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Prior Seismic Performance Assessment for Building Community with High-Resolution Remote Sensing Images

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Abstract. The seismic performance assessment of building community prior to the occurrence of earthquakes is important to the disaster prevention and relief planning. However, one big challenge is the available information for assessment is generally limited, which makes the reliability of the assessment low. In this paper, a new approach to extraction and analysis of high-resolution remote sensing images is proposed to facilitate its prior seismic performance assessment. The proposed approach is finally verified by the case study of Dujiangyan urban area in Wenchuan earthquake. In the case study, the performance of the buildings during the earthquake were extracted from the aftershock remote sensing images by the application of the image change detection technology, and it is compared with the results from the prior assessment with the proposed approach. The comparison shows that the consistency is well between the prior assessment and the aftershock investigation.

1. Introduction

Seismic hazard as one of the most serious natural hazards has caused great damage and loss to our society. Seismic performance assessment for building community with large area prior to the occurrence of earthquakes provides the basis for the community.

Disaster prevention and relief planning[1]. The acquisition of relevant information, however, is mainly realized by on-site investigation in tradition, with high labor cost and time consuming. In recent years, with the rapid development of remote sensing technology, the high-resolution remote sensing images are available for engineering practice and it becomes presently possible to apply them to the seismic performance assessment.

In general, the existing methods of prior seismic assessment of building community are experience/statistics based, see e.g. [2]-[5] for references. Recently, the assessment is improved in the respective of the new development of the platforms and the models that describe the building performance. The first author and her colleagues developed a prediction system[6] for seismic performance of urban buildings, which integrated the attribute data, the buildings vulnerability model and seismic performance assessment results into the GIS platform, and the batch production and automation of performance assessment is realized, and the assessment results are illustrated through the interactive visualization. Meanwhile, Han Bo et al. refine the fine model (finite element model and discrete element model), together with the nonlinear time history analysis combined with the



GPU/CPU parallel computing technology to develop a regional earthquake damage simulation system[7].

In spite of the rapid development in the platforms and the models, the reliability of the results is not improved greatly due to the information adopted in the assessment is not increased.

In the present paper, a new approach to extraction and analysis of high-resolution remote sensing images of building community is proposed to facilitate its prior seismic performance assessment[8]. It will be introduced what is the building information relevant to the seismic performance assessment and how such information could be extracted from the high resolution remote sensing image and be adopted in the application of the earthquake damage matrix approach for the assessment. Finally, the present paper takes the Dujiangyan area, as a typical building community, with Wenchuan earthquake as an example. In the case study, the information of the buildings with damages was extracted from the comparison between the original and aftershock remote sensing image in, which will be compared with the prior seismic performance assessment results.

These high-resolution remote sensing images should be geometric registrated and clipped before analysis.

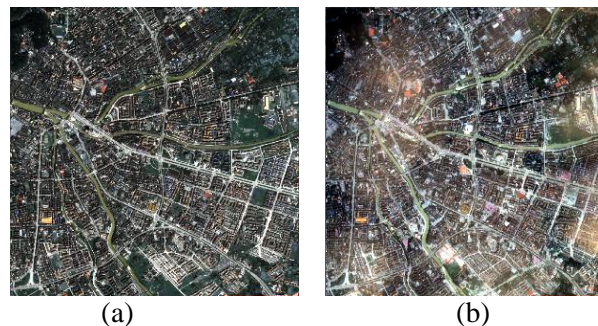


Figure. 1. This is a Figure, it shows the remote sensing image of Dujiangyan area before and after the earthquake.

2. Building information extraction and prior seismic performance assessment

2.1. 3D building information extraction

In this paper, the feature extraction module of ENVI: "object-oriented spatial feature extraction module -- Feature Extraction" is used to extract information. ENVI FX segments the image according to the pixel, brightness, texture, color and so on, which is an edge-based segmentation algorithm [9]. According to the image features of buildings and their shadows, the classification of remote sensing images is carried out, and the 3D building information is extracted following shadow theory.

In order to improve the extraction accuracy, the original remote sensing images are further divided into 100 small sub-areas, and the buildings together with their shadows are extracted respectively in each sub-area. The schematic diagram of the partition is shown in Figure 2. The first part in the first row corresponds to sub-area 1, and the second part in the first row corresponds to sub-area 2, and so on.

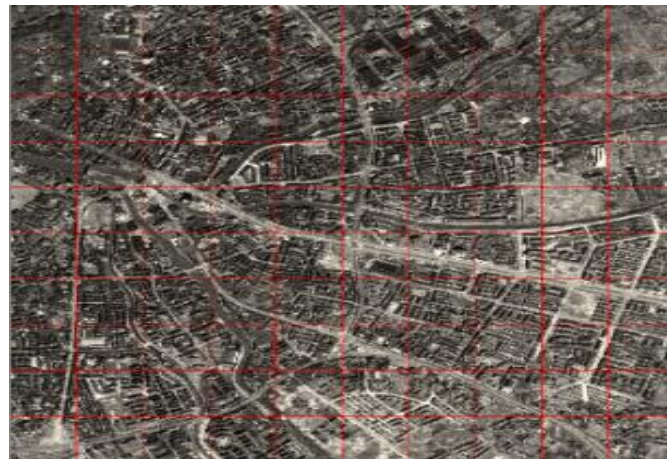


Figure. 2. This is a Figure, it shows the illustration of the partition diagram of the study area.

The classification rules of different districts are different, it therefore, is necessary to classify object-oriented rules for different districts. Part of the district classification rules, corresponding attribute expression and the classification results was shown in Figure 3~ Figure 4.

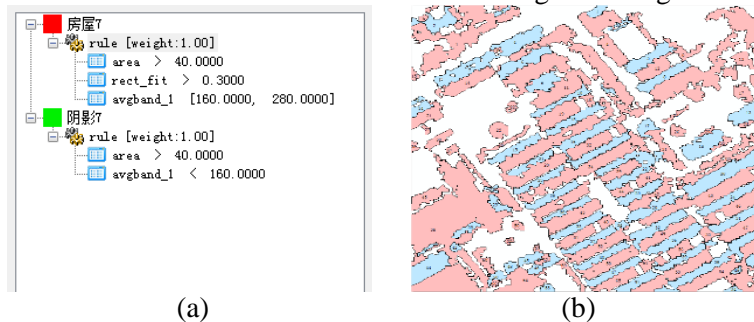


Figure. 3. This is a Figure, it shows the classification rules and results of District 7.

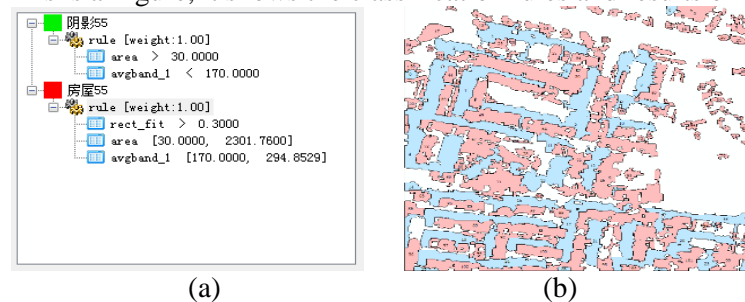


Figure. 4. This is a Figure, it shows the classification rules and results of District 55.

According to the architectural shadow of the image, we can calculate and extract building information such as height, structure type, stories and so on. According to the results of extraction, the types and the corresponding areas of the building with the 100 partitions are counted, and the statistical results of building information in the first 7 partitions are given in Table 1. While the rest partitions won't give any more details.

Table 1. This is a table. It shows the building Information Statistics

| Partition | Masonry-concrete structure area | Frame structure area | Total building area |
|-----------|---------------------------------|----------------------|---------------------|
| 1 | 14419.20 | 0.00 | 14419.20 |
| 2 | 31706.56 | 0.00 | 31706.56 |
| 3 | 64508.48 | 40392.75 | 104901.23 |
| 4 | 107530.05 | 17527.19 | 125057.24 |
| 5 | 123214.22 | 41672.03 | 164886.25 |
| 6 | 79101.60 | 0.00 | 79101.60 |
| 7 | 100612.85 | 19113.60 | 119726.45 |

2.2. Prior seismic performance assessment of buildings

Considering the complexity and diversity of the buildings in different areas, it is difficult to find two areas with identical types of buildings with same or similar area with Dujiangyan area we have interests here. However, there are still some areas with existing and similar seismic damage matrix. The seismic damage matrix means the probability of different building types under different earthquake intensity to a certain failure state by investigating the history of earthquake damage or computing theory. Which can be used for the prior seismic performance assessment of Dujiangyan area.

The seismic damage matrix [10] of Chengdu and its surrounding regions is adopted here due to the similar properties in types of buildings and their area. Table 2 and table 3 show the seismic damage matrix of masonry structure and frame structure in that area respectively.

Table 2. This is a table. It shows the seismic damage matrix of masonry structure in Chengdu and its surrounding regions

| Intensity | Basically-intact | Slightly-damaged | Moderately-damaged | Heavily-damaged | Collapsed |
|-----------|------------------|------------------|--------------------|-----------------|-----------|
| 7 | 40.16 | 25.30 | 17.54 | 11.53 | 5.47 |
| 8 | 24.29 | 20.84 | 22.11 | 19.85 | 12.91 |
| 9 | 10.64 | 14.82 | 21.00 | 27.68 | 25.86 |

Table 3. This is a table. It shows the seismic damage matrix of frame structure in Chengdu and its surrounding regions

| Intensity | Basically-intact | Slightly-damaged | Moderately-damaged | Heavy-damaged | Collapsed |
|-----------|------------------|------------------|--------------------|---------------|-----------|
| 7 | 100.0 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8 | 76.42 | 20.26 | 3.32 | 0.00 | 0.00 |
| 9 | 0.90 | 25.04 | 47.36 | 21.30 | 5.40 |

From the collected data of the masonry and frame structure types in each district, together with the seismic damage matrix, the seismic performance of such buildings could be assessed in prior. Further, with large amount of analysis and calculation, the global vulnerability matrix of Dujiangyan City with such buildings was obtained, as provided in table 4.

Table 4. This is a table. It shows the global vulnerability matrix of Dujiangyan (%)

| Intensity | Basically intact | Slightly-damaged | Moderately-damaged | Heavily-damaged | Collapsed |
|-----------|------------------|------------------|--------------------|-----------------|-----------|
| 7 | 51.40 | 20.55 | 14.24 | 9.36 | 4.44 |
| 8 | 34.08 | 20.73 | 18.58 | 16.12 | 10.48 |
| 9 | 8.81 | 16.74 | 25.95 | 26.48 | 22.02 |

3. Inspection of real seismic performance of buildings within Dujiangyan area after Wenchuan Earthquake

In this paper, the image change detection technology is used to assess the seismic performance of Dujiangyan urban area which suffered greatly from the Wenchuan Earthquake. Based on the extracted collapsed buildings, the collapse rate of the city is calculated.

3.1. pre-processing of image

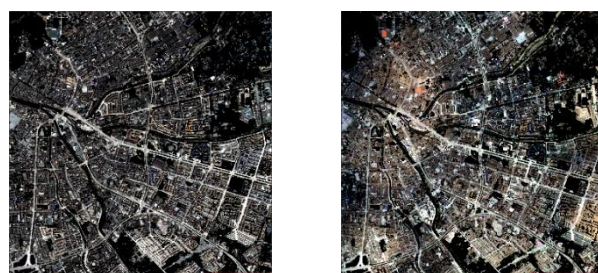
A mask image of vegetation and rivers can be built up by using NDVI index, the process was shown in Figure 5.



(a) The NDVI index image (b) Mask image of vegetation covered area (c) Mask image of rivers

Figure. 5. This is a Figure, it shows the process of building up the mask image of vegetation and rivers by using NDVI index image of Dujiangyan city.

Thanks to the mask map applied to the remote sensing images obtained prior to and after the earthquake, distraction from non-priority areas can be removed such as vegetation covered area and river.(Figure 6.)



(a) Prior to the earthquake (b) After the earthquake.

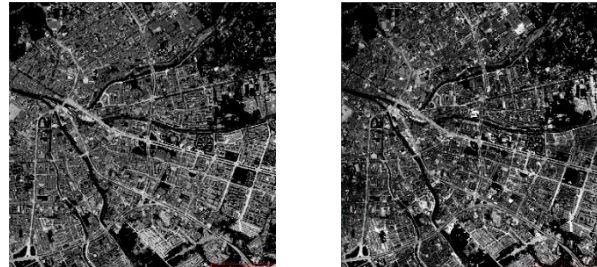
Figure.6. This is a Figure, it shows the image with the removal of the "non-building area" image prior to the earthquake and after the earthquake.

After the removal of the "non-building area", these first principal component images without noise are extracted by the principal component transformation technology, and it is enhanced linearly to highlight the image features. Finally, its results can be shown by the histogram explicitly.

The target of change detection is the two high resolution remote sensing images of the area at two different phases. Either large or small gray scale produced by the image at different time will lead to certain error in information extraction[11]. Therefore, after the image geometric correction, gray matching is utilized to reduce the misjudgment probability and improve the accuracy before the

change detection. The original image before the earthquake is adopted as the base image to match the grayscale image after the earthquake due to its own high quality.

After the image enhancement and gray matching, the grayscale of the images prior to and after the earthquake tend to be consistent, which indicates that the histogram matching is reliable. The matching image is shown in Figure 7.



(a) before the earthquake

(b) after the earthquake

Figure.7. This is a Figure, it shows the image enhancement and gray matching before and after the earthquake.

3.2. Change detection of seismic damage

The improved differential method is used to calculate the image before and after earthquake, and the results are shown in Figure 8.

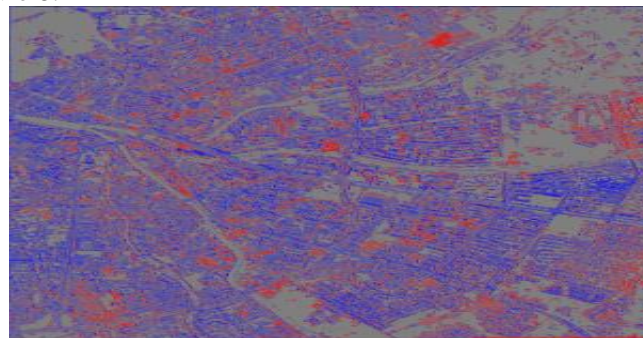


Figure.8. This is a Figure, it shows the result of differential method.

3.3. Extraction of collapsed buildings

Based on the selection of the 11 levels of the control thresholds, the result of differential method is divided by threshold into areas with different colors, as shown in Figure 9.

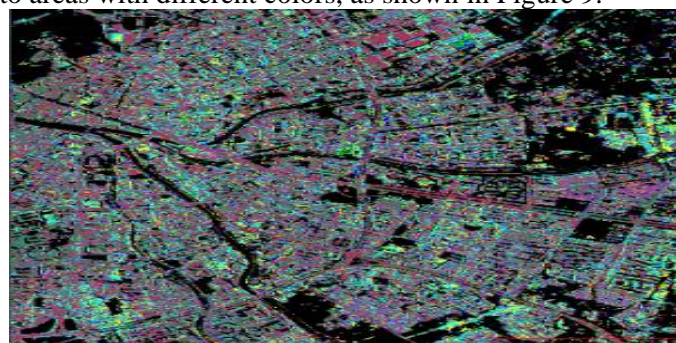


Figure.9. This is a Figure, it shows the thresholds-based division results by differential method.

Through visual interpretation, taking the threshold value 40% as the control range, the ratio of the difference greater than 40% is considered as the collapsed building in the earthquake. The classified image of collapsed buildings was extracted and then analyzed by Majority Element Algorithm, if the “set” pixel of certain threshold value range was extracted, the total area of collapsed buildings was calculated to be 86732.8m², as shown in Figure 10.

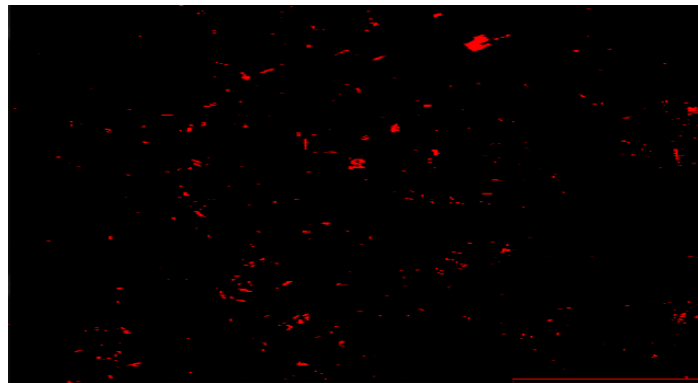


Figure.10. This is a Figure, it shows the extraction result of collapsed buildings.

4. Comparison between the prior seismic performance assessment with the proposed approach and the on-site inspection result of the area after the earthquake

The blocks of Dujiangyan are divided into districts, as shown in Figure 11.



Figure.11. This is a Figure, it shows the division of the districts of Dujiangyan.

According to the on-site inspection result of the collapse rate of block, the comparison between the prior seismic performance assessment and the on-site inspection results (the predicted collapse rates in the table are in condition of eight and nine degree intensity respectively).

Table 5. This is a table, it shows the comparison on the collapse rate between the prior seismic performance assessment and the on-site inspection after the earthquake of Dujiangyan

| Block Number | Seismic damage assessment results | Seismic damage prediction results | | Relative error | |
|--------------|-----------------------------------|-----------------------------------|----------|----------------|----------|
| | | 8 degree | 9 degree | 8 degree | 9 degree |
| 1 | 0.0737 | 0.0950 | 0.2046 | 29.0% | 177.7% |
| 2 | 0.0757 | 0.0930 | 0.2013 | 22.8% | 166.0% |
| 3 | 0.1374 | 0.1173 | 0.2399 | 14.6% | 74.6% |
| 4 | 0.0786 | 0.0878 | 0.1931 | 11.7% | 145.7% |
| 5 | 0.1071 | 0.1218 | 0.2471 | 13.8% | 130.7% |
| 6 | 0.1025 | 0.1291 | 0.2586 | 25.9% | 152.2% |
| 7 | 0.0516 | 0.0637 | 0.1549 | 23.4% | 200.3% |
| 8 | 0.0585 | 0.1077 | 0.2246 | 84.1% | 284.2% |
| 9 | 0.0000 | 0.0939 | 0.2028 | / | / |
| 10 | 0.0489 | 0.1122 | 0.2319 | 129.7% | 374.6% |
| 11 | 0.0838 | 0.1015 | 0.2148 | 21.1% | 156.5% |
| 12 | 0.1060 | 0.1145 | 0.2355 | 8.0% | 122.1% |
| 13 | 0.0455 | 0.1186 | 0.2420 | 160.7% | 431.9% |

| | | | | | |
|----|--------|--------|--------|--------|--------|
| 14 | 0.1072 | 0.0929 | 0.2013 | 13.3% | 87.8% |
| 15 | 0.2658 | 0.0945 | 0.2038 | 64.4% | 23.3% |
| 16 | 0.0965 | 0.1238 | 0.2503 | 28.4% | 159.4% |
| 17 | 0.0498 | 0.1149 | 0.2360 | 130.5% | 373.7% |
| 18 | 0.0257 | 0.1188 | 0.2424 | 361.7% | 841.4% |
| 19 | 0.1691 | 0.1291 | 0.2586 | 23.7% | 52.9% |

The collapse rate of the buildings for post-earthquake assessment is displayed by the 2-D image, as shown in Figure 12.

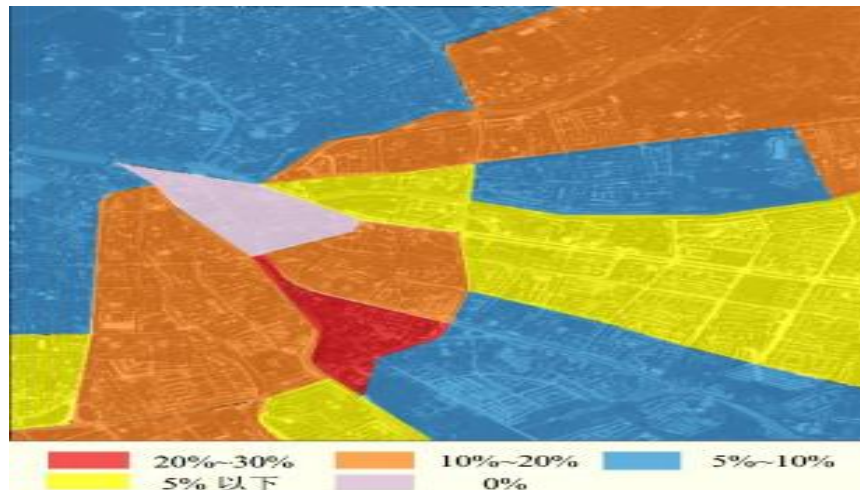


Figure.12. This is a Figure, it shows the colored graph of collapse rate.

5. Conclusion

According to the above analyses:

(1) The collapse rate of this area from the on-site inspection is close to the proposed prior assessment with the proposed approach here in the intensity of eight degree, which is also consistent with the seismic intensity released by China Earthquake Administration after Wenchuan earthquake[12], notice on Seismic fortification of the city's new construction and notice on seismic evaluation and reinforcement of urban buildings released by the Dujiangyan Construction Bureau in June 2008.

(2) The seismic damage matrix chosen in Chengdu and surrounding areas is accurate enough, especially for frame structure. Seismic damage prediction methods based on vulnerability analysis, and seismic damage matrix is feasible, and the results can be applied into earthquake prevention planning.

(3) The numerical deviation of masonry structure is relatively large. That is, the seismic damage matrix of Chengdu cannot apply to Dujiangyan well. Consequently, further study is necessary to calculate seismic damage matrix of masonry structure in similar areas with the considered area, i.e. Dujiangyan area. The proposed approach relies on the accurate choice of corresponding seismic damage matrix.

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