Statistical Analysis on Earthquake Fatality Vulnerability in China

Y.Y. Li, G.F. Su, and H.Y. Yuan

Abstract—**In order to study earthquake fatality vulnerability in China, a comprehensive Chinese casualty database is compiled firstly. Based on this database, statistical analysis is conducted to discuss the influence of occurrence time on fatalities and seismic mortality trends from the year of 1900 to 2010. The results indicate that influence of occurrence time on low-fatality earthquakes is not obvious while earthquakes occurred at night tend to cause huge deaths. Earthquake mortality seems to show a high point every fifty years. Further, the ratio of injuries to fatalities based on epicenter intensity is studied by regression analysis, and the logarithmic relationship between fatality rate and epicenter intensity is obtained. The relationships can be used for preliminary casualty estimation in rapid emergency response after earthquakes.**

Index Terms—**earthquake, casualty database, vulnerability, statistical analysis**

I. Introduction

Due to the unpredictable nature and significant influences, earthquake is regarded as one of the most lethal natural disasters in the world. China is a seismically vulnerable country, because of high population density and poor building quality in rural regions, significant earthquakes often cause huge fatalities and economic losses. For instance, 1976 Tangshan earthquake is ranked among the deadliest earthquakes in the world and the recent 2008 Wenchuan earthquake lead to 69227 deaths and 17923 missing.

Scholars have conducted many researches on seismic fatality vulnerability. Study on factors which contribute to seismic casualties is one of these issues. At present, it is recognized that besides seismic parameters (magnitude, intensity), factors including time of the day, population density, intensity, building quality and individual behavior have major influence on deaths and injuries. At the same time, characteristics of casualties in earthquakes were studied. For instance, statistical method is used to analyze deaths distribution according to timeline or distance from the epicenter. For the research on the change of seismic casualties during long period, the ratio of injured to fatalities was studied for loss prediction before earthquakes. Moreover, in order to make rapid loss estimation after earthquakes, correlations between seismic parameters, geographic information and the number of deaths/fatality rate were established, among which intensity, magnitude and population density were the most commonly used parameters.

In this paper, seismic fatality vulnerability in Mainland China was studied. First of all, a Chinese earthquake casualty database was built by compiling five authorized published/online data sources in Chinese. Based on this database, the influence of occurrence time on fatalities, earthquake mortality trend from 1900 to 2010, and the ratio of injured to fatalities were presented. Finally, the relationship between fatality rate and epicenter intensity was stated.

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II. Data and Methodology

A. Data

In order to investigate earthquake fatality vulnerability in mainland China, it is necessary to collect earthquake casualty data and geodemographic data of earthquake events. There are some global and local earthquake casualty databases, such as USGS Preliminary Determination of Epicenters (Sipkin, Person and Presgrave, 2000), the UTSU catalog of deadly earthquakes (Utsu, 2002) and EM-DAT (Hoyois, Below, Scheuren and Guha-Sapir, 2007). In particular, USGS compiled eight catalogs and built a global earthquake catalog PAGER-CAT (Allen, Marano, Earle and Wald, 2009). In terms of Chinese earthquake catalogs, China Earthquake Data Center (http://www.china-disaster.cn) provides an online earthquake database, including information on dates, magnitudes, casualties and economic losses of earthquakes events. However, because of not scientifically organized and lack of necessary explanation, this database makes it difficult to understand. There are also couples of Chinese published earthquake catalogs, because they are from different data sources and lack of necessary duplicate checking, there are some duplicate earthquake events and different records for the same earthquake event. Therefore, we compiled five authorized earthquake catalogs (Lou, 1996; Zhang, 1988, 1990, 1999, 2000; Chen, 2002; China Earthquake Administration, 1996, 2001, 2010; Mi, Li and Hou, 2006) and derived a Chinese earthquake casualty database. The casualty database includes 520 earthquake events where magnitude equal to 5.0 and greater and bring at least one injury ever recorded until December 2011. For each earthquake, information on seismic parameters, deaths toll, the number of heavy injuries and light injuries, as well as areas and population of affected regions from intensity VI to intensity IV is contained. When available, the areas and population within macroseismic intensity is also provided.

B. Methodology

Statistic and fitting methods are widely used to analyze the characteristic and relevance for large amount of data. At present, statistic and fitting methods are used to estimate the vulnerability of natural disasters, such as earthquake, flood, etc. In the paper, we also use this approach and apply Origin software for data analysis.

III. Results and Discussions

A. Influence of occurrence time on fatalities

Influence on earthquake fatality loss. The reason of selecting these fifty years is that specific to the earthquake occurred-hour time is recorded from 1960s. Fatal earthquake events are classified into six columns according to the number of earthquake-induced deaths, for each death range, the number of earthquakes occurred at nighttime and daytime are counted respectively. "Nighttime" refers to 7:00 PM to 7:00 AM, while "daytime" means the other 12 hours during a day. The result is shown in Fig. 1. Generally speaking, earthquakes occurred nearly equal times at the two time periods, there are 71 earthquakes occurred at nighttime and 69 earthquakes at daytimes. Specifically, we can see that the number of earthquakes at the two time periods shows slight difference within each death range. It is necessary to point out that the top 3 high-fatality earthquakes during these five decades: 1976 Tangshan (Hebei province) earthquake at night, caused 242000 deaths; 1970 Tonghai (Yunnan province) earthquake at night, left 15621 deaths; 2008 Wenchuan (Qinghai province) earthquake during the day, lead to 69227 deaths.

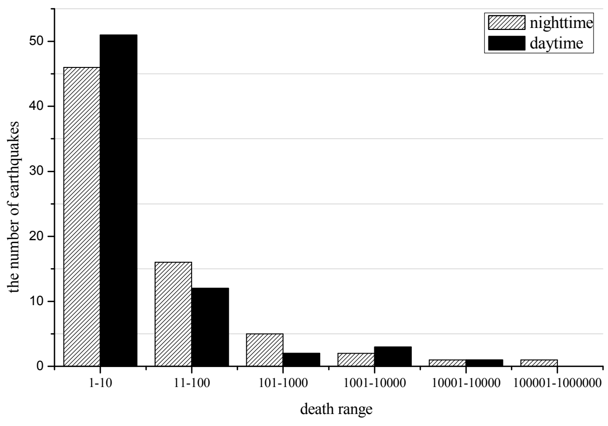

Fig. 1. The number of earthquakes occurred at nighttime and daytime within different death ranges.

Fatalities of 137 earthquakes except the top 3 high-fatality ones are counted based on four death ranges. Fig. 2 indicates fatality distribution at nigthtime and daytime within different death ranges. Compared with Figure 1, it is shown that the difference in the number of fatalities at nighttime and daytime is positively related to the difference in the number of earthquakes in the corresponding period of time. That is to say, for earthquakes which caused fatalities less than ten thousand, the influence of occurrence time on fatalities is not obvious; however, for high-fatality earthquakes, earthquakes occurred at night tend to cause huge deaths.

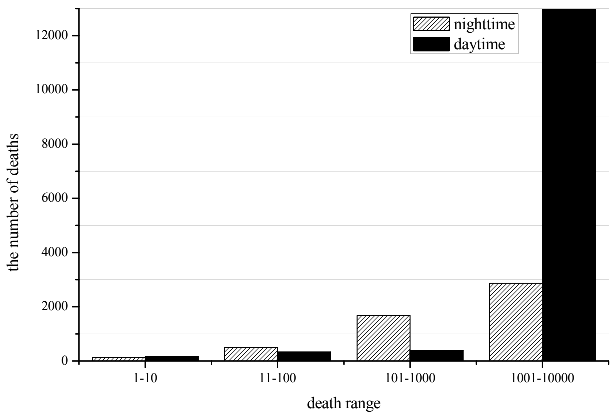

Fig. 2. Fatality distribution at nigthtime and daytime within different death ranges.

B. Ratio of injuries to fatalities

In this casualty database, the injured is divided into heavy injured and light injured, heavy injured is defined as the one who need to hospital for treatment, whereas light injured refer to the one who do not require hospital treatment. Ratio of injured to fatalities is defined as the number of heavy injured to the number of deaths. The ratio was examined based on epicenter intensity of each earthquake event. The epicenter intensity is from VI to XI. On the whole, 202 earthquake events that with magnitude >= 5.0 and have record of deaths and injuries are investigated. The number of earthquakes events within each epicenter intensity, as well as the overall number of heavy injured and fatalities is shown in Table 1.

TABLE I
THE NUMBER OF EARTHQUAKES DEATHS AND HEAVY INJURIES

Epicenter intensity	The number of earthquakes	The overall number of deaths	The overall number of heavy injuries
VI	53	48	281
VII	76	345	3152
VIII	46	561	2679
IX	18	4085	17678
X	3	25884	17883
XI	6	318864	556633

Based on Table 1, ratio of injuries to fatalities is computed and the regression analysis is made, the result is shown in Fig. 3. We can see that there is a liner relationship between the ratio and epicenter intensity, the ratio decreases when epicenter intensity increases. That is to say, when epicenter intensity goes up, more people tend to die immediately rather than be injured. The fixed ratio 3:1(heavy injuries: fatalities) is widely used as a preliminary estimation after earthquake, it is shown that when the ratio comes to 3, epicenter intensity reaches about 10. Epicenter intensity is a parameter that easy and quick to obtain after earthquake, so the equation between epicenter intensity and the ratio is useful for relief supplies' deployment in emergency response.

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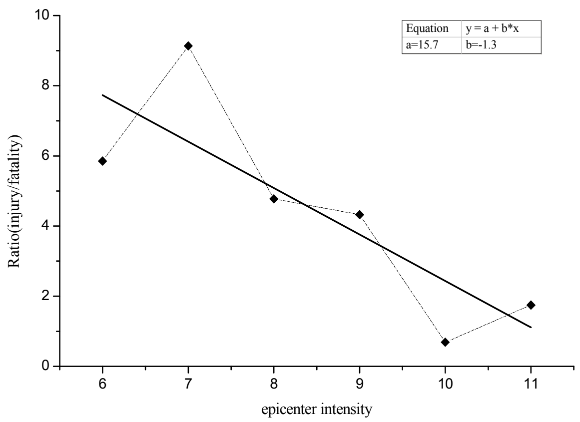

Fig. 3. The ratio of injuries to fatalities.

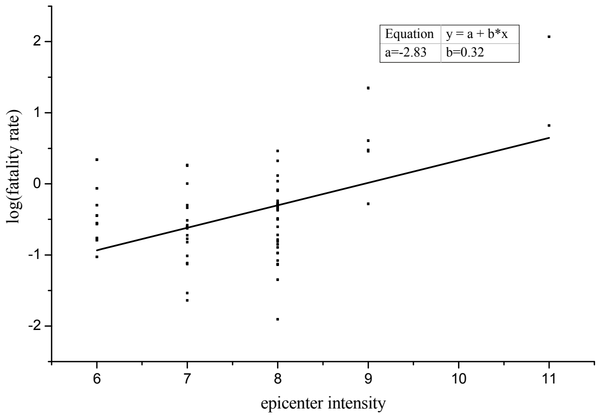

Fig. 5. The relationship between fatality rate and epicenter intensity.

C. *Mortality trends from the year of 1900 to 2010*

Fatal earthquake events that with magnitude >=5 between the year of 1900 and 2010 were examined to investigate the change of seismic mortality for more than one century. The result is show in Fig. 4. It indicates that earthquake-induced deaths change every decade according to seismic activity lifetime, the number of deaths show two high points in 1920s and 1970s, exceeding 250000, and the interval is 50 years. Except the two points, fatality changes smoothly and keeps under 25000. It seems to show that high seismic fatalities come out every fifty years.

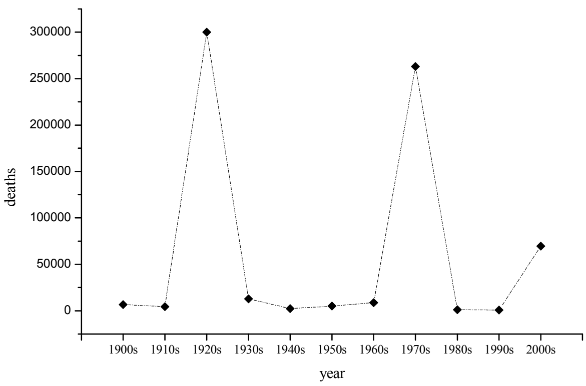

Fig. 4. The number of seismic deaths each decade from 1900 to 2011.

D. *The relationship between fatality rate and epicenter intensity*

Limited to earthquake field survey, fatality is usually recorded based on administrative areas rather than shaking intensity, so fatality data based on shaking intensity is difficult to collect. The epicenter intensity can be obtained at the first time after earthquake, for rapid emergency response purpose, epicenter intensity is an ideal index for fatality rate regression. A logarithmic correlation between fatality rate and epicenter intensity is illustrated in Fig. 5.

Let FT represents fatality rate, and I represents epicenter, the relationship is expressed as below. The function is useful for preliminary fatality estimation after earthquake when shaking intensity map cannot be drafted.

$$FT = 10^{0.32I - 2.83}. \quad (1)$$

IV. CONCLUSION

Earthquake casualty data derived from authoritative Chinese published seismic catalogs was used to examine fatality vulnerability in mainland China. Based on this database, influence of occurrence time on fatalities and mortality trends from the year of 1900 to 2010 were discussed at first, the results indicate that earthquake at night tend to cause huge fatalities. Further, mortality trends between the year of 1900 and 2010 were examined, it shows that earthquake mortality appear to show a high point every five decades. Then ratio of injured to fatalities is computed and the regression analysis based on epicenter intensity is made, it indicates that ratio decreases when epicenter intensity increase, that is to say, when epicenter intensity goes up, more people tend to die immediately rather than be injured . Finally, the logarithmic relationship between fatality rate and epicenter intensity is illustrated, which can provide preliminary fatality estimation for rapid emergency response after earthquakes.

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