

# Improvement of Methods for Earthquake-induced Landslides Assessment

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## SUMMARY:

In order to mitigate the damage caused by the landslides, a wide variety of approaches are used to predict the earthquake-induced landslides susceptibility area. To the simplest approaches, the usually used one is to define the area which will be affected by landslides during the seismic shaking at some special location. So the relationship between the seismic magnitude and the affected area is established through the study of a large number of earthquake-induced landslides worldwide. Generally, lots of the analysis of earthquake-induced landslides about the seismic magnitude and the affected area are consistent with the knowledge obtained by Keefer in 1984. But more deep studies show that the size of areas affected by landslides could change enormously even under the same earthquake magnitude. For example, in southwest China, areas affected by landslides changed greatly from 2600 to 8843km<sup>2</sup> with the same seismic magnitude 7.0. While at the same tectonic place or fault belt, areas affected by landslides present similar outline and size. This implies that the development of methods for assessing earthquake-triggered landslides hazard should comparatively consider local geological condition and historical earthquake background in order to get more precise landslides hazard assessment maps, even at the initial stage of land-use planning.

*Keywords: earthquake-induces landslides, hazard assessment, local geological condition, potential seismic source zones*

## 1. INTRODUCTION

Due to the tremendous hazard caused by earthquake-induced landslides, more and more attention has been focused on the development and refinement of assessment methods for estimating seismically induced permanent deformations in landslides and earth structures. Compared with landslides triggered by other phenomena (e.g., meteorological events), distribution of earthquake-induced landslides shows different characteristics in the aspects such as affected area sizes, landslides scales, landslides locations with seismic faults and so on. During a strong earthquake occurred in mountainous area, hundreds of landslides are triggered simultaneously and spread in a region covering hundreds to thousands square kilometers. Sometimes a lot of giant landslides are formed to cause fatal damage to residents. In spite of the documents about fatalities caused by landslides in the ancient time, there are many casualties events occurred in the modern time. For instance, during Wenchuan earthquake in 2008, China, there are 11 landslides which caused the fatalities more than 100 persons.

Due to its characteristics, earthquake-induced landslides pose more severe problems to the disaster-management community in terms of timely and effective emergency response. So the issue of

earthquake-induced hazard assessment has received much more attention in recent years. Till now, the assessment can be performed at different levels ranging from regional studies to the site-specific evaluation of individual slopes aimed to different demands (ISSMGE, 1999; Australian geomechanics society landslide zoning working group, 2007; Bommer et al, 2002;). Generally, according to the applicability of landslides hazard zoning map, these approaches have been classified into three grades at scales in the following ranges: Grade 1, 1:1,000,000–1:50,000; Grade 2, 1:100,000–1:10,000; and Grade 3, 1:25,000–1:5000 (ISSMGE, 1999). Consequently, variety approaches of landslide hazard assessment have been stimulated to meet different demands.

Wilson and Keefer (1985) proposed to identify potential conditions of seismic-landslide triggering for a “scenario event” in terms of exceeding significant thresholds for some relevant parameters such as Arias intensity and Newmark’s displacement. For Newmark’s displacement, this approach is based on physical analysis and has been applied to assess single slope stability. But when facing a wide region, this method becomes impracticable because it needs sufficient underground information, such as rock friction coefficient, friction angle and so on. Besides analysis based on the object balance, many researches are conducted to obtain the knowledge and understanding of the relationship between failures distribution and affecting factors, which mostly depend on the study of past and present earthquakes.

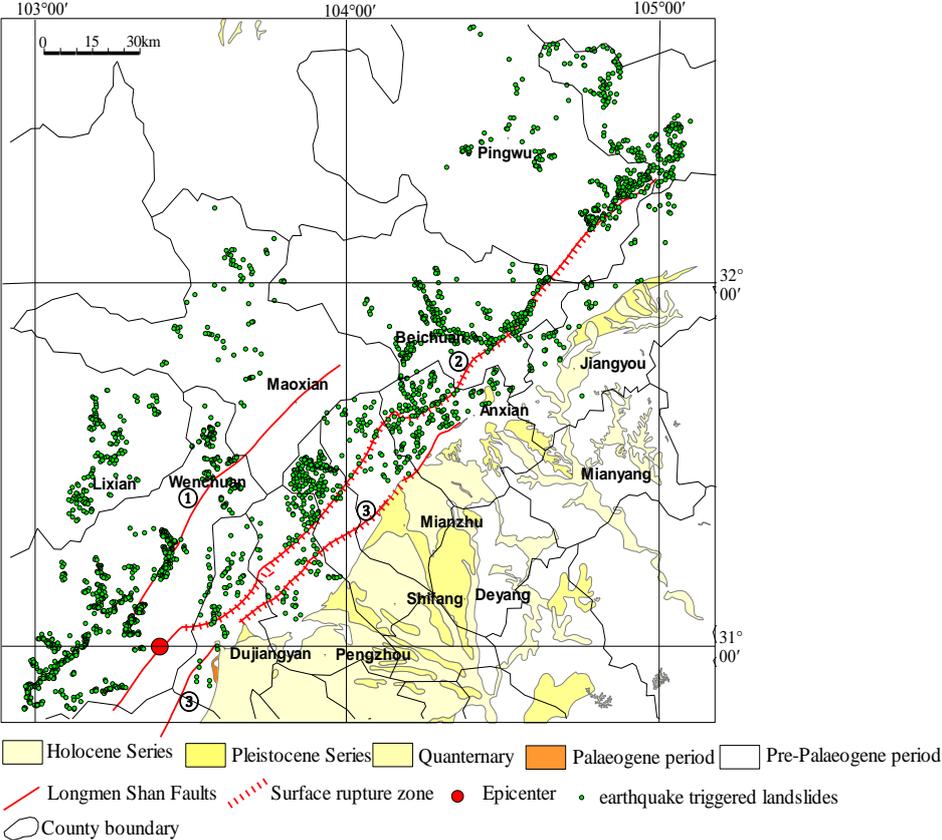
For regional hazard assessment, the simplest and usually used approach is to define the area which will be affected by landslides at some special location during the seismic shaking. Keefer compiled an earthquake-triggered landslides database which included 40 historical world-wide earthquakes, and based on it, he studied the characteristics, geological environment of landslides, as well as the relations between landslide distribution and seismic parameters (Keefer, 1984). Then the relationship between the seismic magnitude and the affected area is established, landslide hazard is expressed as a binary function defining geographical limits within which landslides will be expected from an earthquake of specified magnitude and location. (Bommer et al, 2002).

However, with the rapid development of society economics, expectation of high precision is put on the landslide hazard assessment. Research on earthquake-induced landslides in southwest China found that the relationship between the earthquake magnitude and the area affected by landslides in this region are consistent with what have been obtained from the worldwide. But it is also seen that the size of areas affected by landslides change enormously from 2600 to 8843km<sup>2</sup> even under the same earthquake magnitude in the study region. While at the same tectonic place or the same fault belt, areas affected by landslides presented similar outline and size. This phenomenon means that local geological conditions and historical earthquake background have important influence on landslides spacial distribution. The paper discusses an approach to predict landslides hazard exposure boundary based on the potential seismic source zones and seismic belts, and it can be used as a reference for primary land planning and sites selection for important projects at Grade 1 according to ISSMGE.

## 2. INFLUENCING FACTORS RELATED TO EARTHQUAKE-INDUCED LANDSLIDES

It is well known that landslides are more likely to occur in some special area. Researches of lots seismic events show that rock type, landform, slope degree, earthquake intensity, earthquake magnitude and distance from the seismic faults or seismic epicenter and so on are the important factors that affecting landslides distribution and other characteristics during an earthquake.

Generally, a strong earthquake can cause thousands of landslides simultaneously over a large area which is more than hundreds square kilometer. Spatially, earthquake-triggered landslides have much more closer relationship with geological structures compared with rain-triggered landslides. Lots of researches on the earthquake-induced landslides show that tectonics will control the spacial development of landslides. For example, during 5.12 Wenchuan Earthquake 2008, more than 15,000 landslides were triggered by the earthquake (Yin et al., 2009), and they are dominantly developed along the Longmenshan fault zone (Fig 1.).

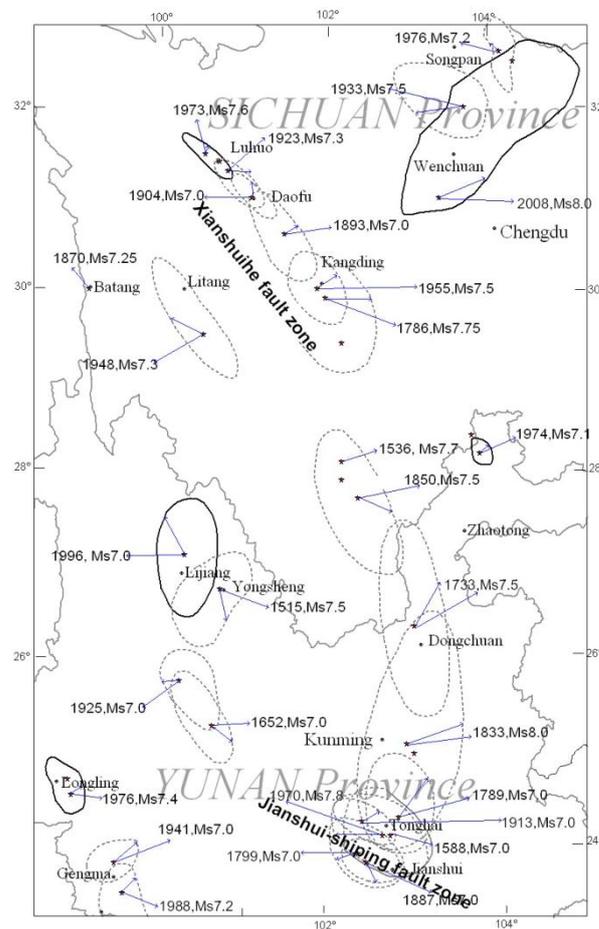


**Figure 1.** Distribution of landslides and geological stratum  
 (①): Longmen Shan Back Fault; (②) □ Longmen Shan Central Fault; (③) Longmen Shan Front Fault;  
 landslides is from National Wenchuan Earthquake experts committee)

Guzzetti et al. (1999) thought the definition of landslides should incorporate the concepts of magnitude, geographical location and time recurrence. As to earthquake-induced landslides assessment, earthquake magnitude and the location of earthquake occurring in the future are important factors for the hazard prediction and assessment.

Besides Keefer's study in 1984, Rodríguez extended Keefer's work with other 36 world-wide earthquakes, and used the similar approach to analyze his new data. The knowledge of the seismic magnitude and affected area obtained by Keefer and Rodríguez are very similar except the presence of extreme outliers in some of the correlations (Rodríguez et al, 1999). With the increasing magnitude, the size of affected area will increase. This relationship has been used as the simple method in the assessment of earthquake-induced landslides.

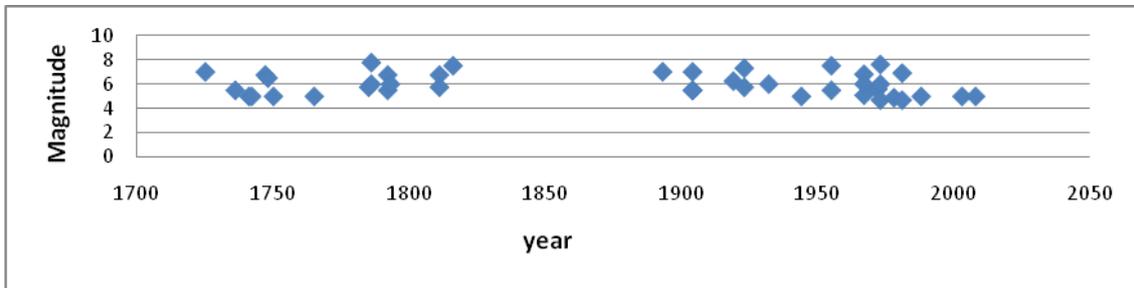
But more deep studies show that the size of areas affected by landslides could change enormously even under the same earthquake magnitude. For example, in southwest China, areas affected by landslides changed greatly from 2600 to 8843km<sup>2</sup> with the same seismic magnitude 7.0. However, the size and shape of the landslide-affected area are very similar in some areas where there are frequent occurrence of strong earthquakes, such as in Xianshuihe fault zone and Shiping-Jianshui fault zone (Fig.2).



**Figure 2.** Earthquake epicenters and area of associated landslides in southwest China (solid lines are the earthquakes having detailed landslides records, dash lines are inferred from the history documents, which using seismic intensity line of VII for instead )



zone for its high seismicity and activity. According to the latest earthquake statistics in the study area, there are more than 40 earthquakes documented with magnitude 4.7 or greater occurred in Xianshuihe seismic zone, in which there are 4 earthquakes with magnitude 7.0 or greater occurred since 1900 (Figure 4).



**Figure 4.** Seismicity in Xianshuihe seismic belt from 1725 to 1988

Although the earliest earthquake record dates back to 1725 (Earthquake-resistant and damage prevention department of State Seismic Bureau, 1995; Earthquake-resistant and damage prevention department of China Earthquake Administration Bureau, 1999), only a few of historical earthquakes are documented with landslides reports due to sparsely inhabited and uncultured situation. The data used for affected area analysis in this paper is shown in Table 1. This data includes earthquake with magnitude from Ms6.0 to 7.75. Of these data, only Luhuo earthquake which occurred on Feb. 6, 1973 had detailed field inspection on the landslides, and its affected area was measured 409km<sup>2</sup>. To other events' affected area calculation, a region enclosed by the isoseismic line of seismic intensity VII is used instead. As to the earthquake M5.0 occurred in current time in 1988 and 2003, there is no report of landslides, so they are not listed in the following table.

**Table 3.1** Earthquake-induced landslides data in Xianshuihe seismic belt

No.	Date (yy-mm-dd)	Epicenter		Magnitude	Epicenter seismic intensity	Area affected by landslide (km <sup>2</sup> )	Reference *
		Latitude	Longitude				
1	1748-8-30	30.4	101.6	6.5	IX	2134	E
2	1786-6-1	29.9	102.0	7.75	X+	2724	E
3	1793-5-15	30.6	101.5	6.0	VIII	1156	E
4	1893-8-29	30.6	101.5	7.0	IX	4938	E
5	1904-8-30	31.0	101.1	7.0	IX	1307	E
6	1955-4-14	30.0	101.9	7.5	X	4416	E, S
7	1967-8-30	31.61	100.33	6.8	IX	1423	E, ES
8	1973-2-6	31.48	100.53	7.6	X	409	E, GS, C
9	1981-1-24	30.98	101.10	6.9	IX	610	E, GS

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**E:** Earthquake disaster prevention department of China Earthquake Administration, 1995, 1999;

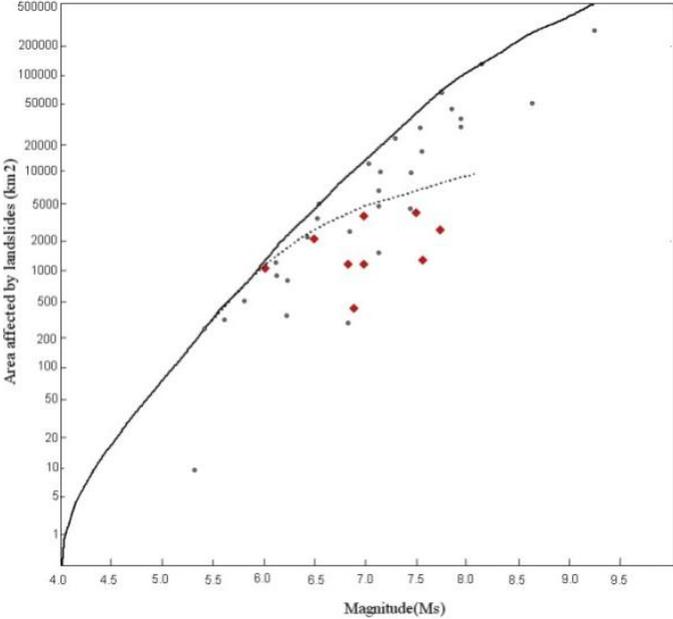
**ES:** Earthquake Administration of Sichuan Province.

**C:** Chengdu earthquake investigation team of State seismological Bureau

**GS:** Institute of Geography of Sichuan province

**S:** Southwest China Intensity Zoning team, State Seismological Bureau,

Generally, area affected by earthquake shows strong correlation with earthquake magnitude, and earthquakes with bigger magnitude can cause wider influencing area(Keefer, 1984; Bommer et al, 2002; Rodri'guez et al, 1999). The plot dots of landslide affected area in Xianshuihe seismic belt shows that trend of upper bound line of landslide affected area is not as the same shown by Keefer (1984). The gradient of the upper bound line in Xianshuihe seismic belt is more gentle that Keefer's (Fig. 5).



**Figure 5.** Areas affected by landslides triggered by earthquakes within Xianshuihe seismic belt in southwest China as a function of magnitude.

(Upper bound line and dots are from Keefer (1984). The squares refer to the identification of individual events in Table 1. The dashed line is the upper bound line of landslide affected area in Xianshuihe seismic belt)

Due to incompleteness of the landslides data in Xianshuihe seismic zone, landslides affected area of each event may not accurate, but this trend of seismic magnitude with affected area will illustrate something of the localized geological structures effects on the landslides development.

**4. CONCLUSIONS**

The various approaches of current earthquake-induced landslide assessment rely on some widely accepted principles or assumptions. One of these principles is that slope failures in the future will be more likely to occur under the conditions which led to past and present instability. Based on this knowledge, people create many approaches to estimate the potential landslides. And the relationship between the seismic magnitude and the maximum area affected by the landslides is applied in the landslides assessment at a regional scale.

This paper's study shows different region has its own features of landslides development due to geological context and evolution history. Strong earthquakes which can cause serious geohazards are always presented in the delineated potential seismic source zones. It would be more scientific and

reasonable to stress on the influence of local geological condition and historical earthquake background when assessing earthquake-induced landslide hazard. Therefore, taking potential seismic source zones as assessment region unit will improve the precision of the hazard assessment. In Xianshuihe seismic belt, earthquake-induced landslides are narrowly spread along the Xianshuihe fault zone in the past and at present time. The biggest earthquake in current time (Ms7.6 on Feb 6, 1973) triggered landslides with affected area around 400km<sup>2</sup>, which is much smaller with respect of other earthquake with same magnitude.

## ACKNOWLEDGEMENT

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