Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 789

BUILDING DAMAGE DISTRIBUTION IN THE SOUTHERN PART OF BEICHUAN COUNTY BY THE 2008 WENCHUAN, CHINA, EARTHQUAKE DETECTED FROM SATELLITE OPTICAL IMAGES

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ABSTRACT

In order to evaluate the building damage distribution in Beichuan county that is severely damaged in the 2008 Wenchuan, China, earthquake, visual damage detection is conducted to satellite optical images. ALOS and FORMOSAT images with the spatial resolution of 3m and 2m are used as pre- and post-event images, respectively. Locations of about 5,000 buildings are identified from the pre-event image. By comparing the characteristics of the buildings between the pre- and post-event images, damage level of each building is classified into three categories; complete collapse, severe damage and negligible to moderate damage. The result shows that about 45% of the buildings are classified into completely collapse or severe damage. The damage ratio in Qushan town, the capital of the county, is more than 80%. The distribution of the damage shows that the damage ratios on the hanging wall of the earthquake fault are higher than those on the footwall.

Introduction

On May 12, 2008, a gigantic inland earthquake (M_S8.0, M_W7.9) attacked the Sichuan province in China, that was named the 2008 Wenchuan, China, earthquake. About 87,000 people were killed or missing, 370,000 were injured, and more than six million houses were destroyed. Severe building damage is mainly distributed in mountainous areas along the fault. Landslides and slope failures buried lots of buildings in mountain villages.

After the Wenchuan earthquake, the International Charter was immediately activated and a lot of remote sensing data was acquired in the severely damaged areas (International Charter 2008). In the atlas complied by the Chinese remote sensing project team (Guo 2008), landslide areas, building damage areas, quake lakes, damaged road and infrastructures detected from the satellite images and aerial photographs are presented. It, however, seems that the building damage distribution has not been quantitatively evaluated in detail because the damaged areas are quite widely spread.

In this study, the distribution of the building damage in the southeastern part of Beichuan

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county that is one of the severely damaged areas is estimated from visual damage detection using pre- and post-event satellite optical images. The distribution of the building damage ratios calculated for each town is examined with respect to the locations of the towns and the earthquake fault.

Target Area and Satellite Images

Figure 1 shows the isoseismal map of the 2008 Wenchuan earthquake (China Earthquake Administration 2008) with the locations of major cities in Sichuan province, China. The seismic intensity scale in China almost corresponds to the Modified Mercari intensity scale. The seismic intensity XI areas are distributed not only in Wenchuan county located near the epicenter but also in Beichuan county located about 130km northeast from the epicenter.

Surface projection of the fault planes estimated by Koketsu et al. (2008) are also shown

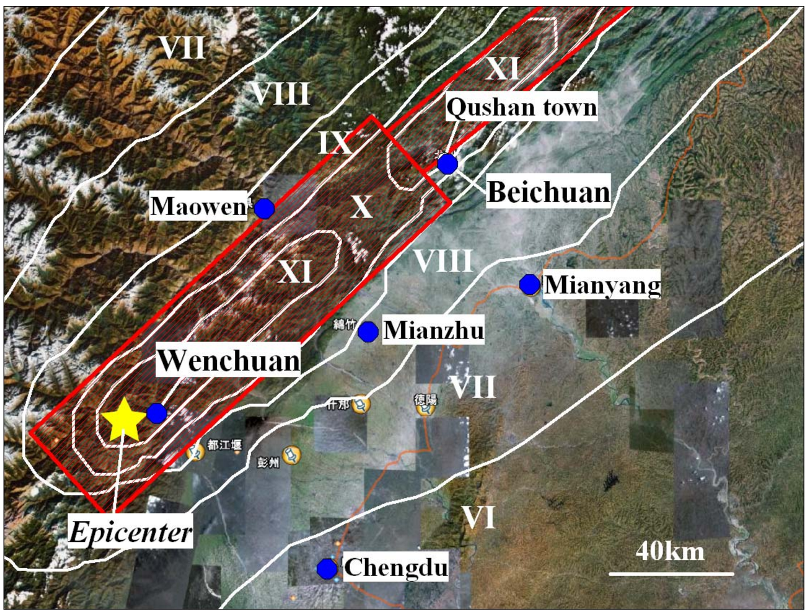


Figure 1 Isoseismal map of the 2008 Wenchuan, China, earthquake (China Earthquake Administraion 2008) with surface projection of fault planes (Koketsu et al. 2008)


Figure 2 Photograph at southern part of Qushan town, Beichuan county (Munich Re Group 2008)

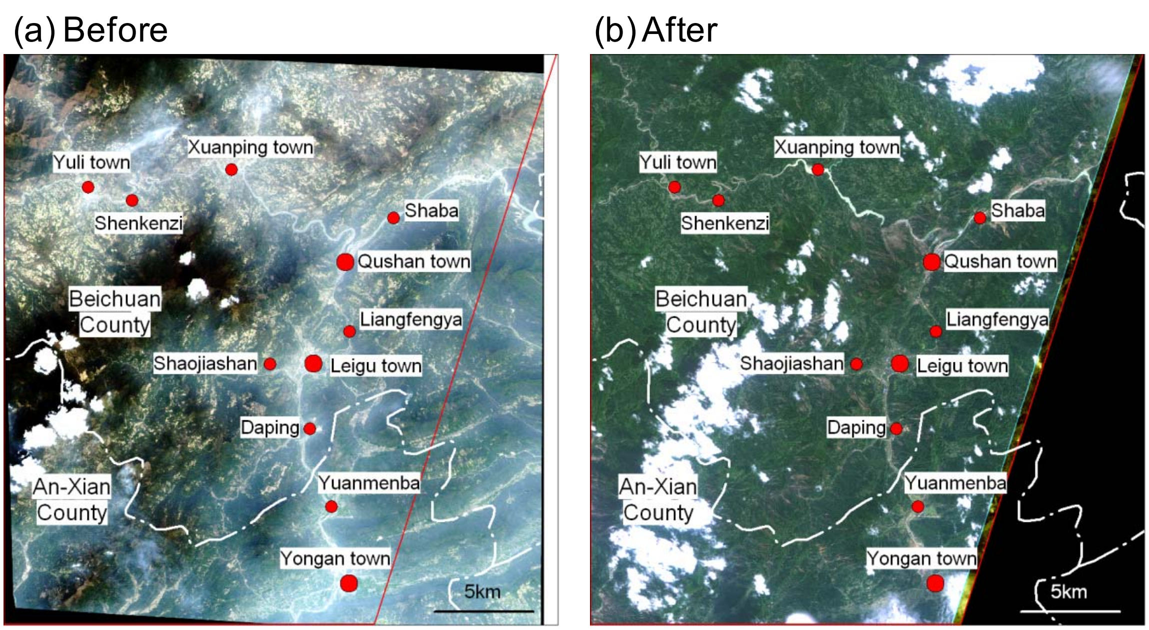
by solid rectangles in Fig. 1. The fault model was determined from distribution of the aftershocks, observed ground motion data, and the results of the field investigation of the surface ruptures (Hao et al. 2009). Two reverse faults dipping to northwest were estimated in the earthquake. The southern fault located beneath Wenchuan county has dip angle of 35 degree while the northern fault located beneath Beichuan county has dip angle of 65 degree. The lengths of the both faults are 140km.

The target area of this study is the southeastern part of Beichuan county that was severely damaged in the earthquake. Especially, Qushan town, the capital of the county, was catastrophically damaged. Figure 2 shows the aerial photograph observed in Qushan town just after the earthquake (Munich Re Group 2008). The photo shows that numerous buildings are collapsed and buried in debris of a large landslide. Number of the residents in the town was about 22,000 before the earthquake. About 12,000 people that correspond to 55% of the residents were killed in the earthquake. Because of the heavy damage, the town was abandoned and all the survived residents were evacuated from the town.

Unfortunately, high-resolution satellite images with spatial resolution of 1m or less, such as QuickBird and IKONOS, are not available in the target area because the area was covered with clouds during their observations. A FORMOSAT image with less clouds was urgently acquired two days after the earthquake and the image is used as a post-event image. The

Table 1 Characteristics of satellite images

Timing	Pre	Post
Date	Mar. 31, 2007	May 14, 2008
Sensor	Optical	Optical
Satellite	ALOS (PRISM/AVNIR2)	FORMOSAT
Resolution	3 m	2 m



Figures 3 Pre- and post-event images in Beichuan county

resolution of the image is 2m. The pre-event FORMOSAT image, however, is not available because the target area is located outside of the regular observation range. The pre-event image observed from ALOS (PRISM/AVNIR2) with the spatial resolution of 3m is used in this study. The characteristics of the images are shown in Table 1. Figures 3 (a) and (b) show the pan-sharpened images of the target area. The images cover 11 towns and villages in the southeastern part of Beichuan county and the northern part of Anxian county, extending 28km by 28km in NS and EW directions.

Visual Damage Detection

In order to evaluate the distribution of the building damage, visual damage detection is applied to the pre- and post-event images. Firstly, locations of the buildings are identified from the pre-event image by detecting object's shape, shadow, and color difference between the object

Figures 4 Pre- and post-event satellite images and ground photographs

and its background. Totally the locations of about 5,000 buildings are identified. Minimum building size identified in the image is approximately 10m, indicating that the buildings larger than 3pixels on the image are identified. It is, however, difficult to detect smaller buildings because the shapes and shadows of the buildings are not clear on the image. In this study, the damage of the buildings visually identified from the image are analyzed.

Field survey was conducted in October 2008 in Qushan town, Beichuan county to confirm the building damage and the landslides. Figures 4 show the comparison of the pre- and post-event satellite images and the ground photographs in the survey. Rectangles in the pre-event image represent the outlines of the buildings. In the completely collapsed building, the roof and outline of the building cannot be identified from the post-event image and many rubbles are observed around the building. In the severely damaged building, although the roof and outline of the building can be identified, the rubbles are observed around the building in the post-event image. In the negligibly damaged building, the significant change cannot be identified between the images.

Because it is difficult to classify moderate damage, slight damage and negligible damage even from a high-resolution satellite image (Miura et al. 2006), the damage levels are finally classified into three categories; complete collapse, severe damage, and negligible to moderate damage, that almost correspond to the damage grade 5, 4, and 1 to 3 in the European macroseismic scale (Grunthal 1998). The characteristics of the buildings in the post-event image for each damage level are summarized in Table 2. The buildings buried in debris of landslides and the buildings sunken in quake lakes are classified into complete collapse. The buildings located in shadows of clouds and mountains in the post-event images are classified into unknown. Based on the criteria shown in Table 2, the damage level for building by building is interpreted.

To examine the accuracy of the visual damage detection, the damage level classified by the satellite image is compared with the damage classified by the ground photographs and videos in the field survey at the central part of Qushan town. Table 3 shows the cross table for the

Table 2 Criteria for classification of building damage

Damage level	Characteristics of post-event image
Complete collapse	Roof and outline of building are not identified. Many rubbles are observed around building. Building is buried in soils of a landslide. Building sunken in a quake lake.
Severe damage	Rubbles are observed around building although roof and outline of building are identified. Damage on building roof is identified.
Negligible to moderate damage	Significant change on roof and around building is not identified.

Table 3 Cross table of damage level classified by satellite image and by ground photos

Damage level by ground photos	Damage level by satellite image				
	Negligible to moderate	Severe	Collapse	Total	Accuracy (%)
Negligible to moderate	9	2	1	12	75.0
Severe	3	12	2	17	70.6
Collapse	3	3	23	29	79.3
Total	15	17	26	58	44/58 =75.8%

number of the buildings classified by the satellite image and by the ground photos. The accuracy is calculated from the number of correctly classified buildings divided by the total for each damage level. Totally the damage for about 75% of the buildings is correctly classified. For the severely damaged building whose wall was cracked, the classification by the satellite image is underestimated because it is difficult to identify the crack of wall from the satellite image. For the collapsed buildings whose ground floor was vertically crushed while upper floors and roof were intact, the classification by the satellite image is also underestimated because it is difficult to identify the crush of ground floor from the satellite image.

Building Damage Distribution

The result of the visual detection of the building damage is shown in Fig. 5. The number of the damaged buildings and their percentages are summarized in Table 4. The numbers of completely collapsed and severely damaged buildings are 1,222 and 988 that are about 25% and 20% of the total, respectively. The number of negligibly to moderately damaged buildings is 2,652 that is about 50% of the total. The result shows that approximately 45% of the buildings are classified into severe damage or complete collapse in the area.

To discuss the extent of the building damage, damage ratio in each town and village is calculated from the result of the visual detection. The damage ratio is defined as the ratio of the

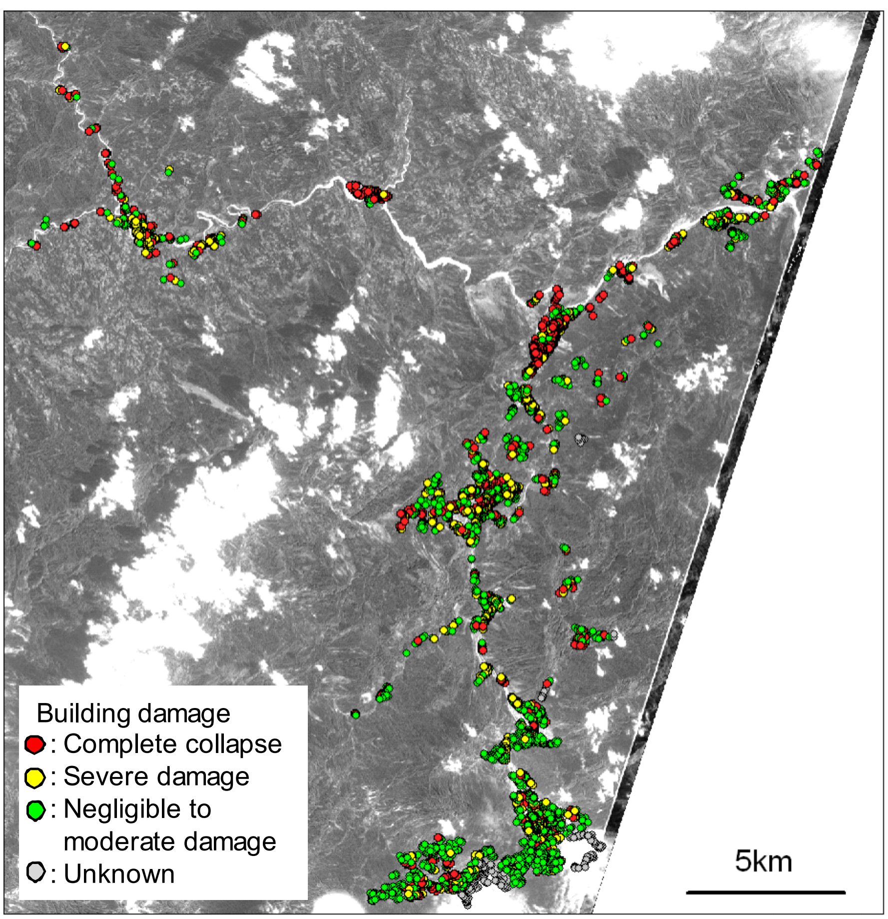


Figure 5 Result of building damage detection

number of the completely collapsed buildings and the severely damaged buildings to the number of the identified buildings. The damage ratios are calculated for totally 34 towns and villages. Figure 6 shows the distribution of the damage ratios. The damage ratios in Qushan town and Xuanping town are more than 80%. The damage ratios in Yuli town and Leigu town are about 50-60%. The damage ratio in Yongan town is about 20%. The result shows that most of the damage ratios in the northern part of the area are higher than 50% while those in the southern part of the area are lower than 50%.

The distribution of the damage ratios is evaluated with respect to the locations of the towns and the earthquake fault. The surface fault of the earthquake is shown by a dotted line in Fig. 6. Upper part of Fig. 7 shows the cross section of the damage ratios along the fault normal

Table 4 Number and percentage of classified buildings

Damage level	No. of buildings	Percentage (%)
Complete collapse	1,222	24.3
Severe damage	988	19.7
Negligible to moderate damage	2,652	52.8
Unknown	160	3.2
Total	5,022	100.0

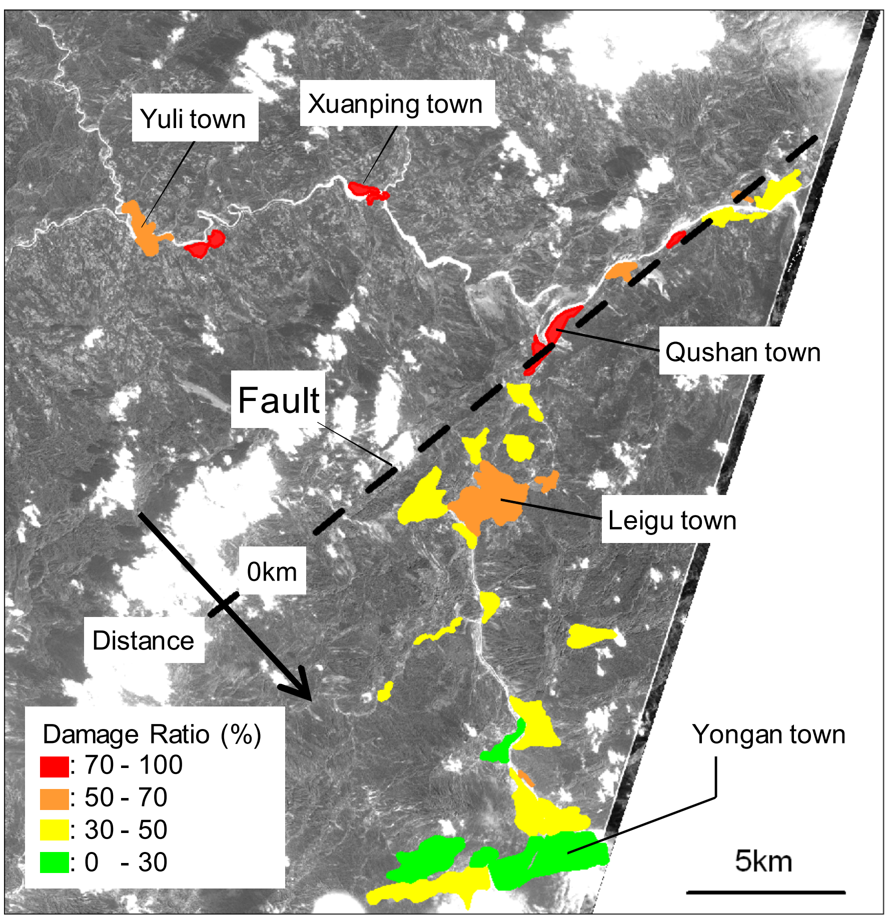


Figure 6 Distribution of damage ratios with fault line of the earthquake

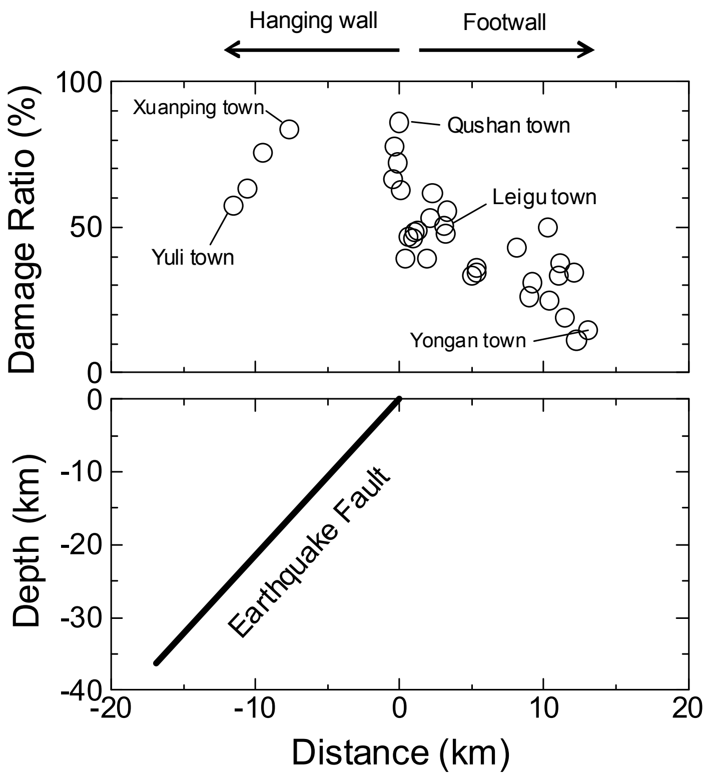


Figure 7 Cross section of damage ratios (upper) and fault (lower) for fault normal direction

direction as shown by an arrow in Fig. 6. Lower part of Fig. 7 shows the cross section of the fault. From the dip of the fault, the hanging wall side and the footwall side are classified as arrows in Fig. 7. The figure shows that the damage ratios on the hanging wall are higher than those on the footwall. In a dipping fault, sites located above the fault rupture on the hanging wall have larger ground motions than sites at the same rupture distance located on the footwall because the hanging wall sites are closer to the source area in total than the footwall sites. (Abrahamson and Somerville 1996). This effect would explain the higher damage ratios on the hanging wall area.

Conclusions

In this study, the visual damage detection technique is applied to the satellite optical images observed in the southeastern part of Beichuan county that is severely damaged in the 2008 Wenchuan, China, earthquake. ALOS and FORMOSAT images with the spatial resolution of 3m and 2m are used as pre- and post-event images, respectively. Locations of about 5,000 buildings are identified from the pre-event image. Minimum building size identified from the image is about 10m that corresponds to 3pixels on the image. By comparing the characteristics of the buildings between the pre- and post-event images, the damage level for each building is classified. The result shows that about 45% of the buildings are classified into complete collapse or severe damage in the area. Especially, more than 80% of the buildings in Qushan town, the capital of the county, are damaged. The distribution of the damage ratios calculated from the result of the damage detection indicates that the damage on the hanging wall of the earthquake fault is larger than that on the footwall.

Acknowledgments

A part of this study was done by the Global COE Program "International Urban Earthquake Engineering Center for Mitigating Seismic Mega Risk" supported by Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

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