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Application and prospect of high-resolution remote sensing and geo-information system in estimating earthquake casualties

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Abstract

An accurate estimation of the number of casualties can help respond earthquake disaster and increase the number of survivors. Building damage is considered as the major cause of earthquake casualties in many developing countries. The high-resolution satellite imagery (HRSI) can be used to detect the damage of buildings in a short time. This advantage provides the possibility to estimate the earthquake casualties immediately after earthquake. With respect to capability of HRSI, this paper builds a new model for estimating the casualty number in an earthquake disaster based on the attributes and damage of buildings. Three groups of earthquake data, 2003 Bam earthquake, 2008 Wenchuan earthquake and 2010 Yushu earthquake, were used to evaluate our proposed model. The estimating results indicate that the model has improved the accuracy significantly. Meanwhile, the parameters in model should be different from earthquake between developed and developing countries. This study can provide valuable information to help develop an efficient rescue operation.

1 Introduction

Estimating human losses due to earthquakes in real-time and scenario mode is becoming more necessary as the world population increases and concentrates in town and city dramatically (Wyss and Trendafiloski, 2011). In recent years, earthquakes that caused great damage have occurred frequently all over the world, such as the 2008 Wenchuan earthquake (der Hilst, 2008), the 2009 L'Aquila earthquake (Ameri et al., 2009), the 2010 Chile earthquake (Lay et al., 2010), the 2010 Hati earthquak (Daniell et al., 2013), the 2010 Yushu earthquake (Ni et al., 2010), the 2011 Japan Great earthquake (Mimura et al., 2011) and the 2013 Ya'an earthquake (Tang and Zhang, 2013). In this situation, the prevention and relief of earthquake drew a great deal of attention. Building damage is the main contributor to earthquake casualty except some countries, such as Japan (Yamazaki et al., 1996). Compared to developed countries, buildings hit by an earthquake in developing countries are damaged more seriously, thus more casualties were caused by building damage in developing regions. This is because most of buildings in developed countries were designed to withstand quakes, such as buildings in 1994 Northridge earthquake (Peek-Asa et al., 1998), while there are still a great number of buildings in developing countries were not designed to seismic standard mainly due to the lack of funds (Kenny, 2012). The lack of earthquake knowledge worsens the situation further. Therefore, in the present stage, a high efficient rescue plan which needs the support from all source (Brunner et al., 2009) can largely increase the number of survivors after an earthquake that happen in developing countries (Zhang et al., 2012).

Among all rescue activities, casualty estimation is the primary information to support the design of rescue plan. The less time is used to prepare for the rescue, the more people can be saved. Many methodologies were developed to estimate the earthquake casualties in the past. In 1977, Anagnostopoulos and Whitman suggested a method to estimate casualties. In their study, they thought building type, time when earthquake occurs, population distribution affected the casualty number and then proposed an estimating model, but no real case was discussed (Anagnostopoulos and Whitman, 1977). In 1989, Tiedemann emphasized the quality of building was a very critical factor affecting the number of casualties. The final number of casualties could be calculated from the earthquake intensity, the time when the earthquake occurs, the season of the year, the influence of any warning and local habits (Tiedemann, 1989). Study of Coburn not only emphasized the same factors but also make a preliminary statistics (Coburn, 1994). Shiono built a functional relationship between collapse rate and fatality rate. Several earthquakes were discussed in his study and reported the casualty functional relationships of each earthquake were not same (Shiono, 1995). Therefore, there was not a common model to estimate earthquake casualties. Due to technical restriction, predicting earthquake casualties only could be used to assess the loss caused by earthquake at that time. These results did not show obvious help for earthquake relief. As the information techniques were widely used in the early years of the 21st

Century. Real-time prediction of earthquake casualties was discussed by Max Wyss. He used information of local shaking intensity to calculated the damage of buildings and then estimated the casualties (Wyss, 2004). Based on this theory, a framework was built (Jaiswal et al., 2011). Because of the geographic differences, Aghamohammadi et al. started to use the machine-learning method to build casualties estimation model (Aghamohammadi et al., 2013). Besides, the direct methods and some factors relating with the casualty were also discussed (Gutiérrez et al., 2005; Petal, 2011; Wyss and Trendafiloski, 2011).

Previous researches can contribute much to the prevention of earthquake, but new technique must be introduced to help the relief of earthquake. Earthquakes don't cause deaths, buildings do (Petal, 2011). If we can know the damage condition of buildings immediately after earthquake, the accuracy of casualty estimation in a short time can be improved much. Recent studies have used high-resolution satellite imagery (HRSI) to detect the height change of one building after earthquake in a region (Teeuw et al., 2013; Lu et al., 2013; Tong et al., 2013; Huang et al., 2013) owning to its large coverage, lower prices, short revisit time, adaptable capability of stereo imaging (Tao et al., 2004; Tack et al., 2012).

As the development of society, people-oriented research will be paid more attention. However, most researches of remote sensing just focused on the change of geological landscape and access the risk or the loss caused by earthquake (Dell'Acqua et al., 2011; Ehrlich et al., 2010; Dekker, 2011). Results of remote sensing should be used to improve the quality of the living of human being. For this reason, this paper built a casualty estimation model based on remote sensing. Compared to other existing methods, the advantages of the proposed model was built from the mechanism of casualty rather than simple machine learning method (Aghamohammadi et al., 2013) or fitting method (Feng et al., 2013). Besides a potential high accuracy of estimation, a deep analysis of casualty mechanism in different countries can also be achieved with quantitative evidence. Based on our experience on the scene of earthquake, it is valuable to know the change of survivor number in the scene. Therefore, the change

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was also discussed in this study based our proposed model. Three sets of earthquake data were used to evaluate our model. The detailed steps of modeling and problems that arose during the process were illuminated in the Sect. 2.

The remainder of this paper is organized as follows. In Sect. 2, we describe our model carefully and propose a framework of casualty estimation. The model was evaluated and discussed with real earthquake data in Sect. 3. Finally, in Sect. 4 a conclusion is made

2 Methods and data

This model was constituted by 3 parts (Fig. 1). In the first part, The HRSIs covering the affected area were collected. In idea situation, the DI (Damage Index) of one building was calculated by the high change of the pixel on a building before and after a earthquake. Due to the reasons such as the resolution of images and so on. Other alternative methods, such as visual interpretation (Shalaby and Tateishi, 2007), automatic (Benz et al., 2004) were appropriate methods. In the second part, attributions of buildings including materials and structure were collected from local GIS database and used to calculate the MSI (Materials and Structure Index) of buildings. In the third part, a casualty estimation model based on MSI and DI was proposed. To evaluate the model, 3 sets of data of earthquake were used. The whole process was described in next sections.

2.1 Methods

2.1.1 Damage detection

The damage level of one building can be classified into 6 groups (Yano et al., 2004; Barbat et al., 2008), shown in Table 1. However, the classification was based on the field survey. Does the classification agree with the damage grade detected by remote sensing? The three reports of Wang et al. (2013), Hisada et al. (2005), and Yamazaki

et al. (2005) addressed this issue. The Kappa value between field survey and HRSI increased, from 0.2 to 0.55, if we clustered damage condition of building into three groups rather than five group. D5 and D4 belong to two groups, respectively. Damage grade less than D4 are grouped. The three kinds of damage condition could be distinguished using HRSI. In the view of casualty estimation, damaged buildings belong to D4 and D5, are the major determinants of injury and mortality in an earthquake in developing countries. Factors that cause the casualties in other classification of damaged buildings are various very much, even some casualties were not caused by building damaged. This situation occurred more in developed counties. Without a very detailed epidemiological statistics, the regularity of casualties from D0 to D3 buildings was hard to sum up. Therefore, this study only focused on the D4 and D5 buildings and used the method mentioned in Tong et al. (2012), including visual Interpretation (Gamba and Casciati, 1998; Saito et al., 2004), automatic classification (Turker and Sumer, 2008) and DEM differences (Turker and Cetinkaya, 2005), to evaluate the damage grade. The visual interpretation is a directly method to assess the damaged condition of buildings from 2-D remote sensing images, It, though has high accuracy, needs more time. The automatic classification based on the spectral band and textural feature of buildings utilizes a variety of information tools to assess the damaged condition of buildings. The DEM difference was a new method and had a high accuracy. At the first step, the DEM of pre-earthquake was generated by points cloud (Ma, 2005) which were marked on the digital topographic map, if the resolution of images before earthquake were not high enough to generate the digital evaluation model (DEM). Otherwise the DEM of pre-earthquake was generated by 3-D HRSI (Feng et al., 2013; Tong et al., 2012). The DEM of post-earthquake must be generated by 3-D HRSI, for there won't be the digital topographic map of post-earthquake. From the height change of points belonging to a same DEM between pre- and post-earthquake, the damage grade of one building was calculated. If the decrease of nearly all points of one building were more than 80 %, the building belongs to D5. If the decease of some points of one building were more than 60 % and less than 80 %, the building belongs to D4. The DI were calculated

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by Eq. (1).

$$\mathrm{DI} = 1 - \frac{\sum_{i=1}^{n} \frac{hc_i}{h_i}}{n} \tag{1}$$

where h_i was the pre-event height of a point on a building and hc_i was the value of a point after earthquake.

2.1.2 Building attributes

In our previous work (Feng et al., 2013), we thought the structure and the materials of buildings have high relationship with earthquake casualty. When people in rooms felt the quake, they started running for the exits and grew to a stream. A good structure can increase velocity of the stream and exposure less people to suffer from building damage. The velocity is also affected by the quantity of the people in the stream. The escaping rate is as following

$$r_e = \frac{vt}{N} \tag{2}$$

where v is the velocity of the people stream, t is the available time to escape and N is the usual number of people in the building. v is the dependent variable of the function. v was affected by features of the structure, such as the number of stairs, corridor width, stair width, pedestrians in the corridor and stairs bias strength. The interval of the independent variable t is from the time (t_0) at which people felt the shake of an earthquake to the time (t_1) at which the shake stopped.

After the special time passed, people who were still in the building suffered from building damage, mainly the falling objects. Small falling objects might only hit people while big ones could trap people, even caused death. The key factor that helped trapped people survive was whether there was still survival space (Macintyre et al., 2011) in the damaged building. The death rate of different material buildings, when

they collapsed, were displayed in Fig. 2 (Feng et al., 2013). We referred the death rate as C_{max}.

In general, 40 %–60 % trapped people in collapsed buildings died at once. The number of death tends towards stability after 72 h (Yu et al., 2013). People who were buried under one wooden materials building can gain some more survival space than ones buried under adobe masonry or brick masonry buildings so that more trapped people may be still alive in wooden frame buildings. The principle can be described in the Eq. (3) as following,

$$\frac{\mathrm{d}N_s}{\mathrm{d}t} = -N_s r \tag{3}$$

where N_s is the number of still alive people in damaged building, r is the scale factor and changes along with the building materials. Therefore, $N_s(t) = N_s(t_1)e^{-r(t-t_1)}$, where $N_s(t_1)$ was the initial number of trapped people who were still alive.

By combining Eqs. (2) and (3), the MSI was shown as the followings,

$$\mathrm{Ln(MSI)} = \mathrm{Ln}\left(\frac{N - vt_1}{N}\right) - r(t_2 - t_1) \tag{4}$$

where t_2 is the time at which the possibility of survival is nearly none. Usually, the time is 72 h. One kind of buildings has its own special MSI. v and r were different for each kind of buildings. Using Eq. (4), we can derive

$$D \cdot e^{\frac{\mathrm{Ln}(N-vt_1)}{N} - r(t_2-t_1)} = D \cdot \left(\frac{N - vt_1}{N}\right) \cdot e^{-r(t_2-t_1)} = 1 - C \tag{5}$$

where $(\frac{N-vt_1}{N})$ was the living rate of people who were still trapped in the damaged buildings, equating to $N_s(t_1)$, D is the parameter relating to DI and other factors except structure and materials, $e^{-r(t_2-t_1)}$ is the change rate of survivals from t_1 to t_2; and $1 - C$ is the survival rate. C is the final casualty rate.

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2.1.3 The other factors

Besides the damage grade and attributes of buildings, other factors we called software indices, such as the time when earthquake happened, the educational level of local resident, the training strength of escape in earthquake and the economic level, were discussed in our study.

2.1.4 The casualty-predicting model

Because the relationship between the damage grade of one building and the casualty number is not a linear function, we did not use the DI to replace the D in Eq. (5) directly. The relationship between damage grade and casualty number could be descripted as $\frac{dC}{dDI} = \mathrm{DI} \cdot s$, where s is the scale factor. Then $C = \frac{1}{2}sDI^2$, for $C(\mathrm{DI}_0) = 0$. Based on our earlier numerical simulation results (Feng et al., 2013), we changed the $C = \frac{1}{2}sDI^2$ into

$$C = e^{2\mathrm{Ln}\frac{1}{2}(\mathrm{DI})+\mathrm{Ln}(s)}. \tag{6}$$

By combining Eq. (5) and (6), we proposed a casualty-predicting model as the followings,

$$C = 1 - e^{a\mathrm{Ln}(\mathrm{DI})+b\mathrm{Ln}(\mathrm{MSI})+c} \tag{7}$$

2.2 Data

In our study, we used three datasets, 2003 Bam earthquake, 2008 Wenchuan earthquake and 2010 Yushu earthquake, to evaluate our model. 2003 Bam earthquake measured $M = 6.6$ happened at 05:27 LT on 26 December 2003. Its epicenter whose depth was 10 km located at 29.°6′ N and 58.°17′ E near the city of Bam, 180 km southeast of the provincial capital of Kerman and 975 km southeast of Tehran. It was reported that at least 26 271 people were killed and 30 000 injured (USGS, 2003). One part of Bam city descripted in Aghamohammadi et al. (2013) was chosen as the research

area. The detailed casualty number, the number of damaged buildings and the type of damaged buildings were described in Kuwata et al. (2005). Data reported by Kuwata et al. (2005) were prepared by the Iranian government. The way of data-collected was similar with the method of visual interpretation. The magnitude of 2008 Wenchuan earthquake that attacked Wenchuan at 14:28 LT on 12 May 2008 was $M = 7.9$. The epicentre was at 31.°11′ N and 103.°22′ E and the focal depth was 19 km (Stone, 2008). The official documents reported that approximately 15 million people were affected by the earthquake, nearly 70 000 died, more than 370 000 were injured and more than 17 000 were missing. One of the affected cities, Dujiangyan city, was chosen as the research area. According to the statistical data from local documents, 3091 people died and 10 560 people were injured in Dujiangyan City. The detailed casualty number, the number of damaged buildings and the type of damaged buildings were described in Feng et al. (2013) and Tong et al. (2012). The time when 2010 Yushu earthquake happened was at 07.49 LT on 14 April 2010. The magnitude was $M = 7.1$. The epicenter of 2010 Yushu earthquake, located at 33°12′ N, 96°36′ E at a focal depth of 14 km (Chen et al., 2010). In this earthquake, 2968 people died and 12 135 injured. Jiegu town which is the center of Yushu was affected seriously. Jiegu town was involved in our study. In the affected area of Jiegu, 1942 people died and 8283 injured. The detailed casualty number, the number of damaged buildings and the type of damaged buildings were described in Chen et al. (2011). The remote sensing images that covered Jiegu town were displayed in the work of Dou et al. (2012).

3 Results and discussion

In this section, we not only provided the numerical experimental results of the three earthquakes but also expound the whole process from the beginning to the end. The process included collecting various kinds of data that were indispensable, transformating the data into the expression that accorded with the criterion of the model, solving and evaluating the model. Further discussions were made based the results and findings.

3.1 Essential data and solving model

To estimate the casualty number in a short time after an earthquake, our study required data regarding damage buildings, the material and the structure of damaged buildings and the distribution of resident in damaged buildings. Through a pair of HRSIs of the post-earthquake and the points cloud marked on the digital topographic map of Dujiangyan, we calculated height difference of each point on each buildings. From the Eq. (1). The DI of each building was calculated. To reduce the error, we did not estimate how many casualties in one building rather than in a group of buildings with similar condition. In the case of Dujiangyan, damaged buildings were classified into 6 categories. We denoted each category by one letter with two subscript letters. For instance, N_{ac} indicated the number of collapsed buildings of type A. The other 5 other kinds of buildings were damaged type A buildings (N_{ad}), collapsed type B buildings (N_{bc}), damaged type B buildings (N_{bd}), collapsed type C buildings (N_{cc}) and damaged type C buildings (N_{cd}). Type A buildings were built from either wood or bricks and wood. Most of them were not with seismic design principles. This type of buildings had similar structure with wooden framework. Compared to the other types, the casualty rate of type A was lower. Type B buildings were built from gravel without seismic design principles. Once they collapsed, there were nearly no survival space. Therefore, the casualty rate of collapsed type B buildings was very high. This type of buildings had similar structure with gravel structure. Type C buildings whose structure was similar with Low-quality reinforced concrete shear walls were seismically designed and the casualty rate of these building was very low. After we combined the distribution of damaged buildings calculated from remote sensing with the distribution of different structure and material buildings in local GIS database, we can describe the information available mathematically. As one of the seriously affected regions in Dujiangyan, description of Guankou town was as followings, $N_a : N_b = 3:7$, $N_{ac} : N_{ad} = 7:3$ and $N_{bc} : N_{bd} = 4:6$. Then, it was deduced

that $N_{ac} : N_{ad} : N_{bc} : N_{bd} = 21:9:28:42$. Because the number of occupants has high correlation with the number of buildings, approximately the distribution of occupants in each kind of buildings was written as followings, $R_{ac} : R_{ad} : R_{bc} : R_{bd} = 21:9:28:42$. It was reported that the casualty number in Guan town were about 3366. Therefore, $R_{ac} \times C_{ac} + R_{ad} \times C_{ad} + R_{bc} \times C_{bc} + R_{bd} \times C_{bd} = 3366$, where C_{**} is the casualty rate of one kind of buildings. Same subscript letters in this paper have same meaning. From the local survey report, we calculated, $R_{ac} \times C_{ac} : R_{ad} \times C_{ad} = 4:1, R_{bc} \times C_{bc} : R_{bd} \times C_{bd} = 5:1, R_{ad} \times C_{ad} : R_{bd} \times C_{bd} = 2:3$. Then, we worked out, $C_{ac} : C_{ad} : C_{bc} : C_{bd} = 96:56:135:18$. And then, $21v \times 96k + 9v \times 56k + 28v \times 135k + 42v \times 18k = 3366$. C_{**} were less than 1. Therefore, we made the C_{bc} equal to 0.98 when $k = 0.0073$ and $v = 65.4$. v represented the percentage of affected people in one unit of affected areas. Then, $C_{ac} = 0.71, C_{ad} = 0.41, C_{bc} = 0.98, C_{bd} = 0.13$.

To calculate the parameters of Eq. (7), we also need to calculate the value of DI and MSI. According to Eq. (1), DI of most of collapse buildings were aroud 0.9. For we had grouped damaged buildings, we set DI = 0.9 when buildings collapsed and DI = 0.7 when buildings were damaged seriously. Parameters of Eq. (4) were not easy to determine. For $(\frac{N-vt_1}{N})$ had some relation with the damage grade of buildings besides the materials of buildings and $e^{-r(t_2-t_1)}$ was related to C_{max}, we proposed a functional relationship as followings,

$$\mathrm{MSI} = -1.63e^{\mathrm{DI}} + 0.015e^{C_{max}} + 5.12, \quad (8)$$

with adjusted R square of 0.99, p value of 0.021 and RMS error of 0.001. Using this function, we worked out, $\mathrm{MSI}_{ac} = 0.14$, $\mathrm{MSI}_{ad} = 0.62$, $\mathrm{MSI}_{bc} = 0.12$ and $\mathrm{MSI}_{bd} = 0.63$. With the combination of Eq. (7), DI and MSI, the model was listed followings:

$$C = 1 - e^{100\mathrm{Ln(DI)}+17.4\mathrm{Ln(MSI)}+43.6}, \quad (9)$$

where adjusted R square equaled to 0.998, $p = 0.026$ and RMS = 0.006. Using the Eq. (10).

$$C_{sum} = v \times (R_{ac} \times C_{ac} + R_{ad} \times C_{ad} + R_{bc} \times C_{bc} + R_{bd} \times C_{bd}) \quad (10)$$

The predicting and actual casualties were listed in Table 2. The maximum error between predicting and actual result was 0.25. In the view of rescue, the information was valuable.

To estimate the casualties using our model, one firstly needed to collect two paired of HRSIs, pre- and post-earthquake respectively, both of which covered the affected areas. In some situation, the resolution of pre-earthquake satellite images was not high enough to generate the DEMs. Instead, the digital map covered by point cloud could be used. Through two correction of coordinate, the DI of damaged buildings was calculated. If the resolution of pre-earthquake and post-earthquake satellite images both was not high enough to build DEM, methods of visual interpretation and automatic classification were the alternatives. The attribution of each damaged buildings was found from local GIS database through the coordination of damaged buildings. After the cluster of different kinds of buildings in the term of damaged grade and attributions, the distribution of all kinds of buildings was calculated. DI and MSI of each kind of damaged building were calculated by Eqs. (1) and (8) respectively, and then the value of C_{**} was figured out using Eq. (9). With the segmentation scales of the distribution of all kinds of buildings, we confirmed the number of occupants per scale unit. In the case of Wenchuan earthquake, the number of occupants per scale unit equaled to 64.5. At this time, the casualties could be estimated by Eq. (10). In extreme situations, only HRSIs were available. The distribution of buildings of different structure and materials could be deduced from the region where the geographical feature was similar with the affected region. The structure and materials distribution of buildings that belonged to collapsed or damaged group were speculated from history data. The error of the casualty counts estimated with the deduced information could be limited in first order.

3.2 Application of the model

To evaluate the practicality of this model, we also applied this model in another two earthquakes, the 2010 Yushu earthquake and the 2003 Bam earthquake.

The casualties of Yushu earthquake were concentrated in the Jiegu town. The structures of buildings in Jiegu town are mainly two types that were similar with the gravel structure and stone structure. We referred gravel structure and stone structure as type A and type B respectively. Using the method of automatic classification, the distribution of buildings was as the followings in the scale with the case of Dujiangyan, $R_{ac} : R_{ad} : R_{bc} : R_{bd} = 45 : 5 : 35 : 16$. In the scale, the v that equaled to 65.4 could be used. After consult Fig. 2, The MSIs of these four kinds of damage building were calculated, $MSI_{ac} = 0.95$, $MSI_{ad} = 0.32$, $MSI_{bc} = 0.88$, $MSI_{bc} = 0.25$. And $DI_{ac} = 0.90$, $DI_{ad} = 0.70$, $DI_{bc} = 0.90$, $DI_{bd} = 0.70$. Because Jiegu town is the center of Yushu city, the population density is about 2 times larger than towns of Dujiangyan. Therefore, $C_{sum} = 2 \times v \times (R_{ac} \times C_{ac} + R_{ad} \times C_{ad} + R_{bc} \times C_{bc} + R_{bd} \times C_{bd})$. The result was 10 302 while it was reported that the actual casualty number was 10 269. The error was 0.03 %.

The bam earthquake happed to a populated area. The population density is about as four times as Dujiangyan. Most of buildings in bam areas were not seismic design. It was expected the older buildings with unreinforced masonry to suffer their masonry is heavy, brittle and vulnerable to earthquake shaking. In this case, we referred them as type A building that were similar with gravel structure. Besides, there were small amounts of buildings that were similar with low-quality reinforced concrete frame. We referred them as type B building. Using the visual interpretation method, the distribution of an affected area discussed in Kuwata et al. (2005) generally, was as the followings in the same scale with case of Dujiantyan, $R_{ac} : R_{bc} : R_{ad} : R_{bd} = 83 : 4 : 2 : 11$, And $MSI_{ac} = 0.95$, $MSI_{ad} = 0.32$, $MSI_{bc} = 0.85$, $MSI_{bc} = 0.22$. And $DI_{ac} = 0.90$, $DI_{ad} = 0.70$, $DI_{bc} = 0.90$, $DI_{bd} = 0.70$, Then, $C_{sum} = 4 \times v \times (R_{ac} \times C_{ac} + R_{ad} \times C_{ad} + R_{bc} \times C_{bc} + R_{bd} \times C_{bd})$. The estimated result is 22 060 while the actual casualties were 21 924. The error is less than 1 %.

3.3 Change of survival rate

The casualty in official report is the final number. In real disaster site, the casualty rate increased for three or four days after an earthquake attacked. Intervention from rescue

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could reduce the increasing rate of casualty. However, the change of survival rate of each kind of buildings was different. During the time when earthquake were attacking, about 40 % to 60 % people died or were harmed seriously in a very short time. The rate was various and depended on the attribution and the damage grade of buildings. The survival rate decreased as time went. Using the value of final casualty rate calculated from and the Eq. (5), the changes of survival rate of different buildings in collapsed state and damaged state were plotted in Figs. 4 and 5, respectively. When buildings collapsed, the change of survival rate of each kinds of buildings was very different. For instance, the survival rate of gravel structure buildings remained at a low level from the beginning, while the survival rate of wooden framework with different infill walls remained a relative high level; and the survival rate of low quality reinforced concrete shear walls changed much from the beginning to the end. Under the limitation of earthquake relief materials and personnel in the disaster areas, the change of survival rate of each kind of collapsed building should be considered when administrators designed the rescue plan. When buildings in damaged state, the change of survival rate of each kind of buildings were nearly similar and the survival rate remained at a high level. Though some occupants did not escape from buildings when the earthquake were attacking, they may still be unharmed. After the attack of earthquake passed, many occupants who were hardly hurt could save themselves on their own effort. Compared to other factors, such as the traffic line and so on, the areas filled with damaged buildings had less weight value. The change of survival of buildings was helpful, especially in initial stage of earthquake relief. In the disaster areas of earthquake, the relief goods and rescuer were in shortage in the beginning (Li et al., 2013). The crisis last for one or two days. It is very important to decide where are the emergency sites. The fate of trappers changed along with the decision of administrator. Weight of sites would change along with factors, such as the arrival of more relief goods and rescuer and the clear of road. It is crucial to know the change of survival rate at each stage.

3.4 Advantage and disadvantage of the model

Casualty estimation helps administrators properly respond this crisis and limit its impacts and losses. This study based on the mechanism of casualty proposed a model to estimate the casualty number in a short time with the help of remote sensing. To achieve this model, we decomposed the problem into several smaller questions in each step along with timeline. The final question was solved by integrating the solutions of small questions. Compared with other methods (Table 3), methods of this study had some advantages. The methods used in our model are similar with the work of Aghamohammadi et al. (2013). Compared to the “black box” mentioned in Aghamohammadi et al. (2013), we illuminated the meaning of each parameter in our model. And the parameter could be modified accordance with the actual situation. Using this methods in this study, the casualties could be estimated in two days, even less time. We used 3 cases to confirm the effectiveness of our model. From the results of 3 numerical simulation experiments, the difference between the estimation and the actual counts of some cases was lest among all methods. It may be that the characteristics of the three place were highly similar, such as less developed, high population density, most of building without seismic design. If the model were used to estimate the casualties in developed counties, the parameters should be corrected according to actual situations, or the estimating count will differ much from actual casualties. During the literature review, we found most of literatures just reported from their point of view. Therefore, based on our model, we suggested a general data-input standard that might be essential to a statistical part of a report regarding earthquake casualty. This work might help the epidemic researchers make a more useful and practical report and let their work contribute more to the earthquake relief. The model is required to improved when it would be used in developed countries. Because the datasets that were available to solve the model were insufficient, we did not improve the model. From some literature that reported the earthquake in developed countries, we have found that even the buildings were damaged seriously the casualty number was relative lower

(Mahue-Giangreco et al., 2001). And the proportion of casualties caused by building damage was also relative lower, many casualties were caused by secondary disasters, such as fire and traffic accident (Osaki and Minowa, 2001). And the intensity of training regarding earthquake relief and escaping in earthquake was also relative higher. All the factors indeed reduced the casualty numbers, but there were not sufficient recordings to help build a model to analyze the situation quantitatively.

4 Conclusions

The first step of earthquake relief is to know the number of casualties, which help the administrators distribute the relief supplies and rescuers optimally. However, if the casualty number cannot be gained in a short time, the results can only be used to evaluate the loss of an earthquake disaster but earthquake relief. Remote sensing has the advantage of large coverage, lower prices, and short revisit time. As the resolution of satellite images improved, the 3-D shape of a building can be reconstructed with little error. In the other side, because of the weak awareness of disaster prevent and poor seismic design of buildings, most earthquake casualties in developing countries were caused by building damage. Based on the two conditions, the study discussed the application and prospect of high-resolution remote sensing in estimating earthquake casualties with a proposed model and 3 numerical experiments. From this process, we concluded that: (1) the results demonstrated that this model with high value of adjusted R square and statistically significant p value could estimate the earthquake casualties in developing counties in a low error; (2) the casualty number was hard to estimate only by the damage grade of building. The attribution of damaged buildings and the distribution of occupants in affected areas were essential; (3) the change of casualty rate in damaged buildings is important to the design of recuse plan in macro level. Because the earthquake relief is a complicated project, this study not only proposed the primary method based on remote sensing to estimate the earthquake casualties

but also mentioned the rescue activities after the casualties had been estimated so that our work can be referred easily by other peers.

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Table 1. Damage index and classification of damage to masonry buildings (EMS98).

Damage grade	Damage description	Damage condition
$D0$	No damage	No damage.
$D1$	Negligible to sight damage	Hairline cracks in very few walls. Fall of small pieces of plaster only; fall of loose stones from upper parts of buildings in very few cases.
$D2$	Moderate damage	Cracks in many walls; fall of large pieces of plaster; partial collapse of chimneys.
$D3$	Substantial to heavy damage	Large and extensive cracks in most walls; roof tiles detached; chimneys fractured at the roofline; failure of individual non-structural elements (partitions, gable walls).
$D4$	Very heavy damage	Serious failure of walls; partial structural failure of roofs and floors.
$D5$	Destruction	Total or near-total collapse.

Table 2. Estimating casualties and the actual casualties.

		Actual	Prediction	error
Guankou Town	Collapsed type A	975	964.1	0.01
	Damaged type A	241	199.1	0.21
	Collapsed type B	1795	1778.6	0.01
	Damaged type B	357	352.5	0.01
	Total	3368	3294	0.02
Xingfu Town		2846	3545	0.25
Xujia Town		383	447	0.17
	Mean			0.10

Table 3. Comparison of different methods.

Method	Time-used[a]	Case-involved[b]	Error rate	Real-time[c]
Aghamohammidi et al. (2013)	More than 1 week	One case	2.1 %	No
Coburn and Spence (1994)	More than 1 week	More than 5 cases	32 %	No
Feng et al. (2013)	less than 2 days	One case (three subcases)	10 %	No
Method of this studying	less than 2 days	3 case	10 % (0.1 %,25 %)[d]	Yes

[a] The time used to estimate the earthquake casuslties.
[b] The number of cases to evaluate the model.
[c] Whether considering the essence of real-time estimation.
[d] Mean (minimum, maxium).

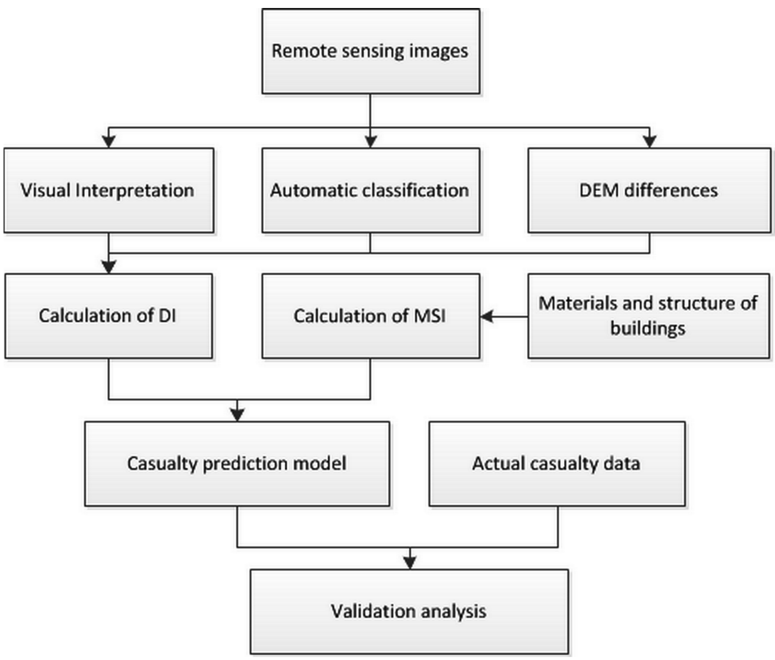

Fig. 1. Framework of earthquake casualty estimation.

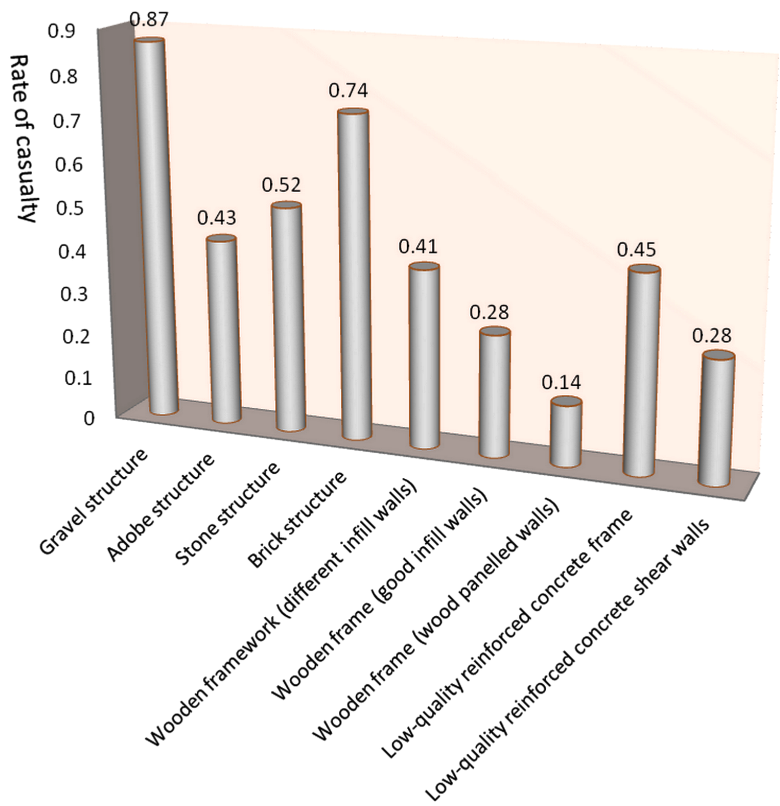

Fig. 2. Death rate of different material collapsed buildings.

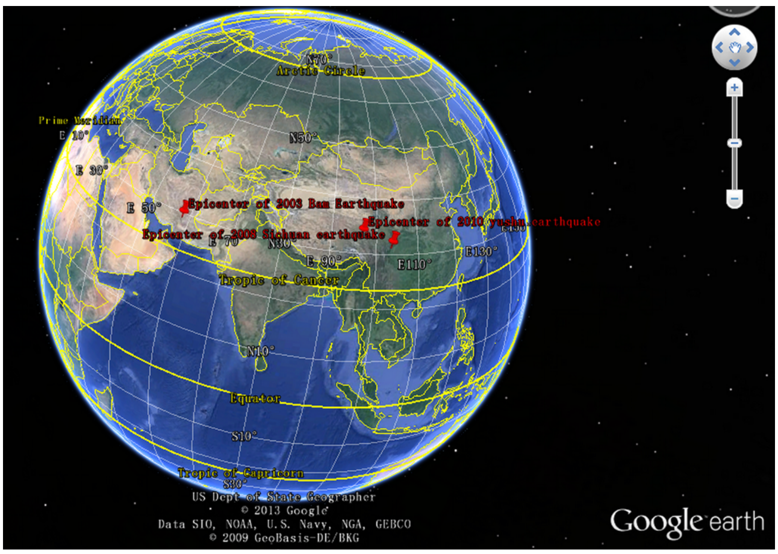

Fig. 3. The study areas.

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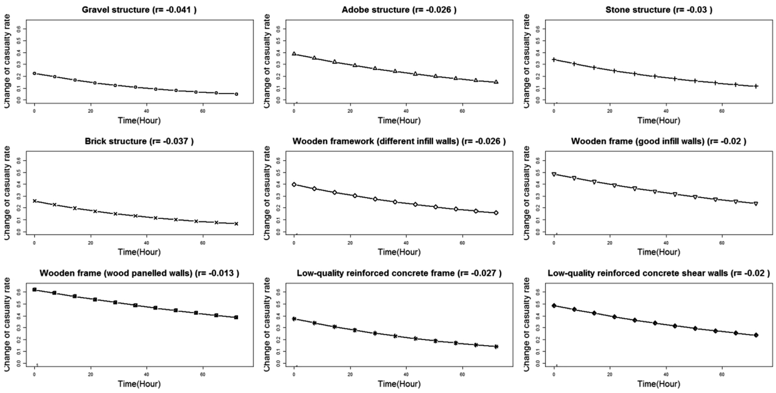

Fig. 4. Change of survival rate of different buildings in collapsed state.

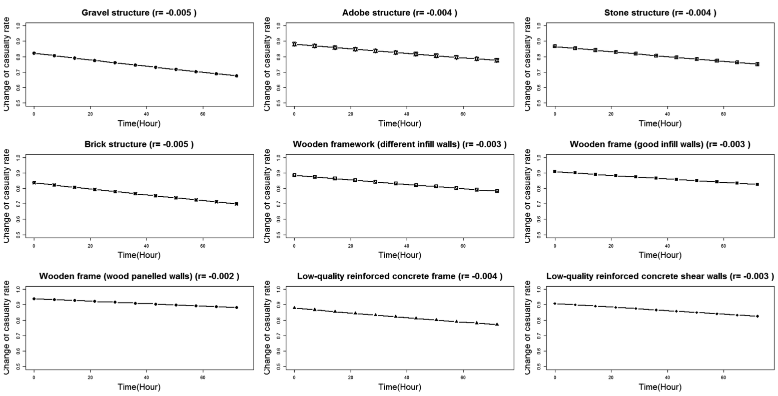

Fig. 5. Change of survival rate of different buildings in damaged state.