Study on Seismic Risk Exposure and Vulnerability of Buildings in Southwest China Based on AI Technology

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Abstract: In this paper, we made building taxonomy for Southeastern Tibet in Southwest China and attempted to apply the 3D image pattern recognition technology in UAV aerial image processing and pattern recognition, for the statistics of building types and numbers, and explore more applications of AI technology in geoscience research. We compared our vulnerability models with parts of vulnerability models of buildings in Nepal in the research of Nepal’s seismic hazard and risk assessment. The comparison between our vulnerability models and Nepal ones shows that public and private houses have better seismic resistance than the houses in Nepal.

1. Introduction

With the social modernization, the concept of Seismic Risk is being used more and more frequently. The seismic risk of a region refers to the possibility and degree of loss caused by earthquake that the region may suffer, which included seismic hazard, vulnerability and exposure. Seismic risk can be defined by the following equation [1]:

\[ \text{Seismic Risk} = \text{Seismic Hazard} \times \text{Vulnerability} \times \text{Exposure} \]  

Image Pattern Recognition (Image Pattern Recognition) technology is an important branch of Artificial Intelligence (AI) technology. It is a technology that establishes pattern classes based on the characteristics of image objects, and determines the affiliation of objects based on the value of the object's pattern. Image pattern recognition has been widely used in the research of two-dimensional image processing such as satellite images and remote sensing [2-4]. However, the processing and recognition technology of three-dimensional features in images has not been widely used in the statistics of building structure types. This article attempts to apply the 3D image pattern recognition technology in UAV aerial image processing and pattern recognition, for the statistics of building types and numbers, and explore more applications of AI technology in geoscience research.

Southeastern Tibet is located in Southwest China, and includes Lhasa, Shannan and Nyingchi, and has a total number of 3 cities and 24 towns, as shown in Figure 1. This area is the most populous and economically developed part of Tibet. Meanwhile, Southeastern Tibet is located at the boundary between Eurasia Plate and India Plate, with a number of large-scale tectonic faults distributed. The occurrence of major earthquakes is frequent. In recent years, the government has been committed to giving priority to supporting the economic construction of Southeastern Tibet. Therefore, it is of great significance to understand the seismic risk in Southeastern Tibet. In this paper, we made building
taxonomy for Southeastern Tibet and investigated the distribution of every building type. We analyzed the vulnerability of every building type and made a comparison with the buildings in Nepal.

2. Study area and Data used
The study area is Southeastern Tibet in Southwest China, as shown in Figure 1.

We did a scientific investigation to get the building taxonomy. The investigation visited 13 of the 27 counties in Southeastern Tibet and more than 1,000 buildings were collected as samples. During the investigation, it was found that the distribution of buildings in the southeastern Tibet has the following characteristics:

1. Population and buildings are mostly distributed in valleys, and concentrated in downtowns.
2. Residential structures and their vulnerability characteristics are difficult to identify on satellite pictures, but can be identified by UAV aerial photography.
3. There is a difference in housing structure and vulnerability between urban and rural residents. Urban buildings there do not have much difference between cities in Eastern China. There are many newly built private houses and old traditional Tibetan buildings in rural areas.
4. In the forests of Nyingchi there are quite a large number of wood houses.

3. Building Taxonomy and Distribution Investigation

3.1. Building Taxonomy
According to the scientific investigation, we divide buildings in Southeastern Tibet into four types as follows: Public; New-built Private; Old; Wood. Typical images of the four types are shown in Figure 2.
3.2. Building Distribution Investigation
The authors investigated the number of four types of building in each town using sample survey. Sample areas are shown in Table 1. The samples are taken by UAV aerial photography. Images of each sampling point are shown in Figure 3.

| Residential Type       | Sampling Point                                           |
|------------------------|----------------------------------------------------------|
| City center            | City center of Shannan                                    |
| City suburbs           | Niangre County, Lhasa                                     |
| Downtown               | Qushui Town, Lhasa                                        |
| Country                | Lulang County, Nyingchi                                  |
| Wood distributed area  | Gangdui Village, Bomi and Bangjia Village, Milin          |
Figure 3. UAV aerial images of each sampling point. Top left: City center of Shannan; top right: Niangre County; middle left: Qushui Town; middle right: Lulang County; bottom left: Gangdui Village, bottom right: Bangjia Village.

We used 3D image pattern recognition, a kind of AI technology to recognize and count every type of building in the pictures. To perform pattern recognition on the image of a building, it is necessary to determine the mode under consideration. Through the analysis of the characteristics of the four building types in Section 3, three modes of building are considered: number of stories (F), window area ratio (W) and dense grid-like texture (T). The three modes are described as follows:

(1) Number of stories F: The number of stories of the building. This mode is mainly used to identify public housing.

(2) Window area ratio W: The ratio of external wall window area to wall area. This mode is mainly used to identify old traditional Tibetan buildings.

(3) Dense grid-like texture T: If the exterior wall has dense grid-like texture, it is recorded as T=1, otherwise, it is recorded as T=0. This mode is mainly used to identify wooden buildings.

The pattern vector corresponding to the three patterns can be expressed as the layer number pattern (FPUB, FPRV, FOLD, FWOD), the window area ratio pattern (WPUB, WPRV, WOLD, WWOD) and the grid texture pattern (TPUB, TPRV, TOLD, TWOD). The idea of pattern recognition is to convert the image into a pixel information matrix; identify the sub-matrix in the pixel information matrix that meets the characteristics of the building matrix as a building unit and count the number of buildings; take each building as a unit to read the building image pattern separately F, W and T are recognized as
PUB when $F \geq 3$; when $F < 3$ and $W < 0.1$ are recognized as OLD; when $F < 3$ and $W \geq 0.1$ and $T = 1$, they are recognized as WOD; the rest are recognized as PRV. The flow chart of pattern recognition is shown in Figure 4. Numbers and proportion of buildings at sampling points are shown in Table 2.

*Figure 4. Flow chart of pattern recognition.*
Table 2. Building statistics at sampling points.

| Sampling Points       | Total number | Public | Private | Old | Wood | Public proportion | Private proportion | Old proportion | Wood proportion |
|-----------------------|--------------|--------|---------|-----|------|-------------------|-------------------|----------------|-----------------|
| Niangre County        | 122          | 14     | 56      | 52  | 0    | 11.48%            | 45.90%            | 42.62%         | 0               |
| Qushui Town           | 456          | 283    | 118     | 55  | 0    | 62.06%            | 25.88%            | 12.06%         | 0               |
| City center of Shannan| 360          | 219    | 131     | 100 | 0    | 60.83%            | 36.39%            | 2.78%          | 0.00%           |
| Lulang County         | 73           | 2      | 28      | 41  | 2    | 2.74%             | 38.36%            | 56.16%         | 2.74%           |
| Gangdui Village       | 21           | 1      | 7       | 6   | 7    | 2.94%             | 14.71%            | 30.88%         | 51.47%          |
| Bangjia Village       | 47           | 1      | 3       | 15  | 28   |                   |                   |                |                 |
| Total of wood distributed areas | 68         | 2      | 10      | 21  | 35   | 2.94%             | 14.71%            | 30.88%         | 51.47%          |

4. Vulnerability Model

We built vulnerability models for all the four types of buildings. The data we used is the recent building damage reports in earthquake events in Southwest China, such as the 2010 Yushu Ms7.1 Earthquake [5-8]; the 2015 Nepal Ms8.1 Earthquake [9-13] and the 2017 Milin Ms6.9 Earthquake. Some examples of the building damage in those events are expressed in Figure 5.

Figure 5. Pictures of damage in recent earthquake events in Southwest China. Top left: Nepal Earthquake shocked Zhangmu in 2015; top right: Nepal Earthquake shocked Jilong in 2015; bottom left: Yushu Earthquake shocked Jiegu in 2010; bottom right: Milin Earthquake shocked Nyingchi in 2017 [5-13].

We built structural vulnerability curves to get the economic losses, and built occupancy vulnerability curves to get the casualties. The vulnerability curves of the four types of buildings are shown in Figure 6. In which the standard deviation where PGA<0.6g is 0.3, and in other cases is 0.1.
Figure 6. Vulnerability curves of the four types of buildings. Left: structural vulnerability; right: occupancy vulnerability.

We also compared our vulnerability models with parts of vulnerability models of buildings in Nepal built by Chaulagain et al. [14] in the research of Nepal’s seismic hazard and risk assessment. The building taxonomy of Nepal we chose to compare included Concrete, Unreinforced brick masonry (UBM), Adobe and Wood. The comparison between our vulnerability models and Nepal ones are shown in Figure 7. Figure 7 shows that public houses in Southwest China have better seismic resistance than concrete houses in Nepal. Private houses in Southwest China have better seismic resistance than unreinforced brick masonry houses in Nepal. Old houses in Southwest China have similar vulnerability curves with Adobe houses in Nepal. Wood houses in the two countries also have similar vulnerability curves.

Figure 7. Vulnerability models comparison between buildings in Southeastern Tibet and Nepal. Top left: Public vs Concrete; top right: Private vs UBM; bottom left: Old vs Adobe; bottom right: Tibetan Wood vs Nepal Wood.
5. Conclusion and Discussion
In this paper, we built building taxonomy and vulnerability model for Southeastern Tibet using investigation data and building destruction data in history earthquake disasters, and made a comparison with the buildings in Nepal. We conclude as follows:

(1) Most private houses can resist middle-level ground motion (PGA<0.4g), but may get destroyed if the ground motion was larger. Public and wood houses have better seismic resistance, but old houses are even worse in seismic resistance.

(2) Public houses in in Southwest China have better seismic resistance than concrete houses in Nepal. Old houses in Southeastern Tibet and Adobe houses in Nepal have similar vulnerability models, and vulnerability models of wood houses in both areas are also similar.

(3) Private houses in Southwest China have better seismic resistance than unreinforced brick masonry houses in Nepal.

(4) Old houses in Southwest China have similar vulnerability curves with Adobe houses in Nepal.

(5) Wood houses in Southwest China and Nepal also have similar vulnerability curves.

In this article, the authors only separated four types for all the buildings in Southeastern Tibet. In fact, buildings in Southeastern Tibet is more complex than what we described. For some complex buildings, the types treated in the research increases the uncertainty of the result.

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