central Yunnan, the average number of the dead due to each $M \geqslant 5$ earthquake in central Yunnan is about 836, and is 1.7-fold that in northwestern Yunnan, 23-fold that in southwestern Yunnan. The major reasons of the difference are as followings:

The seismicity level in central Yunnan is the highest in Yunnan Province, 5 $M \geqslant 7$ earthquakes have occurred in the region, including the Songming $M8$ earthquake in 1833 and the Tonghai $M7.7$ earthquake in 1970.

In the history, the population density of central Yunnan is higher than those of northwestern and southwestern Yunnan.

The total casualties and maximum epicentral distance in a seismic casualty area are increased with its magnitude. The casualty in each area attenuates with the increase of epicentral distance.

Ground failures on a small scale may occur in the region where the seismic intensity is higher than 5 degree. In the region where seismic intensity is higher than 8 degree, ground fissure, lanslide and landslip may widely occur. The maximum epicentral distance in a ground failure area is increased with magnitude.

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云南破坏性地震的人员伤亡和地面破坏特征

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摘 要

云南是一个地震多发区。1652年至1994年间云南地区共发生613次破坏性地震,其中5.0- 5.9级地震553次,6.0- 6.9级地震49次,7.0- 7.9级地震12次,8级地震1次。云南的破坏性地震除了直接造成人员伤亡和建(构)筑物破坏外,还在震区形成包括滚石、崩塌、滑坡、泥石流、地面沉陷和喷砂冒水等地面破坏现象,这些地面破坏造成人员伤亡,毁坏建筑物和农田,形成云南破坏性地震灾害特点。云南地区破坏性地震的人员伤亡和地面破坏主要集中发生在滇中、滇西北和滇西南地区。根据统计分析,云南地区破坏性地震的平均人员伤亡人数(N)与地震震级(M)的关系为: $\lg N = 1.5M - 7.4$ 人员伤亡数(N)与震中距 D(km)的关系为: $\lg N = 0.8 - 0.027D$(6.0- 6.9级地震)和 $\lg N = 3.2 - 0.05D$(7级以上地震)。出现地面破坏现象的最大震中距离(D_{max})和震级的关系为: D_{max}(km) = $52M - 298$ (地表裂缝); D_{max}(km) = $18M - 93$ (崩塌滑坡); D_{max}(km) = $50M - 281$ (滚石)。

主题词: 破坏性地震 云南 地面破坏 人员伤亡

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THE FEATURE OF CASUALTIES AND GROUND FAILURE CAUSED BY DESTRUCTIVE EARTHQUAKES IN YUNNAN

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Abstract

Casualties and ground failure caused by earthquakes are major earthquake disasters in Yunnan, their distribution are of obvious regional feature and mainly concentrated in center, northwestern and southwestern Yunnan. The occurrence and distribution range of the casualties and ground failure in Yunnan are related with magnitude and intensity of earthquakes obviously.

Key words: **Destructive earthquake**, **Yunnan**, **Ground failure**, Casualty

1 Introduction

Yunnan is one of the provinces with the strongest seismicity in China. From 1652 to 1994, 613 destructive earthquakes occurred in Yunnan, including 553 $5 \leqslant M \leqslant 5.9$ earthquakes, 49 $6 \leqslant M \leqslant 6.9$ earthquakes, 12 $7 \leqslant M \leqslant 7.9$ earthquakes and one of $M = 8$.

Based on analysis and statistics of earthquake records, the casualty and building damage caused by destructive earthquakes from 1652 to 1988 in Yunnan are following:

Casualty: total number: 104 186 persons,
killed number: 52 582 persons,
wounded number: 51 604 persons.

Building destruction: total number 2 488 000 rooms,
collaped number: 924 000 rooms,
seriously damaged: 1 564 000 rooms.

Yunnan is not only a province with frequent destructive earthquakes, but also a plateau-mountain province. Destructive earthquakes generally triggered the ground failures in earthquake region besides the casualty and building damage. For example, the Lancang M 7.6 and Gengma M 7.2 earthquakes occurring in the mountainous area of southwestern Yunnan Province on November 6 in 1988, the casualties and building damage caused by the earthquakes are:

casualty: 748 killed, 7 751 wounded,
collaped building: 753 500 rooms,
seriously damaged building: 554 500 rooms.

Besides above hazards, a lot of ground failures were formed in the earthquake regions (Fig. 1).

The distribution and feature of ground failures caused by the earthquakes are listed in table 1.

Based on analysis of historic earthquake records and modern earthquake investigation data from 1900 to 1988, 20 percent $5 \leqslant M \leqslant 5.9$ earthquakes, 58 percent $6 \leqslant M \leqslant 6.9$ earthquakes and 100 percent $7 \leqslant M \leqslant 8$ earthquakes occurred in Yunnan Province caused obvious ground failures in their regions. According to data, the ground failures triggered by destructive earthquakes in Yunnan usually lead to casualties and building, bridge, highway, railroad and farmland destructions.

Above informations show that the casualties, building damage and ground failure caused by destructive earthquakes are the major types of earthquake disaster, and they should be the major contents of earthquake disaster study in Yunnan.

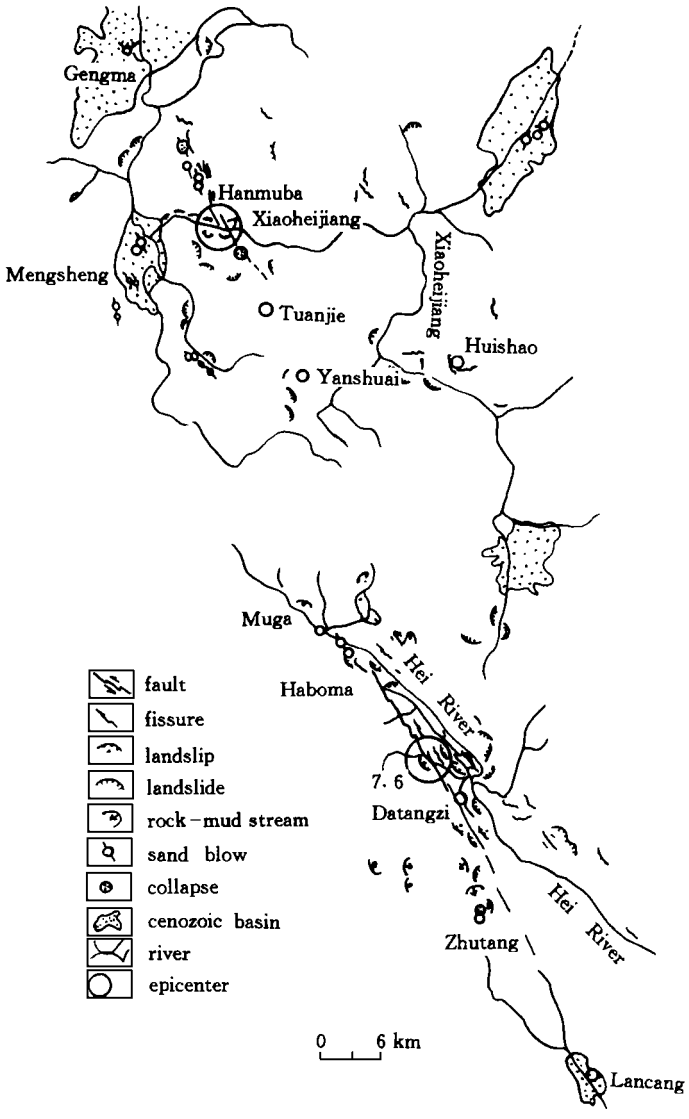

Fig. 1 Ground failures caused by the Lancang-Gengma earthquake, 1988 in Yunnan Province, China.

In this paper, the distribution features of casualties and ground failures from earthquakes and their relation to magnitude are discussed based on analysis of the casualties and ground failures in Yunnan. The result should be useful to earthquake disaster forecast and prevention of Yunnan.

2 Distribution and Feature of Casualties Resulting from Earthquake in Yunnan

2.1 Casualty Distribution

Table 1　The ground failure feature of the Lancang-Gengma earthquakes on November 6 in 1988.

Region	South region (Lancang M 7.6 earthquake)		North region (Gengma M 7.2 earthquake)
Length of earthquake fault(km)	50		15
types of non-tectonic ground failures	rolling stone, landslide, landslip and mud-rock flow in mountain area, and sand blow in basin and valley area		
area of region with dense ground failure (km^2)	North part 5×10	South part 5×26	13×9
maximum length of single ground failure belt (km)	35		15

The casualties during earthquakes in Yunnan mainly resulted from building damage, then the ground failures due to earthquakes, including the rolling stone, landslide, landslip, mud-rock flow. For example, only one landslide during the Daguan M 6.7 earthquake on July 31 in 1917 killed 500 persons. 9 persons were killed by a landslip resulting from the Gejiu M 5 earthquake in June, 1932. The Tengchong M 5.7 earthquake on May 13 in 1941 triggered 7 landslips, and 16 persons were killed and 19 persons were wounded by these landslips. The rolling stones resulting from the Yiliang M 5.1 earthquake on April 22 in 1973 killed 2 persons and wounded 66 persons.

Yunnan is province with frequent major earthquakes, and most regions belong to plateau-mountain areas. The residential areas and villages in these regions are usually small and scanty. Therefore, the average level of casualties due to earthquakes in Yunnan are usually lower than the dense population areas of other provinces. Based on analysis and statistics of casualties data from 106 earthquakes which occurred in Yunnan from 1652 to 1988 and have casualty records, 45 $5 \leqslant M \leqslant 5.9$ earthquakes killed 225 persons and wounded 837 persons totaly, the average casualties from each one are 5 killed and 18.5 wounded; 48 $6 \leqslant M \leqslant 6.9$ earthquakes killed 14 523 persons and wounded 6 913 persons, the average casualties each one are 302.6 killed and 144 wounded; 13 $7 \leqslant M \leqslant 8$ earthquakes killed 37 834 persons and wounded 43 854 persons totaly, average casualties from each one are 2 910 killed and 3 373 wounded.

According to Table 2, 8 percent $5 \leqslant M \leqslant 5.9$ earthquakes in Yunnan have casualty records, almost all $M \geqslant 6$ earthquakes have casualty records.

Table 2　The percentage of earthquakes causing casualties and ground failures in Yunnan.

Magnitude	$5 \leqslant M \leqslant 5.9$	$6 \leqslant M \leqslant 6.9$	$7 \leqslant M \leqslant 8$
Percentage of earthquakes which have casualty records	8%	100%	100%
Percentage of earthquakes which have ground failure records	20%	58%	100%

The distribution of casualties due to earthquakes in Yunnan is illustrated in Fig. 2. It is shown that the casualties from earthquakes in Yunnan are mainly distributed in central, northwestern and southwestern Yunnan. The casualties in central Yunnan mainly occurred in Daguan, Qiaojia, Dongchuan, Songming, Eshan, Tonghai, Jianshui, Shiping counties etc. The casualties in northwestern Yunnan mainly occurred in Dali, Lijiang, Yongsheng counties etc. The casualties in southwestern Yunnan are mainly distributed in Longling, Gengma, Lancang, Simao counties etc. The casualties in each region are listed in Table 3.

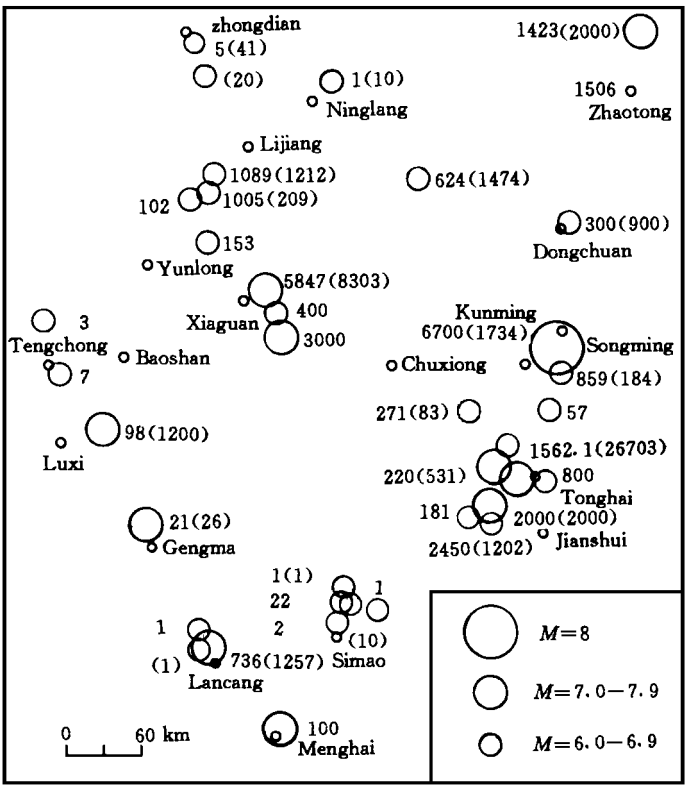

Fig. 2 The distribution of casualty caused by earthquake in Yunnan.

Table 3 The earthquakes and casualties in each region of Yunnan from 1652 to 1988

Region	Magnitude (M)	Number of events	Number of the dead	Number of the injured	Average death number	Average number of the injured
Southwestern Yunnan	5– 5.9	14	40	279	2.8	20
	6– 6.9	11	117	494	10	49
	7– 8	4	955	3 483	238	870
Northwestern Yunnan	5– 5.9	10	28	141	2.8	14
	6– 6.9	12	2 873	1 901	239	158
	7– 8	2	8 847	28 303	4 423	39 151
Central Yunnan	5– 5.9	21	177	455	8.4	21
	6– 6.9	22	11 949	3 070	543	139
	7– 8	5	28 032	32 268	5 606	6 453

According to Table 3, the following regional features of casualties due to earthquakes in

Yunnan are very obvious.

2.1.1 Difference of casualty number in each region

The total casualties from earthquakes which have casualty records in each region since 1652 are 1 112 killed and 4 256 wounded in southwestern Yunnan, 11 748 killed and 80 345 wounded in northwestern Yunnan, 40 158 killed and 35 793 wounded in central Yunnan. The total casualty number in central Yunnan is the highest, then the northwestern region.

2.1.2 Difference in frequency of events causing casualties

The numbers of $M \geqslant 5$ earthquakes which have casualty records and occurred since 1652 are 29 in southwestern Yunnan, 24 in northwestern Yunnan, 48 in central Yunnan. The frequency of the events in the central Yunnan is the highest.

2.1.3 Difference in average casualty level of each earthquake

The casualties resulting from earthquakes with the same magnitude are different in different regions. The average casualty level in central Yunnan is the highest, then in the northwestern Yunnan. The average number of casualties from each $M \geqslant 5$ earthquake in each region is following:

Southwestern Yunnan: 38 killed and 146 wounded,

Northwestern Yunnan: 489 killed and 3 347 wounded,

Central Yunnan: 836 killed and 748 wounded.

2.2 Correlation between Magnitude and Casualties

Based on statistics of the casualties from earthquakes and magnitude of events (Fig. 3) in Yunnan Province, the correlation between magnitude (M) and average number (N) of casualties in Yunnan is:

$$\lg N = 1.5M - 7.4 \pm 0.8$$

2.3 The Range of Casualty Occurrence

The casualty distribution of some major earthquakes in Yunnan is listed in Table 4.

Fig. 4 and Fig. 5 give the attenuating curve of casualties with epicentral distance of some destructive earthquakes in Yunnan. Fig. 6 is the correlation curve between magnitude and maximum epicentral distance within which there are casualtis.

According to statistics, the correlation between casualty number(N) and epicentral distance(D) in Yunnan is following:

For $M \geqslant 7$ earthquake,

$$\lg N = 3.2 - 0.05D \pm 1.8$$

For $6 \leqslant M \leqslant 6.9$ earthquake,

$$\lg N = 0.8 - 0.027D \pm 0.7$$

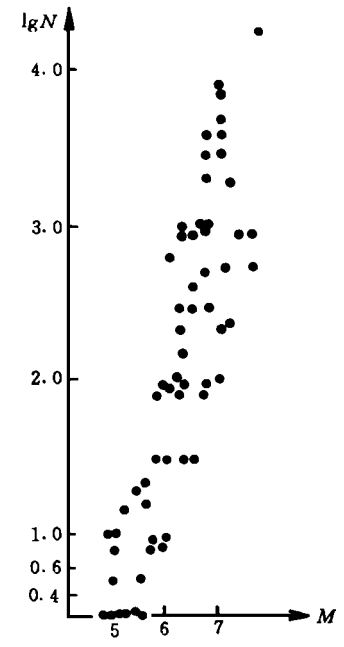

Fig. 3 Correlation between casualty number (N) caused by earthquakes in Yunnan and their magnitude (M).

Table 4 Casualty distribution of some major earthquakes in Yunnan

Earthquake date	Epicenter location	Magnitude	Casualty site	Epicentral distance (km)	The dead	The injured
1725-01-08	Yiliang	$6\frac{1}{4}$	Guandu, Yanglin	32	194	35
			Tangchi, Yiliang		384	17
			Longfengli, Xundian	82	20	37
			Minhe, Lunan	34	20	20
			Yangzhonghai	19	45	75
1761-11-03	Yuxi	6	Yuxi	10	52	37
			Pumiao, Jiangchuan	24	22	20
			Ningzhou	48	2	2
			Hexi	30	4	1
1833-09-06	Songming	8	Songming		6 700	1 754
			Chenggong	60	108	127
			Xundian	4	1 024	447
			Heyang	10	1 237	253
			Jiangchuan	136	4	9
			Mengzi	250	285	100
			Amizhou	246	36	51
			Jinning	100	76	117
1887-07-12	Shiping	7	Shiping city	15	200	300
			Dongxiang, Shiping		800	800
			Nanxiang, Shiping		200	400
			Jianshui city	25	7	10
			Xixiang, Jianshui	10	249	156
1913-12-21	Eshan	7	Eshan city	5	1 900	
			Hexi	28	343	500
			Xinxing		16	10
			Tonghai	4	9	20
			Yuxi	30	16	1
			Pengzhou, Shiping	56	3	
			Antong, Kaiyuan	110	1	
1925-03-16	Dali	7	Dali city	5	3 736	726
			Fengyi	20	1 215	552
			Midu city	56	43	30
			Midu region		100	82
			Xiangyun	50	21	19
			Binchuan	40	831	2 695
			Dengchuan	38	1	23
1948-10-10	Zhaotong	$5\frac{3}{4}$	Zhaotong city	10	9	118
			Yiliang	50	16	28
			Ludian	26	8	
			Weining	90	2	
1955-09-23	Yuza	$6\frac{3}{4}$	Huili	10	485	1 183
			Yongren	90	114	167
			Wuding	140	3	35
			Yuanmou	120	2	30
			Miyi	30	20	
			Yanbian	80	0	4

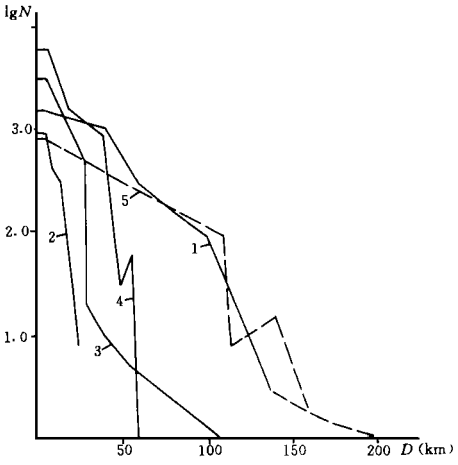

Fig. 4　Attenuating curve of casualties resulting from some major $7 \leqslant M \leqslant 8$ earthquakes in Yunnan.

1 The 1833 Songming M 8 earthquake
2 The 1887 Shiping M 7 earthquake
3 The 1913 Eshan M 7. 7 earthquake
4 The 1925 Dali M 7 earthquake
5 The 1988 Lancang M 7. 6 earthquake

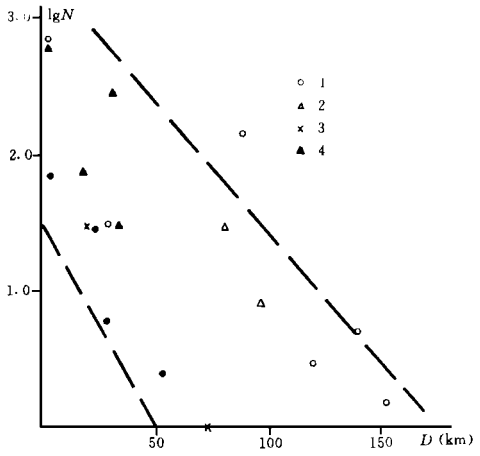

Fig. 5　Attenuating curve of the casualties caused by some major $6 \leqslant M \leqslant 6.9$ earthquakes in Yunnan.

1 The 1761 Yuxi M 6 earthquake
2 The 1925 Yiliang M $6\frac{1}{4}$ earthquake
3 The 1799 Baoxiu M $6\frac{3}{4}$ earthquake
4 The 1955 M 6. 7 Yuzha earthquake

3　The Feature of Ground Failures from Earthquakes in Yunnan

3. 1　Types and Distribution of Ground Failures from Earthquakes in Yunnan

Based on historic earthquake records and modern earthquake investigation data, 20 percent $5 \leqslant M \leqslant 5.9$ earthquakes, 60 percent $6.0 \leqslant M \leqslant 6.9$ earthquakes and all $M \geqslant 7$ earthquakes in Yunnan triggered ground failures in their regions. The major types of seismic ground failures occurred in Yunnan are rolling stone, landslide, landslip, ground subsidence. The occurring times of ground failure phenomena in Yunnan are listed in Table 5.

Table 5　The frequency and percentage of each seismic ground failure in Yunnan

Type	Rolling stone	Sand blow	Ground subsidence	Ground fissure	Landslide Landslip
Times	69	26	7	59	59
Percentage	31. 36	11. 82	3. 18	26. 82	26. 82

The distribution of ground failures from earthquakes in Yunnan is illustrated in Fig. 7. It is shown that the seismic ground failures are mainly distributed in southwestern, northwestern and central Yunnan. The distribution feature of seismic ground failures is similar to that of casualties from earthquakes.

3.2 The Correlation between Seismic Ground Failures and Seismic Intensity in Yunnan

Based on statistic analysis of intensity and ground failure types at the sites where occurred seismic ground failures in Yunnan (Fig. 8), the following correlation between seismic ground failures and intensity can be concluded:

(1) The rolling stone on a small scale could occur in the region with seismic intensity 5 degree.

(2) The rolling stone, ground fissure, landslide and landslip on a small scale could occur along slope in the region with seismic intensity 6 degree.

(3) Rolling stone, ground fissure, landslide and landslip on a middle scale could occur in the region with intensity 7 degree.

(4) Rolling stone, ground fissure, landslide and landslip could widely occur in the region with seismic intensity 8 degree.

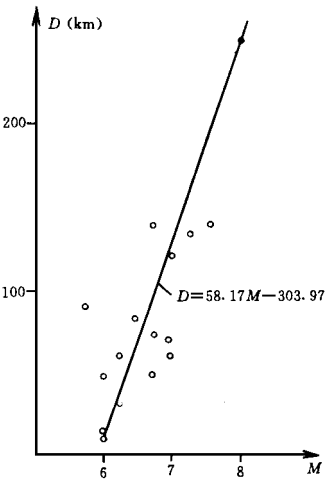

Fig. 6 Correlation between the maximum epicentral distance in a seismic casualty area and magnitude.

(5) All types of ground failure, including rolling stone, tectonic ground fissure, landslide, landslip, mud-rock stream, ground subsidence, sand blow, etc. could widely occur in region with intensity larger than 9 degree.

Fig. 7 The type and distribution of seismic ground failures in Yunnan.

1 ground fissure; 2 landslide and landslip; 3 ground subsidence; 4 Sand eruption water blow; 5 Rolling stone

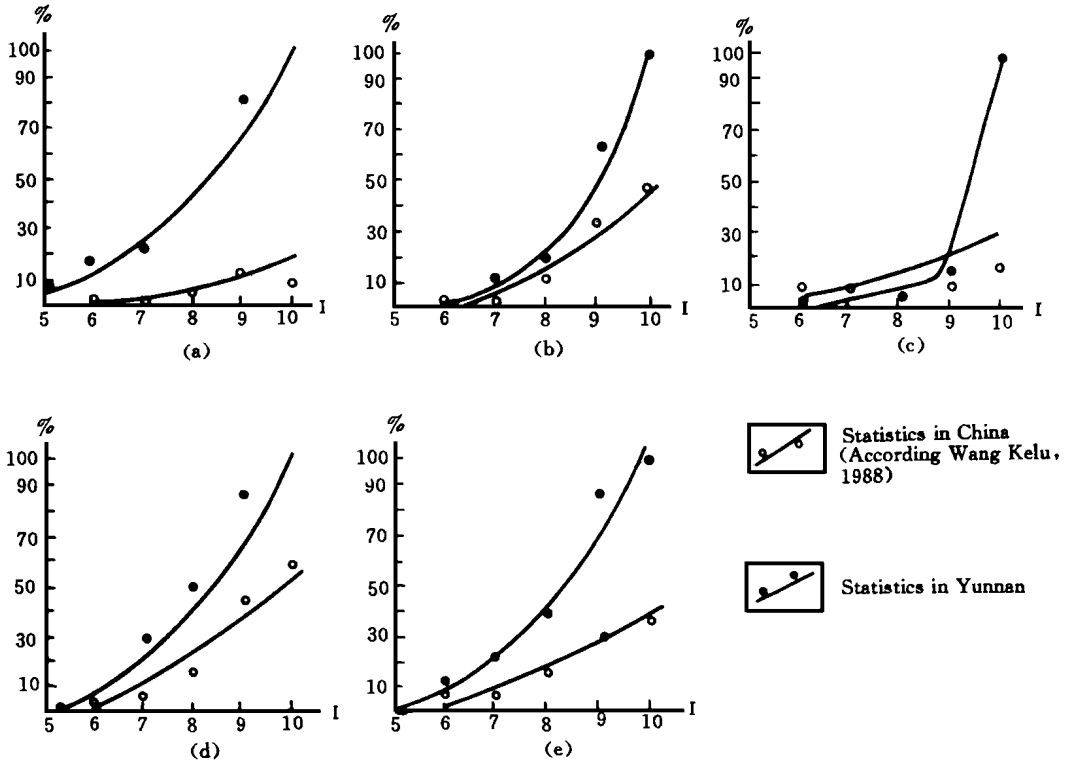

Fig. 8　The correlation between of seismic ground failure type and intensity.
(a) Rolling stone; (b) Sand eruption and water blow; (c) Ground subsidence;
(d) Ground fissure; (e) Landslide and landslip

3.3 Range of Seismic Ground Failures in Yunnan

Based on regressive analysis of the maximum epicentral distance (D_{max}) of ground failure area and the magnitude(M) in Yunnan, the following correlations are gotten:

For ground fissure, $D_{max} = 52M - 298$;

For landslide and landslip, $D_{max} = 18M - 93$;

For rolling stone, $D_{max} = 50M - 281$.

4 Discussion

Through analysis of casualties and ground failures resulting from destructive earthquakes in Yunnan, as well as their distribution, feature and relation to magnitudes of the earthquakes, the following major points are been concluded:

(1) The regional feature of earthquake hazards in Yunnan is very obvious. Casualties and ground failures were mainly concentrated in Qiaojia, Dongchuan, Songming, Tonghai and Shiping counties in central Yunnan, in Dali, Lijiang and Yongsheng counties in northwestern Yunnan, and in Longling, Gengma, Lancang and Simao counties in southwestern Yunnan. These regions are the major earthquake areas in Yunnan.

(2) The casualties in the regions were different from each other. The most serious is in