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The housing loss assessment of rural villages caused by earthquake disaster in Yunnan Province*

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Abstract

Based on the assessment report of destructive housings caused by more than 20 earthquakes occurred in Yunnan Province in 1990~2004, the vulnerability models of 4 types housings of rural residents in Yunnan Province are setup. The scenario earthquake disaster loss model is used to simulate the housing loss if the historical earthquakes that occurred since A.D. 886 in Yunnan Province reoccur in 2002. The analyses show the simulation deviation of the usual earthquakes is less than 30% and the method is of high practicality. Meanwhile, the simulation result of 398 historical earthquakes in Yunnan Province shows that the annual economic loss caused by the earthquakes is about RMB 410 million Yuan that accounts for 0.18% of GDP of Yunnan Province for the year. Because the per capita living area and the price of the housing increases year by year, if the historical destructive earthquake reoccurs today, the loss of Yunnan Province will be greater than in those years.

Key words: earthquake disaster; loss assessment; scenario earthquake; rural village; Yunnan Province

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Introduction

In accordance with the systematical theory of natural disaster, the intensity of disaster-causing factor and the frangibility of the disaster-bearing body decide the disaster degree (SHI, 1991, 2002). The building facilities is the uppermost disaster-bearing body in the earthquake disaster system, as the population and fortune in the city are concentrated, the density of the housings is large, the antiseismic and disaster reduction of the city have always been an important aspect of earthquake disaster research. Owing to the backward rural economy, the housings of residents have disadvantages in terms of design and construction, *etc.*, and the antiseismic performance of the housings is far inferior to that in cities. Therefore, for the rural area where more than 70% of Chinese population lives, equal attention has been given to the seismic safety issue there (GAO, 1995; YAN and HAO, 2003).

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Earthquake is one of most principal natural disasters in Yunnan Province and almost all the areas are influenced by the earthquake disaster except Qujing, eastern Wenshan and Dianzhong corridor in the middle of Honghe fault where earthquakes seldom occur. Compared with the five areas such as Xinjiang, Gansu, Qinghai and Sichuan where earthquakes frequently occur, the frequency of strong earthquake activities in the unit area in Yunnan Province is the highest. According to statistics on earthquakes from 1900 to 2000, the frequency of earthquakes of $5.0 \leq M_S < 7.0$ in one hundred years is $72.8/10^5 \text{ m}^2$, that of $M_S \geq 7.0$ in one hundred years is $2.86/10^5 \text{ m}^2$ in Yunnan Provinces, which ranks first in the provinces and regions of China. In addition, the earthquakes are of high intensity in history of Yunnan Province, for example the 1833 Songming $M=8$ earthquake occurred in the east of Kunming is the strongest in history. From the comprehensive evaluation based on three indices such as the scale of greatest magnitude of earthquakes, the number of earthquakes of $M_S \geq 5$ and that of $M_S \geq 7$, the severity of earthquakes in Yunnan Province ranks in the first place in Chinese mainland (LIU *et al*, 2002). Therefore, accurate assessment on the economic loss caused by the future earthquakes is important for disaster reduction program that must be done by the disaster risk management departments and insurance companies.

According to the administrative division in 2002, there are 16 regions in Yunnan Province, including 9 districts within the jurisdiction of cities, 10 cities at county level and 109 counties. Owing to the backward economy, the 5th census results show that these districts are low urbanization except for Wuhua district and Panlong district, and the non-agriculture population ratio is less than 30% (Statistical Bureau of Yunnan Province, 2003). So the rural village in the research considers all districts with low urbanization except Wuhua district and Panlong district, including 1 557 administrative unit.

1 Scenario earthquake disaster loss simulation model

The occurrence of earthquakes is related to faults and many earthquakes occur in the same places or near them (XU, 2003). At present, the simulation model for scenario earthquake loss is widely used in the world (CHEN *et al*, 1999; CHEN and LI, 2003; CHEN *et al*, 1997; CHEN, 2000) and it simulates the possible economic loss in a place when historical earthquakes reoccur with the same magnitude in the completely same place. This simulation puts emphasis upon the research on vulnerability of hazard-affected bodies. In the aspects of disaster-causing factors, it totally uses data of historical earthquakes and there is no need to predict the occurrence of earthquakes. So this method is usually used to simulate the earthquake loss in large cities where the population is dense and the economy is developed. For example, Risk Management Solutions (RMS) sets the simulation of earthquake loss in some metropolitans in the world and the results show the direct economic loss will reach US \$1 000 billion if the Japan Kanto $M_S=8.3$ earthquake that occurred on September 1, 1923 reoccurs^①.

What is often used is the estimation method of earthquake loss based on structural category list. Firstly, it classifies the building structures and facilities on the fixed site and creates corresponding earthquake loss probability matrix, and the expected loss in t years on the fixed site is

$$E_t = \sum_{B_k} \left\{ \sum_{I_i} P(I_i | B_k) \cdot \left[\sum_{df_j} P(df_j | I_i, B_k) \cdot (df_j | B_k) \right] \cdot V_{B_k} \right\} \quad (1)$$

^① Risk Management Solutions. 1995. What if the 1923 earthquake strikes again? Risk Management Solutions Inc., 84.

Where E_t is total loss, B_k stands for type of building facilities on the site, I_i is earthquake intensity that may cause the loss on the site, df_j is expected loss rate, V_{B_k} is total value of building facilities of type B_k on the site, $P(I_i|B_k)$ is risk probability for building facilities of type B_k caused by earthquakes with intensity I_i in t years on the site, $P(df_j|I_i, B_k)$ is probability of expected loss rate df_j when housings of type B_k are exposed to earthquakes with intensity I_i .

In the simulation method for scenario earthquake loss, the earthquake intensity of site is known and as a result, its expected loss is

$$E_t = \sum_{B_k} \{ [\sum_{df_j} P(df_j | I, B_k) \cdot (df_j | B_k)] \cdot V_{B_k} \} \quad (2)$$

If the average loss rate of housings of type k under intensity i is expressed by D_k , then

$$D_k = \sum_{df_j} P(df_j | I, B_k) \cdot (df_j | B_k) \quad (3)$$

Equation (2) can be simplified as

$$E_t = \sum_{B_k} (D_k \cdot V_{B_k}) \quad (4)$$

On the assumption that there are n residential areas (sites) in an earthquake region, expected economic loss caused by the earthquake is

$$E = \sum_n \left[\sum_{B_k} (D_k)_n \cdot (V_{B_k})_n \right] \quad (5)$$

Where $(V_{B_k})_n$ is value of housings in the n th residential area, $(D_k)_n$ is average loss rate of housings of type k on the site in the n th residential area, $(D_k)_n$ is determined by two factors: intensity of residential area, the average loss rate of different types of housings under the corresponding intensity. Equation (5) is the basic formula to simulate the scenario earthquake loss, the expression of model is relatively simple and it is suitable to estimate the simulation of macroscopic earthquake loss.

The processes of scenario earthquake simulation analysis are shown in Figure 1. Firstly calculate the distance from a historical earthquake epicenter to each site, then simulate the intensity of each site in the earthquake according to the intensity attenuation formula, and the economic loss of each site in the earthquake is obtained from the vulnerability model for various estate facilities on each site. The sum of losses on all the sites is the total economic loss caused by the earthquake. For all the earthquakes in the historical earthquake catalog, the above procedures are conducted and the economic loss probability of an area can be known by combining with the time span of occurrence of historical earthquakes. In the practical application, there are main four parts of calculation.

1) Estate estimate. For insurance companies, the estates here are loss exposure units, namely, estates with risks undertaken by insurance companies, including housings such as civic housings, public housings and so on, business property, public facilities, lifeline engineering and various indoor estates.

2) Vulnerability model. According to data of historical earthquakes or test data, the loss rate model for various housings is built up by the category list under different conditions of seismic ground motion. It is generally expressed by probability vulnerability matrix of earthquake or the curve of intensity *versus* average loss rate.

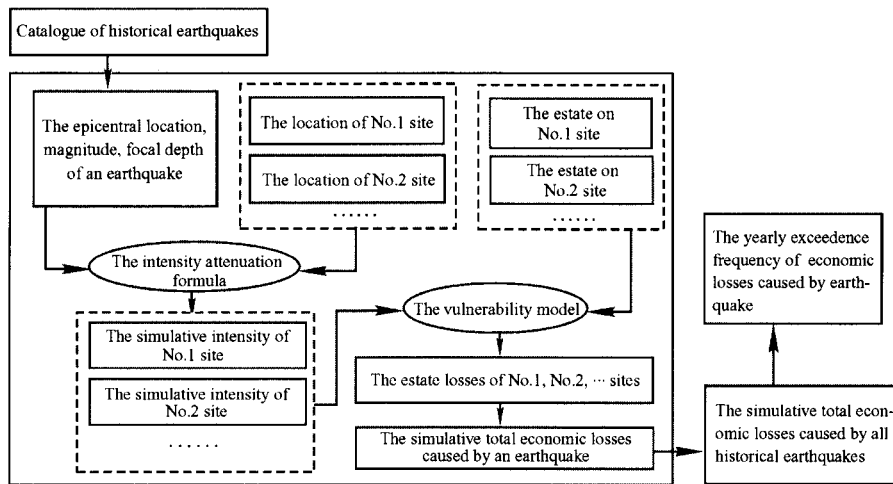


Figure 1 Diagram for scenario earthquake loss simulation processes

3) Scenario earthquake. Simulate the influence range and degree caused by the earthquake according to complete historical earthquake records including epicenter location, earthquake magnitude and focal depth. It is generally expressed by earthquake intensity.

4) Economic loss and yearly exceedance frequency. The above results are substituted into Equation (5), the economic losses caused by the earthquakes in the history are simulated and the yearly exceedance frequency of economic losses to all extents is obtained according to the occurrence frequency of earthquakes causing the losses.

2 Scenario earthquake disaster loss simulation in rural villages

2.1 Data source

We select the earthquakes occurred in Yunnan Province recorded in the *Catalogue of Chinese Historical Strong Earthquakes (23th Century B.C.~A.D.1911)* and *Catalogue of Earthquakes in China of Modern Times (A.D.1912~1990, $M_S \geq 4.7$)* (Department of Earthquake Disaster Prevention, State Seismological Bureau, 1995; Department of Earthquake Disaster Prevention, China Seismological Bureau, 1999) and input them to the database. According to the longitudes and latitudes of the earthquake epicenters, the Spatial Information System of Earthquakes in Yunnan Province is set up. The system includes the original time, epicentral location, magnitude, focal depth, epicentral intensity, casualty of each earthquake, the collapsed housings, and economic losses caused by destructive earthquakes.

After the destructive earthquake occurs, aftershocks continuously occur near the earthquake focus. The aftershocks will produce accumulative effects in a region and aggravate the disaster loss, but after some disaster reduction measures are taken, the loss caused by the aftershocks is small with respect to that caused by the earthquake. Therefore, it is required to firstly eliminate aftershocks in the earthquake catalogue from the view of stress disturbance in two aspects of time and space before analyzing the scenario earthquake disaster (LIU *et al*, 2002). In this way the Spatial Information System of Main Shocks in Yunnan Province is re-established according to the earthquake records after eliminating aftershocks, there are 398 earthquake records of $M_S \geq 5$ in total and the time span is from A.D. 886 to 2002.

In China, since 1990, once a destructive earthquake occurred, China Earthquake Administration or seismic departments of each province will organize the disaster damage assessment work of seismic site together with relevant departments and submit corresponding assessment report on seismic disaster loss. In *Collection of Assessment Report on Seismic Disaster Loss of Chinese Mainland* (1990~1995) and (1996~2000), recorded all survey data of destructive housing caused by more than 20 earthquakes occurred in Yunnan Province in recent 10 years (State Seismological Bureau and State Statistical Bureau, 1996; Department of Monitoring and Prediction, China Seismological Bureau, 2001). These survey data are input to Yunnan Earthquake Disaster Status Database, including the damage ratio and the losses ratio of housings caused by earthquake, etc.

Yunnan Rural Villages Economic Geographic Information System is also set up. The system includes the survey economic data of 1 557 villages in 2002, such as the name, family number, population, area, net income per capita, and the housing area per capita of village regions. These data are obtained from *Statistic Summary of Rural Villages in Yunnan Province*^①. The locations of each village are digitized from *Atlas of Yunnan Province*^②.

2.2 Exposure classification and estimate in rural villages of Yunnan Province

At present, the principal exposures owned by rural population in Yunnan Province are houses for living and housings for production that accounts for about 87% of belongings (Statistical Bureau of Yunnan Province, 2003; Rural Social Economic Investigation General Team of State Statistical Bureau, 2002). Therefore, the exposure estimate of rural villages in Yunnan Province is to calculate the value of housings in the villages.

There are more than many seismic destructive areas in Yunnan Province reported in *Collection of Assessment Reports on Seismic Disaster Loss of Chinese Mainland* (1990~1995), (1996~2000). These areas are located in differences rural regions where earthquakes frequently occurred. So the housings survey data of seismic areas in the assessment report can be extended to the usual rural housings of Yunnan Province.

In *Collection of Assessment Reports on Seismic Disaster Loss of Chinese Mainland* (1990~1995), (1996~2000), the rural housings are classified into 4 types: adobe-and-timber, brick-and-timber, brick-and-concrete, and frame structure. The cost ranges of 4 types housings in 1990~2000 are shown in Table 1. The fluctuating cost of the same type housing in different regions is 100~200 Yuan/m², and the housing cost only rises a little after 1996. So the cost of every type of rural housings is taken as the uniform price in Yunnan Province, and the most founded-price in *Collection of Assessment Reports on Seismic Disaster Loss of Chinese Mainland* (1996~2000) are taken as the average cost of rural housing in 2002. The costs of 4 types of housings respectively are 300 Yuan/m², 450 Yuan/m², 750 Yuan/m², and 1 000 Yuan/m².

Table 1 Average cost of rural housings in Yunnan Province Yuan/m²

The structure types of housing	Adobe-and-timber	Brick-and-timber	Brick-and-concrete	Frame
Cost range of rural housings in 1990~1995	300~100	480~250	550~450	750~600
Cost range of rural housings in 1996~2000	380~200	520~350	750~450	1200~850
Average cost	300	450	750	1 000

The survey about the housing data of China was only done in 1985, but the economic is developed rapidly in Chinese cities and counties, and the housings are changed largely. So the hous-

^① Rural Society Economic Investigator of Yunnan Province. 2003. *Statistic Summary of Rural Villages in Yunnan Province*, 246.

^② Geodesic Bureau of Yunnan Province. 2002. *Atlas of Yunnan Province*, 200.

ing data of rural residents just can be concluded from the annual income of residents. Usually, the more income the more cost of housings, the more per capita area of reinforced concrete structures housing. Because the climates in north and south of China are very different, the housing types of the north and the south are quit different. The paper selects the data of 15 south provinces, *i.e.*, Shanghai city, Jiangsu, Zhejiang, Chongqing, Sichuan, Yunnan, Guizhou, Anhui, Fujian, Jiangxi, Hubei, Hu'nan, Guangdong, Guangxi and Hainan, to calculate the relation of the per capita income and the per capita area of reinforced concrete structures housing. The regression relation of the per capita income (x) and the per capita area proportion of reinforced concrete structures housing (P_g) in 1991~2001 are shown in Figure 2. There is the marked correlativity between x and P_g , the correlative coefficient R^2 is 0.7525. Because of the maximum per capita housing area proportion is 100%, the limited condition of Equation (7) is $P_{g,max}=100$.

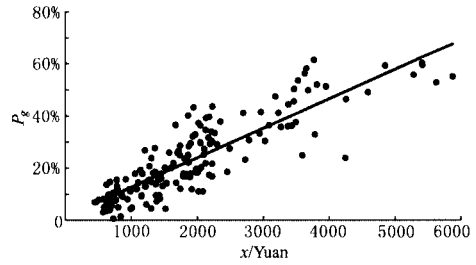


Figure 2 The per capita income x and the per capita area proportion P_g of reinforced concrete structure housing of rural resident in south China

$$P_g = 0.0113x + 1.3387 \tag{7}$$

Based on the data of seismic areas in the assessment reports and the sample survey data in some regions of Yunnan Province, the ratio of frame structure housings area to brick-and-concrete structure housings area are 30% to 70%, the ratio of brick-and-timber to adobe-and-timber are 15% to 85%. So the area ratios of 4 types housings are got from Equations (8)~(11).

The ratio of frame housings area to the total housings area $P_1=0.3P_g$ (8)

The ratio of brick-and-concrete housings area $P_2=0.7P_g$ (9)

The ratio of brick-and-timber housings area $P_3=0.15(1-P_g)$ (10)

The ratio of adobe-and-timber housings area $P_4=0.85(1-P_g)$ (11)

The per capita incomes of each rural villages of Yunnan Province in Yunnan Rural Villages Economic Geographic Information System are input to Equation (7), the per capita area proportion of reinforced concrete structure housing is got, then P_1, P_2, P_3, P_4 can be got from Equations (8)~(11). Together with the per capita housings area, the population and the average cost of 4 types housings, the value of 4 types housings of rural residents in 1 557 villages of Yunnan can be assessed.

2.3 Vulnerability model

The vulnerability model for 4 structure types in rural districts in Yunnan Province is obtained from the data of destruction ratio and loss ratio of four types of housings in over 20 earthquakes in Yunnan Earthquake Disasters Status Database, namely, average loss rate D of four types of housings under different earthquake intensities. The result is shown in Figure 3. Since 1990, the greatest earthquake in Yunnan Province is Lijiang earthquake of magnitude 6.9 that occurred in 1996 and the building damage data of intensity X is absent, which are supplemented after calculating the data according to probability vulnerability matrix of earthquake for housings established by YIN (1995) in this paper, the earthquake-resistant design is not considered for housings in rural districts and its value is taken as minimum magnitude VI of defended area.

It can be seen from Figure 3 that the earthquake resistance of housings with brick-and-concrete structures is slightly better than that of adobe-and-timber structures and brick-and-timber structures, but under the intensity IX some housings collapse and are destroyed seriously and the average loss rate is also more than 35%. Under the intensity of X in magnitude, most of housings with adobe-and-timber structures and brick-and-timber structures collapse, the average loss rate of brick-and-concrete structures is 55%; only the earthquake-resistant performance of frame structures is best, the housings are most moderately destructive and they do not collapse basically.

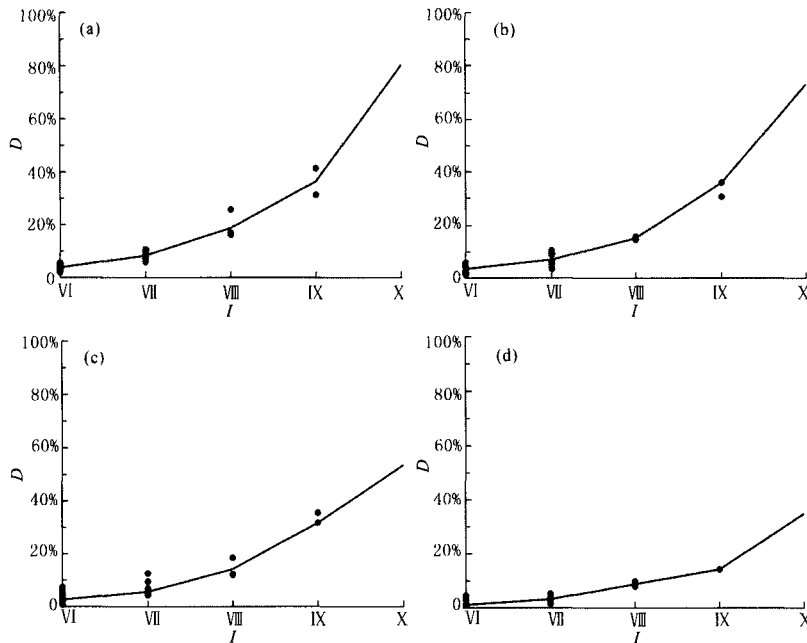


Figure 3 Average loss ratios of four types of housings in rural villages and towns in Yunnan
(a) Adobe-and-timber structure; (b) Brick-and-timber structure; (c) Brick-and-concrete structure;
(d) Frame structure

In Yunnan Province, the vulnerability of adobe-and-timber structures is almost same as that of brick-and-timber structures. Under the conditions of the same intensity, the loss rate of adobe-and-timber structures is slightly higher than that of brick-and-timber structures. The reason for this is the houses with adobe-and-timber structures are most in the form of column-and-tie wooden skeleton in Yunnan Province and its bulking property is stronger and earthquake-resistant performance is better than double-slope wooden skeleton in North China (YIN *et al*, 1997). For this type of house, the wooden frames support the roof and the floor and the walls only play the role in retaining. So there is no joint between the wooden frames and walls and this type of houses has certain earthquake-resistant performance. Under the action of earthquakes with the intensity of VI~VII, no evident deformation happens to most wooden roof trusses, but relative high walls will crack and for the old houses whose tile roofing is shuttling tile, that have not been repaired for many years and whose wooden roof trusses are rotten, wooden roof trusses will also deflect, the walls will crack seriously, the head walls collapse and plenty of shuttling tiles appear on the roofing. Under the intensity of VIII, tenon pull-out, out-of-joint, displacement and inclination happen to some wooden roof trusses, most walls crack, head walls collapse, shuttling tile roof windows

universally appear in the roof, roof fall also possibly happens to some timeworn houses. In addition, the farmers pay much attention to the quality of houses when they build houses in the areas where earthquakes frequently occur. Therefore, as a whole, the earthquake-resistant performance of adobe-and-timber structures in Yunnan Province is better than that in other provinces.

2.4 Earthquake intensity simulation

In China, many scientists have studied the attenuation of earthquake intensity in land areas of China according to different data and fitting methods, for example, the intensity attenuation relation [Equation (12)] of mean axis in western China that is used in seismic intensity zoning map of China issued in 1990 (State Seismological Bureau, 1996). WANG *et al* (2000) has built up the intensity attenuation [Equations (13-1) and (13-2)] in the eastern and western China by using abundant isoseismal data such as earthquake intensity and so on.

$$I = 4.524 + 1.443M - 1.844 \ln(d + 16) \quad \sigma^2 = 0.610 \quad (12)$$

where *M* stands for earthquake magnitude and *I* is site intensity at distance *d* (in unit of km) from the epicenter.

$$I_a = 5.253 + 1.398M - 4.164 \lg(d + 26) \quad \sigma = 0.632 \quad (13-1)$$

$$I_b = 2.019 + 1.398M - 2.943 \lg(d + 8) \quad \sigma = 0.632 \quad (13-2)$$

The above intensity attenuations are substituted into the model for simulation calculation. The results show that the operation of Equation (12) is simple and at the same time, the accuracy

Table 2 Earthquake catalogue of *M_S*≥5 in Yunnan Province during 1993-2002

No.	Earthquake	Date a-mo-d	Epicentral location		<i>M_S</i>	Focal depth /km	Simulated losses on housings* /10 ⁴ Yuan	Actual losses on housings /10 ⁴ Yuan	Simulated deviation**
			φ _N / (°)	λ _E / (°)					
1	Pu'er	1993-01-27	101.08	22.93	6.2	14	21 347 (37 391)	5 521	286.7% (577.3%)
2	Dayao	1993-02-01	101.35	25.87	5.3	10	3 517 (6 051)	703	400.3% (760.7%)
3	Zhongdian	1993-07-17	99.70	27.78	5.6	10	8 247 (9 906)	1 554	430.7% (537.5%)
4	Yao'an	1993-08-14	101.25	25.45	5.3	8	9 327 (15 088)	1 270	634.4% (1088%)
5	Jinping	1995-04-25	102.73	22.77	5.6	20	4 123 (12 636)	547	653.7% (2210.1%)
6	Wuding	1995-10-24	102.32	25.83	6.5	15	86 199 (186 558)	45 116	91.1% (313.5%)
7	Lijiang	1996-02-03	100.22	27.30	6.9	10	68 702 (116 365)	196 081	-64.9% (-40.7%)
8	Lijiang	1996-07-02	100.10	26.92	5.2	10	5 455 (7 241)	1 882	189.9% (284.8%)
9	Lijiang	1996-09-25	100.40	27.32	5.7	23	1 770 (6 240)	1 400	26.4% (345.7%)
10	Mengla-Jinghong	1997-01-25	101.10	21.90	5.1	10	718 (1 535)	670	7.2% (129.1%)
11	Jinghong-Jiangcheng	1997-01-30	101.40	22.40	5.5	9	852 (1 414)	2 100	-59.4% (-32.7%)
12	Lijiang	1997-10-23	100.30	26.80	5.3	10	8 137 (11 126)	1 660	390.2% (570.2%)
13	Ninglang	1998-11-19	100.90	27.30	6.2	10	9 561 (19 927)	25 255	-62.1% (-21.1%)
14	Chengjiang	1999-11-25	102.80	24.50	5.1	10	4 545 (11 121)	5 320	-14.6% (109%)
15	Yao'an	2000-01-15	101.12	25.58	6.5	30	94 722 (167 861)	81 204	16.7% (106.7%)
16	Qiubei-Mile	2000-01-27	103.63	24.15	5.5	10	7 938 (18 339)	8 010	-0.9% (129%)
17	Border of China and Myanmar	2000-10-06	97.60	24.30	5.8	18	6 286 (10 592)	5 532	13.6% (91.5%)
18	Lancang	2001-03-12	99.82	22.30	5.0	10	1 445 (3 655)	3 431	-57.9% (6.5%)
20	Shidian	2001-04-12	99.02	24.83	5.9	6	45 826 (70 595)	33 660	36.1% (109.7%)
21	Shidian	2001-06-08	99.00	24.83	5.3	5	10 928 (17 789)	2 440	347.9% (629.1%)
22	Chuxiong	2001-07-10	101.38	24.93	5.3	13	1 332 (3 336)	1 287	3.5% (159.2%)
23	Jiangchuan	2001-07-15	102.63	24.40	5.1	8	4 357 (8 556)	3 016	44.5% (183.7%)
24	Jinggu	2001-09-04	100.55	23.63	5.0	8	1 705 (3 693)	2 507	-32% (47.3%)
25	Yongsheng	2001-10-27	100.57	26.23	6.0	15	22 606 (48 322)	27 367	-17.4% (76.6%)

* The value in brackets means that the simulated losses on housings and the deviation calculated from Equation (13), respectively.

** Deviation=(Simulated losses on housings - Actual losses on housings)/Actual losses on housings. The negative value means the simulated losses less than the actual losses.

of its simulation result is relatively high. What is shown in brackets in Table 2 is the deviation of simulation result calculated by Equation (13) from the simulated value. In the loss simulation results of 25 earthquakes, the deviation of 21 simulation results is larger than that by Equation (12).

Equation (12) is the attention relation for areas to the west of 105°E in China. Most areas of Yunnan Province are to the west of 105°E except Funing, Guangnan and Malipo counties in Wenshan city and Zhenxiong and Weixin counties in Zhaotong city, where earthquakes seldom occurred in the history. Therefore, Equation (12) is adopted in this paper to simulate the earthquake intensity in Yunnan Province.

2.5 Analysis on simulation results

According to the estate estimate, the vulnerability model and the earthquake intensity simulation formula obtained above and on the assumption that basic parameters of 398 historical earthquakes are invariable, Equation (5) is used to simulate and calculate the sum of economic losses caused by the earthquakes in 1 557 villages in Yunnan Province.

In order to check the precision of simulation result, the actual loss assessment of housings caused by the destructive earthquakes with $M_S \geq 5$ in 1993~2002 is compared with the simulation results (Table 2). Except No. 7~9, No. 12, 13 and 21 earthquakes whose deviations are relatively large, the deviation of simulation result of the earthquakes after 1996 from the actual result is below 60%. The reason for this is that the Lijiang $M_S=6.9$ earthquake on February 1996 has serious effect on Lijiang region and the actual loss of No. 8 earthquake is the result after eliminating the loss of the $M_S=6.9$ earthquake. As a consequence, the statistical figures of actual earthquake loss caused by these earthquakes are relatively small and the simulation result is much larger than the actual result. The actual loss of houses caused by the No. 13 Ninglang earthquake is the accumulative losses by two former earthquakes of $M_S=5.3$ and $M_S=5.2$. So, the simulation result is much less than the actual result. The No. 21 Shidian earthquake is the aftershock of the No. 20 earthquake. Most of housings have been destroyed in the No. 20 earthquake and it is difficult to measure and calculate the actual loss caused by this earthquake. Thereby the simulation result is by far different from the actual result. The difference of simulation results of the No. 1~5 earthquakes in 1993~1995 from the actual loss is relatively large. The reason is that the value of hazard-affected bodies has changed. As listed in Table 1, the unit construction cost of four types of housings before 1996 is low and the average construction cost per square meter is about 100 Yuan lower than now. In addition, the area proportion of various housings also changes greatly. Therefore, the simulation result before 1996 is by far larger than the actual loss of that year. This shows that the earthquake loss will increase with the value of hazard-affected bodies.

As has been discussed above, for general earthquake cases except some special ones, the deviation of simulation result and calculation in this paper from the actual losses is below 60%. The deviation range is allowable in the assessment on the actual earthquake losses. Therefore, the estate estimate method, earthquake intensity simulation formula and established vulnerability model in this paper are reasonable and the simulation method is correct and feasible.

The simulation results of the 398 earthquakes are ranked from large to small, there are 372 earthquakes causing losses. Among them, only 4 earthquakes occurred before A.D. 1400 and their losses order is after the 90th. So 4 earthquakes will be removed, and the simulation span is 600 a. The maximum yearly exceedance frequency is $1/600 \approx 0.167\%$, the second is $2/600 \approx 0.333\%$, and the rest will be deduced by analogy. So the exceedance frequency curve of simulated housing losses caused by earthquakes in Yunnan Province is got (Figure 4).

It can be seen from Figure 4 that the maximum economic loss on housings per 500 years is up to 24 billion Yuan and the maximum economic loss on housings caused by earthquake per 100 years is 5.76 billion Yuan in Yunnan Province. The average loss is obtained by summing the economic losses on housings caused by the 361 historical earthquakes and the annual economic loss on housings caused by earthquakes is 0.328 billion Yuan in Yunnan Province. According to economic losses caused by earthquake cases in rural districts in Yunnan in *Collection of Assessment Reports on Seismic Disaster Loss of Chinese Mainland*, the economic loss on housings caused by earthquakes in rural districts accounts for about 80% of total economic loss (State Seismological Bureau and State Statistical Bureau, 1996). The annual total economic loss caused by earthquakes is up to 0.41 billion Yuan, accounting for 0.18% of GDP of Yunnan Province in 2002, which is 223.232 billion Yuan. Thereby, it is of great importance to alleviate the losses caused by earthquake disasters and to reduce the negative effect of natural disasters on economy so as to ensure the rapid development of economy in Yunnan Province.

The situation of earthquake disaster depends on earthquake intensity and earthquake-resistant performance of structural hazard-affected bodies. All the earthquakes that have caused largest economic losses on housings in rural villages of Yunnan Province are over 7 in magnitude and their epicentral locations are in the places where the economy is relatively developed in Yunnan. These earthquakes that had much damage to the economic development of Yunnan Province in history also have great effect on the society and economy today if they reoccur. The Yuxi-Tonghai earthquake of magnitude 7.7 is taken as an example. If this earthquake occurred in 2002, the total economic loss caused by it will up to 20.7 billion Yuan, accounting for 9.27% of GDP of Yunnan Province in 2002. In 1970, the total economic loss caused by the Yuxi-Tonghai earthquake of magnitude 7.7 is 300 million Yuan (LOU, 1996), accounting for 7.79% of GDP of Yunnan Province in that year, which is 3.852 billion Yuan. This illustrates that the 1970 Tonghai earthquake will have great effect on inhabitants living in the disaster areas and their effect on economy of Yunnan is even more than that in that year by far if they reoccur.

Through the 32-year economic development, much residential housing have changed from adobe-and-timber structures and brick-and-timber structures to framed structures in Yunnan Province and the vulnerability of structural housings reduces. Why the economic effect caused by earthquake is not lower but larger? The reason is that the unit area construction cost of housings has increased gradually during 1970~2002. The decrease of vulnerability is often less than the increase of price though the vulnerability of houses lowers. Therefore, the relative economic loss on housings caused by earthquakes will be larger in the future in Yunnan Province and its economic effect on society will also increase.

However, if casualty caused by housing damage is also taken into account, the destruction rate and serious damage rate of framed structures are low in the intensity areas with scales IX and X, that is to say, few housings collapse and the casualty can be avoided to the greatest extent and the vulnerability of human hazard-affected bodies lowers. Therefore, the vulnerability of structural and human hazard-affected bodies should be taken into account, framed structures have compre-

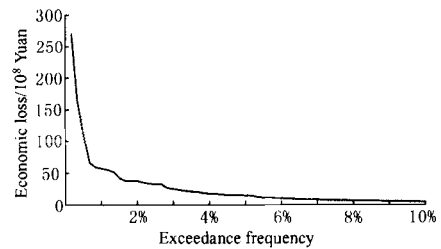


Figure 4 Exceedance frequency curve of simulated housing losses caused by earthquakes in Yunnan Province

hensive disaster reduction effect and they are preferred for housings in the places where earthquakes frequently occur.

3 Discussion and conclusions

Based on the assessment reports of destructive housings caused by more than 20 earthquakes occurred in 1990~2002 in Yunnan Province, the vulnerability models of 4 types housings of rural residents in Yunnan Province are setup. The scenario earthquake disaster loss simulation model are used to simulate the housing loss if the historical earthquakes that occurred in A.D. 886~2002 in Yunnan Province reoccurs in 2002. The analyses show the simulation deviation of the usual earthquake is less than 30% and the method is of high practicality.

The simulation result of the 398 historical earthquakes in Yunnan Province show that the annual economic loss caused by earthquakes is about RMB 410 million Yuan which accounts for 0.18% of GDP of Yunnan Province. Because of the larger average living area and the rising price of housings the loss and the impact on Yunnan Province will be greater than in those years if the historical destructive earthquake reoccurs today.

The key subject of the vulnerability of seismic disaster in rural villages is that how to improve the housings quality of rural residents and strengthen the antiseismic of adobe-and-timber housings. In most rural villages of Yunnan Province, the ratio of the adobe-and-timber structure housings area is more than 80%. The governmental departments of Yunnan Province must pay highly attention to the improving capability for disaster prevention and reduction in rural areas.

It was the lack of the building standard about the housings in rural region of China that leads to the lack of the data of antiseismic properties of rural housings. So when the paper extends the vulnerability model that comes from the survey data of some seismic areas to the total province area, it will bring some large deviations in some regions. On the other hand, in order to simplify the simulation model, the paper ignores the effect of different soil condition on the actual disaster status. Moreover, the assessment system will try to obtain the data about the vulnerability mode of housings and the soil condition so as to improve the simulation accuracy.

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