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Relationships between ground motion parameters and landslides induced by Wenchuan earthquake*

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Abstract The M_S8.0 Wenchuan earthquake induced severe landslide hazards. For the first time in China, large numbers of strong motion records were obtained during the Wenchuan earthquake, providing the opportunity to study the relationships between ground-motion parameters and the earthquake-induced landslides. Nearly 40 groups of records from the main shock distributed along the Longmenshan fault lines were used to carry out this study. The results appropriate to the Longmenshan area are as follows: ① The threshold of the peak ground acceleration (PGA) is about 0.7 m/s^2. When the PGA reaches 2 m/s^2, the landslide hazards are very serious; ② The threshold of the peak ground velocity (PGV) is about 0.5 m/s. When the PGV reaches 1.5 m/s, severe landslide hazards will be induced; ③ The threshold for the Arias intensity (I_a) is about 0.2 m/s. When the I_a in one horizontal direction reaches 2 m/s, landslide hazards will be very serious; ④ As for the relevance order of the parameters to earthquake-induced landslides, I_a is the leading parameter, followed by PGV, and finally PGA. The results presented in this paper are consistent with the results from other studies, indicating that the threshold of the ground motion parameters for strong earthquakes is of the same order of magnitude as that of moderate earthquakes. Landslide density of local sites fluctuated with the increase of ground motion intensity if the thresholds were reached. When the upper limits are exceeded, the landslide density remains at a certain level with relatively little variation.

Key words: **Wenchuan earthquake; earthquake-induced landslide; peak ground acceleration; peak ground velocity; Arias intensity**
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1 Introduction

A strong earthquake of M_S8.0 occurred on 12th May 2008 in Wenchuan county, Sichuan province, and it not only caused great economic losses and human casualties, but also induced extremely serious landslide disasters. According to the field investigation carried out by the Ministry of Land and Resources in China immediately after the earthquake, more than 20 000 landslides were triggered (Yin, 2008), and over 100 000 km^2 was seriously affected by the geological disasters (Liu, 2008).

Landslides induced by the earthquake caused communication disruption in disaster areas after the earthquake, and all roads leading to the hardest-hit areas were blocked, e.g., 20 km of the road section from Yingxiu to Wenchuan was seriously damaged by more than 340 landslides and collapses (Yin, 2008), seriously hampering access to information as well as the implementation of emergency rescue work in the disaster areas after the earthquake.

Earthquake-induced landslides also created more than 30 severe barrier lakes, seriously threatening the life and property of inhabitants in the lower reaches. The most dangerous barrier lake after the earthquake was the Tangjiashan Barrier Lake in Beichuan county, where the volume of landslide debris was over 20 million km^3.

A large number of casualties were also caused by the earthquake-induced landslides. According to statistics, the death toll directly due to earthquake-induced landslides and related geological disasters was about 20 000; and 1 600 people died as a result of the Wangjiayan landslide in Beichuan county alone (Yin, 2008).

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The Wenchuan earthquake also triggered a number of landslides with enormous volumes and especially long running distances, e.g., the Daguangbao landslide in Anxian county had a slippage across 4 500 m and a volume of 1.1 billion m^3, and the Donghekou landslide in Qingchuan county had a landslide mass of 10 million m^3 and a slippage across about 2 400 m (Yin, 2008, 2009).

Earthquake-induced landslide is a common hazard in China, especially in the western mountainous areas, which are more prone to earthquakes, but there is a lack of systematic research, especially on the relationships between earthquake-induced landslides and ground motion parameters.

Before the Wenchuan earthquake, a large number of ground motion instruments were deployed in Longmenshan area, which fortunately, for the first time in China, enabled the acquisition of large quantities of ground motion records on the main shock and after shocks from a major earthquake. This provides basic data from a strong earthquake for analyzing the relationship between earthquake-induced landslides and ground motion parameters.

Prior to the Wenchuan earthquake, researchers studied the relationships between earthquake-induced landslides and ground motion parameters using the induced landslide data and ground motion data from several earthquakes. These included the M6.9 Loma Prieta earthquake in 1989 (Keefer, 2002; Khazai and Sitar, 2004), the M6.7 Northridge earthquake in 1994 (Harp and Wilson, 1995; Jibson et al, 2000; Parise and Jibson, 2000; Keefer, 2002; Khazai and Sitar, 2004) and the M7.3 Taiwan Jiji (Chi-Chi) earthquake in 1999 (Liao, 2000; Keefer, 2002; Wang et al, 2002; Khazai and Sitar, 2004). The general consensus has been reached that ground motion is one of the most important factors affecting landslides. However, due to the limited number of ground motion records, these studies were constrained to moderate earthquakes of M5 to 7. The M_S8.0 Wenchuan earthquake provides an opportunity to study the relationships between landslides induced by a strong earthquake and the corresponding ground motion parameters, using the abundant data of landslides and ground motion records.

Various parameters are used to describe different characteristics of ground motion including amplitude, spectrum, duration, or their combination (Hu, 2006). The two parameters, peak ground acceleration (PGA) and the Arias intensity (I_a), are most widely used to study the relationships between earthquake-induced landslides and ground motion parameters. Wilson and Keefer (1985) were the first to apply the Arias intensity to the study of earthquake-induced landslides. Harp and Wilson (1995) studied the relationship between the earthquake-induced landslide and the Arias intensity by using the data obtained from two moderate earthquakes. Khazai and Sitar (2004) found that there existed a high correlation between shallow earthquake-induced landslides and the PGA from the study on the Jiji (Chi-Chi) earthquake.

Using geological disaster data, as well as nearly 40 groups of strong ground motion records obtained from the main shock of the Wenchuan earthquake in the Longmenshan area, this paper analyzes the relationships between landslides induced by the Wenchuan earthquake and the peak ground acceleration (PGA), peak ground velocity (PGV) and Arias intensity (I_a). It provides an understanding on the relevance ranking of the three parameters to the triggered landslides, on the basis of calculation and comparison. The large quantity of landslide data and strong earthquake records from the Wenchuan earthquake provide the opportunity to re-evaluate the research results on earthquake-induced landslides and ground motion parameters acquired in previous studies. It also gives the opportunity to better understand the distribution of landslides induced by strong earthquakes and their relationship with ground motion parameters.

2 Data

The Wenchuan earthquake occurred on the central Yingxiu-Beichuan fault of the Longmenshan fault zone, which belongs to the transitional zone between Qinghai-Tibet plateau and Sichuan basin, and features complex geological structure, topography and hydro- geological conditions (Xu et al, 2008), resulting in a considerable number of secondary geological disasters during the earthquake.

There were a large number of ground motion observation instruments deployed along the Longmenshan fault zone and its vicinity before the Wenchuan earthquake, so a large quantity of ground motion records were obtained from this earthquake (Li et al, 2008; Yu et al, 2008). From data acquired from the main shock, we selected nearly 40 groups of records distributed along the earthquake faults, and collected and collated data on nearly 3 000 landslides which were also distributed along the Longmenshan fault zone in the earthquake-hit area. All the stations and landslides used in this paper were distributed along the earthquake rupture and on both the hanging and base walls of the rupture, which belonged to the most serious geological disaster hit region, ranging from flat areas in the lower plane to vertical slopes in the upper plane. Figure 1 shows the distribution of these stations and landslides.

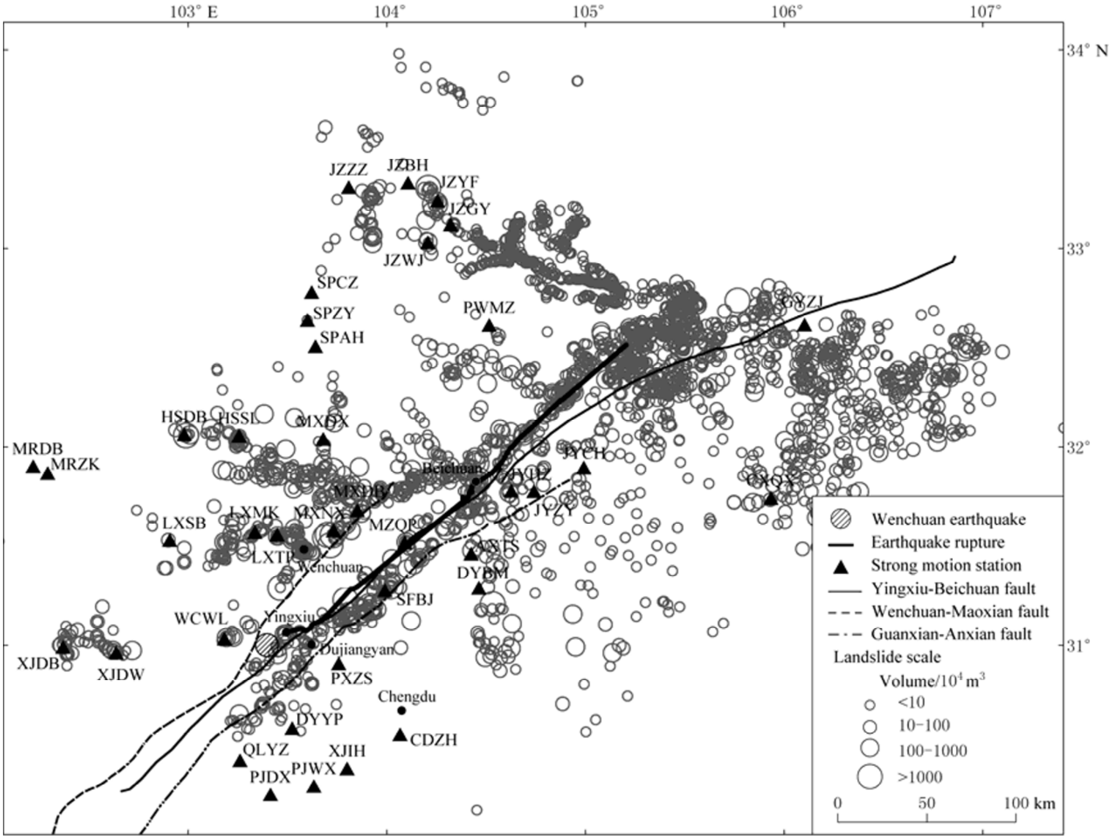

Figure 1 Distribution of earthquake-induced landslides, ground motion observation stations in the Longmenshan fault zone and the Wenchuan earthquake rupture (denoted by thick solid line).

Table 1 Some PGA, PGV and I_a values used in this study

Station code	PGA/(m·s^{-2})			PGV/(m·s^{-1})			Arias intensity/(m·s^{-1})		
	EW	NS	Vertical	EW	NS	Vertical	EW	NS	Vertical
WCWL	9.763	6.648	9.664	3.276	3.546	2.594	12.45	10.12	9.580
MZQP	8.409	8.192	6.356	2.831	2.923	1.822	11.13	10.56	4.309
SFBJ	5.694	5.925	6.459	4.962	4.652	2.618	15.66	15.41	6.736
JYHZ	5.299	3.342	4.534	3.196	2.290	2.101	8.024	3.950	3.386
JYZY	5.223	4.682	2.022	3.866	3.122	1.371	10.55	6.509	1.299
GYZJ	4.331	4.190	1.871	1.782	1.978	0.831 1	3.033	4.212	0.636 1
MXNX	4.299	3.564	3.597	2.597	2.707	2.290	4.744	4.719	3.676

From the records used, the largest PGA was about 9.8 m/s^2 in the east-west direction of Wolong (WCWL) station in Wenchuan county, and its distance both to the epicenter and to the earthquake fault is about 21 km. This was followed by the PGAs from Qingping (MZQP) station in Mianzhu, Bajiao (SFBJ) station in Shifang, Hanzeng (JYHZ) station in Jiangyou, and so on. Table 1 shows some of the PGA, PGV and I_a values used in this study.

3 Relationships between the three parameters and earthquake-induced landslides

3.1 Analysis based on the Wenchuan earthquake geological disaster zonation

After the Wenchuan earthquake, the China Institute for Geo-Environmental Monitoring, which belongs to the Ministry of Land and Resources, divided the regions affected by geological disasters (mostly landslides) into three categories based on field investigation data, see Figure 2.

Region I, the most serious affected areas of geological disaster with average disaster-point densities greater than 12 per 100 km^2;

Region II, secondary to region 1 with average disaster-point densities between 3 and 12 per 100 km^2;

Region III, with average disaster-point densities less than 3 per 100 km^2.

We assume a region category where the observation station located on the zonation map has the corresponding disaster point density. All the stations which do not belong to the three regions mentioned above are classified as region IV, where we observe the average landslide density is very low. Figure 3 shows the three parameters of PGA, PGV and I_a in three directions (east-west, north-south and vertical) and their corresponding region categories.

The following can be observed from Figure 3.

1) The three parameters of PGA, PGV and I_a obviously correspond well to the landslides hazard categories. In regions I and II with the most severe landslide disasters, the three ground motion parameters have higher values; while they obviously decrease in regions III and IV which had relatively slight geological disasters. This is consistent with the overall attenuating trend of geological disasters in the earthquake-hit area.

2) For the three parameters of PGA, PGV and I_a, the horizontal components are mostly greater than the corresponding vertical ones. This trend is especially apparent for PGV and I_a, indicating that the horizontal components play a leading role in surface damage. Thus earthquake-induced landslides are more closely related to the horizontal ground motion components. This analysis is in accord with the conclusions of Arias (1970) and Wilson and Keefer (1985).

3) The vertical components in regions I and II with the serious geological disasters are obviously greater than those in regions III and IV. Thus, taking the regions as a whole, we can see that when the horizontal components of ground motion are large, the induced landslide hazards are particularly serious if the vertical components are also large. The vertical components provide an impetus to the horizontal ones, which can exacerbate the extent of the disasters.

4) There is a boundary line for peak acceleration at 2 m/s^2 in the earthquake-hit Longmenshan area. In the two regions with severe earthquake-induced geological

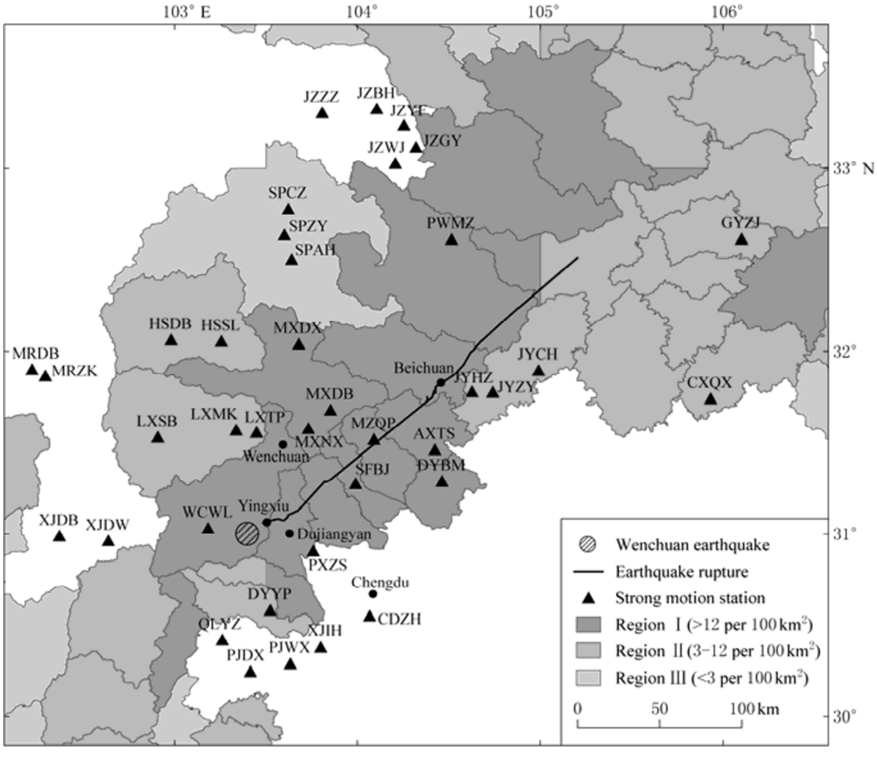

Figure 2 Geological disaster zonation map and strong motion stations.

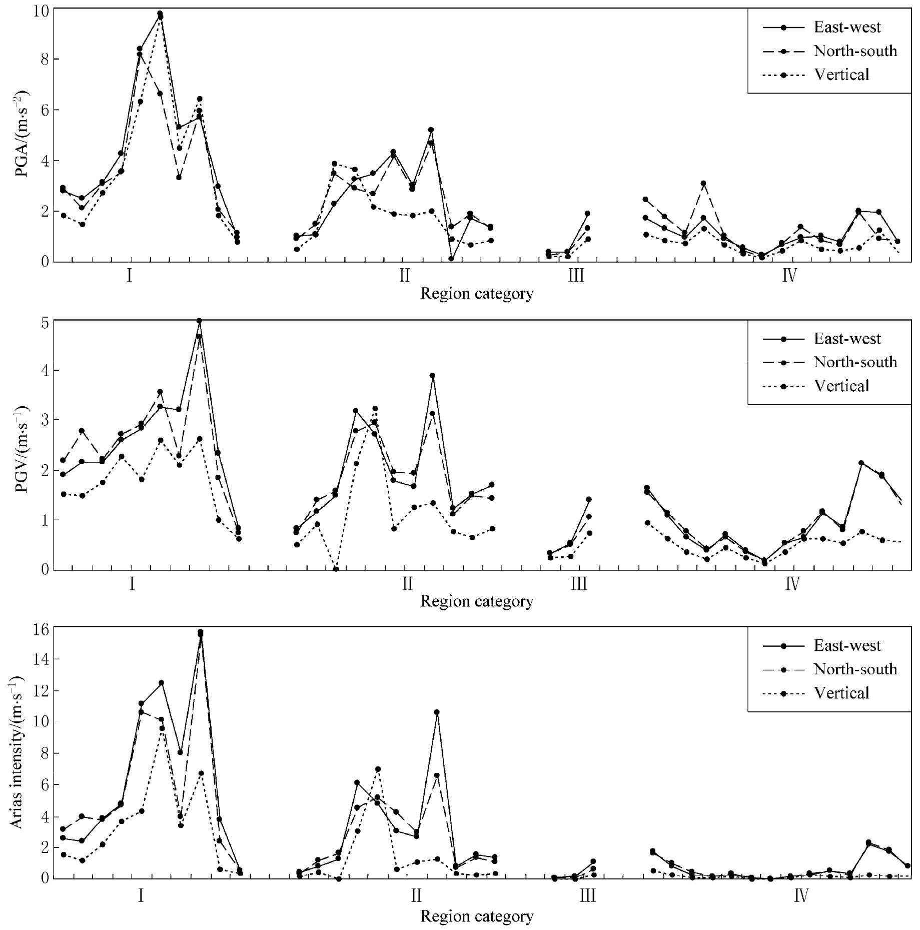

Figure 3 Relationships between ground motion parameters of PGA, PGV, I_a and region categories of geological disasters induced by the Wenchuan earthquake.

disasters, most of the PGAs are greater than 2 m/s^2, while in regions with slight disasters the vast majority of them are less than 2 m/s^2.

5) I_a also has a clear dividing line in the Longmenshan area at 2 m/s. The landslide disasters are very serious when I_a is greater than this value, and the disasters are relatively light if it is less than this value.

6) The PGVs correspond well with the first three geological disaster categories in the Longmenshan area when taking 1.5 m/s as the dividing line, but there are higher PGVs in region IV. With reference to the landslide distribution (Figure 1), we see that, among the higher PGV points in region IV, two stations are intensively subjected to landslides, while the others located in the relatively flat plains, have fewer landslides because of the topography.

7) In the regions where slight geological disasters occur, the PGV seems to be more relevant to the distribution of landslides in local sites. We infer that the PGV can make some local sites, which were affected by serious landslide disasters but concealed by averaging the disasters, stand out.

By comparing the relationships of the three parameters with geological disaster divisions based on the whole earthquake-hit area, we can see that all three parameters show an attenuation law consistent with the geological disasters occurring in the large area. However, divisions can only reflect the severity of the disaster in their area as an average because the administrative division is taken as the statistical unit. In fact, earthquake-induced landslides are obviously impacted by local topography, lithology, geological structure and so on. Some small areas with intensive landslides will increase the average density for the whole administrative division, or reduce the density of landslides in local sites after averaging, so their true relationship is unclear. As shown in Figure 3, the PGV highlights this situation, although the stations in region IV with higher PGVs are not categorized as geological disaster regions according to the zonation map, which means the average extent of disaster is very slight, but the landslide hazard in the areas around some stations is indeed very serious. Consequently, we need to study further their relationships by analyzing the landslide distribution in the locality of these station sites.

3.2 Analysis based on the landslide density in local sites

Earthquake-induced landslides are closely related with the topographical, geomorphologic, lithologic, etc, condition in the locality. Analysis based on the regional scale data can only reflect the average result. However, analysis based on the landslides density and ground motion parameters in the local station can reflect the effect of these geological conditions, since the ground motion records incorporate the source, propagation path, and site response information. Moreover, the slopes' response to the earthquake can be analyzed by the ground motion acceleration time history. Therefore, the result based on the local data will be more accurate if more depth analysis is carried out.

Here, we directly compared the density of landslides (number of landslides in a defined area around the station) in the local sites of ground motion observation stations with the three foregoing ground motion parameters. We believe this method can better reflect the correlation between the ground motion in local sites and the landslide distribution, than by calculating the number of landslides per unit area within the contours of the ground motion parameters.

To this end, we calculated a number of landslides located at 20 km and 30 km from the stations. We believe the distance of 20 km is suitable because there may be no data in local sites if the distance is too small. In addition, not all the landslides in this region are included in the data sets used in this paper, because the investigation focused on dwelling districts and on areas of greater economic losses. Statistics were also carried out in the range of 30 km, for comparison.

Nevertheless, there are no statistical data on landslides for several stations, because these stations are in the relatively flat region at the base wall of the rupture. This flat area is unlikely to have a large number of earthquake-induced landslides due to the topographic conditions, so it is unnecessary to consider these stations in carrying out the analysis.

The histogram of local landslides density versus the corresponding PGA, PGV and I_a parameters is given in Figure 4. In Figure 4, the density of the landslides in local sites of observation stations shows almost identical laws to the three ground motion parameters. Where the ground motion parameters are small, there are fewer or no induced landslides. Where the parameter is greater than a certain value, namely, PGA over 0.7 m/s^2, PGV over 0.5 m/s, and I_a over 0.2 m/s (indicated by the first arrow of the corresponding chart), the number of landslides increases markedly. We can use these values as threshold values (lower limits) of the three parameters for inducing landslides in the Longmenshan area. When the PGA is greater than 3 m/s^2, the PGV greater than 2.0 m/s, and I_a greater than 3.0 m/s (indicated by the second arrow of the corresponding chart), the landslide density will remain at a certain level with relatively little variation. These values can be used as the upper limit of ground motion for affecting earthquake-induced landslides. When reaching the upper limits, the ground motion will meet or exceed the maximum intensity of the ground motion that all slopes in the earthquake-hit area can withstand. The changes in landslide density are only relevant to the local topography (e.g., a flat area or a hilly/mountainous area), as well as the level of detail of the survey data. Between the lower and upper limit, there will be larger variations in landslide density with the increase in ground motion parameters. The distribution density of the landslides in local sites will be affected by many factors such as topography of local sites, geological lithology and degree of fragmentation, intensity of ground motion and thoroughness of the survey data, thus there will be a larger variation in landslide density.

We can see that the upper limit of the ground motion parameters acquired from the analysis of landslide density at local sites is different from the results acquired from the landslide hazard divisions. Now we analyze the following situation: when the landslide density in some local sites is especially intensive, the average disasters based on an administrative unit will increase, and the disaster seriousness of these local sites will decrease, after averaging. Thus, the upper limits of the ground motion will reduce correspondingly. However, we believe the average disasters on a regional scale are affected by the disaster levels in different local sites, so the results acquired from it can be adapted to more places in the earthquake-hit areas. Conversely, the results from local site analyses can only adapt to a few places, since only those places where there is strong motion station took part in the analyses. Therefore, we assume the result from the regional analyses as the upper limit.

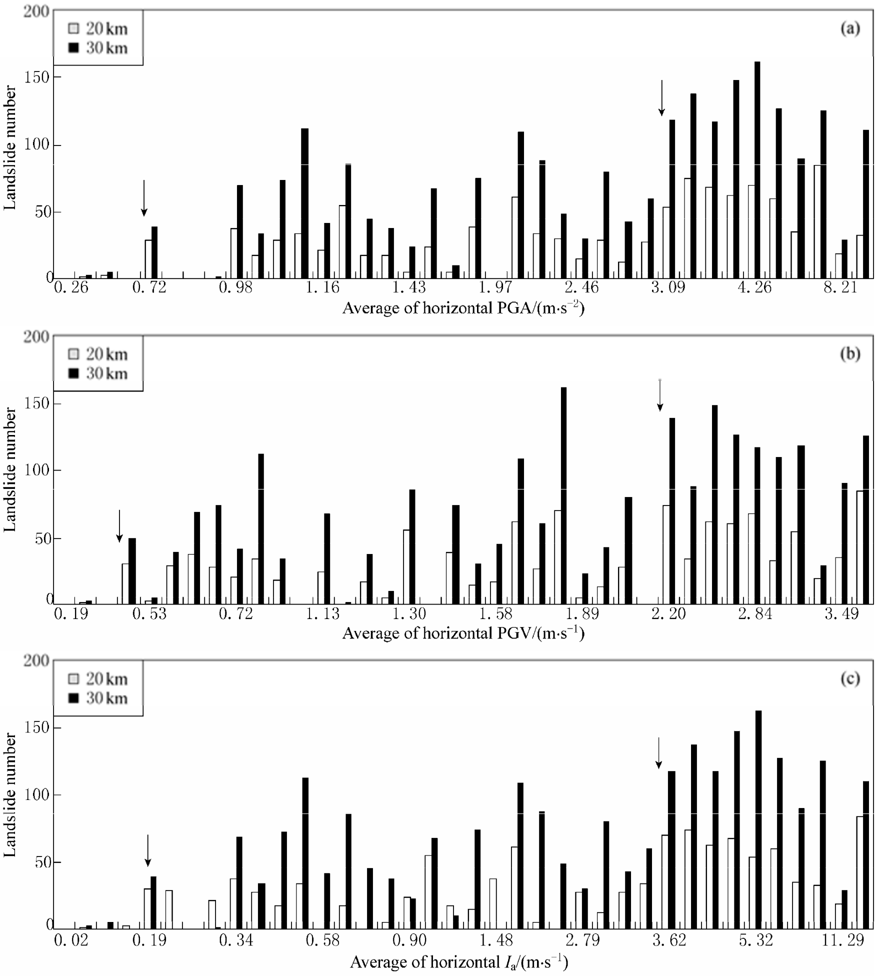

Figure 4 Relationships between landslides density in local sites of ground motion stations and PGA (a), PGV (b) and I_a (c). The first arrow denotes the value, from which the parameter is greater than a certain value, namely, PGA over 0.7 m/s^2, PGV over 0.5 m/s, and I_a over 0.2 m/s, the number of landslides increases markedly. The second arrow denotes the value, from which the parameter is greater than a certain value, that is, PGA is greater than 3 m/s^2, PGV greater than 2.0 m/s, and I_a greater than 3.0 m/s, the landslide density will remain at a certain level with relatively little variation.

When targeting different-sized research areas, the lower and upper limit of the ground motion parameters will change. Analysis results for a large area can well reflect the relationships of earthquake-induced landslides and ground motion parameters on a regional scale. Studies on local sites can reflect the fact that earthquake-induced landslides also have good correlation with ground motion parameters on a smaller scale, and the ground motion intensity is the main factor affecting the occurrence of earthquake-induced landslides.

Through analysis using landslide information on both regional and local situations, all three ground motion parameters show close relationships with earthquake-induced landslides. We seek to resolve which of the three parameters is the most relevant to earthquake-induced landslides, and to establish the ranking order of the three parameters according to their relevance to earthquake-induced landslides.

4 Relevance comparison of the three parameters to earthquake-induced landslides

As with the destruction of surface constructions or buildings, earthquake-induced landslides will be affected by the combination of ground motion amplitude, spectrum and duration (Hu, 2006). Parameters that can comprehensively reflect these three ground motion characteristics can better reflect the overall intensity of ground motion at observation points, and can be more relevant to the level of surface damage.

The three parameters, PGA, PGV and I_a, describe the ground motion intensity from three different perspectives, and their ability to reflect the ground motion intensity can reflect their closeness to earthquake surface damage. Therefore, if a parameter can represent the overall level of ground motion intensity, it can better reflect the probable level of surface damage.

In addition, we believe that a ground motion parameter that can comprehensively reflect the level of ground motion should not only have relevance to other ground motion parameters, but have a better correlation to them. Correlation may exist between parameters that describe the ground motion only from certain aspects, but the correlation between them will not be better than the former ones.

Therefore, if a ground motion parameter is strongly related to other ground motion parameters, its ability to represent the level of ground motion intensity should be better than that of other parameters to do so; as a result, its relevance to the extent of surface damage will be stronger than the other parameters.

According to the definition of the three parameters, PGA, PGV and I_a, PGA and PGV only reflect the ground motion intensity from the aspects of amplitude of acceleration and velocity, while I_a combines the three characteristics of amplitude, spectrum and duration, therefore intuitively, I_a should have stronger relevance to earthquake-induced landslides.

We can also reach the same conclusion through the quantitative analysis and comparison between the three parameters. According to the analyses in section 3, whether in a large or a small region, the three parameters have good correlation with earthquake-induced landslides. They also have good correlation between one another because they reflect the same ground motion from different aspects according to their definition, so we compare the correlation between the three parameters.

Figure 5 shows the relevance of PGA versus I_a, PGA versus PGV, and PGV versus I_a in east-west direction. Through calculation, we can get the correlation coefficients between the three parameters in three directions (Table 2). The relevance ranking of the three parameters obtained by analysis and comparison is also given in Table 2.

Analyzing Table 2, we can see that I_a, as expected, occupies the leading position in all the results of correlation calculations in three directions. It is quite obvious that I_a has the highest correlation with other parameters according to quantitative calculations, therefore I_a could better represent the ground motion intensity compared with the other two parameters, and its correlation with earthquake-induced landslides is also the best.

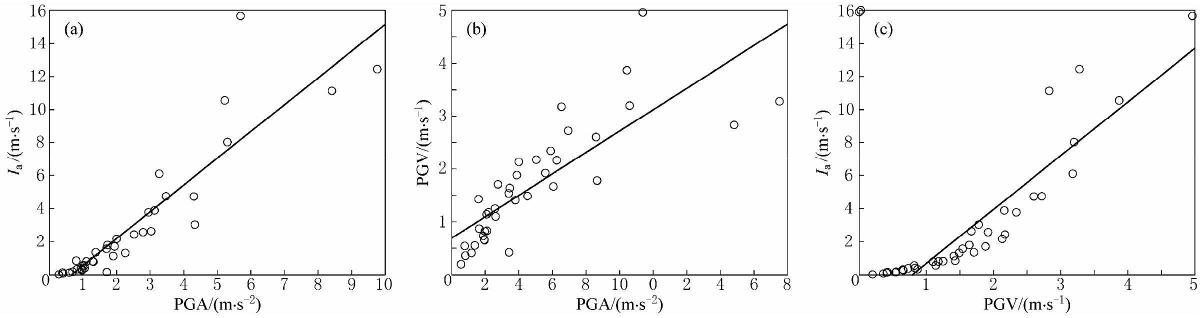

Figure 5 Correlation comparison of PGA vs. I_a (a), PGA vs. PGV (b), and PGV vs. I_a (c) in east-west direction.

Table 2 Relevance coefficients and sorting of comparison results for PGA, PGV and I_a in three directions

Direction	Relevance coefficient			Sorting of results
	PGA vs. I_a	PGA vs. PGV	PGV vs. I_a	
East-west	0.907 4	0.805 8	0.915 8	I_a, PGV, PGA
North-south	0.897 7	0.813 3	0.912 7	I_a , PGV, PGA
Vertical	0.938 2	0.811 1	0.898 8	I_a, PGA, PGV

The PGV has better correlation to earthquake-induced landslides than PGA in two horizontal directions, but the result is opposite in the vertical direction. According to the conclusions in this paper and results from other researches (Arias, 1970; Wilson and Keefer, 1985; Liao, 2000), earthquake-induced landslides are correlated better to the horizontal components of ground motion, so we believe that the ranking results in the horizontal direction are more credible. Therefore, PGV is more relevant to earthquake-induced landslides than PGA.

PGA is the most commonly used parameter for ground motion analysis and it has been thoroughly studied, therefore many of the results from those studies can be used here. It must be noted that PGA changes randomly and great changes can be generated with small variations in site conditions. Furthermore, the PGA measurements can be saturated or limited when the observation point is near the epicenter or the rupture (Hu, 2006).

The results based on data from the Wenchuan earthquake show that PGA can generally reflect the intensity of ground motion in different regions, but this relationship is only a general correlation, which may not fully correspond to the actual data. As shown in Table 1, the maximum PGA was measured at Wolong station (WCWL) in Wenchuan county, but it was at Bajiao station (SFBJ) in Shifang where the maximum release of seismic energy was recorded. We can see more examples of this kind in Table 1.

Newmark (1965) also shows that the results of slope damage are the cumulative process of displacements from the continuing action of the ground motion on the slope. Although the instantaneous maximum value of ground motion acceleration, PGA, may exceed the critical acceleration of the slopes, it will not necessarily result in enough accumulated displacement to cause permanent slope damage. Therefore, in places with higher PGA, it does not mean landslides must be triggered.

The velocity of ground motion is related to the energy of ground motion because we know that $mv^2/2$ represents the kinetic energy of a particle movement, so the ground motion velocity is proportional to the energy of the particle movement (Hu, 2006). Therefore, we believe that the PGV can reflect the intensity of releasing energy on the Earth's surface during earthquake movement, which in turn reflects the intensity of surface damage.

In accordance with its definition, I_a combines amplitude, frequency and duration of ground motion, and is proportional to the energy release in ground motion (Wilson and Keefer, 1985; Harp and Wilson, 1995), therefore it can better reflect the actual destruction of the Earth's surface.

5 Discussion and conclusions

Based on the analysis of the relationships between landslides induced by the Wenchuan earthquake and ground motion parameters of PGA, PGV and I_a from a regional and local scale, we consider that earthquake-induced landslides correspond well to the three ground motion parameters.

In the Longmenshan area, the minimum PGA that can induce landslides is about 0.7 m/s^2, which is consistent with the result of 0.5 m/s^2 obtained according to the comparison of historical maximum distances of earthquake-induced landslides and the ground motion records from other earthquakes by Wilson and Keefer (1985).

Landslides induced by the Wenchuan earthquake are mostly concentrated in the area with a PGA$>$2 m/s^2. Liao (2000) believed that earthquake-induced landslides are mainly located in regions with a PGA$>$2.5 m/s^2 based on his study on the Jiji (Chi-Chi) earthquake, but Khazai and Sitar (2004) held that landslides are more concentrated in areas with PGA$>$1.5 m/s^2 in his study of the Jiji (Chi-Chi) earthquake. Our result from the Wenchuan earthquake is consistent with these results from the Jiji (Chi-Chi) earthquake.

With regard to I_a, landslides are more serious in the regions where I_a reaches 2 m/s. The lower limit of I_a for inducing landslides is about 0.2 m/s, which is consistent with the result obtained from the Superstition Hills earthquake of *M*6.6 (Harp and Wilson, 1995). Wilson and Keefer (1985) believed that the thresholds of I_a are different for different types of landslides and can vary between 0.15 m/s and 0.5 m/s. The results from the Wenchuan earthquake are within this range.

The above analysis shows that the ground motion parameters of landslides induced by strong earthquakes have the same order of magnitude as those of moderate earthquakes. When the ground motion parameters are greater than the corresponding thresholds, the number of induced landslides increases significantly; but when the ground motion parameters exceed certain values (upper limits), the difference between the landslides induced by strong earthquakes and by moderate earthquakes will be reflected more by the scale and disasters of the landslides, e.g., the Jiji (Chi-Chi) earthquake induced only a few large scale landslides with serious effects, but there were hundreds of large or even giant landslides induced by the Wenchuan earthquake. Daguangbao landslide in Anxian county, as mentioned above, is the largest earthquake-induced landslide recorded in China or even in the world so far (Huang and Li, 2008; Yin, 2009).

There are relatively few studies on the relationship between PGV and earthquake-induced landslides, and the study in this paper shows that the PGV is well related to earthquake-induced landslides. In the Longmenshan area, the lower limit of the PGV which can trigger landslides is about 0.5 m/s, and serious landslide hazard can be induced when the PGV reaches 1.5 m/s.

The result of quantitative and comparative analysis shows that PGV is better related to earthquake-induced landslides than PGA, while I_a has the highest relevance to earthquake-induced landslides. Wilson and Keefer (1985) concluded that I_a can represent the earthquake intensity since it is proportional to the released energy of ground motion, and Harp and Wilson (1995) believed that I_a is better related to earthquake-induced landslides than PGA because I_a contains information such as amplitude and duration. Boatwright et al (2001) held that PGV is better related to seismic intensity than PGA by comparing ground motion parameters with seismic intensity using data obtained from the Northridge earthquake. The results in this paper based on the ground motion data of the Wenchuan earthquake are consistent with all these conclusions.

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