Earthquake loss analysis and assessment of group buildings in Songyuan area

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Abstract. To study the earthquake damage and loss of group buildings in towns and urban areas of Songyuan, the simulation analysis of earthquake damage of group buildings in some areas of Chaganhua town and urban areas of Songyuan was conducted. In this paper, based on the building performance evaluation method in FEMA-P58 and the Standard for seismic resilience assessment of buildings (GB/T 38591-2020), the different methods between China and the US were eliminated. Firstly, the distribution of earthquake damage of various buildings was analyzed. The economic losses of the two regions are analyzed and compared by using PACT software to evaluate the repair costs and repair time of buildings under different earthquake levels.

1. Introduction

The earthquakes have caused the huge economic losses in the last years, so it is very important to predict and evaluate the seismic risk and loss of building structures. At present, earthquake damage and loss have been mostly concerned in large and medium-sized cities, but the earthquake damage in small cities and towns has not received enough attention. Therefore, this paper analyzes the losses caused by the recent earthquakes in Songyuan city, Jilin Province.

On May 28, 2018 and May 18, 2019, earthquakes with magnitudes of 5.7 and 5.1 occurred in Songyuan area, respectively. Figure 1 shows the building damage in Songyuan area.

![Figure 1: The building damage in Songyuan area](image)

In recent years, the researches on seismic loss assessment have been carried out in the world. Esmaili et al. [¹] used the RSLA method to assess general regional seismic loss of more than 10% of earthquake disasters in Los Angeles in 50 years. Omid Moammer et al. [²] studied the economic loss of building with eccentric braced frame as the lateral load resisting system under earthquake. Sadiq Amin Muhammad et al. [³] used deep learning techniques to recognize potentially harmful objects in the building during earthquake. Zheng Shansuo et al. [⁴] used the vulnerability classification method to establish a model to evaluate the direct economic losses of the Huaxian earthquake in 1556, and the
input-output method was used to evaluate the indirect economic losses of the 2008 Wenchuan earthquake. Wang Lijian et al. [5] used the IDA method to analyze the vulnerability curves and evaluate the economic losses of earthquakes. Zong Xuejun et al. [6] used the model integrating gray relation analysis and SA-PSO-Elman method to evaluate the direct economic losses caused by earthquakes.

Therefore, based on FEMA-P58 and its accompanying PACT software, the fragility parameters of components in PACT are adjusted by the GB/T 38591-2020. The economic losses of buildings in the small cities and towns under different levels of earthquakes are evaluated, and a comparative analysis of various buildings is made.

2. Amendment of differences between Chinese and American standards

2.1. PACT modelling process
PACT modelling process: 1) Model building structures; 2) Establish the population flow models; 3) Select vulnerability components; 4) Establish the structural collapse models; 5) Input structural response data; 6) Calculate losses.

2.2. Amendment according to Chinese code
In this paper, the population model, fragility function, repair cost, and repair time in the vulnerability component library are modeled in PACT software, which are adjusted according to the GB/T 38591-2020 Standard for seismic resilience assessment of buildings.

According to section 7 of GB/T 38591-2020: calculation of repair time, it can be concluded that the internal worker density of 1 person /1000 square feet is reasonable.

Based on the investigation of a two-story shop in Chaganhua town, the population flow model is determined. According to section 8 of GB/T 38591-2020: casualty calculation, a specific number of indoor personnel is provided. Since the personnel density did not meet the standard of 0.6 persons /m², the actual survey result is taken: 6 persons /100m².

According to Appendix C of GB/T 38591-2020: structure component vulnerability information, the loss coefficient of components under different damage states and repair coefficient values is given, and the component repair cost is equal to the cost multiplied by the loss coefficient, the coefficient of repair. The quantities and influence of the floors are taken into account in the calculation.

According to the specification Appendix E of GB/T 38591-2020: vulnerability information of non-structural components; the vulnerability grouping of non-structural components, the criteria of damage states, the repair cost coefficients, and the repair time coefficients are determined.

After adjustment, the parameters of PACT software are basically in line with the actual situation of construction projects in China and can be used for earthquake damage analysis.

3. Earthquake loss analysis of group building earthquake in Songyuan area

3.1. Analysis of earthquake loss under earthquake in Chaganhua town
According to the GB 50011-2010 Code for Seismic Design of Buildings, the seismic fortification intensity in the Songyuan area is 8. According to field investigation and mapping software such as Baidu Street View and SXEarth, the group buildings in some areas of Chaganhua town (accounting for about 25% of the total area of Chaganhua town) were counted and classified, as shown in figure 2.
According to the calculation process of PACT software above, input the information of various buildings for calculation, and statistically check the repair costs and repair time of various single buildings in some areas of Chaganhua town, as shown in table 1.

| Building type          | Story number | Quantity | Monomer building repair costs (USD) | Monomer building repair time (Day) |
|------------------------|--------------|----------|-------------------------------------|-----------------------------------|
|                        |              |          | Frequent EQ | Medium EQ | Rare EQ | Very rare EQ | Frequent EQ | Medium EQ | Rare EQ | Very rare EQ |
| Unfortified residence  | 1            | 4985.6   | 73          | 719       | 1900    | 2200        | 3.1         | 6.3       | 19.5    | 28.1        |
| Brick-concrete Residence 1<sup>a</sup> | 1           | 20608    | 110         | 740       | 3800    | 4989        | 0.9         | 3         | 10.5    | 25.9        |
| Brick-concrete Residence 2<sup>b</sup> | 2           | 6951     | 103         | 333       | 2476    | 6390        | 1.9         | 3.5       | 12.7    | 23.9        |
| Shop building          | 2            | 7760     | 195         | 396       | 1052    | 3620        | 2.2         | 4.3       | 9.9     | 26.5        |
| Office building        | 3            | 4752     | 138         | 598       | 2231    | 6642        | 0.3         | 1.6       | 7.7     | 46          |
| School building        | 4            | 4984     | 267         | 2246      | 5274    | 24186       | 0.2         | 1.9       | 7       | 48.6        |
| Uninhabited house      | 7            | 5439     | 250         | 769       | 1427    | 7582        | 0.1         | 2         | 30      | 61.8        |

<sup>a</sup> 1-story brick-concrete structure  
<sup>b</sup> 2-story brick-concrete structure

Under the actions of frequent and very rare earthquakes, the damage of group buildings in Chaganhua town is shown in figure 3 and figure 4, in which yellow is basically intact (1), pink is slight damage (2), green is moderate damage (3), red is severe damage (4), and black is collapse (5).

Figure 3 Schematic diagram of damage grade of group structures under frequent earthquake  
Figure 4 Schematic diagram of damage grade of group structures under very rare earthquake

By multiplying the repair costs of various individual buildings under different earthquakes by the number of buildings of the same type, and the repair costs of the same type of buildings are obtained. The repair costs of each type of buildings are divided by the total of all buildings under the same...
earthquake, and the ratios of the repair costs of various buildings to the total repair costs of group buildings can be obtained, as shown in table 2.

| Building type                | Frequent EQ repair (USD) | Medium EQ repair (USD) | Rare EQ repair (USD) | Very rare EQ repair (USD) |
|-----------------------------|--------------------------|------------------------|----------------------|---------------------------|
| Unfortified residence       | 5548                     | 24.55                  | 54644                | 35.99                     | 144400                  | 22.53                  | 167200                | 17.96                    |
| Brick-concrete residence 1  | 12320                    | 54.51                  | 82880                | 54.59                     | 425600                  | 66.41                  | 558768                | 60.01                    |
| Brick-concrete residence 2  | 2122                     | 9.39                   | 6860                 | 4.52                      | 51006                   | 7.96                   | 131634                | 1.41                     |
| Shop building               | 1950                     | 8.63                   | 3960                 | 2.61                      | 10520                   | 1.64                   | 36200                 | 3.89                     |
| Office building             | 248                      | 1.10                   | 1076                 | 0.71                      | 4016                    | 0.63                   | 11956                 | 1.28                     |
| School building             | 214                      | 0.95                   | 1797                 | 1.18                      | 4219                    | 0.66                   | 19349                 | 2.08                     |
| Uninhabited house           | 200                      | 0.88                   | 615                  | 0.41                      | 1142                    | 0.18                   | 6066                  | 0.65                     |

It can be seen from table 2 that the economic losses of Chaganhua town are mainly concentrated in a large number of unfortified residences and the one-story brick-concrete residences. With the increased earthquake intensities, the proportion of repair costs of the unfortified residence buildings is gradually reduced due to the limitation of its own cost. Because of the high cost, the proportion of repair costs of brick-concrete residence buildings increases gradually. The damage of a type of building gradually developed, which resulted in the increment of economic loss of the type of building.

With the increase of earthquake intensities, the repair times of various buildings have increased. After the earthquake, every individual building can be repaired at the same time. Figure 5 compares the repair times of a single building under various levels of earthquakes. The resilience analysis results of group buildings also have referential significance.

![Figure 5 Proportion of repair time of various buildings under earthquake action of different levels](image)

3.2. Analysis of earthquake losses in Songyuan city

The same method was used to make statistics and classification of typical buildings in the specific area of Songyuan city.

The PACT software is also used to calculate and analyse all kinds of individual buildings according to building information, and the repair costs and repair time of all kinds of individual buildings in the area of the Songyuan city are obtained and calculated, as shown in table 3.

| Building type        | Story number | Quantity | Frequent repair costs (USD) | Medium repair costs (USD) | Rare repair costs (USD) | Very rare repair costs (USD) | Frequent repair time (Day) | Medium repair time (Day) | Rare repair time (Day) | Very rare repair time (Day) |
|----------------------|--------------|----------|-----------------------------|---------------------------|------------------------|----------------------------|---------------------------|-------------------------|------------------------|-----------------------------|
| Residence 1          | 6            | 602      | 785                         | 9254                      | 17956                  | 41132                     | 5.2                       | 21.2                   | 48.5                   | 105.6                      |
| Shop building        | 2            | 30       | 195                         | 396                       | 1052                   | 3200                      | 2.2                       | 4.3                    | 9.9                    | 26.5                       |
| School building      | 5            | 10       | 487                         | 2279                      | 6657                   | 34643                     | 0.3                       | 1.5                    | 27.5                   | 219                        |
| Office building      | 5            | 14       | 1265                        | 3645                      | 8565                   | 31645                     | 0.8                       | 2.1                    | 18.6                   | 101                        |
For all levels of earthquakes, the total earthquake losses of various buildings can be obtained through analysis and calculation, as well as the ratio of earthquake losses of various buildings to total building losses under the earthquake of a specific magnitude, as shown in table 4.

| Building type | Frequent EQ repair (USD) | Medium EQ repair (USD) | Rare EQ repair (USD) | Very rare EQ repair (USD) |
|---------------|--------------------------|------------------------|----------------------|--------------------------|
| Residence 1   | 472570                   | 92.84                  | 5570908              | 96.98                    |
| Shop building | 5850                     | 1.15                   | 11880                | 0.21                     |
| School building | 4870                    | 0.96                   | 22790                | 0.40                     |
| Office building | 17710                  | 3.48                   | 51030                | 0.89                     |
| Residence 2   | 7104                     | 1.40                   | 51336                | 0.89                     |
| Residence 3   | 896                      | 0.18                   | 36631                | 0.64                     |

The economic losses of buildings in Songyuan city are mainly concentrated in the multi-story buildings represented by 6-story houses, which is due to their large quantity and high cost.

With the increment of the earthquake intensity, the damage rate of high-rise buildings increases faster than that of shop buildings, which leads to the increasing of their repair costs. Under the action of rare earthquake, the ratio of repair costs of high-rise residential buildings decreases, because a large amount of indoor property loss and structural component damage are in the school buildings.

4. Comparative analysis of earthquake losses between Chaganhua town and Songyuan city

4.1. Comparative analysis of repair costs between Chaganhua town and Songyuan city

The repair costs of Chaganhua and Songyuan under the action of frequent, medium, rare, and very rare earthquakes were summarized, and the repair costs per unit area were obtained according to the size of the selected area. The comparison results are shown in table 5.

| Area/ km² | Songyuan city | Frequent EQ | Medium EQ | Rare EQ | Very rare EQ |
|-----------|---------------|-------------|-----------|---------|--------------|
|           | Total area    | 509000      | 5744575   | 11594790| 26622168     |
|           | Unit area     | 115158.37   | 1299677.60| 2623255.66| 6023114.93   |
| Chaganhua town | Total area | 22602       | 151832    | 640903  | 931173       |
|           | Unit area     | 41094.55    | 276058.18 | 1165278.18| 1693041.82   |

By comparison, under the same earthquake magnitude, the repair costs per unit area in Songyuan city is much higher than those of Chaganhua town, because the building types in Chaganhua are mainly one-story residential buildings, while the buildings in the urban area are mainly high-rise buildings (residence 2 and 3), and the building density and indoor property of urban houses are higher.

The economic losses per unit area can be obtained by dividing the individual economic losses of various buildings by the corresponding total building area, as shown in table 6 and table 7.
Table 6 Repair costs of various building units in Songyuan city

| Building type      | Total area (sq.m) | Repair costs per unit area (USD/sq.m) |
|--------------------|-------------------|--------------------------------------|
|                    |                   | Frequent EQ | Medium EQ | Rare EQ | Very rare EQ |
| Residence 1        | 2755354           | 0.172       | 2.022     | 3.923   | 8.987        |
| Shop building      | 30420             | 0.192       | 0.391     | 1.037   | 3.570        |
| Teaching building  | 44000             | 0.111       | 0.518     | 1.513   | 7.873        |
| School building    | 77490             | 0.229       | 0.659     | 1.547   | 5.717        |
| Residence 2        | 82392             | 0.086       | 0.623     | 3.549   | 5.956        |
| Residence 3        | 70483             | 0.013       | 0.520     | 3.899   | 6.696        |

Table 7 Repair costs of various building units in Chaganhua town

| Building type                      | Total area (sq.m) | Repair costs per unit area (USD/sq.m) |
|------------------------------------|-------------------|--------------------------------------|
|                                    |                   | Frequent EQ | Medium EQ | Rare EQ | Very rare EQ |
| Unfortified residence              | 65.6              | 1.113       | 10.960    | 28.963  | 33.537       |
| Brick-concrete residence 1         | 184               | 0.598       | 4.022     | 20.652  | 27.114       |
| Brick-concrete residence 2         | 331               | 0.311       | 1.006     | 7.480   | 19.305       |
| Shop building                      | 776               | 0.251       | 0.510     | 1.356   | 4.665        |
| Office building                    | 2376              | 0.058       | 0.252     | 0.939   | 2.795        |
| School building                    | 4984              | 0.054       | 0.451     | 1.058   | 4.853        |
| Uninhabited house                  | 5439              | 0.046       | 0.141     | 0.262   | 1.394        |

It can be seen that the costs of restoration per unit area of high-rise buildings in Songyuan city are higher than those of low-rise building, because more high-cost components are contained in the high-rise buildings in the urban area. It can be seen that the costs of restoration per unit area of unfortified residence buildings in Chaganhua town are higher than those of the other buildings, because the seismic performance of unfortified residence buildings is worst, so the same earthquake magnitude would cause more damage in the type of building. For the same structural type of buildings, such as school buildings, the repair costs per unit area of urban buildings are higher than those of town buildings, mainly because the construction and decoration costs of urban buildings are higher.

4.2. Comparison of repair time between Chaganhua town and Songyuan city

In this paper, it is assumed that the repair of various types of buildings will be carried out simultaneously. The total repair time of all buildings under one earthquake is the sum of the repair time of various types of buildings, which can be calculated with the number of this type of building in the selected area multiplied by the corresponding individual repair time. The total repair time is divided by the total area to get the repair time per unit area. As shown in table 8, the earthquake repair time of Songyuan city and Chaganhua town is compared under the action of frequent, medium, rare and very rare earthquakes.

Table 8 Comparison of repair time

|          | Area/ km² | Repair time/Day | Frequent EQ | Medium EQ | Rare EQ | Very rare EQ |
|----------|-----------|-----------------|-------------|-----------|---------|-------------|
| Songyuan | 4.42      | Total repair time | 4.73        | 19.07     | 44.85   | 105.3       |
| Chaganhua town | 0.55 | Repair time per unit area | 1.07 | 4.31 | 10.15 | 23.82 |
|          |           | Total repair time | 1.24        | 3.23      | 13.90   | 37.26       |
|          |           | Repair time per unit area | 3.25 | 7.65 | 25.08 | 48.97 |

It can be seen that under the action of frequent and medium earthquakes, the buildings in Chaganhua town have been severely damaged due to the weak seismic performance, and the repair time is higher than that in the city. Under the action of rare earthquakes, the seismic performance of buildings in the urban area is generally higher than that in Chaganhua town, resulting in the repair time per unit area in Chaganhua town is about twice that in the urban area.
The seismic performance of unfortified buildings in Chaganhua town is poor, and severe damage or even partial or overall collapse occurred under the earthquakes. The unfortified buildings in Chaganhua town have high damage and reconstruction rate, so the repair time is long. Building components and indoor property values in Songyuan city are higher than those in Chaganhua town, so the repair costs are higher. However, due to the relatively concentrated distribution of buildings in Songyuan city, and the partial restoration of the buildings is easy to conducted to meet the residence requirements. So the repair time per unit area in Songyuan city is less that in Chaganhua town.

4. Conclusions
Based on the PACT software, the earthquake losses in some areas of Chaganhua town and Songyuan city are analyzed and compared, and some conclusions are drawn:

(1) According to the analysis of the proportion of economic losses of various buildings in the earthquake, it can be found that the losses in Chaganhua town are mainly concentrated in one-story unfortified houses and brick-concrete houses which account for 61.42% losses in the very rare earthquake, while the losses in Songyuan city are mainly concentrated in mid-rise houses (residence 1, 2, and 3) which account for 95.97% losses in the very rare earthquake. Therefore, seismic reinforcement should be conducted for these buildings.

(2) Under the action of frequent earthquakes, losses mainly occur on non-structural components, such as windows, etc. With the increment of earthquake magnitude, the acceleration response and inter-story displacement of the group structures are increasing, and the indoor property loss and structural component damage are the main sources of earthquake losses. Compared with low-rise buildings, the damage of high-rise buildings grow rapidly, and the proportion of its repair costs is also increasing.

(3) Under the actions of various earthquakes, the seismic performance of buildings in Songyuan city is better than that of Chaganhua town, so the repair time of which is less. Due to the high value of building components and indoor property in Songyuan city, the repair costs are higher than those of Chaganhua town.

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