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SOME CHARACTERISTICS OF EARTHQUAKE-INDUCED LANDSLIDE IN SOUTHWESTERN CHINA

Zhou Bengang, Zhang Yuming

(*Institute of Geology, SSB, Beijing, China*)

Abstract Based on the data of the landslides caused by several historical strong shocks since 1970 in southwestern China, this paper concluded the geological and geomorphological conditions of earthquake-induced landslide In this region, and discussed the relationship of landslide distribution and earthquakes. Finally, the main points on evaluating the hazards resulting from earthquake-induced landslide were also put forward in this paper.

Key Words: Southwestern China; Earthquake-induced landslide

1 Introduction

As a kind of severe seismic hazards, earthquake-induced landslide can destroy civil engineering faciiities, cause foundation damage or collapse of buildings, block roads, sever lifelines such as water pipers, power lines or gasmains, and thereby cause a great losses of lives and properties. A large earthquake in a mountainous region can generate thousands of landslides in a few minutes, the overall impact on the population is thus increase far beyond that of any single landslide. Losses caused by landslides account for about 40 percent in all the losses resulting from earthquake (Slonenko, V. P., 1976)[1]. The great 1964 Alaska earthquake, for example, caused an estimated 1.2 billion 1984 dollars in damage, 0.64 billion 1984 dollars (56 percent of the total) was due to landslides. Landslides also caused at least 48 of the 130 deaths reported in this earthquake (Wilson and Keefer, 1985)[2]. In a study of large ($M>6.9$) Japanese earthquakes since 1964, Koibayashi (1981) determined that more than half of all earthquake-induced deaths were caused by landslides.

China is located in the joint area of Around Pacific seismic zone and Alps-Himalayas seismic zone. Intense earthquakes occur in China frequently. These shocks can induce lots of landslides due to complex geological and geomorphological conditions, therefore, landslide remains one of the most serious seismic hazards in China. The regions that suffer earthquake-induced landslide most severely are the loess plateau region and southwestern China, where many strong earthquakes have been recorded. In the loess plateau region, landslides and avalanches develop very easily because of its loose feature, abundant plump joints, unstability of slope, and etc.. Magnitude of the smallest earthquake that generated landslides was 4 on Richter scale (Yao Qinglin 1986)[3]. The 1967 earthquake with magnitude of 4 near Xiyang county, Shanxi province, for example, induced loess collapse. In southwestern China, in addition to dangerously steep landform, thick deluvium and weathering crust, there is amount of rainfall. Earthquakes in this region may cause landslides and slope collapse on a large scale. According to historical data, magnitude of the smallest earthquake (on Feb. 25, 1977, Yanyuan county, Sichuan) that generated landslides is 4.7 on Richter scale in southwestern China (Gu Gongxu, 1983)[4]. On Aug. 25, 1933, large amount accumulative matters generated by Diexi earthquake ($M=7.5$) formed a large dam 160 meters above the water level to blocked Mianjiang River. Huge damages were caused when the water poured down due to collapse of the dam after 40 days. A landslide at Laozaibao generated by 1974 Zhaotong earthquake ($M=7.4$), for another example, killed 70 people. Therefore, for the sake of harzard assessment, it has a great meaning to study the features of earthquake-induced landslide in southwestern China.

2 Geological and geomorphological Background

The neotectonic movement in Yunnan provinceand western Sichuan provinceappears very intense. This region has risen more than 1500 meters since Neogene period. With extremely deep ravines and complex geomorphology it developed better slope conditions for landslide. In addition, thick loose matters on slopes can provide abundant substances for landslide also. Moreover, the traces of tectonic activities remain very conspicuous and thereby complicated structures and broken rocks exist widly in this region. Active faults are distributed in the whole area especially. The famous Xianshuihe fault and Honghe fault run through this region (Fig. 1). Seismicity here is extremely strong and earthquakes with magnitude larger than 7 occurred very often. Of all the 11 earthquakes ($M>6.7$) which have occurred since 1970, shocks of magnitude larger than 7 account for 9. All these earthquakes generated large numbers of landslides and rock avalanches (Table 1). Fig. 1 showed the distribution ranges of some earthquake-induced landslides with detailed information. The largest landslide of all the landslides is the one at Tuanbozai caused by 1976 Longling earthquake. Its volume reached 1,200,000 cubic meters.

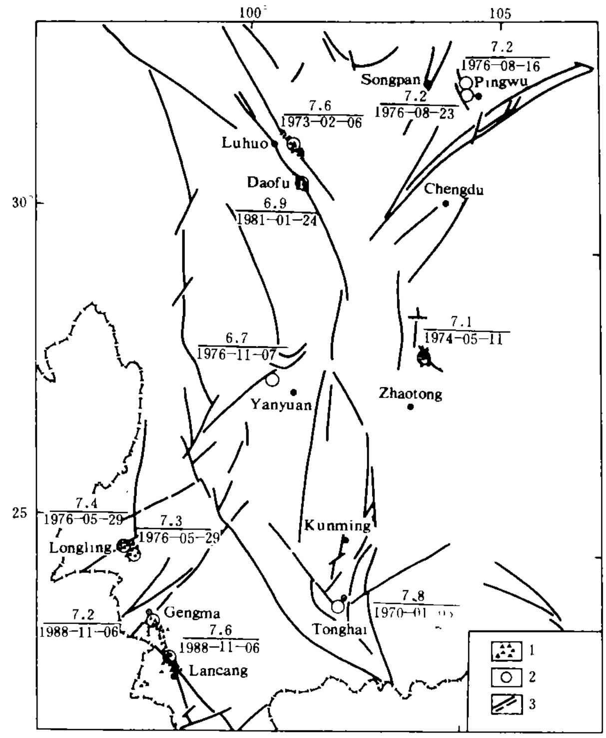

Fig. 1 Distribution of earthquakes with $M\geqslant 6\frac{3}{4}$ in southwestern China since 1970

1. Landslide; 2. Epicenter; 3. Active fault

Table 1　Landslides caused by earthquakes(M>6.7) since 1970

Time	Location	M_s	Depth (km)	I. M	L. I	Max. D (km)	Max. A (km^2)
1970—01—05	Tonghai, Yunnan	7.8	13	Ⅹ	Ⅶ	45	
1973—02—06	Luhuo, Sichuan	7.6	11	Ⅹ	Ⅷ	40	1200
1974—05—11	Zhaotong, Yunnan	7.1	14	Ⅸ	Ⅶ	12	900
1976—08—16	Songpan, Sichuan	7.2	15	Ⅸ	Ⅶ		
1976—08—23	Songpan, Sichuan	7.2	23	Ⅷ+	Ⅵ		
1976—05—29	Longling, Sichuan	7.3	24	Ⅸ	Ⅶ	22	1500
1976—05—29	Longling, Sichuan	7.4	21	Ⅸ	Ⅶ		
1976—11—07	Yanyuan, Sichuan	6.7	15	Ⅸ	Ⅶ	12	400
1981—01—24	Daofu, Sichuan	6.9	12	Ⅷ	Ⅶ	20	450
1988—11—16	Lancang, Yunnan	7.6	13	Ⅹ	Ⅶ−	80	1500
1988—11—16	Gengma, Yunnan	7.2	8	Ⅹ	Ⅷ	25	1800

I. M: Intensity of meizoseismal area;　L. I: Lowest intensity of landslide area;
Max. d: Maximum epicentral distance;　Max. A: Maximum area of landslide distribution

3 Landslide Classification

Landslide can be classified differently according to its composition, formed age, thickness, scale, mechanical condition, and so on[5]. The way in which a landslide moves determine how to evaluate and deal with landslide hazards. Therefore, classification in the light of the way of landslide movement was adopted here. The landslides in this region can be classified as four types; that is pushing-landslide, hauling-landslide, bedding-landslide, and avalanching-landslide* (Fig. 2).

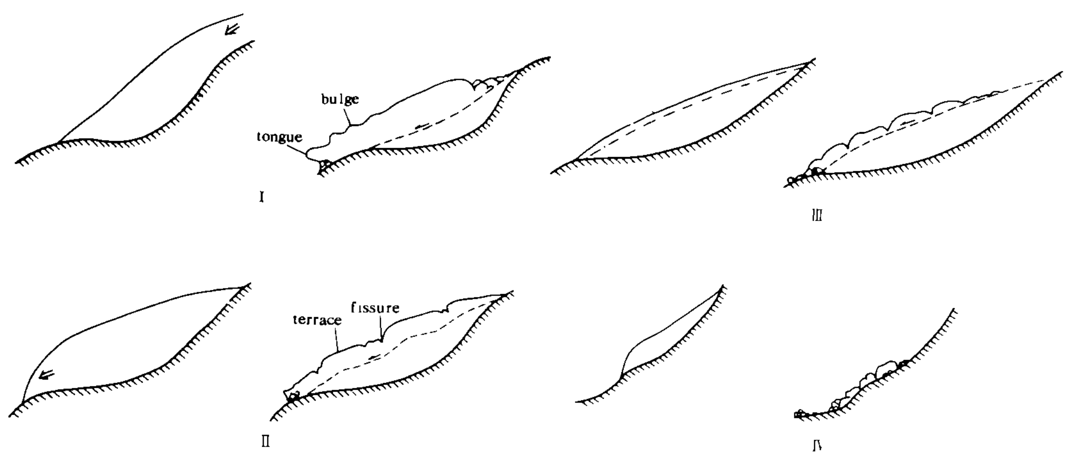

Fig. 2　Sketch of four types of the landslides
Ⅰ. Pushing-landslide;　Ⅱ. Hauling-landslide
Ⅲ. Bedding-landslide;　Ⅳ. Avalanching-landslide

* Institute of Geography of Sichuan Province. Investigating Report of Rock Falls, Landslides and Mud-Rock Flows by 1974 Yongshan-Daguan Earthquake. 1974.

(1)Pushing-landslide refers to the one that slides down along a shearing bed due to the above pushing force. In the lower part of this landslide often develop bulges and sliding-tongues. This kind landslide appears on large scales and has good integrity.

(2)Hauling-landslide is defined in the light of the following circumstances: When the front rock and soil on the slope are vibrated to loose the behind geological bodies cannot maintain its balance and thus slide down along the slope. Body of this kind landslide often develop many fissures and terrances.

(3)Bedding-landslide means that deluvial layer slides along the surface of base rock, or the contact surface of deluvium and the lower sand-gravel bed, or the surface of weathering bed. This kind landslide is 0.5—1.5 meters thick generally. Its landslide body appears in tatters and has a bad integrity.

(4)Avalanching-landslide develops on higher and steeper hillside. The balance of slope is suddenly broken and thereby geological bodies slide down with great speed. Most of this kind landslides have the feature of "Avalanche in the front and slide in the rear".

Pushing-landslides dominate all the landslides of the four types induced by 1974 Zhaotong earthquake, with hauling-landslide the second. 1976 Longling earthquake developed more pushing-landslides and avalanching-landslides. Nevertheless, avalanching-landslides account slightly high in all the landslides caused by 1973 Luhuo earthquake while the landslide numbers of other types are nearly equal(Table 2).

Table 2 Percent of landslides of different types

Type	Zhaotong earthquake		Luhuo earthquake	
	Number	Percent	Number	Percent
Pushing-landslide	11	39.3	25	18.2
Hauling-landslide	8	28.6	35	25.6
Bedding-landslide	6	21.4	36	26.3
Avalanching-landslide	3	10.7	41	29.9

4 Geological and Geomorphological Conditions

The occurrence of landslide needs other necessary conditions also. Earthquake-induced landslides in this region rely on the composition of geological bodies, existence of weak structural interface, as well as landform to some extent.

4.1 Strata

Nearly all the earthquake-induced landslides in southwestern China develop in Quaternary accumulative layers except that very a few occur in base rocks along beddings. The accumulative layers include eluvium, deluvium, weathering layer of base rocks, and alluvial gravel layer. Landslides by 1974 Zhaotong earthquake, for example, mainly consist of eluvial and deluvial Permian basalt, as well as weathering layers of Permian basalt. The percentage is 60.7%.

4.2 Weak Structural Interface

The occurrence of earthquake-induced landslides has a strong relation with weak interface. In the studied area exist the following kinds of weak interfaces:

(1) Bedding of base rock and joint plane;

(2) Contact interface between accumulative layer and base rock ;

(3) Interface between accumulative layers of different types;

(4) Interface of frozen earth in the northwest area with high level.

Of all the four kinds of weak interface earthquake-induced landslide develop along the contact surfaces of accumulative layers of different types dominantly.

4.3 Slope Gradient

As other kind of landslides, earthquake-induced landslide slide along slope toward the dipping direction of valleys. Nearly all the landslides generated by earthquake in this region occurred on some steep slopes with sliding space, and artifical slopes. Take 1974 Zhaotong earthquake and 1973 Luhuo earthquake as examples, the favorable gradients of landslide are 35°—45° ans 30°—50° respectively (Fig. 3). Combining with other earthquake-induced landslides, it is concluded that the range of favorable gradient is 30°—50°, and that the most favorable one is 35°—45° in southwestern China.

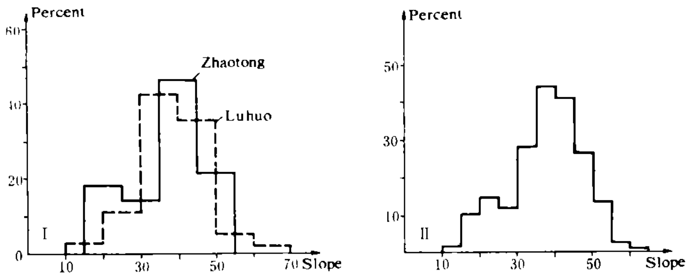

Fig. 3 Statistical map of slopes easily to generate landslide

I. Statistical map; II. Synthetical map

5 Landslide Size

Earthquake-induced landslide bodies in this region appear smaller except very a few with larger volume(Table 3). In all the landslides generated by 1973 Luhuo earthquake, for example, landslides of volume smaller than 1000 m^3 account for 73.9 percent, and landslides with volume between 1000 m^3 and 50000 m^3 account for 21.2 percent. Another example is Zhaotong earthquake, landslides with volume smaller than 50000 m^3 account 67.9 percent of all the landslides. Therefore, landslides smaller than 50 thousand cubic meters dominate all the earthquake-induced landslides in this region.

Another feature of landslides caused by earthquake in southwestern China is that they are thinner than the natural ones generally. The thickness of the landslides induced by 1973 Luhuo earthquake concentrates within a range of 0.5—5 meters in which the number of landslides with thickness of 1—3 meters remains higher. In addition, landslides generated by 1974 Zhaotong earthquake have a thickness concentration of 0.5—5 meters(Fig. 4). Therefore, earthquake-induced landslides are dominated by shallow and small ones in the studied area.

Table 3 Maximum volume of landslide(10,000m²)

Location	X	IX	VIII	VII	VI
Luhuo		24			
Longling				120	
Zhaotong		60			
Tonghai		3.2			

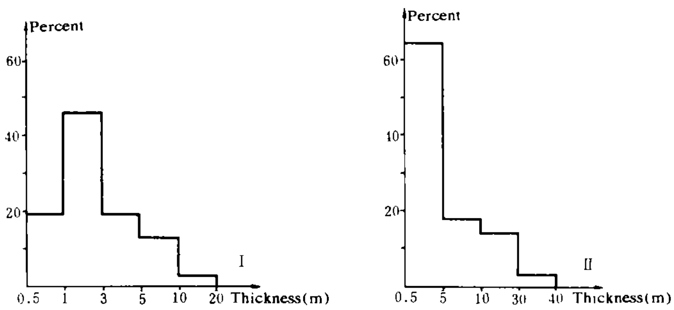

Fig. 4 The thickness of landslides
I . Luhuo; II . Zhaotong

6 Distribution Extent

There is a conspicuous connection between earthquake-induced landslide and seismic intensity, as well as the seismic faults.

6.1 Relation between landslide distribution and seismic intensity

In light of the information of the 11 strong earthquakes occurred since 1970 (Table1), the lowest intensity generating new landslides remains VII except 1973 Luhuo earthquake which induced new landslides in the area of intensity larger than VII. Earthquakes with detailed data, as 1974 Zhaotong earthquake, 1973 Luhuo earthquake and 1976 Longling earthquake. show that in the area of VI intensity exist no new landslides generally(Table 4). As to old landslide, which is at balance before earthquake, the smallest intensity to reactivate these landslides is I intensity lower than that generating new landslides. 1976 Longling earthquake and 1973 Luhuo earthquake, for example, cause new landslides at a lowest intensity of VII and VIII separately, nevertheless, the corresponding lowest intensity at which old landslides are reactivated is VI and VII intensity(Table 5).

Table 4 Relation of intensity and landslide distribution

Intensity		X	IX	VIII	VII	VI
Zhaotong	Number		17	4	7	0
	Percent		60.7	14.3	25.0	0
Luhuo	Number	96	37	4	0	0
	Percent	70	27	3	0	0
Longling	Number		3	10	8	0
	Percent		14.1	47.6	38.3	0

After a study of the earthquake-induced landslides in the loess region of China, Yao Qinglin

(1986)[3] concluded that between earthquake magnitude and the maximum epicentral distance as well as the maximum distribution area of earthquake-induced landslides exists a relation of exponential function. However, in southwestern China there is no such a corresponding relation although the maximum epicentral distance and the maximum distribution area increase generally acompanying the increase of magnitude.

Table 5　Minimum intensity generating landslide

Earthquake	Lowest intensity	
	New Landslide	Reactivated old landslide
Longling	VI	VI
Luhuo	VII	VI

6.2 **Landslide distribution and seismic fault**

The distribution of earthquake-induced landslide is controlled by seismic fault to small extent. In given geomorphological conditions, landslides occur along the direction of seismic ruptures generally. As a good example, 1973 Luhuo earthquake and 1981 Daofu earthquake which occurred on Xianshuihe fault of large strike-slip generated landslides within a range of a narrow elliptical shape along the seismic ruptures (Fig. 5, Fig. 6).

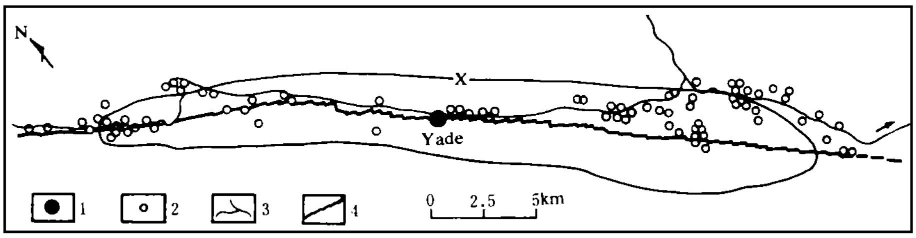

Fig. 5　Distribution of landslides generated by 1973 Luhuo earthquake
1. Epicenter;　2. Landslide;　3. River;　4. Main seismic rupture

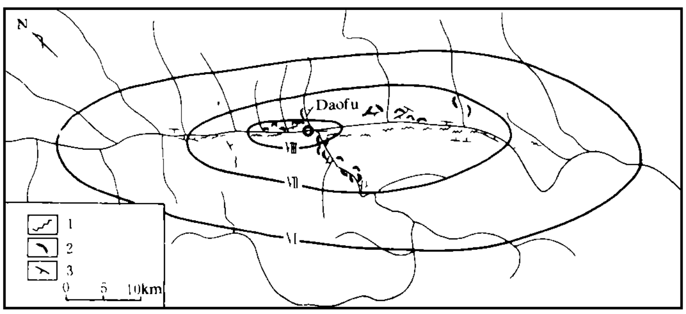

Fig. 6　Ground failures caused by 1981 Daofu earthquake
1. Seismic rupture;　2. Landslide;　3. Fissure

In most cases, except for the seismic fault there exist other active faults crossing with seismic fault in this region. The distribution of landslides is influenced by these active faults and the distribution extent of landslides may thereby increase due to the existence of these faults. For instance, the distribution of landslides and rock avalanches by 1988 Lancang-Gengma earthquake (M=7.2, 7.6) has intimate relation to the NE active faults traversing the NW seismic fault (Fig. 7). Especially, near

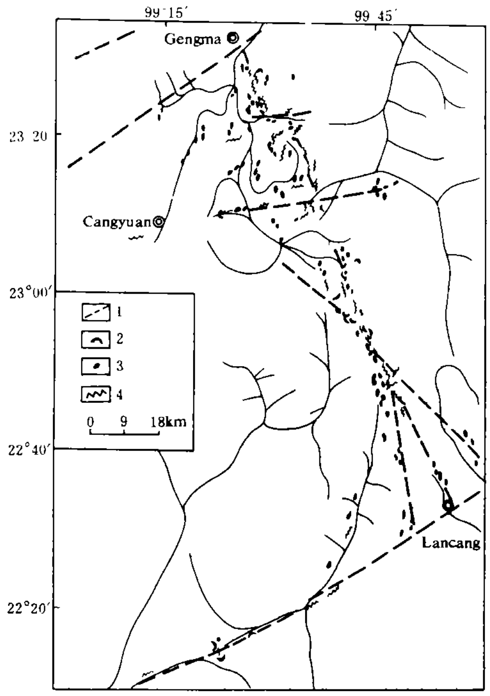

Fig. 7 Ground failures caused by 1988 Lancang-Gengma earthquake (Wang Yanglong, 1990)
1. Active fault; 2. Landslide; 3. Avalanche; 4. Rupture

Menglian about 70 kilometers from the seismic fault a few landslides develop on a NE active fault. Therefore, for the sake of the assessment of landslide hazards, it is important to investigate in detail the active structural conditions of each intense seismic area in southwestern China of complex active structures.

7 Earthquake-Induced Landslide Hazards

Landslide hazards by earthquake can be divided as direct hazards and indirect ones after earthquake. Hazards of these two kinds remain very conspicuous in southwestern China.

7.1 Direct hazards

Direct hazards of earthquake-induced landslide in southwestern China are concluded as follows:

(1) Destroying villages: Some buildings which are ont collapsed or destroyed by seismic vibration may be ruined thoroughly due to landslide, and thus cause injures and deaths. For example, 1976 Longling earthquake-induced landslides wrecked 180 village buildings.

(2) Blocking traffic facilities: Landform in southwestern China is very steep, many traffic routes on slopes have changed the original balance conditions of the slopes to some extent. So earthquake-induced landslides often develop along traffic routes.

(3) Destroying irrigation works and hydropower stations: The landslides by 1976 Longling earthquake, for instance, destroyed a 240,000 watt hydropower station and three other ones smaller than 20,000 watts.

(4) Large landslides block river and thereby cause floods.

7.2 Indirect hazards

(1) Rains after an earthquake may induce rock avalanche and landslides in the areas existing fissures formed by earthquake. Pushing-landslides induced by earthquake which slide very slowly might accelerate their sliding speed.

(2) After shock mud-rock flows: Earthquake-induced landslides provide large amount of loose accumulative matters for the occurrence of mud-rock flows, and thereby cause larger secondary hazards.

7.3 Assessment of earthquake-induced landslide

Based on the above characteristics of earthquake-induced landslide in southwestern China, reasonable assessment can be made out through studying seismicity, seismic structure, as well as the other conditions of landslide. The procedures are summed up as follows:

(1) Determining seismic risk area through seismic risk analysis.

(2) Delineating the distribution extent of different seismic intensities or ascertaining seismic mo-

tion of different areas according to field conditions.

(3) Analysing features of strata, properity of rock, rock structure, and other geological conditions related to landslide.

(4) Studying the possible types of landslide.

(5) Investigating active structures in seismic area, and thus to determine the sensible structural area for landslide.

(6) Synthetically analysing all data gained through the above work to give out the distribution and intensity of the possible hazards that may caused by the future earthquake.

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中国西南地区地震滑坡的基本特征

周本刚　　张裕明

（国家地震局地质研究所，北京 100029）

摘　要

本文总结了中国云南、川西地区 1970 年以来 M≥6.7 级强震的滑坡资料，归纳了该区地震诱发滑坡的地质地貌特征。认为把地震滑坡按其运动方式而划分为推移式滑坡、牵引式滑坡、溜滑性滑坡和崩塌性滑坡这四种类型有利于对地震滑坡灾害的评估。统计结果表明，大部分滑坡体的体积小于 50000m^3，滑坡体的厚度以 0.5—5m 为主，因而西南地区的地震滑坡以浅层小型滑坡为主；滑坡均发生于第四系堆积层中，其中又以残积层中最为发育；这些滑坡主要沿四种结构软弱面发生；边坡的坡度对滑坡亦有一定的控制作用，一般来说，滑坡主要发生在坡度为 30°—50° 的斜坡上，其中最有利的坡度为 35°—40°；地震滑坡的分布面积则主要取决于震级的大小，虽然它们之间没有明显的相关关系，但随震级的加大，地震滑坡的最大震中距和最大分布面积大致是增加的。一般来说，产生新的滑坡所需的最小地震烈度为 7 度，而诱发老滑坡所需的最小烈度则为 6 度，二者相差约 1 度左右。此外，滑坡的分布在很大程度上受地震断层的控制，其分布主方向和地震断层的方向大致相同。最后，本文在归纳了西南地区地震滑坡灾害特点的基础上，提出了在西南地区进行地震滑坡灾害评价的若干要点。

关键词：　西南地区；地震滑坡；灾害