Pre-Assessment of earthquake-induced losses: a case study from Xiangning County, Shanxi Province, China

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Abstract. Rapid assessment of earthquake disaster loss is the main method of earthquake emergency response after an earthquake. China has a vast territory, the accuracy and current situation of regional basic data are generally low, and the houses in rural areas are not subject to mandatory seismic fortification requirements, which are the key factors affecting the accuracy of rapid assessment results. The regional field investigation is applied to the process of earthquake disaster loss pre-assessment. Through the investigation of the building structure, personnel mobility and major hazard sources, the accuracy of rapid assessment of casualties will be improved. Taking Xiangning County of Shanxi Province as an example, the method of earthquake disaster loss pre-assessment is studied.

1. Introduction
After the occurrence of a destructive earthquake, it is necessary to investigate the casualties, economic losses, destruction of buildings and structures, geological disasters caused by the earthquake, and other secondary disasters. Thus, it will provide scientific basis for emergency rescue, material allocation, restoration, reconstruction, and revision of earthquake emergency plan. It takes a long time and a lot of manpower to carry out detailed disaster loss investigation and assessment in disaster areas, which is difficult to meet the needs of emergency command decision-making and deployment [1]. The rapid assessment of earthquake disaster is a common method for government agencies to estimate the disaster situation after an earthquake. It refers to that giving a quick assessment of the loss within the shortest time (generally 30 min) after obtaining the parameters of earthquake time, location and depth[2]. The rapid assessment of earthquake disaster requires the results produced in short time. However, the disaster information of the disaster area after the earthquake cannot be obtained in a short period of time. Due to the lack of completeness and current situation of the basic data, the accuracy of the assessment results is low [3]. Sometimes, there may have several times of differences comparing to the actual disaster situation. This deviation is especially large after the earthquakes respectively occurring on August 3, 2014 in Ludian County and on October 7, 2014 in Jinggu County, leading to the government to active an inappropriate emergency response level[4]. As early as 1997, China's relevant institutions have begun to study the earthquake disaster loss prediction and assessment using GDP and population data[5]. After the earthquake on May 12, 2008 in Wenchuan County, more attention has been paid to the pre-assessment of earthquake disaster loss. Its theoretical basis has also been greatly developed. In Yunnan Province, a lot of earthquake samples can be obtained. The experiential model of earthquake casualty is put forward by studying on the relation between the casualty and earthquake magnitude[6]. After the earthquake on Apr 14, 2010 in Yushu County, rapid emergency assessments were implemented, including the experience seismologic zoning
map and preliminary loss assessment results. Compared with the final survey results, the accuracy of the loss assessment results was satisfactory[7].

Generally speaking, the results of rapid assessment of earthquake disaster losses must be reviewed by experienced experts. Besides relying on their own experience, experts mainly rely on the knowledge of the disaster region. The pre-assessment of earthquake disaster loss is a complex process. The first step is to simulate the occurrence of an earthquake in some areas, calculate the possible casualties, economic losses, building damage and emergency disposal requirements in peacetime by combining with the existing population, economy, buildings, geological structure, historical earthquake and other data. The second step is to carry out site survey, sampling survey, interview, expert analysis and judgment. Through on-the-spot understanding of seismic situation, geological structure, major hazard sources and traffic conditions of regional buildings, the reliability of rapid assessment results is analyzed. The methods and results of the quick assessment results are obtained. The earthquake emergency preparation measures and post-earthquake disposal characteristics with regional characteristics are put forward. Thus to improve the accuracy of rapid post-earthquake assessment. Taking Xiangning County of Shanxi Province as an example, this paper studies the method of earthquake disaster loss pre-evaluation.

2. Basic information of Xiangning County

2.1. Physical geography
The Xiangning county is located in the southwest of Shanxi Province, the west corner of Linfen City, with an area of 2029 square kilometers. It has jurisdiction over 5 towns and 5 townships (Changning Town, Guanghua Town, Taitou Town, Guantou Town, Xipo Town, Shuanghe Township, guanwangmiao Township, Weizhuang Township, xijiaokou Township, Zaoling township), 175 administrative villages and 1063 natural villages. The county government is located in Changning town.

In Xiangning County, there are more slopes and less plains, and soil erosion is serious. The northeast part is higher than the southwest part. The altitude is generally between 900 and 1500 meters. The Gaotian mountain is the highest mountain in the territory, with an altitude of 1820 meters. Along the Yellow River in the west, the altitude is below 500 meters.

Xiangning county has a warm temperate continental climate, with an annual average temperature of 10.2℃, an average temperature of -4.6℃ in January, a minimum temperature of -20.1℃, an average temperature of 23℃ in July and a maximum temperature of 37.2℃. The average annual precipitation is about 536 mm.

There are more than 7000 rivers in Xiangning County, most of which are seasonal. Due to the leakage of underground faults, the groundwater is relatively poor. The annual surface water volume is 95.45 million cubic meters. There are two reservoirs in the territory, all of which are small reservoirs.

2.2. Socio economic situation
According to the statistical results in 2018, there are 233167 permanent residents in Xiangning County, with a total number of 58911 households and a population density of 115 people per km². The total output value of Xiangning county is 10.9449 billion yuan, including 329.68 million yuan for primary industry, 6,497.3 billion yuan for secondary industry, 2533.63 billion yuan for tertiary industry, 3996.99 million yuan for public financial revenue and 2147.84 million yuan for public financial expenditure.

The traffic in Xiangning county is mainly highway. There are National Highway 209 and 309, three provincial roads, five trunk roads. By the end of 2016, the total mileage of domestic highway lines was 1232,1 km.

There are 5 primary schools, 2 kindergartens and 5 middle schools in Xiangning county. There are a total of 1 class-A hospital, 1 class-B hospital and 16 first-class hospitals in the county. There are about 800 beds and 730 medical staff.
2.3. Geological structure characteristics and historical earthquakes
The Lishi fault is the main active fault in the uplift area of Luliang Mountain in Xiangning county. The fault is distributed in the west slope of Luliang City in the east of the Yellow River. It is composed of several faults extending intermittently, and its strike is nearly north-south. The fault starts from Jiaoloushen in Xingxian County in the north, passes through Lishi and Puxian, and reaches Yuli in Linfen City in the south. It is 270km long and mainly consists of five faults. To the north of Zhongyang County, the fault plane inclines to the West with an inclination of 60° to 80° and to the south of Zhongyang County, the fault plane dips eastward with an inclination of 45° to 70°.

According to historical records, there has no destructive earthquake in the territory. However, the large earthquakes around Xiangning county have caused great seismic damages. In A.D. 1303, the Hongdong M8 earthquake in Shanxi Province caused the seismic intensity of 7-8 degrees in Xiangning county. In A.D. 1695, the Linfen earthquake of $M^\frac{3}{4}$ in Shanxi Province caused the seismic intensity of 6-7 degrees in Xiangning county. The influence of large earthquakes around Ningxian County should not be ignored, especially in Linfen fault basin. Due to the complex landform and occurrence rate of geological disasters in Xiangning County, huge damage may occur due to the influence of large earthquakes.

2.4. Division of ground motion parameters
According to national standards No. GB 18306-2015 [8], 10 townships of Xiangning county are located in 0.10-0.20g seismic peak acceleration. See the Table 1 below for details.

| Name of Township | Peak ground motion acceleration(g) | Characteristic period of response spectrum(s) | Name of Township | Peak ground motion acceleration(g) | Characteristic period of response spectrum(s) |
|------------------|-----------------------------------|-----------------------------------------------|------------------|-----------------------------------|-----------------------------------------------|
| Changning        | 0.10                              | 0.45                                          | Shuanghe         | 0.20                              | 0.40                                          |
| Guanghua         | 0.20                              | 0.40                                          | Guanwangmiao     | 0.15                              | 0.45                                          |
| Taitou           | 0.15                              | 0.45                                          | Yuzhuang         | 0.15                              | 0.45                                          |
| Guantou          | 0.15                              | 0.45                                          | Xijiaokou        | 0.15                              | 0.40                                          |
| Xipo             | 0.15                              | 0.40                                          | Zaoling          | 0.15                              | 0.40                                          |

2.5. Other regional characteristics
The main tourist attractions in Xiangning County include Yunqiu mountain scenic spot, RongZi winery and Fengling scenic spot. The peak season of scenic spots is mainly from March to October. The average daily number of tourists in Yunqiu mountain scenic area is 3000, RongZi winery is 200 and Fengling scenic spot is 150.

Xiangning county is rich in coal reserves. The coal field area is about 1600 square kilometers, accounting for 78% of the total area. The exploration reserves are 15.3 billion tons. It is one of the three major high-quality coking coal bases in China and one of the 100 key coal producing counties in China. There are about 14 coal mines in the county, with about 7000 employees. The main hazard sources in Xiangning county are gas stations, with a total reserve of about 2600 m³. There are five shelters in Xiangning County, all of which are located in Changning town. They are all outdoor shelters with a total area of about 135000 square meters and the number of people to be evacuated is about 18000.
3. Pre-assessment and correction of earthquake disaster loss

3.1. Pre evaluation calculation principle

The attenuation relationship of seismic intensity in Xiangning county adopts the intensity attenuation relationship model of eastern China.[9] The intensity attenuation relationship of sub model considers the mutual independence between magnitude and seismic intensity isolines, and considers the attenuation characteristics of near-field and far-field, which is suitable for Shanxi Province.

\[ I_a = 6.046 + 1.480 \times M - 2.081 \times \ln(R_a + 25) \]
\[ \sigma = 0.49 \]

\[ I_b = 2.617 + 1.435 \times M - 1.441 \times \ln(R_a + 7) \]
\[ \sigma = 0.56 \]

In the formula, \( I \) is the intensity, \( M \) is the magnitude, \( R \) is the epicentral distance (unit: km), \( \sigma \) is the standard deviation, \( a \) and \( b \) are the long and short axes of the ellipse respectively.

The calculation formula of casualties is as follows[10]:

\[ \log RD = 12.479 \times A^{0.1} - 13.3 \]

In the formula, \( RD \) is the death ratio, \( A \) is the house damage ratio.

Calculation formula of house damage ratio: \( A = \text{collapse rate} + \frac{\text{serious damage rate}}{2} \).

When calculating the number of people to be resettled urgently, the following algorithm is adopted: all the population in above earthquake intensity 9 degree zone, 20% of the population in the earthquake intensity 8 degree zone, and 5% of the population in the earthquake intensity 7 degree zone. The sum of the above three items is taken as the number of persons to be resettled urgently.

When calculating the number of rescue teams and the number of tents needed, the following algorithm is adopted: the number of rescue teams is 0.2% of the total population in the earthquake intensity 6 degree zone. The number of victims to be resettled by emergency divided by 6 is roughly equal to the number of tents mobilized in the first batch.

The earthquake pre assessment adopts the earthquake emergency response system based on grid data [11], which uses kilometer grid population, economy, buildings and other data as data sources, and carries out post-earthquake loss assessment combined with the above assessment model.

3.2. Earthquake disaster pre-assessment

Considering the homogeneity and representativeness of the simulated earthquake, five points are selected for pre evaluation in Xiangning county. The Figure 1 shows the spatial distribution map (Map Extents: 12281316.4, 4229661.1: 12439999.6, 4337895.9, Coordinate Reference Systems: EPSG 3832) of selected points.

![Figure 1. Schematic map of earthquake site selection in Xiangning County.](image-url)
3.3. Field investigation of regional characteristics
The earthquake casualties are the core of rapid post-earthquake assessment. Therefore, the key data needed for field investigation in earthquake pre-assessment are local personnel flow information, farmers' income and their sources, proportion of housing structure and building age. The investigation of housing data needs a lot of work, and the investigators need to have certain professional knowledge, which takes the most time. Taking Changning Town, which has the largest population in Xiangning County, as an example, this paper describes the situation of housing site investigation. The structural proportions of buildings in all villages of the town are shown in the Table 2. The main house structure types are shown in Figure 2-5. There are a large number of cave houses in rural houses of this county. The main structural type of rural houses is brick concrete structure. Generally, rural houses have not passed the standard seismic fortification design, and the seismic performance is general.

Table 2. Structure type proportion table (Fawangmiao Village).

| Village name | Cave structure | Brick concrete structure | Other structures |
|--------------|----------------|--------------------------|-----------------|
| Fawangmiao   | 5%             | 92%                      | 3%              |
| Longmen      | 5%             | 95%                      | 5%              |
| Longbi       | 30%            | 68%                      | 2%              |
| Fujiayuan    | 30%            | 68%                      | 2%              |
| Xiaxian      | 45%            | 50%                      | 5%              |
| Tianjiayuan  | 20%            | 77%                      | 3%              |
| Sishang      | 20%            | 70%                      | 10%             |
| Niuta        | 5%             | 92%                      | 3%              |
| Shangkuan    | 20%            | 75%                      | 5%              |
| Nianjiao     | 50%            | 40%                      | 10%             |
| Dashitou     | 30%            | 68%                      | 2%              |
| Zhangma      | 35%            | 63%                      | 2%              |
| Menjiagou    | 3%             | 90%                      | 7%              |
| Chengguan    | 40%            | 35%                      | 25%             |
| Maitian      | 10%            | 88%                      | 2%              |
| Yingli       | 30%            | 60%                      | 10%             |
| Shijian      | 30%            | 65%                      | 5%              |

Figure 2. Front of brick concrete structure house.  
Figure 3. Side of brick concrete structure house.
3.4. Pre evaluation results and corrections

The rural houses in Xiangning county are mainly brick kiln buildings and brick concrete structures. The brick kiln structure was built earlier, and some walls were damaged to varying degrees, including cracking, local falling, dampness and water leakage. Some brick kiln houses have been strengthened and protected, but some houses are not treated. Some brick kiln houses have chimneys outside, which may cause damage of non-structural components after earthquake. The brick concrete structure houses are stronger than the brick kiln structure houses, but some of them have not taken anti-seismic measures. Brick concrete structure building has ground beam, but its ring beam is not closed. There are no structural columns in brick concrete structure buildings, and the openings in the walls and doors are large, which can easily lead to the weakening of seismic capacity and uneven stiffness of the walls, and the integrity of the buildings is not good, and the seismic performance is general. The buildings lack quake-proof design. According to the comprehensive analysis, the house performance may aggravate the earthquake disaster. At the same time, Xiangning county is prone to secondary geological disasters due to its many slopes and few plains. When the magnitude is above 6.4, most of the intensity in the meizoseismal area is 8. The damage of buildings in the 8 degree zone will be aggravated rapidly. Therefore, it is necessary to revise the evaluation results of earthquakes with \( M \geq 6.5 \). To sum up, the estimated number of casualties is revised as shown in the Table 3 below.

![Figure 4. Front of cave structure house.](image1)

![Figure 5. Side of cave structure house.](image2)

Table 3. Pre-assessment of casualties and its and correction.

| NO. | Longitude | Latitude | Name of Township | Magnitude | Pre-assessment of casualties | Casualties correction |
|-----|-----------|----------|------------------|-----------|-----------------------------|----------------------|
| 1   | 110.65    | 35.85    | Zaolting         | 5.5       | 0-5                         | 0-5                  |
|     |           |          |                  | 6         | 5-20                        | 5-20                 |
|     |           |          |                  | 6.5       | 30-60                       | 40-70                |
|     |           |          |                  | 5.5       | 0-5                         | 0-5                  |
| 2   | 110.79    | 35.96    | Changning        | 6         | 5-20                        | 5-20                 |
|     |           |          |                  | 6.5       | 40-70                       | 50-80                |
|     |           |          |                  | 5.5       | 0-5                         | 0-5                  |
| 3   | 110.93    | 35.84    | Yuzhuang         | 6         | 5-20                        | 5-20                 |
|     |           |          |                  | 6.5       | 40-70                       | 50-80                |
|     |           |          |                  | 5.5       | 0-5                         | 0-5                  |
| 4   | 111.12    | 35.89    | Guanwangmiao     | 6         | 5-20                        | 5-20                 |
|     |           |          |                  | 6.5       | 50-80                       | 60-90                |
|     |           |          |                  | 5.5       | 0-5                         | 0-5                  |
| 5   | 111.23    | 36.00    | Guanghua         | 6         | 5-20                        | 5-20                 |
|     |           |          |                  | 6.5       | 40-70                       | 50-80                |
4. Conclusion
In this paper, through the earthquake emergency response system based on kilometer grid, the disaster loss of scenario earthquake in Xiangning county is quickly evaluated. Due to the influence of the accuracy and current situation of the grid data used by the software, the calculation results may be quite different from the real situation. Since there is no seismic fortification requirement for rural buildings in China, the structural type of rural houses is often an uncertain factor in post-earthquake evaluation. Due to the influence of regional natural conditions, economic conditions and residents' habits, the rural housing structure has the characteristics of regional similarity. Through the sampling survey of the region characteristic data, such as the rural housing structure, construction time and population mobility, etc., the evaluation results are revised. This pre-evaluation method can improve the reliability of the rapid evaluation results, and provide more scientific guidance for the decision-making and deployment of earthquake relief command after the earthquake. The problem of this method is that the more accurate damage matrix is not obtained by the vibration testing of the building structure investigated on site. The relationship between the destruction degree of buildings and intensity of earthquake peak ground acceleration should be studied more in the future.

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