion of the two ground motion parameters.

In this research, we study the relationship between CAV and PGA in Wenchuan earthquake according to the horizontal strong ground motion records of Wenchuan earthquake, and adopt a linear model to describe the correlation between the two. According to the least square method, we estimate the model parameters and obtain the empirical relation (shown in Figure 1(a)). From figure 1 (a), we can see that CAV and PGA have a good correlation in the logarithmic coordinates, with the correlation coefficient as high as 0.90.

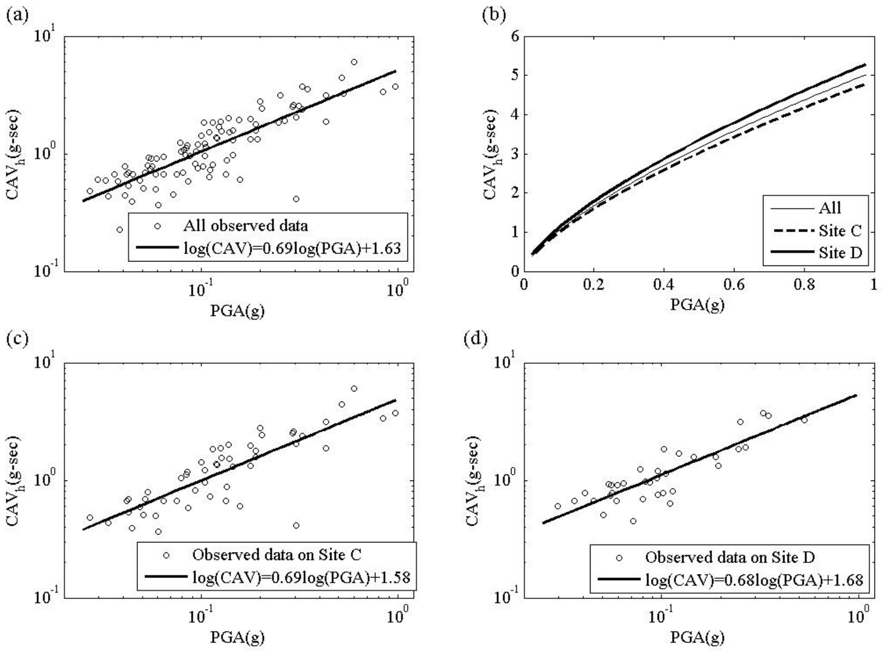


Figure. 1 The correlation between CAV_h and PGA
(a) The relationships between CAV_h and PGA fitted by all observation data; (b) The relation curves between CAV_h and PGA under different site conditions; (c) and (d) The relationships between CAV_h and PGA fitted according to the data of C site and D site, respectively.

Site conditions can have a significant impact on the strong ground motion of earthquakes, so site conditions will also affect the correlation between CAV and PGA. In order to study the influence of site conditions on their correlation, we also fit the relationships between CAV and PGA under the conditions of C site and D site (Figure 1 (c) and (d)). Furthermore, we can see from figure 1 that site conditions do have a significant impact on the correlation between CAV and PGA: under the same PGA, the softer the site is, the higher the CAV value is.

Keywords: Ground Motion; CAV; PGA; Relationship; Wenchuan Earthquake

1. Introduction

Ground motion parameters are important measurement parameters to characterize ground motion characteristics. At present, peak acceleration and spectral acceleration are the most commonly used ground motion parameters in seismic design of buildings. However, seismic wave is a very complex time series, and only a single seismic parameter cannot fully and effectively reflect all seismic characteristics, which cannot meet the application needs of scientists and engineers. For example, the effect of peak acceleration on indicating liquefaction of sand is very limited. Another important ground motion parameter, cumulative absolute velocity (CAV), was found to be correlated with pore water pressure in sandy liquefaction areas [1].

Cumulative absolute velocity (CAV) is the ground motion parameter obtained by integrating the absolute value of the acceleration time history against time, which was first proposed by Electric Power Research Institute [2].CAV is an indicator to indicate the initial damage caused by ground motion to the engineering structure. Subsequently, EPRI [3] proposed the famous standard CAV, which is obtained by integrating the absolute value of the part of acceleration time history greater than 0.025g with time, removing the contribution of low-amplitude and high-frequency ground motions to the CAV value. By studying the correlation between seismic damage data of buildings and seismic parameters [3, 4, 5], scientists set the standard CAV threshold as 0.16g-s: when the CAV is greater than 0.16g-s, the ground motion will cause damage to buildings; When the CAV is less than 0.16g-s, the damage to the building caused by the ground motion is negligible. Because of this excellent performance, standard CAV has been adopted by the U.S. Atomic Energy Regulatory Commission to determine whether a reactor needs to be shut down if the operating baseline seismic response spectrum of a nuclear power plant is exceeded. In addition, seismologists have found that CAV is strongly correlated with seismic parameters such as PGA and Housner intensity [6, 7], which indirectly explained the correlation between CAV and earthquake damage.

In view of the important role of CAV in characterizing the characteristics of ground motion and earthquake disaster prediction, it is of great scientific significance and application value to carry out relevant research on CAV for expanding our understanding of the characteristics of ground motion and improving the level of earthquake disaster prediction.

On May 12, 2008, a magnitude of Ms8.0 earthquake occurred in Wenchuan county, Sichuan province, China. In this paper, we will study the relationship between CAV and PGA based on the strong earthquake data of Wenchuan earthquake, which is of great scientific significance for us to understand the characteristics of CAV in Wenchuan earthquake and even in the seismic-tectonic environment of western China.

2. The data of Wenchuan earthquake

2.1 Seismogenic structure and finite fault model of Wenchuan earthquake

In this study, we adopt the finite fault model of USGS [8] as the seismogenic structural model of Wenchuan earthquake based on the principle of scientificity and accessibility, to calculate the distances between station points and fault. The finite fault model consists of three parts. The southern section consists of two parts--the Yingxiu section of Yingxiu-Beichuan fault and the Guanxian-Jiangyou fault, both of which incline to the west and are imbricately arranged. The rupture of this section is mainly thrust, combining the strike-slip component. The northern section consists of the north of Beichuan section of Yingxiu-Beichuan fault, which is mainly strike-slip (Fig.1).

2.2 Strong ground motion records of Wenchuan earthquake

We collect a total of 1215 records of acceleration time-histories from 407 strong seismic stations. After removing the incomplete, low SNR and non-free field records, we obtain a total of 528 available records from 177 stations (Fig.1). The peak acceleration of the acceleration time history of these stations ranges from 2 to 957gal. And the range of distances is from 1.7 to 916.6km. In this study, we select 440 pieces of data from 147 stations within 500km away from the fault for processing and analysis due to the large magnitude of Wenchuan earthquake and the wide impact range of ground motion generated from this earthquake.

The site conditions of stations are classified according to the site classification principle of NEHRP (National Earthquake Hazards Reduction Program) [9]. The sites are mainly divided into category C and category D according to this principle, while those with the category of bedrock are divided into category B.

2.3 Baseline correction

Baseline drift is an important problem that seriously affects the scientific application of strong earthquake records. It can lead to the distortion of velocity and displacement records obtained by the integral of acceleration records, which will seriously affect the use of acceleration records. Taking the 051AXT station as an example, it can be seen from the velocity and displacement records in the left figure of Fig.2 that the strong earthquake records of this station produce serious baseline drift phenomenon. In this study, we adopt an automatic baseline correction method [10] to conduct baseline correction for the strong ground motion records of Wenchuan earthquake (see the example at the right part of Fig.2).

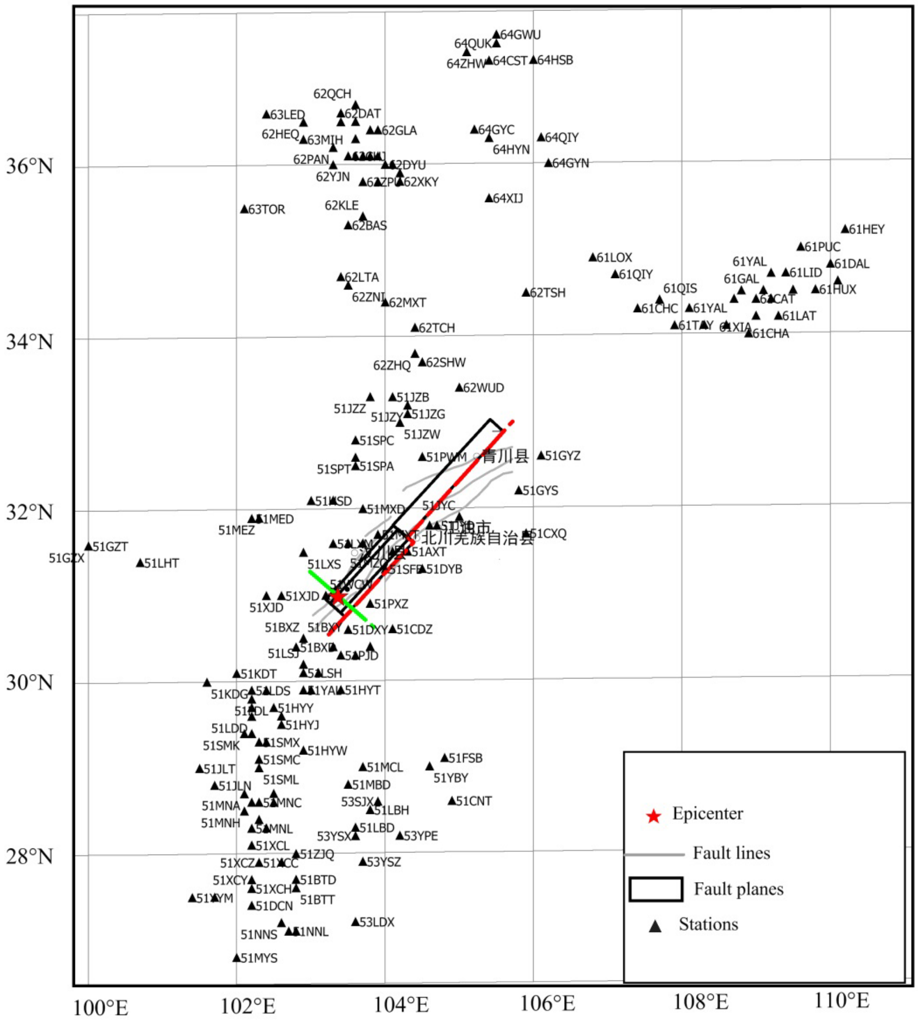
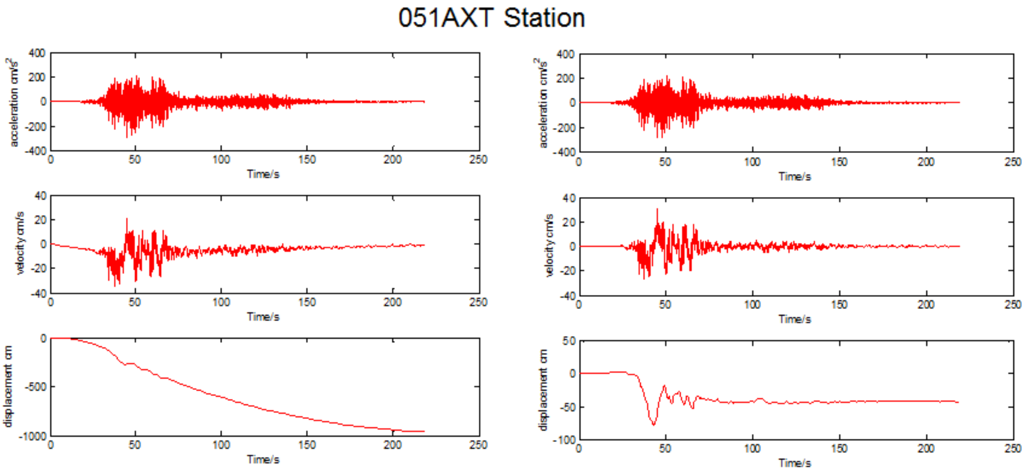


Fig. 1 – The finite fault model and the distribution of stations of Wenchuan earthquake



051AXT Station

Fig. 2 – The results of integral of acceleration record before (left) and after (right) baseline correction for 051AXT station

3. Calculation of CAV

3.1 Calculation of general CAV

According to the definition of CAV in the introduction, its mathematical expression can be written as [2, 11]:

$$\mathrm{CAV} = \int_0^{t_{\max}} \left| a(t) \right| dt \tag{1}$$

Where |a(t)| is the absolute value of the acceleration time history at time t, and $t_{\max}$ is the duration of the whole ground motion. Fig.3 is a certain acceleration record and its corresponding calculation schematic diagram of CAV. In Fig.3, the CAV value is the accumulation of the blue shaded area. As can be seen from Fig.3, with the increase of the duration of ground motion, the CAV value also increases until the maximum duration is reached. Therefore, the CAV value contains the continuously accumulated effect of the whole seismic time history.

Although CAV is called cumulative absolute velocity and has a dimension of velocity, it has no direct relationship to the velocity of ground motions. Therefore, scientists generally write its dimension as g-s in the process of using it.

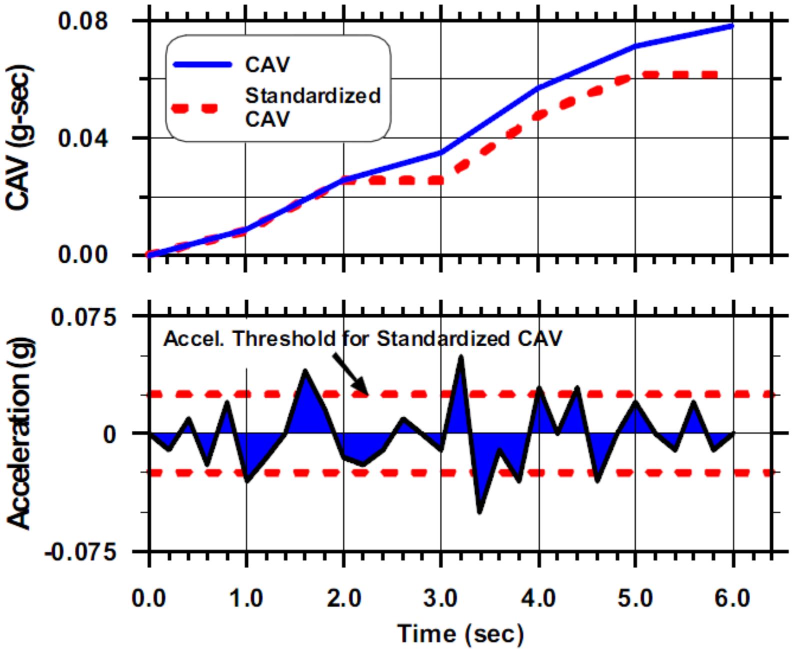


Fig. 3 – The calculation schematic diagram of CAV [12]

3.2 Calculation of standard CAV

Also according to the introduction, the standard CAV, marked as $\mathrm{CAV}_{\mathrm{STD}}$, it only integrates the parts with an acceleration value greater than 0.025g, removing the contribution of ground motions with low amplitude and no damage to the structure to CAV. Therefore, the mathematical expression of $\mathrm{CAV}_{\mathrm{STD}}$ [3] is:

$$\mathrm{CAV}_{\mathrm{STD}} = \sum_{i=1}^{N}\left(H\left(PGA_i - 0.025\right)\int_{i-1}^{i}\left|a\left(t\right)\right|dt\right) \tag{2}$$

Where N is the number of time intervals, the general time interval is 1s, and the time intervals do not overlap each other; PGA_i is the peak acceleration within the ith time interval; $H(x)$ is the unit step function, which can be expressed as:

$$H\left(x\right) = \begin{cases} 0 & x<0 \\ 1 & x>0 \end{cases} \tag{3}$$

In Fig.3, we can see that the part of blue shaded area outside the region surrounded by two red dashed lines is used to calculate the standard CAV, which is smaller than the value of general CAV.

4. Relationship between CAV and PGA in Wenchuan earthquake

As mentioned above, PGA is widely used in the seismic design of buildings and has a strong correlation with the damage characteristics of buildings caused by earthquakes. CAV can be used to indicate the damage and non-damage of ground motion to buildings and is the optimal threshold parameter indicating the potential damage of ground motion [4]. The research of the relationship between CAV and PGA plays an important role in the effectiveness of the mutual calibration of these two ground motion parameters and the mutual conversion of ground motion parameters.

4.1 Relationship between general CAV and PGA

In this section, we study the relationship between general CAV and PGA using the horizontal strong ground motion records of Wenchuan earthquake. We adopt linear model to describe the relationship of the two. We estimate the model parameters according to the least square method, and obtain the following empirical relationship:

$$\ln\left(CAV_h\right) = 0.69\ln\left(PGA\right) + 1.63, \sigma_{\ln CAV_h} = 0.36 \tag{4}$$

Where CAV_h is the geometric mean of the two horizontal CAV values in units of g-s, and the unit of PGA is g. As can be seen from Fig.4(a), general CAV and PGA have a good correlation in the logarithmic coordinate system, and the correlation coefficient is as high as 0.90.

Site conditions can have a significant impact on the strong ground motion generated from earthquakes, so site conditions will also affect the relationship between CAV and PGA. In order to study the influence of site conditions on their correlation, we also fit the relationship between general CAV and PGA under the conditions of C and D sites:

$$\begin{cases} \ln\left(CAV_{\mathrm{h}}\right)=0.69\ln\left(PGA\right)+1.58, \sigma_{\ln CAV_h}=0.39 \quad \text{for site C} \\ \ln\left(CAV_h\right)=0.68\ln\left(PGA\right)+1.68, \sigma_{\ln CAV_h}=0.29 \quad \text{for site D} \end{cases} \tag{5}$$

From Fig.4(b), we can see that site conditions have a significant impact on the relationship between CAV and PGA: under the same value of PGA, the softer the site, the larger the CAV value. It may be due to the fact that under the ground motions with the same PGA, the softer the site is, the slower the amplitudes of acceleration record decays. According to Fig.3, we can infer that the blue shadow area surrounded by the acceleration record curve is relatively bigger under the condition of softer site, so the corresponding CAV value is relatively larger.

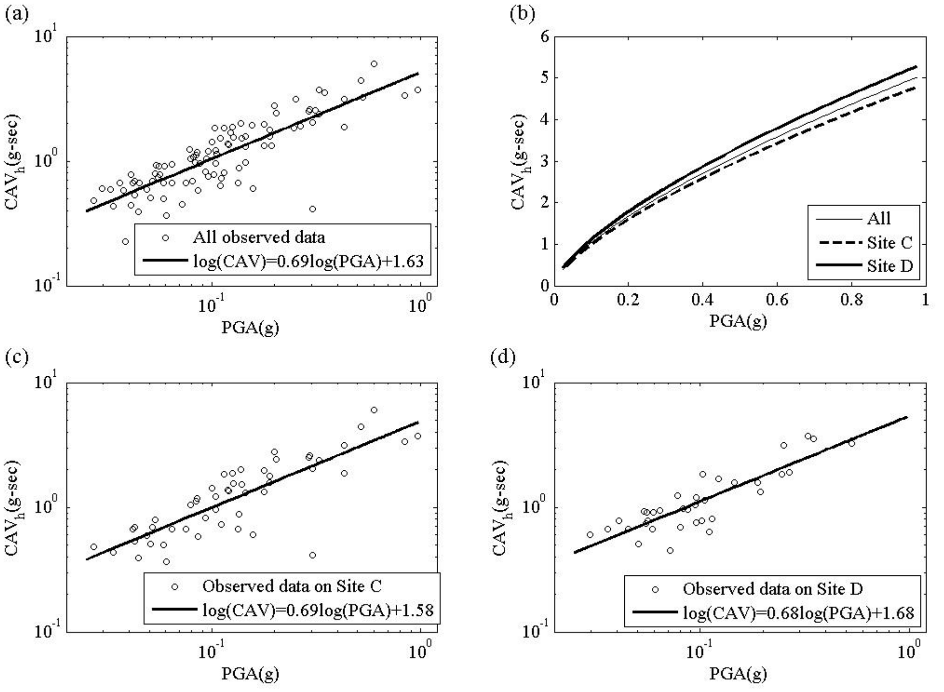


Fig. 4 – The relationships between CAV$_{\mathrm{h}}$ and PGA
(a) The relationship between CAV$_{\mathrm{h}}$ and PGA fitted by all observation data; (b) The relationship curves between CAV$_{\mathrm{h}}$ and PGA under different site conditions; (c) and (d) The relationships between CAV$_{\mathrm{h}}$ and PGA fitted according to the data of C site and D site, respectively.

4.2 Relationship between standard CAV and PGA

In this section, we study the relationship between standard CAV and PGA also using the horizontal strong ground motion records of Wenchuan earthquake. From the scatter plot (Fig.5), we can see that the standard

CAV and PGA show a non-linear relationship. We adopt the model of EPRI (2006) [4] to describe the relationship between the standard CAV and PGA according to the records of Wenchuan earthquake, and use the nonlinear least square method to regress the coefficients of model:

$$\ln\left(CAV_{\mathrm{std}}\right) = 4.92 - 0.33\left(\ln\left(PGA\right)+2.5\right) - 13.77\Big/\left(\ln\left(PGA\right)+5.01\right),\ \sigma_{\ln CAV_{\mathrm{std}}} = 0.48 \tag{6}$$

And the relationships between standard CAV and PGA under the conditions of C and D sites, respectively, are as follows:

$$\begin{cases} \ln\left(CAV_{\mathrm{std}}\right) = 3.99 - 0.23\left(\ln\left(PGA\right)+2.5\right) - 10.01\Big/\left(\ln\left(PGA\right)+4.72\right),\sigma_{\ln CAV_{\mathrm{std}}} = 0.48 \quad \text{for Site C} \\ \ln\left(CAV_{\mathrm{std}}\right) = 3.98 + 0.066\left(\ln\left(PGA\right)+2.5\right) - 11.69\Big/\left(\ln\left(PGA\right)+5.13\right),\sigma_{\ln CAV_{\mathrm{std}}} = 0.47 \quad \text{for Site D} \end{cases} \tag{7}$$

We also compare the models regressed in this paper with the models fitted by EPRI (2006) [4], respectively. As can be seen from Fig.5, when the PGA is less than about 0.05g, the standard CAV calculated by our regression formula (Eq. (6) or Eq. (7)) is smaller than the value calculated by the model of EPRI (2006) under the same PGA, respectively. It may be caused by more high-frequency and low-amplitude components of the ground motion generated by Wenchuan earthquake being filtered out. This also indirectly illustrates that Wenchuan earthquake produced more high-frequency components, and its rupture process was more complex. However, When the PGA is greater than 0.05g, the standard CAV calculated by our regression formula (Eq. (6) or Eq. (7)) is larger than the value calculated by the model of EPRI (2006) under the same PGA, respectively. It may be related to the large magnitude and longer rupture time of Wenchuan earthquake.

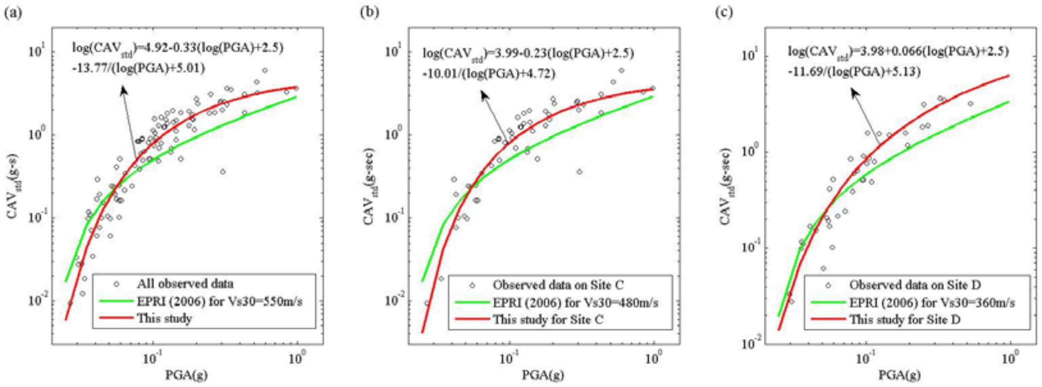


Fig. 5 – The relationships between standard CAV and PGA and comparison with EPRI (2006) [4] models under different site conditions, respectively

5. Conclusion

In this paper, based on the strong earthquake data of Wenchuan earthquake, we calculate the value of CAV and PGA of Wenchuan earthquake, establish the empirical relationship between CAV and PGA, and analyse the influence of site conditions on the correlation between the two ground motion parameters.

The research results show that general CAV and PGA have a good linear correlation in logarithmic coordinates. Site conditions can also have a significant impact on the relationship between the two ground motion parameters: when PGA is the same, the softer the site, the larger the CAV. It may be due to the fact that under the ground motions with the same PGA, the softer the site is, the slower the amplitudes of acceleration record decays.

We also study the correlation between standard CAV and PGA. It is found that there is a nonlinear relationship between standard CAV and PGA, and the model of EPRI (2006) [4] can be used to describe this relationship. When the PGA is less than about 0.05g, the value of standard CAV calculated by the regression formula (Eq. (6) or Eq. (7)) in this paper is smaller than that of the EPRI (2006) model under the same PGA, which may be caused by the filtering of more high-frequency and low-amplitude components of the ground motion generated by the Wenchuan earthquake. When the PGA is greater than 0.05g, the standard CAV calculated by the regression formula (Eq. (6) or Eq. (7)) in this paper is larger than the value calculated by the model of EPRI (2006) under the same PGA, which may be related to the large magnitude and longer rupture time of Wenchuan earthquake. The research also indirectly illustrates that Wenchuan earthquake produced more high-frequency components, and its rupture process was more complex.

The research results of this paper on the relationship between CAV and PGA in Wenchuan earthquake are of great significance for us to understand the characteristics of ground motion and seismic hazard in the seismic-tectonic environment in western China.

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7. Copyrights

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