Fast Assessment on Residential Building Loss and Population Displacement after the Great Wenchuan Earthquake Disaster*

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ABSTRACT :

Based on the statistical data of historical seismic disasters, this paper presents the damage matrixes of residential building of different structure type in Sichuan, Shanxi and Gansu Provinces. By using the Wenchuan Earthquake Intensity Chart by China Earthquake Administration and the social economy statistical data of the three provinces, such as the population, per-capita living space, the proportion of residential building with different structure type, a post-earthquake fast loss assessment has been implemented and preliminary validated through a post-hoc comparison. The estimated residential building damage, population displacement and residential economic loss were provided to help policy-making during the disaster relief. We argue that fast development and distribution of earthquake intensity map plays a key role for quick loss estimation. In addition, full and comprehensive communication among experts from different disciplines is also of vital importance.

KEYWORDS: seismic disaster; fast loss assessment; damage matrix; Wenchuan Earthquake

1.INTRODUCTION

On May 12, 2008 at 14:28 pm (local time), a massive M 8.0 earthquake shook Wenchuan County in Sichuan Province. Its epicenter is located at latitude 31.0° N and longitude 103.4° E, with hypocenter around 14 kilometers deep. The earthquake catastrophic caused tremendous loss of both human lives and properties. It is characterized as the most devastative, the largest impacted area and the most difficult for post-earthquake rescue since 1949, the establishment of P.R. China. The total death toll reached 69,207 nationwide as of 12:00 pm. July 31, Beijing time and 18,194 missing. There were 374,216 people injured. The number of homeless people amounts to over 15.1 million. The percentage of homeless people is over 90% in some disastrous counties, such as Beichuan Country and Qingchuan County (www.xinhuanet.com).

The Great M 8.0 Wenchuan Earthquake was caused by the movement of the NE-directional active rift zone of the Longmen Mountains, which is the middle part of the Chinese South-north Seismic Active Tectonic Zone. The active tectonic zone of the Longmen Mountains is over 530 km long, and about 40 to 50 km wide. The strike is NE, and dip angle is about 30-70 degree. The active rift zone consists of three bare faults and a concealed fault. The three bare faults are Maowen-Wenchuan fault, Beichuan-Yingxiu fault (earthquake fault), and Guanxian-Jiangyou fault (rupture fault). The newest activity characteristics are mainly thrust as well as dextral strike-slip. The active rift zone was divided into two parts at Jiangyou: the west-south part is Holocene active fault, while the east-north part is early-middle Pleistocene active fault. The M 8.0 earthquake just occurred at the west-south part of the active rift of Longmen Mountains (see Fig. 1.1).

The activity of the rift zone of the Longmen Mountains was not violent before the M 8.0 earthquake happened.

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Since earthquake was recorded in Chinese history, the earthquakes larger than M 7.0 never occurred, and the M 6.0-6.9 earthquakes happen about four times, which is showed by Fig. 1.1. Before the massive M 8.0 earthquake, the Longmen Mountain rift zone was classified ordinary active rift zone, and drew little attention.

Some researches argued that the Longmen Mountain rift zone should draw more attention according to the geological tectonics (Jiang Liangwen, 2005). In the region, there are three active rift zones: the NE-directional rift zone of Longmen Mountain, the south margin of the EW-directional rift zone of West Qinling Mountain, and the SN-directional active rift zone of Minshan Mountain which consist of the Minjiang River fault and Huya fault. The three active rift zones constitute an A-type active tectonic system controlling the occurrence of earthquakes (see Fig. 1.1). On the drive of a strong tectonic stress field, they argued that earthquakes of larger than Magnitude 7.0 may happen repeatedly and transfer from south to north regularly and vice versa in the three active rift zones.

It is of great importance for Chinese government to assess the loss on residential building and homeless people, or population displacement, rapidly with relative accuracy so as to dispose relief manpower and materials efficiently.

A variety of methods have been developed in the past studies to have fast loss assessment on earthquake disaster, such as, (1) damage matrix method based on experiential statistical data of historical earthquake disasters (Li Shuzhen, 1993; Yin Zhiqian, 2004); (2) statistics method based on spot check by field investigation; (3) artificial identification by using remote sensing images obtained by satellite or airplane; and (4) vulnerability analysis method based on the performance of building structures (FEMA, 2003; Charles, 2006).

The paper adopted the first method to implement fast loss assessment on the Great Wenchuan Earthquake Disaster. Because it is difficult to have a full inventory of the whole exposure, this paper will focused on the loss of the residential buildings and population displacement, which are two of the most important factors for disaster relief. First, the damage matrix derived from the historical loss data over the disastrous area. Second, the structure types, number and distribution of the residential buildings in the stricken area were collected from local social economic database. Finally, combined with the intensity chart of the Wenchuan Earthquake developed by China Earthquake Administration, a fast loss assessment is implemented by integrating the damage matrix based on the historical earthquake disasters. Compared with the disaster loss and the homeless population released by Chinese government through comprehensive survey, the assessment result of the quick assessment is relatively satisfying.

2. DATA AND METHOD

The paper adopted the damage matrix method based on the statistical data of the historical earthquake disasters to carry on the loss assessment, the procedures of which are as follows:

(1) Combining the county population (including the population in urban area and rural area) with the per-capita living space of the county in the affected area, the total area of living space of the county was calculated.

(2) Based on the spot check result on the structure of the residential building, deriving the proportion of the different types of residential building in urban area and rural area as of reinforced concrete buildings, multi-story brick buildings and ordinary buildings.

(3) According to the intensity map of Wenchuan Earthquake, calculating the population and the floor area of residential buildings of different structure in different intensity zone of every county.

(4) Assessing residential building loss and population displacement based on damage matrix of building, building cost of different structure types and the loss ratio of different damage status.

2.1 Intensity chart of the Great Wenchuan Earthquake

In China, earthquake intensity adopts Modified Mercalli Intensity (MMI). After Wenchuan Earthquake, several seismic intensity maps were developed by China Earthquake Administration according to the investigation data in the disaster area. The earthquake intensity chart, which is used to calculate the loss in the paper, was formerly issued on June 8, 2008 by China Earthquake Administration (see Fig. 3.1).

Prior to the formerly publication, a series of intensity maps were rapidly developed and shared among researchers in an internal working group co-organized by the Ministry of Science and Technology and National Disaster Reduction Committee of China. These maps were also utilized to implement fast loss assessment.

2.2 Classification of Residential Buildings

Required by the disaster relief, the post-earthquake loss assessment should be carried on rapidly (Li Shuzhen, 1993). So, the types of residential buildings can not be divided too elaborately. The buildings with similar use and structure can be incorporated into the same type. The paper divided the residential buildings into three types as reinforced concrete buildings, multi-story brick buildings and ordinary buildings (including brick-wood structure, wood structure, adobe building with brick columns, and other simple buildings).

2.3 Social and Economic Data

The major population data used is total population and its proportion in urban and rural district of every county. The data of Sichuan Province come from Sichuan statistical yearbook of 2007, while those of Gansu and Shaanxi come from the statistical yearbook of 2006. The data on the per capita residential space of every county come from the data of the census in 2000. The data on the proportion of different residential structure in urban and rural district come from the data of the 1% national census of 2005.

2.4 Damage Status, Loss Ratio and the Unit Cost of Residential Buildings

According to a national criterion, Post-earthquake field works - Part4: Assessment of direct loss (GB/T 18208.4-2005), the damage states of residential buildings can be divided into five levels: good, slight damage, moderate damage, severe damage and collapse.

Different damage status of residential building corresponds to the different loss ratio. According to Post-earthquake field works - Part4: Assessment of direct loss (GB/T 18208.4-2005) and the loss investigation on spot, the loss ratio is listed in table 2.1. The unit cost of reinforced concrete buildings is 1200 yuan RMB per square meter, the unit cost of multi-story brick buildings is 800 yuan RMB per square meter, and ordinary buildings is 600 yuan RMB per square meter.

Table 2.1 the mean of loss ratio corresponding to different damage states of buildings

Damage states	good	Slight damage	Moderate damage	Serious damage	collapse
Mean of loss ratio	0.00	0.15	0.40	0.70	1.00

2.5 Homeless Population

The number of homeless people caused by earthquake was estimated by the damage states of residential buildings. All the people whose residential buildings were serious damage or collapse plus half of the people whose residential buildings were moderate damage are defined as homeless people, and other people do not belong to homeless people. The number of homeless people can be calculated by the following formula.

$$M_n = \frac{A_5 + A_4 + A_3/2}{\bar{A}} - M_d \qquad (2.1)$$

Among which, M_n is the number of homeless people, A_3, A_4 and A_5 represent the area of the residential buildings, of which are moderate damage, serious damage, and complete collapse, respectively. $\overline{A}$ is the per capita living space, and M_d is the death toll caused by earthquake.

2.6 Damage Matrix

The M 8.0 Wenchuan Earthquake resulted in serious loss in Sichuan, Gansu and Shaanxi Province. The paper offered the damage matrix for the residential buildings with different structures (see table 2.2 to 2.5). The damage matrixes of the different structure in Sichuan are adopted those of Chendu Basin and its circumjacent regions, which come from the paper (He Yulin, 2002). Because there has been not devastating earthquake occurred in Shanxi since 1996, Shanxi's damage matrixes are same as those in Sichuan. For Gansu Province, the damage matrixes of reinforced concrete building and of multi-story brick buildings can be same as those in Sichuan and Shanxi (see table 2.2 and 2.3), but the matrix of ordinary buildings has been offered in the paper (see table 2.5), which is based on the loss data of the M 5.8 Yongdeng Earthquake occurred on July 22, 1995, of the M 4.7 Wenxian-Wudu Earthquake occurred on April 15, 1999, and of the M 5.9 Jingtai Earthquake occurred on June 6, 2000.

Table 2.2 the damage matrix of reinforced concrete buildings in Sichuan, Shanxi and Gansu Province

MMI	Good	slight damage	Moderate damage	Serious damage	collapse
VI	100.0	0.00	0.00	0.00	0.00
VII	100.0	0.00	0.00	0.00	0.00
VIII	76.42	20.26	3.32	0.00	0.00
IX	0.90	25.04	47.36	21.30	5.40
X	0.01	2.29	28.41	44.56	24.73
XI	0.00	0.00	15.00	35.00	50.00

Table 2.3 the damage matrix of multi-story brick buildings in Sichuan, Shanxi and Gansu Province

MMI	Good	slight damage	Moderate damage	Serious damage	collapse
VI	51.29	30.32	12.95	5.14	1.30
VII	40.16	25.30	17.64	11.63	5.47
VIII	24.29	20.84	22.11	19.85	12.91
IX	10.64	14.82	21.00	27.68	25.86
X	1.77	5.44	13.91	27.99	50.79
XI	0.00	0.00	5.00	15.00	80.00

Table 2.4 the damage matrix of ordinary buildings in Sichuan, Shanxi Province

MMI	Good	slight damage	Moderate damage	Serious damage	collapse
VI	61.00	28.00	10.00	1.00	0.00
VII	24.00	46.00	13.00	11.00	6.00
VIII	0.00	16.00	49.00	20.00	15.00
IX	0.00	5.00	17.00	45.00	33.00
X	0.00	0.00	2.00	10.00	88.00
XI	0.00	0.00	0.00	5.00	95.00

Table 2.5 the damage matrix of ordinary buildings in Gansu Province

MMI	Good	slight damage	Moderate damage	Serious damage	collapse
VI	24.80	40.00	25.00	10.00	0.20
VII	10.00	31.00	35.00	20.00	4.00
VIII	2.00	14.00	20.00	35.00	29.00
IX	0.00	5.00	17.00	40.00	38.00

X	0.00	0.00	2.00	10.00	88.00
XI	0.00	0.00	0.00	5.00	95.00

3 RESULTS AND POST-HOC COMPARISON

3.1 Exposure Population

According to the Wenchuan Earthquake intensity chart (from the Chinese Earthquake Adminstration), the paper first gives the exposure population in the different intensity zone, see Table 3.1. The assessment result shows that in the meizoseismal area (earthquake intensity is bigger than and equal to X degree) the exposure population will have over 420,000, while in the IX degree intensity zone the exposure population has over 910,000, the casualty caused by the Wenchuan Earthquake will be quite serious.

3.2 Homeless Population and Residential Building Loss

Based on the number of villages and towns in different earthquake intensity zone and the damage matrix of the different residential buildings, the post-earthquake fast loss assessment is carried on. Because of the limitation of paper length, the economic loss and homeless population of 12 counties, whose economic loss is largest among all the counties, are listed in table 3.2. In the comparison, the per-capita economic loss and the homeless population per ten thousand people of 12 counties, whose per-capita economic loss is largest among all the counties, are listed in table 3.3.

The space distribution of economic loss of every county is demonstrated in Fig.3.1, and that of the per capita economic loss of every county is demonstrated in Fig.3.2. According to the total loss index (the total economic loss or homeless population), Jiangyou Shi, Santai Xian, An Xian, Dujiangyan Shi, Mianzhu Shi and Zhongjiang Xian are six of the most considerable counties in loss. But according to the per-capita loss index (the per-capita economic loss or homeless population per ten thousand people), Beichuan Xian, An Xian, Wenchuan Xian, Pingwu Xian, Mianzhu Shi, and Qingchuan Xian is six of the most disastrous counties in catastrophe.

The results (see table 3.4) showed that the loss of every city, which only resulted from residential building damage. The economic loss can reach 212.32 billion yuan RMB, 28.01 billion yuan RMB and 21.45 billion yuan RMB in Sichuan, Gansu and Shanxi Province respectively, and the number of homeless people can reach 10.037 million, 3.070 million and 1.206 million respectively.

Table 3.1 the exposure population in every intensity zone of Wenchuan Earthquake

MMI	XI	X	IX	VIII	VII	VI
Exposure Population ($\times 10^4$)	18.9402	23.3910	91.3595	432.7313	1969.6491	7110.0670

Table 3.2 the homeless population and economic loss of 12 of the largest economic loss counties

Number	Postcode	City	County	Homeless population (10^4 persons)	Economic Loss (10^4 Yuan RMB)
1	510781	Mianyang	Jiangyou Shi	42.8317	684585.9486
2	510722	Mianyang	Santai Xian	29.1091	666072.1020
3	510724	Mianyang	An Xian	30.1238	634374.9598
4	510181	Chengdu	Dujiangyan Shi	28.6696	541400.8339
5	510683	Deyang	Mianzhu Shi	34.1217	523510.8130
6	510623	Deyang	Zhongjiang Xian	30.6786	499299.8653
7	510182	Chengdu	Pengzhou Shi	28.0056	498002.0795
8	510704	Mianyang	Youxian Qu	17.2557	408812.4607
9	511381	Nanchong	Langzhong Shi	18.4339	388456.6696
10	511321	Nanchong	Nanbu Xian	20.7257	373964.3933

11	510121	Chengdu	Jintang Xian	17.0479	348892.4444
12	510184	Chengdu	Chongzhou Shi	16.6178	347489.8454

Table 3.3 the homeless population per ten thousand people and the economic loss per person of 12 of the largest economic loss per person counties

Number	postcode	City	County	Homeless population per ten thousand people	Economic loss per person (Yuan RMB)
1	510726	Mianyang	Beichuan Xian	7928	13495
2	510724	Mianyang	An Xian	5906	12438
3	513221	Aba	Wenchuan Xian	7908	11254
4	510727	Mianyang	Pingwu Xian	6027	10231
5	510683	Deyang	Mianzhu Shi	6643	10192
6	510822	Guangyuan	Qingchuan Xian	7075	9970
7	510812	Guangyuan	Chaotian Qu	4383	9016
8	510181	Chengdu	Dujiangyan Shi	4707	8889
9	510781	Mianyang	Jiangyou Shi	4874	7791
10	510704	Mianyang	Youxian Qu	3240	7677
11	513223	Aba	Mao Xian	5312	6913
12	510682	Deyang	Sifang Shi	4113	6488

In order to validate the result, a post-hoc validation was implemented by comparing the above fast assessment result with the survey data of every county carried out by the local governments. The performance of our method is relatively good in Sichuan Province which occupies most of the disastrous loss .Whereas, it is somehow overestimated in Shannxi Province.

4. CONCLUSIONS AND DISCUSSION

4.1 Accuracy and Efficiency of Damage Matrix Method

The accuracy of assessment result lies on the precision of the data of exposure, damage matrixes, and earthquake intensity map, etc.

(1) Because the data of exposure used in the paper come from the local social economic yearbook, the statistical spatial unit is in county level and hence it can not fully reflect spatial heterogeneity. For disaster-relief, especially for real-time rescue, exposure data at village level is necessary.

(2) The damage matrix does not adequately consider the discrepancies among every county due to inadequate historical earthquake data accumulation. More structure vulnerability or fragility data of various structure types over different regions should be accumulated through historical earthquake disasters or by engineering experiment.

(3) Accuracy of earthquake intensity map. For Great Wenchuan earthquake, the major axis direction is same with the fault rupture, and the curvature radius of intensity isograms in the west-south end of the rupture should be larger than that of intensity isograms in the east-north end of the rupture considering that the epicenter is the west-south end of the rupture. In addition, considering the hanging wall effect (Yu Yanxiang, 2001), the Longmen Mountain Middle Fault's hanging wall thrust to the footwall in the west-south part of rupture, and transform to strike-slip gradually in the east-north part of rupture. Consequently, the area of certain intensity zone in the hanging wall should be larger than that of the same intensity zone in the footwall. What is more, it took about 80 seconds to finish the fault rupture process from Yinxiu in the west-south end of rupture to Beichuan in the east-north end of rupture. If the Doppler Effect is considered, the curvature radius of intensity isograms in the east-north end of rupture may become smaller, and the intensity isograms in the east-north end

may extend more to outside than in the west-south end.

Regardless the disadvantages of the above data input, a post-hoc comparison shows that the fast residential building and population displacement assessment result is satisfying with a reasonable loss distribution in space. In all for fast response-oriented assessment, the damage matrix method is relatively simple and efficient.

4.2 Accessibility of Earthquake Intensity Map for Fast Assessment

Researchers and knowledge in the disciplines of earthquake science, structure engineering, social scientists and risk modelers should work closely to achieve a fast and efficient assessment of the disaster loss. It is therefore of great importance for risk assessment experts to access earthquake intensity map as soon as possible.

However, the intensity map of the Great Wenchuan Earthquake was not developed automatically or semi-automatically but developed and improved by a group of experts. In the mean time, the publication of the intensity map does not have an automatic mechanism, such as quick publication through internet. On the contrary, the intensity map was obtained through an internal working group co-organized by the Ministry of Science and Technology and National Disaster Reduction Committee. There is a great space for the improvement of the accessibility of earthquake intensity map and the speed of its development.

Since there are a lot of large-scale natural disasters in China, it is very important to setup an open data sharing mechanism or platform for catastrophe modeling. For real-time or quasi-real-time fast assessment, automatic data sharing through internet is a must-do in the future.

4.3 Understanding and Communication of the Modeled Loss

(1) Loss in Total versus in Per-capita. It is of vital importance to understand and communicate modeled loss. From the results of table 3.2, table 3.3, Fig. 3.1 and Fig. 3.2, it shows that the per-capita loss index may express the disaster severity of a district much better than the total loss. If considering the total loss index (the total economic loss or homeless population), Jiangyou Shi, Santai Xian, An Xian, Dujiangyan Shi, Mianzhu Shi and Zhongjiang Xian are six of the most considerable counties in loss. whilst if considering the per-capita loss index (the per-capita economic loss or homeless population per ten thousand people), Beichuan Xian, An Xian, Wenchuan Xian, Pingwu Xian, Mianzhu Shi, and Qingchuan Xian are six of the most disastrous counties in catastrophe. Understanding the obvious difference is simple, but also critical to the disposal of the relief manpower and materials.

(2) Disaster Loss Assessment as an Interactive System. It is important to understand that disaster loss assessment is a combination and interaction of hazard, exposure, vulnerability and a lot of other factors. Therefore, overestimation or underestimation of any of the above factors may lead to fatal bias. Risk communication, regardless their backgrounds and interests, among experts from different disciplines is the key to a successful estimation on disaster loss.

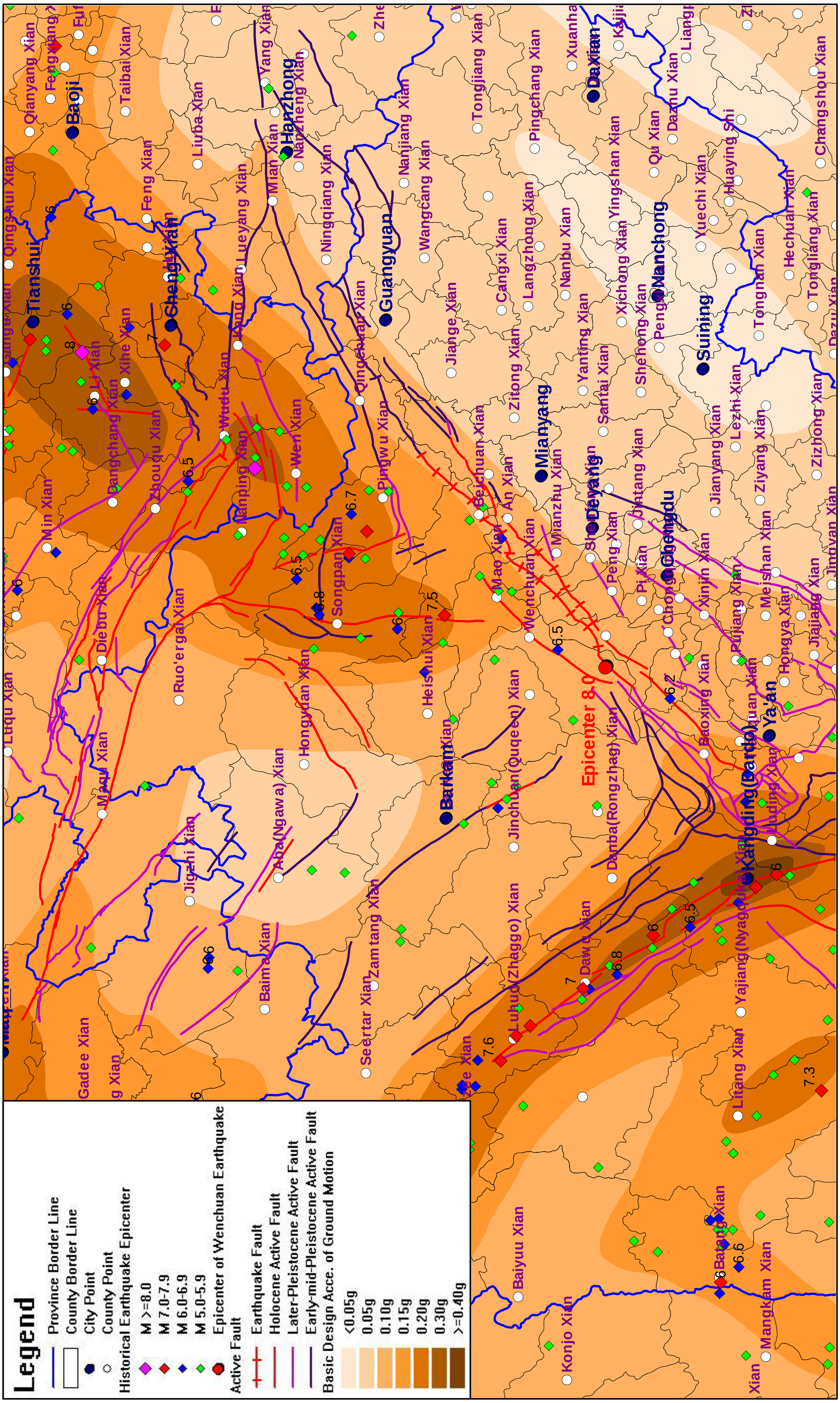

Fig.1.1 the active tectonic and the basic design acceleration zone map of ground motion in the circumjacent area affected by the M 8.0 Earthquake

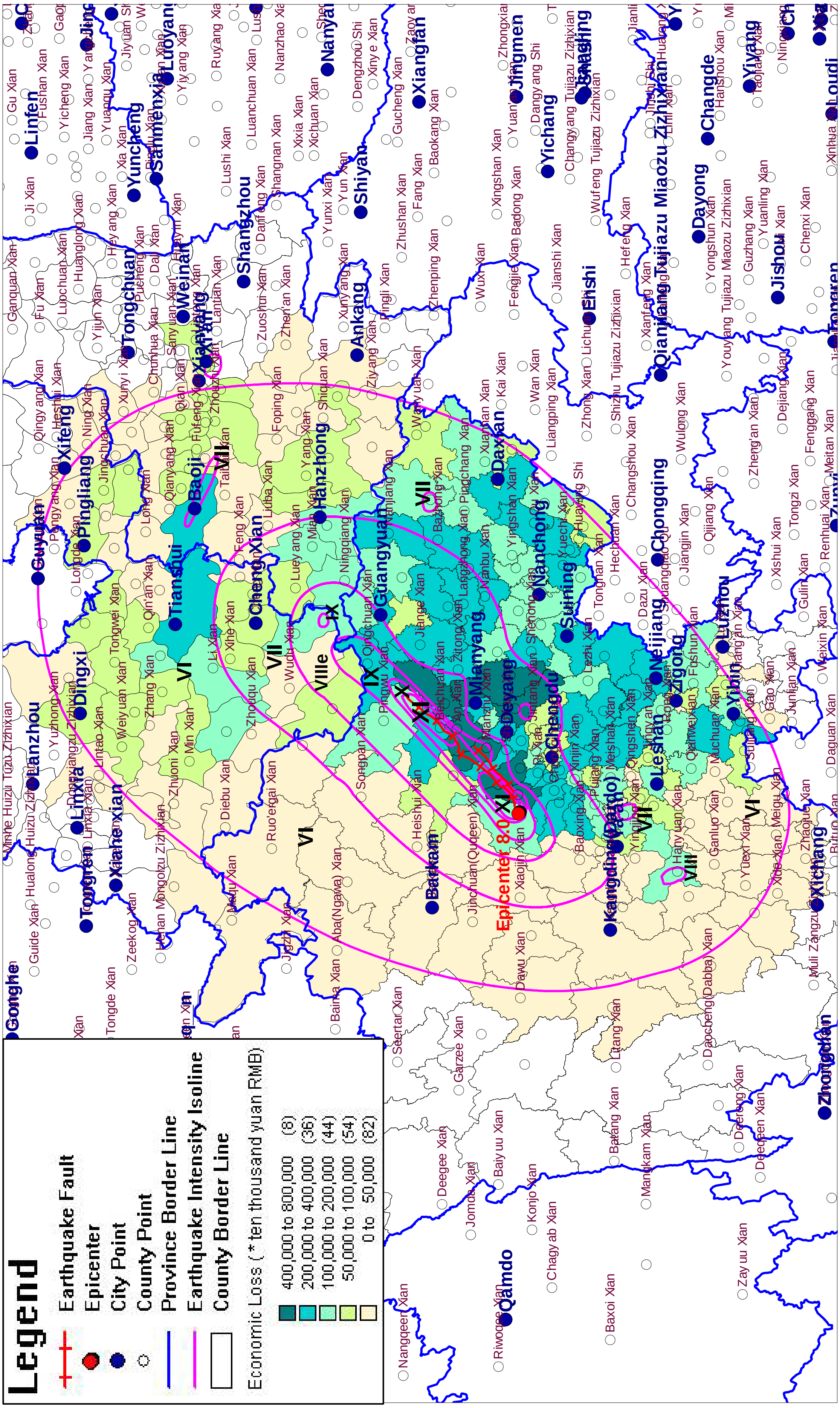

Fig.3.1 the loss assessment map of residential building in every county caused by the M 8.0 Wenchuan Earthquake

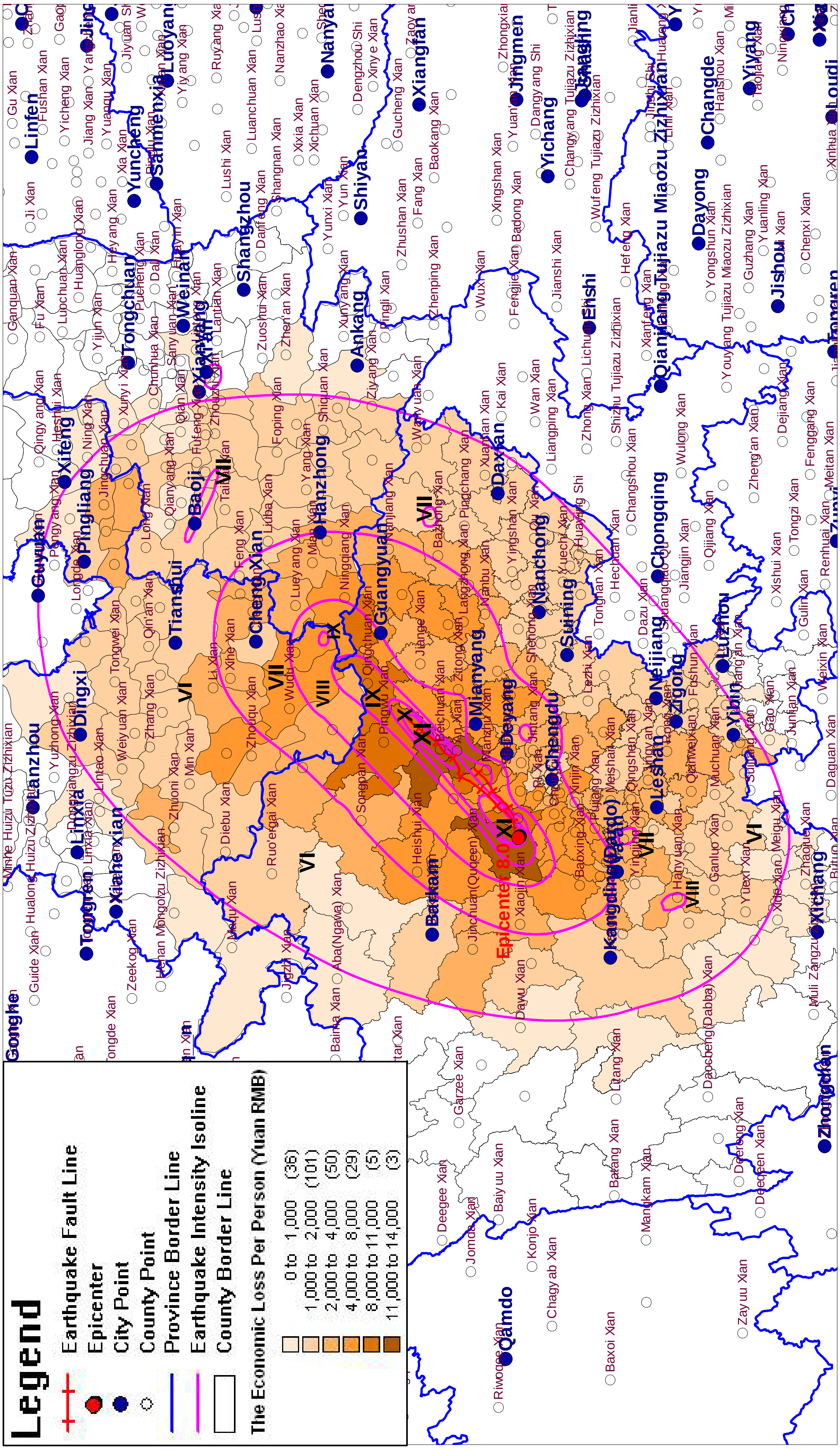

Fig.3.2 The per-capita loss assessment map of residential building in every county caused by the M 8.0 Wenhuan Earthquake

Table 3.4 the assessment result of the damage and economic loss of the residential buildings and homeless population

postcode	Province	City	Serious damage ($10^4 m^2$)	collapse ($10^4 m^2$)	Economic Loss (10^4 yuan RMB)	Homeless (10^4person)
510100	Sichuan	Chengdu	1415.4316	1002.3022	3960395.2488	182.3960
510300	Sichuan	Zigong	50.7687	0.0000	506104.5742	20.2217
510500	Sichuan	Luzhou	22.5913	0.0000	206106.6385	5.7770
510600	Sichuan	Deyang	938.1353	649.6798	1944958.5186	116.4674
510700	Sichuan	Mianyang	1585.6785	1316.4873	3495431.4265	178.8736
510800	Sichuan	Guangyuan	748.1463	473.9470	1539775.1136	89.2784
510900	Sichuan	Shuining	104.5888	22.7669	720832.4171	29.8938
511000	Sichuan	Neijiang	69.0627	0.0000	676942.9947	29.7694
511100	Sichuan	Yueshan	74.1379	2.5357	711818.1809	25.0906
511300	Sichuan	Nanchong	478.1092	208.3152	1733061.8003	80.1332
511400	Sichuan	Meishan	98.2687	13.5123	746030.3761	25.2832
511500	Sichuan	Yibin	49.6375	0.0000	481651.3710	17.6531
511600	Sichuan	Guang'an	77.7175	0.0000	739094.0543	29.2220
511700	Sichuan	Dazhou	101.8623	0.0000	996452.0403	41.4172
511800	Sichuan	Ya'an	172.3719	95.6896	471913.1562	24.2321
511900	Sichuan	Bazhong	258.6173	115.9554	874540.7037	41.2880
512000	Sichuan	Ziyang	117.6733	12.3506	942608.3957	35.9633
513200	Sichuan	Aba	135.6136	136.4142	345266.3081	22.8926
513300	Sichuan	Ganzi	3.6608	0.0000	38976.9637	1.8617
513400	Sichuan	Liangshan	10.8716	0.0000	99860.8432	6.0197
	The loss total in Sichuan		6512.9447	4049.9563	21231821.1255	1003.7340
610100	Shanxi	Xi'an	15.5462	0.0000	240272.8339	11.9249
610300	Shanxi	Baoji	66.7562	18.1964	513136.5333	30.9748
610400	Shanxi	Xianyang	26.4824	0.0000	313700.8516	19.3946
610700	Shanxi	Hanzhong	261.3044	135.1917	931533.2929	52.3963
610900	Shanxi	Ankang	13.0243	0.0000	144365.8377	5.8195
611000	Shanxi	Shangluo	0.2387	0.0000	2340.7125	0.1157
	The loss total in Shanxi		383.3522	153.3881	2145350.0619	120.6258
620400	Gansu	Baiying	25.6515	0.5130	38152.6427	4.6617
620500	Gansu	Tianshui	389.2624	9.2810	692182.2284	77.8123
620800	Gansu	Pingliang	277.9410	5.5588	433254.5060	43.5391
621000	Gansu	Qingyang	76.6880	1.5338	117409.9407	13.0719
621100	Gansu	Dingxi	288.5054	5.6745	481888.4458	52.2495
621200	Gansu	Longnan	760.4323	321.5195	944329.0249	105.9579
622900	Gansu	Linxia	5.0787	0.1016	7596.5800	0.7818
623000	Gansu	Gannan	57.6098	2.8520	85815.5691	8.9033
	The loss total in Gansu		1881.1691	347.0342	2800628.9375	306.9775

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