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A fast approach to regional earthquake hazard evaluation based on population statistical data*

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Abstract

In the prediction process of large-scale earthquake damage occurred in urban and rural regions, new models and approaches, which are different from traditional ones, should be adopted to rapidly predict earthquake damage. This article utilizes sampled population and buildings data that is easily available from the statistical database to conduct vulnerability analysis of buildings on the basis of earthquake damage of existing urban buildings in an analogical way, so as to provide a relation model between population data and disaster losses. In virtue of this model, the average vulnerability matrix of buildings of different structures in Fujian Province is established, the matrix adjustment coefficient of different decades is developed in accordance with the economic conditions, and the rapid evaluation system is set up as well. The result shows: this evaluation model, based on the population statistical data has merits as small investment, automatic data prediction, regular updates, as well as the advantage of easy accessibility.

Key words: **population data**; **evaluation model of earthquake damage**; **matrix of average building vulnerability**; **economic loss**; **casualty**
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Introduction

Earthquake disaster is always accompanied by huge life and property losses. With the rapid development of urbanization, population is migrating from countryside to the urban regions, thus losses caused by earthquake disasters is increasing (CHEN *et al*, 1999, 2001). Rapid evaluation of earthquake damage in the wake of earthquake disaster is of great guiding significance to the emergency relief work. On the subject of how to rapid and effectively carry out the evaluation of earthquake damage, earthquake experts both in China and abroad have conducted in-depth studies on the prediction of urban earthquake damage and the rapid evaluation of earthquake disaster, as well as established a series of emergency earthquake damage evaluation models based on the in-

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vestigation of large-scale mono and group buildings in the urban regions (CHEN *et al*, 2001; WEI *et al*, 2005; PAN *et al*, 2004; GUO and CHEN, 1991). However, detailed study of urban earthquake damage requires large investment, and system data is not easy to update, therefore it is difficult to implement across the country. The radius of destructive earthquake is generally at least 100 km, therefore rapid evaluation of damage on a city-to-city basis has inevitable limitations (CAI *et al*, 2006, 2007).

Different from the traditional earthquake damage evaluation model which is based on the statistical unit of mono building, this paper utilizes sampled population and buildings data easily available from statistical databases to conduct vulnerability analysis of buildings on the basis of earthquake damage of existing urban buildings in analogical way, so as to provide a relation model between population data and disaster losses and establish a rapid evaluation system of earthquake damage. This earthquake damage evaluation model is presented on the basis of population census data analysis and in reference to national experience of earthquake damage prediction and relief work. It fully utilizes the results of Fujian provincial prediction and studies urban earthquake damage prediction and the population census data, classifies different buildings, establishes initial values of buildings in each prediction unit, and incorporates appropriate adjustable parameters to the economic conditions and time of construction for earthquake damage prediction and rapid evaluation and calculation. The result of regional earthquake damage prediction and rapid evaluation shows this evaluation model, based on the population statistical data has merits as small investment, automatic data prediction, regular updates, as well as the advantage of easy accessibility.

1 Rapid evaluation model of regional earthquake damage

1.1 Classification of buildings

Classification of buildings is the basis for rapid evaluation of earthquake damage. In the fifth population census data, the sampled buildings data include floor area of residential houses (10% of total resident houses); purpose of houses; time of house construction; number of building stories (designed in accordance with structural requirements of different number of stories); external wall material of the house (structure). Taken into consideration the publication time of several important building codes since 1949, buildings are classified as follows: before 1979, 1980~1989, and after 1990. Since the statistical data of urban building management and population census data are frequently updated and easily accessible, in order to make sure that the data classifications are in line with that of earthquake disaster prediction, Table 1 is the form of classified buildings data.

Table 1 Form of classified buildings data

Type of Structure	Before 1979			1980~1989			After 1990		
	Bungalow	Building of 2~6 stories	Building of 7 or more stories	Bungalow	Building of 2~6 stories	Building of 7 or more stories	Bungalow	Building of 2~6 stories	Building of 7 or more stories
Reinforced concrete									
Masonry									
Wood-bamboo and straw									
Others									

1.2 Vulnerability analysis of regional buildings

The vulnerability of buildings is a measurement of building damage status in relation to the dynamic parameters of earthquake. The vulnerability of buildings is represented by percentage (percentage of floor area) of different damage levels (in good condition, light damage, moderate damage, severe damage or collapse) under different intensity (magnitude 6, 7, 8, 9 or 10) values.

The vulnerability of building group summarized through buildings sampling, detailed analysis and calculation of vulnerability of each building sample is of high credibility. However, for large-scale building groups, the vulnerability analysis results may be obtained through an analogical method. First of all, establish an analogical principle, adjust the available analogical results, and use the new findings as the initial values of building vulnerability in the prediction unit. The initial values adding to appropriately adjusted parameters will be used for regional earthquake damage prediction and rapid evaluation calculation. Difference of economic conditions will result in different seismic resistant capabilities of buildings, because the implementation of preventative measures and aseismic design requires certain financial supports. The construction investment in developed regions is far more than that of underdeveloped regions; therefore the influence of different economic conditions on the vulnerability of buildings shall be taken into consideration. This paper, on the basis of characteristics of sampled buildings data of the population census data and the existing building vulnerability findings of different regions, produces the average vulnerability matrixes of different structural types, as well as calculates the adjusted values influenced by the regional economic conditions and time when the buildings were constructed.

1.3 Rapid evaluation model of regional earthquake damage

1.3.1 Calculation of earthquake damage

Building damage is the floor area that cannot be used after being destructed by the earthquake. The following equation may be used to calculate floor area inside a predicted building that is damaged by a magnitude-*j* earthquake:

$$A_{sj}(I) = V_{sj}(I) \cdot T_s \tag{1}$$

In this equation, $V_{sj}(I)$ is the prediction unit, which corresponds to the percentage of magnitude-*j* in the classification-*s* building vulnerability matrix in case of *I* intensity; T_s is the total floor area of classification-*s* buildings (unit: m^2).

On the basis of equation (1), addition of different damaged floor areas derives the damaged floor area of all kinds of buildings in the prediction unit:

$$A_s(I) = \sum_{j=1}^{m} A_{sj}(I) \tag{2}$$

In the equation, m is the type of damage, *s* is the classification of buildings in the prediction unit.

1.3.2 Prediction of Economic Losses

Prediction of economic loss considers the direct economic loss caused by the damage of buildings, and shall be represented by the following equation (YIN, 1995):

$$L(I) = \sum_{s=1}\sum_{j=1} b_s(j)\beta_s(j) + \sum_{s=1}\sum_{j=1} Q_s(j)W_s \tag{3}$$

In the equation, *j* is the earthquake damage level in 5 categories (in good condition, light damage, moderate damage, severe damage, collapse); *s* is the type of building; $b_s(j)$ is the loss ratio when classification-*s* building suffers magnitude-*j* damage, that is the recovery or reconstruction cost as percentage of total building cost; $\beta_s(j)$ is the total value of classification-*s* building suffering magnitude-j damage, that is the construction cost of every square meter multiplies the total floor area $A_{sj}(I)$; $Q_s(j)$ is the indoors assets loss ratio when classification-s building suffers magnitude-j damage, that is the lost value of indoors assets as the percentage of total indoors assets value; W_s is the total indoors assets value of classification-s building.

1.3.3 Prediction of casualties

The prediction of casualties includes under given earthquake conditions, the number of deaths, number of severely injured, and number of personnel that need disaster relief efforts in the disaster-hit area. Due to many uncertain factors in the prediction of casualties, the model (YIN *et al*, 1990) is as follows:

Number of death:

$$M_{\mathrm{d}}(I)=c\eta(A_1 r_{\mathrm{d}1}+A_2 r_{\mathrm{d}2}+A_3 r_{\mathrm{d}3}) \tag{4}$$

Number of severely injured:

$$M_{\mathrm{h}}(I)=c\eta(A_1 r_{\mathrm{h}1}+A_2 r_{\mathrm{h}2}+A_3 r_{\mathrm{h}3}) \tag{5}$$

In the equation: c is the percentage of indoors personnel; A_1 is the floor area of collapsed buildings; A_2 is the floor area of severely damaged buildings; A_3 is moderately damaged houses; η is the density of indoors personnel (unit: person/m^2); $r_{\mathrm{d}1}$ and $r_{\mathrm{h}1}$ are death rate and severely injured rate inside the collapsed buildings; $r_{\mathrm{d}2}$ and $r_{\mathrm{h}2}$ are death rates and the severely injured rate inside the severely damaged buildings; $r_{\mathrm{d}3}$ and $r_{\mathrm{h}3}$ are death rates and the severely injured rate inside the moderately damaged buildings.

In the process of prediction, the scenarios may be divided into daytime and nighttime, the density of indoors personnel during daytime is 40% and the density of indoors personnel during nighttime is 100%. The number of personnel that need disaster relief efforts in the disaster-hit area may be predicted in accordance with the following equation (YIN, 1995):

$$M(I)=\left(A_1+A_2+\frac{7}{10}A_3\right)\Big/a-M_{\mathrm{d}}(I) \tag{6}$$

In the equation: a is the living space per capita; A_1, A_2 and A_3 are the floor areas of collapsed, severely damaged and moderately damaged buildings; $M_{\mathrm{d}}(I)$ is the number of death when the intensity value in predicted area is I.

2 Parameters and application of rapid evaluation model of regional earthquake damage in Fujian Province

2.1 Average vulnerability matrix of buildings of different structures[①]

The vulnerability analysis of buildings is the basis for establishing an evaluation system of earthquake damage; and the earthquake damage prediction and vulnerability analysis of buildings mainly adopt the mono-structure prediction statistics method or structural analogy method. In the prediction of regional earthquake damage, the larger the regional area is, the better workability the analogical method will have. On the basis of existing predictions and studies of urban earthquake damage in Fujian Province (Quanzhou, Nan'an, Zhangzhou, Fuzhou, Xiamen, Yong'an, Changle, Fuqing, Longyan, Putian, Jinjiang, Shishi), this paper also references the status of other regions across China, summarized the vulnerability studies of buildings of different structures, and pro-

① WEI Fu-quan, HUANG Hong-sheng, CAI Zong-wen. *Evaluation Report on Medium-scale Regional Earthquake Damage in Fujian Province and Initial Study Report on the Vulnerability of Buildings in Hill and Basin Regions of Fujian Province.*

duces the average vulnerability matrix of buildings of different structures in Fujian Province.

Table 2 Vulnerability matrix of reinforced concrete buildings

Level of earthquake damage	Basically in good condition	Light damage	Moderate damage	Severe damage	Collapse
VI	0.97	0.03	0	0	0
VII	0.93	0.06	0.01	0	0
VIII	0.47	0.43	0.09	0.01	0
IX	0.03	0.42	0.39	0.14	0.02
X	0	0.03	0.19	0.55	0.23

Table 3 Vulnerability matrix of masonry buildings

Level of earthquake damage	Basically in good condition	Light damage	Moderate damage	Severe damage	Collapse
VI	0.84	0.14	0.02	0.00	0.00
VII	0.28	0.66	0.05	0.01	0.00
VIII	0.046	0.28	0.62	0.044	0.01
IX	0.01	0.05	0.27	0.60	0.07
X	0.00	0.00	0.09	0.38	0.53

Table 4 Vulnerability matrix of wood-bamboo and straw buildings

Level of earthquake damage	Basically in good condition	Light damage	Moderate damage	Severe damage	Collapse
VI	0.45	0.51	0.04	0	0
VII	0.18	0.45	0.31	0.06	0
VIII	0	0.22	0.51	0.22	0.05
IX	0	0	0.24	0.42	0.34
X	0	0	0.08	0.34	0.58

Table 5 Vulnerability matrix of buildings of other structures

Level of earthquake damage	Basically in good condition	Light damage	Moderate damage	Severe damage	Collapse
VI	0.53	0.42	0.05	0	0
VII	0.14	0.41	0.42	0.03	0
VIII	0	0.16	0.54	0.28	0.02
IX	0	0.04	0.25	0.49	0.22
X	0	0	0.03	0.25	0.72

2.2 Adjustment of different economic condi tions' impact on average vulnerability

With the development of economic level and improvement of quality requirements on buildings, the building structures and quality are improving, and the seismic performance of buildings is related to the economic conditions; by making vulnerability matrix of similar buildings and conducting comprehensive analysis and comparison on the basis of economic conditions, a vulnerability impact adjustment matrix $\boldsymbol{\varepsilon}_e$ is produced for different economic conditions. Buildings of different times of construction may have different adjustment value $\boldsymbol{\varepsilon}_e$ in reference to different economic conditions (Tables 6 and 7).

2.3 Examples of application

Based on the above findings of model studies, the Earthquake Administration of Fujian Province has established a medium-scale rapid evaluation system of regional earthquake damage in the Fujian Province. The system is realized on a GIS map; taking the urban administrativedistricts, villages and towns as working units; under a given seismologic parameters, the popula-

Table 6 Adjusted values ε_{eg} of average vulnerability (Regions of good economic conditions)

Level of earthquake damage	Basically in good condition	Light damage	Moderate damage	Severe damage	Collapse
VI	+0.010	–0.010	0	0	0
VII	+0.015	–0.015	0	0	0
VIII	+0.040	–0.020	–0.020	0	0
IX	+0.010	+0.030	–0.030	–0.010	0
X	0	+0.010	+0.050	–0.050	–0.010

Table 7 Adjusted values ε_{ed} of average vulnerability (Regions of poor economic conditions)

Level of earthquake damage	Basically in good condition	Light damage	Moderate damage	Severe damage	Collapse
VI	–0.010	0.010	0	0	0
VII	–0.025	0.015	0.010	0	0
VIII	–0.040	0.020	0.010	0.010	0
IX	–0.010	–0.030	0.030	0.010	0
X	0	0	–0.010	–0.030	0.040

tion and buildings data is distributed according to residential area on the basis of population growth rate, statistical data of building floor area growth and automatic updated data. The earthquake damage, economic losses and casualties may be rapidly predicted in accordance with population data and prediction model of earthquake damage. The system is based on WebGIS technology, has integrated such computer technologies as multimedia, *etc*. The above-mentioned basic working information, data and computation modules is integrated into an information system, which is dynamically updated, and performs space analysis, quantitative calculation and visualized functions (CAI *et al*, 2006).

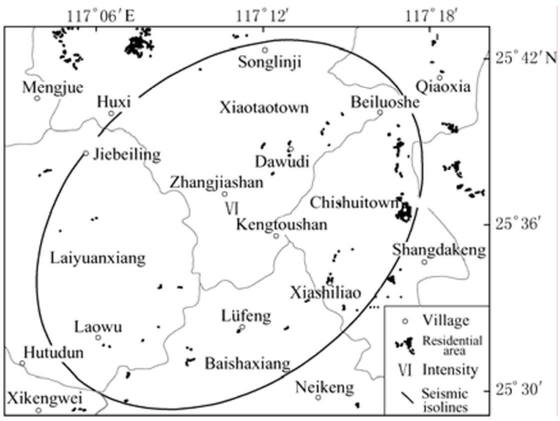

Figure 1 Earthquake effect field distribution map of magnitude 5.2 earthquake in Yong'an by WebGIS system

In order to verify its practical effect, this system was used to conduct analogical analysis of the 5.2 magnitude earthquake which occurred in southwestern part of Yong'an city in May 31st, 1997. By inputting actual earthquake parameters and the foresaid model parameters, as well as referencing to loss ratio of actual earthquake damage and construction cost of that period, the earthquake effect field was simulated as Figure 1, and the earthquake losses were calculated as in Table 8 (Department of Monitoring and Prediction, China Earthquake Administration, 2001).

The analytical findings of Figure 1, Figure 2 and Table 8 show the method of this model is practical, the findings of this model is legible and reliable.

3 Conclusions

The above-mentioned analysis and findings of regional application show that the evaluation model of regional earthquake damage on the basis of population statistical data and sampled

Table 8 Comparison of model calculation results and field investigated economic losses (exclusive lifeline, *etc*)

Region	Number of death	Economic losses calculated by model/10K RMB	Economic losses by field investigation/10K RMB	Quotient of calculated values and field findings
Yong'an City	0	1776	2005	0.89
Zhangping City	0	740	1162	0.64
Liancheng County	0	662	1289	0.51
Xinluo District	0	507	215	2.36
Total	0	3685	4670(4325)	0.79(0.85)

Note: Model calculates the damage of VI magnitude earthquake effect field; while the field investigated economic losses of VI magnitude earthquake effect field are listed in the parentheses.

population and buildings information is well set up in a practical method, therefore the following conclusions are drawn:

1) It is a practical, inexpensive, reliable and rapid solution to conduct evaluation of regional earthquake damage on the basis of population and building statistical data and analogical method;

2) The average vulnerability matrix developed by analogical method may well represent the average earthquake damage of buildings;

3) The population statistical data and earthquake damage prediction model set forth in this article may be used to conveniently establish an management information system of earthquake damage prediction on the basis of population statistical data;

4) The model data is easy to update and the system is dynamic, therefore it is easy to be implemented in other regions.

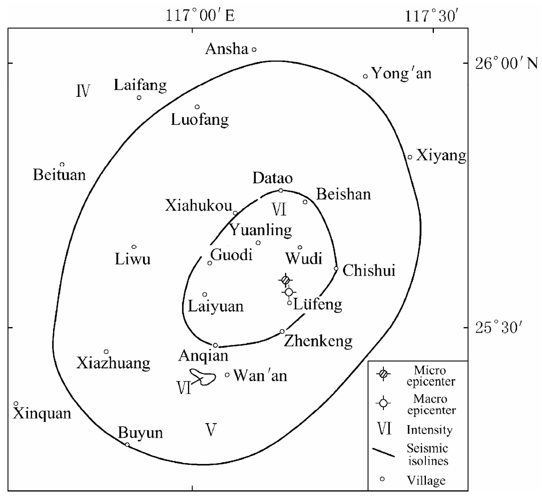

Figure 2 Distribution map of field investigated earthquake intensity (Department of Monitoring and Prediction, China Earthquake Administration, 2001)

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