Fast assessment of earthquake loss and its application to the 2008 M_S 8.0 Wenchuan earthquake *

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Abstract The paper introduces firstly the seismic loss assessment method based on macro-economic indicators and new vulnerability models determined by the data from the on-site damage and loss survey to earthquakes occurred in China during the last two decades. The fast assessment for the 2008 Wenchuan earthquake with M_S 8.0 is given based on an empirical intensity attenuation relationship. Compared with the assessment based on the practical seismic intensity map of the event according to the on-site investigation, the result demonstrates the usability of the seismic vulnerability models introduced in the paper. In addition, it is indicated that the main uncertainty of losses in the fast loss assessment comes from the uncertainty of the estimation of seismic ground motion.

Key words: macro-economic indicator; fast loss assessment; Wenchuan earthquake; uncertainty

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1 Introduction

The Wenchuan, Sichuan province, China, earthquake with magnitude M_S 8.0, which occurred on May 12, 2008 and caused heavy life and property losses, is another disastrous event located in dense population region since the 1976 Tangshan earthquake. Immediately after the event occurred, the authors performed fast assessment of the losses caused by the event. The assessment results were sent formally as a brief report to the related management division of China Earthquake Administration (CEA) in the afternoon on the same day. With the emergency rescue and disaster survey carried out step by step, the seismic intensity map was modified according to the on-site survey, the losses were re-estimated and closer to the actual ones much more.

The paper introduces firstly the seismic loss assessment method based on the macro-economic indicators, then assesses the losses of the Wenchuan earthquake, and finally discusses the main uncertainty of the assessment.

2 Seismic loss assessment method based on the macro-economic indicators

The conventional seismic loss assessment is vulnerability inventory methodology (Applied Technology Council, 1985). According to the method, buildings are classified into several types associated with their anti-seismic behaviors. The seismic losses can be assessed based on the vulnerability analysis of different kinds of buildings. But it is difficult to collect such detailed data of inventory buildings, the detailed fault distribution and site condition that affect vulnerabilities of the buildings. In addition, because of difference in building type and structural form, building quality and the relative ratio of different kinds of buildings from one city to another, the vulnerability models of buildings obtained from one city is usually unsuitable for other cities. It might be best to invest much capital in updating the basic building inventory data in order to get appropriate vulnerability functions for seismic damage prediction. However, it is not economical for macroscopic decision-making. Fast post-earthquake loss assessment aims mainly at assessing quickly the injuries and deaths as well as economic losses due to earthquakes so as to provide the decision-making basis for emergency command and rescue.

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A simplified method was developed by Chen et al (1999) in which the macroscopic economic indicators were used to assess seismic losses. The method has been used in the global wide (Chen et al, 2001, 2002; Mi, 2002). In the method, the gross domestic product (GDP) was used to represent the social wealth directly, and this leads to a basic model (Wang et al, 2006, 2007) as following.

Suppose that $p_1(t, R, I)$ refers to annual occurrence probability of intensity I in region R in the t th year, $Y(t, R)$ refers to the total of prediction objects including population or social wealth, $F(I, Y)$ depicts the loss rate (vulnerability) in the intensity I of the object, then the seismic loss (such as life loss, economic loss) $L(T, R)$ for the region R in time interval $T\{t|t_s \leq t \leq t_e\}$ can be expressed as following:

$$L(T, R) = \sum_I \int_{t_s}^{t_e} p_1(t, R, I) \cdot F(I, Y) \cdot Y(t, R) dt. \quad (1)$$

For a destroyed earthquake event occurred at the moment t_e , suppose that spatial distribution of seismic intensity of the event is deterministic (although there exists great uncertainty in practice, see Wang et al, 2003, 2004), then in the region with intensity I , $p_1(t_e, R, I)=1$. Thus the loss caused by the event can be estimated as following:

$$L(t_e, R) = \sum_I F(I, Y) \cdot Y(t_e, R). \quad (2)$$

Equation (2) can be used for fast assessment of

post-earthquake loss taking into consideration of the variation of population or social wealth and their vulnerabilities to earthquakes with time. Generally, the above equations can be applied to the assessment of injuries, deaths as well as the economic loss based on macroscopic economic indicators or buildings.

3 The seismic vulnerability models

The life and social wealth vulnerabilities to the earthquake are associated with the intensity of seismic ground motion (here the seismic intensity is used) and the anti-seismic ability of the predicting objects. The early seismic vulnerability model took macro-epicenter intensity as the representation of seismic ground motion (Chen et al, 1995a, 1997; Chen et al, 1995b; Mi, 2002). It should be pointed out that the model is not applicable to the loss prediction based on the intensity occurrence probability resulted from seismic hazard analysis, since the effect of seismic ground motion will be over-valuated in the case. In addition, the fast seismic loss assessment results will also be low precision after an event based on the model since only macro-epicenter intensity was used as representative of the actual spatial intensity distribution. As accumulation of more and more on-site survey data, the new seismic vulnerability models can be statistically obtained based on the actual seismic intensity area.

Figure 1 The epicentral distribution of 157 earthquakes occurred in Chinese mainland during from 1989 to 2004.

The present paper collected systematically the damage and loss data from on-site surveying of 207 earthquake events occurred in Chinese mainland during from 1989 to 2004 (State Seismological Bureau and National Bureau of Statistics of China, 1996; Department of Monitoring and Prediction, China Earthquake Administration, 2001; Lou, 1996). 157 earthquake events were chosen to study the vulnerability to earthquakes with epicentral distribution shown in Figure 1. The population, GDP, injuries and deaths as well as direct economic loss in each seismic intensity region are extracted from the data. The data are classified into three groups according to the level of GDP per capita that represents anti-seismic ability in different economic development region. Thus the new seismic vulnerability models applicable to Chinese mainland can be obtained for each group of data.

Figure 2 The economic vulnerability represented by the GDP loss rate $F(I, Y)$ versus seismic intensity in Chinese mainland. Y_{pc} stands for GDP per capita in unit of RMB yuan.

4 The fast loss assessment of Wenchuan earthquake

The fast loss assessment can be performed based on seismic vulnerability, seismic intensity attenuation relation as well as current population and GDP. The authors have been developed the GIS software (MapEDLP 2005 for Windows) for seismic loss prediction and fast assessment based on the macro-economic indicators introduced in the section 2 of the paper. The software have been applied to predict the economic and life

The economic vulnerabilities represented by the GDP loss rate $F(I, Y)$ due to earthquake in China are listed as following (Figure 2):

$$F(I, Y) = \begin{cases} 2 \times 10^{-8} I^{9.8082} & Y_{pc} < 2700 \\ 2 \times 10^{-10} I^{11.585} & 2700 \leq Y_{pc} < 10000 \\ 4 \times 10^{-11} I^{11.377} & Y_{pc} \geq 10000 \end{cases}, \quad (3)$$

where Y stands for GDP, Y_{pc} for GDP per capita in unit of RMB yuan.

The life vulnerabilities represented by the death rate $R(I, Y)$ due to an earthquake in China are listed as following (Figure 3):

$$R(I, Y) = \begin{cases} 6 \times 10^{-13} I^{9.849} & Y_{pc} < 2700 \\ 9 \times 10^{-17} I^{14.977} & Y_{pc} \geq 2700 \end{cases}, \quad (4)$$

where the meaning of Y and Y_{pc} are the same as those in equation (3).

Figure 3 The life vulnerability represented by the death rate $R(I, Y)$ versus seismic intensity in Chinese mainland. Y_{pc} stands for GDP per capita in unit of RMB yuan.

losses due to earthquakes in Chinese mainland from 2006 to 2020 (Wang et al, 2007), which provided the main foundation for determining significant national seismic monitoring and protection regions in Chinese mainland from 2006 to 2020 (Zhang et al, 2007). The system has also been used for fast loss assessment after several earthquakes occurred in China in 2006 and good results were got. The fast loss assessment was done by using the software immediately after the Wenchuan earthquake occurred and the results were sent to the management department of CEA within two hours after the event occurred. The section will briefly introduce the

assessment.

4.1 The seismic intensity attenuation relationship

During the process of fast loss assessment, the seismic intensity attenuation relationship in west China was adopted as following:

$$\begin{cases} I_a = 4.49 + 1.45M - 1.79\ln(R+16) & \sigma_a = 0.6 \\ I_b = 4.52 + 1.44M - 1.94\ln(R+16) & \sigma_b = 0.6 \end{cases}, \quad (5)$$

where I is seismic intensity, M is magnitude of earthquake, R is the distance between hypocenter and the ground site in unit of km, and σ is the standard deviation.

4.2 Population, social and economic data in the Wenchuan earthquake disaster region

A seismic loss prediction database established in 2005 based on macroscopic economic indicators (Wang et al, 2007) has been used in the fast loss assessment of the Wenchuan earthquake. The database includes the GIS information such as the county or city administration boundaries, the administration seats as well as the statistical data such as the population and GDP by the end of 2003.

4.3 The fast loss assessment of the Wenchuan earthquake

Based on the models and data mentioned above, as well as the earthquake parameters such as original time, epicentral location (103.267°E, 31.084°N) and magnitude ($M_s8.0$) through the fast report of the Wenchuan earthquake, the economic and life losses due to the great earthquake were assessed. Figure 4 shows the estimated seismic intensity distribution. The first fast assessment results show the expected death value caused by the event was about 11 000, and the direct economic loss was about RMB 8.66×10^{10} yuan (the constant price of the year 2000). Taking the one third of the figures as the lower limit, we got the estimated death of 3 000–11 000 and direct economic loss of RMB 2×10^{10} – 8×10^{10} yuan (the constant price of the year 2000), which was sent to the related management division of CEA as a formal report.

4.4 Modification of loss assessment of the Wenchuan earthquake

Because of the deficiency of basic data in some cities in the disaster region, the authors did not consider the factors such as the population and economic increases and price index in the first assessment (see section 4.3). Taking the annual average increase rate of population and GDP in the disaster region as 0.35% and 8% respectively, we reassessed the loss after supplement

of the deficiency data. The modified results show that the deaths of the event were assessed at 12 300, and the direct economic loss was expected as RMB 1.987×10^{11} yuan (the current price).

Figure 4 The estimated seismic intensity map immediately after the Wenchuan $M_s8.0$ earthquake occurred.

5 The loss estimation of the Wenchuan earthquake based on the on-site survey

In the fast loss assessment stage, the seismic intensity was estimated empirically, which is obvious different from that determined according to the on-site seismic intensity survey. Figure 5 shows the seismic intensity map of the Wenchuan earthquake published formally by CEA (2008). In order to probe into the factors which have influence on the assessment precision, the seismic losses were reassessed by using the seismic intensity shown in Figure 5. The reassessed expected death value caused by the event was about 86 000, and the expected direct loss value was about RMB 4.48×10^{11} yuan (the

Figure 5 The seismic intensity map of the Wenchuan $M_s8.0$ earthquake (China Earthquake Administration, 2008).

constant price of the year 2000) or 8.3×10^{11} yuan (the current price).

6 Discussion and conclusions

The life and direct economic loss of the Wenchuan earthquake were assessed according to the macroscopic economic indicators based on fast estimated seismic intensities and on-site surveyed seismic intensities, respectively. The assessment results give to the conclusions as following:

1) The deaths and direct economic losses assessed with different data shown above are comparable to actual losses in the order of magnitude.

2) The death and direct economic loss assessed with the actual seismic intensity map based on the on-site survey is very close to the actual ones considering a sum of the death total 69 227 and the missing 17 923. While those assessed with the fast estimated seismic intensity map based on the empirical intensity attenuation relationship shows obvious different results. The fact demonstrates that the great uncertainty affecting the loss assessment comes from the estimation of seismic intensity, while the established life and GDP vulnerabilities are applicable for the fast loss assessment.

3) As there are not enough data to determine the life and economic vulnerability in high seismic intensity (X or greater) region, the losses in the region of seismic intensity X or XI are assessed with the vulnerability extrapolated from the low seismic intensity region. It is also expected to decrease the uncertainty of loss assessment by establishing the seismic vulnerability in the high seismic intensity regions.

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