Investigation of civil building damage and its spatial characteristics under 2019 M_{L}6.0 Changning earthquake

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Abstract. An M_{L}6.0 earthquake occurred at 22:55 on June 17, 2019, in Changning County, Yibin City, Sichuan Province, China. The Changning earthquake killed 13 people and affected an area of 3075 km². The disaster caused by the earthquake is mainly the damage of civil buildings in the affected area. A field investigation on civil building damage was conducted by the authors after the earthquake occurrence. The destruction forms and damage area of civil buildings in 44 villages from different seismic intensity regions were collected and it was found that there are significant differences in the severity of building damage of different structure types. In order to analyse the spatial correlation between building damage and influencing factors, nine indicators are selected including structure type, PGA, elevation, slope angle, population density, per capita GDP, distance to river, distance to fault and NDVI, and damage ratio is defined to measure the degree of building damage in each village. The spatial correlation between civil building damage and influencing factors is analysed in GIS using histogram statistics and correlation analysis. The results show that PGA has the strongest correlation with civil building damage. In the area with greater seismic motion, the civil building damage is more serious. Structure type and economy level also have significant linear relationship with building damage.

1. Introduction

Earthquake has become one of the most serious natural disasters threatening human living environment because of its suddenness and destructiveness. The intense seismic ground motion causes severe casualties, economic loss, building collapse and geological hazards. In recent years, the global strong earthquakes have caused great harm. In 2008, the M_{w} 8.0 Wenchuan earthquake killed about 70000 people and caused civil building collapse of 19.33 million square meters [¹]. In 2010, the Chile earthquake with a magnitude of 8.8 happened offshore, inducing tsunami and severe construction destruction along the coast [²]. In 2011, the M_{w}9.0 great east Japan earthquake triggered severe damage containing 19418 casualties and 121809 completely collapsed buildings [³]. In 2013, the M_{s}7.0 Lushan earthquake occurred in Sichuan Province, China, leading to 196 death, 21 missing, and an affected area of 12500 km² [⁴]. The study on the mechanism and characteristic of seismic disaster offers effective help to improve the seismic capacity and reduce the threat from intense motion.
Building damage is one of the most common forms in seismic disasters. Many scholars have studied the risk assessment of buildings and constructions after earthquake occurrence. Fan and Ge \[5\] used differential equation and frequency analysis to calculate the dynamic vibration response of building structure. Ceccotti et al. \[6\] conducted a shaking table test on the seven-storey full-scale timber building to study the dynamic response and seismic performance of innovative timber construction. Mangalathu and Burton \[7\] constructed a building seismic damage classification model using textual descriptions based on deep learning method. Most of the post-earthquake building risk research focus on the relationship between seismic motion input and building destruction. However, earthquakes have an extensive impact in a wide area and building damage is related to various influencing factors besides ground motion. It is necessary to consider the regional distribution of various factors in building risk assessment in earthquake affected area. Different methods are adopted by scholars to consider the impact of data spatial characteristics on the evaluation results. Brunner et al. \[8\] proposed a novel method to detect destroyed buildings under earthquake using pre-event VHR optical and post-event detected VHR SAR imagery. Dong and Shan \[9\] reviewed the application of remote sensing techniques in obtaining building damage information, including multi-temporal techniques that evaluate the changes between the pre- and post-event data and mono-temporal techniques that interpret only the post-event data. Xu et al. \[10\] established a real-time seismic damage prediction model using intensity measures from ground motion records at different positions based on machine learning algorithm.

The authors conducted a field investigation on civil building damage after the earthquake. The investigated villages and towns are imported into Geographic Information System with spatial position. The civil building damage in different seismic intensity regions are studied and the spatial characteristics of building damage are analyzed in GIS using histogram statistics and correlation analysis.

2. 2019 M\(_{L}\)6.0 Changning earthquake
The Changning earthquake occurred at 22:55 on June 17, 2019. The epicenter of earthquake was located at 28.34°N and 104.90°E, in the southwest edge of Sichuan Basin. The focal depth of earthquake was 16 km. A Richter magnitude of 6.0 was registered by China Earthquake Administration, and the maximum intensity of VIII was observed in Changning County, Yibin City, Sichuan Province. The earthquake affected an area of 3075 km\(^2\), and the area of seismic intensity region VIII, VII, VI are 83.9 km\(^2\), 438.7 km\(^2\), 2552.8 km\(^2\), respectively (figure 1). A total of 13 people were killed in the Changning earthquake.

![Figure 1 Seismic intensity map.](image1)

![Figure 2 Acceleration record.](image2)

The nearest observation station to the epicenter is the 51GXT station in Gong County, with a distance of 22 km. The acceleration wave of ground motion recorded by 51GXT station is shown in the figure 2. The peak value of acceleration record is 599 gal in N-S direction, 499 gal in E-W direction and 413 gal in U-D direction. A principal characteristic of Changning earthquake is the concentrated distribution of aftershocks and its high frequency, magnitude. In figure 3, the distribution of aftershock epicenters from June 17 to June 24 with a magnitude greater than 2.8 is shown. By June
24, three aftershocks of $M_L 5.0-5.9$, five aftershocks of $M_L 4.0-4.9$ and forty aftershocks of $3.0-3.9$ have been recorded by observation stations.

The disaster caused by the Changning earthquake was mainly the damage of civil buildings, accompanying with a small number of geological disasters, such as landslide, rock collapse. The magnitude of historical earthquakes is not high, resulting in the relatively lower seismic capability of civil buildings. Moreover, the intense aftershocks occurred frequently in a short time. Therefore, the damage degree of civil buildings under the Changning earthquake is significantly higher.

Figure 3 Epicenter of aftershocks.                 Figure 4 Damage area ratio.

3. Damage of civil building and influencing factors in the space
In the field investigation, the damaged buildings of 44 villages and towns were investigated. The area of damaged buildings in various villages and towns was counted in detail. There are various factors leading to the damage of civil buildings under earthquake. In order to study the spatial characteristic analysis of civil building damage under the Changning earthquake, several influencing factors are selected to analyse the correlation between the factors and building damage.

3.1. Damage of civil building
The damage area refers to the area where the building was destroyed, destructed, collapsed or needed to be repaired. Here the damage area ratio is applied to quantitively measure the severity of earthquake to building damage in various villages and towns. The damage area ratio is defined as the ratio of damage area of civil buildings caused by the earthquake to the total area of buildings.

Figure 4 shows the spatial distribution of damage ratio of civil buildings in all investigated villages and towns. The average damage area ratio of all villages is about 43.06%. The Yangliu Village has the highest ratio of damage area, with a distance of 8.4 km to the epicenter. The damage area of civil buildings in the Yangliu Village is 33950 m$^2$, and the maximum value of damage area ratio reaches 89.8%. The area having high damage area ratio shows consistence with the region where the aftershocks were concentrated. The damage of some building might be induced by the seismic motion from the aftershocks of Changning earthquake.

3.2. Influencing factors
The influencing factors considered in the research contained structure type (frame structure, masonry-concrete structure, masonry-wood structure), PGA (Peak Ground Acceleration), NDVI (Normalized Difference Vegetation Index), elevation, slope angle, population density, per capita GDP, distance to river, and distance to fault.

The structure types of different villages and towns are illustrated in figure 5(a). The area of different colours in the pie chart represents the proportion of the area of different building types in the area of building in the villages and towns. In the spatial characteristic analysis, masonry-wood structures are considered as the buildings with poor earthquake resistance, determined as simple buildings. The simple building ratio is applied in the analysis, defied as the ratio of masonry-wood
structures to the total area of the buildings. Figure 5(b) shows the PGA map of the main shock under the Changning earthquake, interpolated by the records from the motion observation station network. The PGA data could reflect the maximum instantaneous force exerted by earthquake, and could effectively evaluate the intensity of seismic ground motion at different positions in space [11]. Figure 5(c, d) show the elevation map and slope angle map of study area separately. There is correlation between topography and civil building damage. On the one aspect, the buildings are concentrated on the plains with lower elevation and slope angle; on the other aspect, there is amplification effect of high slope on seismic motion, resulting in the more severe disasters [12].

![Figure 5](image)

Figure 5 Influencing factors.

The influencing factors contain the population density and per capita GDP distribution in the study area too. The population density and per capita GDP are key factors reflecting the quantity and quality of civil buildings. Figure 5(e, f) show the distance to river and fault in the study area separately. The distance to river and fault are significant factors related to seismic geological disasters [13]. Geological disasters could be the important trigger of civil building collapse.

4. Spatial characteristic analysis between civil building damage and influencing factors

The damage area ratio and the corresponding influencing factors values in the different villages and towns are extracted using GIS software, to construct the database for spatial characteristic analysis.

The spatial correlation between civil building damage and influencing factors are partly illustrated in figure 6. The histogram statistics the average damage area ratio within the different factor intervals, which can reflect the related characteristics between spatial distribution of civil building damage and influencing factors. Because of the relatively small number of samples, the damage area ratio is missed in several factor intervals. It can be found that with the increase of simple building ratio, the civil building damage caused by earthquake is gradually increasing (figure 6(a)). It indicates the significant influence of structure type on the civil building damage. The masonry-wood structure exhibits weaker seismic resistance of the three structural forms. It can be observed in figure 6(b) that PGA also has a great impact on the civil building damage. The PGA value of the area with damage area ratio greater than 0.3, is larger than 325 gal. In the figure 6(c, d), the histogram shows that the damage area ratio has certain spatial correlation with distance to river and distance to fault. The area with distance to river 9.0 km -10.5 km and distance to fault 21 km -30 km, has the relative higher damage area ratio. The nearest river to the earthquake affected area is the Changning river as shown in figure 5(h). In addition, there is no active fault in the earthquake affected area. The high damage area
ratio with 21 km -30 km to the fault also reveals that the earthquake was not triggered by the known faults. The study on the seismic mechanism of Changning earthquake is worthy of further study.

![Figure 6](image)

**Figure 6** Correlation between influencing factors and damage area ratio.

| Damage area ratio | Correlation coefficient | Significance test |
|-------------------|-------------------------|-------------------|
| Simple building ratio | 0.341 | 0.013 |
| PGA (gal) | 0.639 | 0.000 |
| Elevation (m) | 0.080 | 0.306 |
| Slope angle (°) | 0.151 | 0.167 |
| Population density (people/km²) | 0.114 | 0.234 |
| Per capita GDP (×10⁴RMB) | -0.328 | 0.016 |
| Distance to river (km) | -0.224 | 0.074 |
| Distance to fault (km) | 0.235 | 0.065 |
| NDVI | 0.115 | 0.252 |

The damage area ratio of civil buildings is related to various influencing factors. The Spearman rank correlation coefficients are calculated to analyse the relationship between civil building damage and influencing factors. The Spearman correlation coefficient and significance test results between damage area ratio and influencing factors are listed in **Table 1**. For factors including elevation, slope angle, population density, distance to river, distance to fault and NDVI, the results of significance test are larger than 0.05, suggesting that the number of samples could be insufficient for these factors and the correlation coefficient results could be accidental. For the factors with significance test results less than 0.05, the highest correlation coefficient is 0.639 between civil building damage and PGA, showing that the damage area ratio has a remarkable PGA positive correlation, and the higher the PGA value, the greater the civil building damage. The second highest correlation coefficient is 0.341 of simple building ratio, indicating the significant impact of structure type on civil building damage under earthquake, being consistent to the result of histogram statistics. Moreover, the correlation coefficient of -0.328 between per capita GDP and damage area ratio also shows a significant negative correlation between economy level and civil building damage under earthquake.

5. Conclusion
The study herein aims at the spatial characteristic analysis of civil building damage under the mainshock, and the main conclusions are as follows:

1) Field investigation on the civil building damage was conducted in 44 villages and towns of different seismic intensity regions. The damaged area of civil building in each village or town was counted and the maximum value of damage area ratio is 89.8% in Yangliu Village.

2) Nine indicators including simple building ratio, PGA, elevation, slope angle, population density, per capita GDP, distance to river, distance to fault and NDVI are selected as influencing factors. The damage area ratio is determined to evaluate the damage of building quantitatively under earthquake. Civil building damage has correlation with several factors, which is a complex result of many influencing factors.

3) The histogram statistics and correlation analysis between damage area ratio and influencing factors suggest that PGA has the strongest correlation with civil building damage. Simple building
ratio and per capita GDP also have significant linear relationship with civil building damage. The area with high damage area ratio is concentrated in certain intervals of distance to river and fault.

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