DETECTION OF BUILDING COLLAPSE FROM THE SHADOW LENGTHS IN OPTICAL SATELLITE IMAGES

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ABSTRACT: Visual interpretation of optical satellite images is widely used to detect building damages after recent earthquakes in the world. However, since optical satellites images are acquired from the vertical direction, they can observe only roofs of buildings. Building damages such as mid-story collapse are often overlooked because the upper surfaces of buildings do not change so much. This paper proposes the method to detect this kind of building collapses from the change in building heights, estimated from the shadow lengths measured before and after an earthquake. Boumerdes city, Algeria, is selected as a case study site where many buildings were collapsed in the 2003 Boumerdes Earthquake. Two QuickBird images, taken before and two days after the earthquake, were employed for analysis. Base on the measurement of shadow lengths, some mid-story collapses were successfully detected, which could not be detected by visual interpretation. Although a limitation still remains in measuring shadow lengths in densely build-up or highly vegetated areas, the proposed method can help to reduce omission errors, which may be associated in visual damage interpretation of vertical satellite/aerial images.

1.INTRODUCTION

After a disaster such as earthquakes strikes, it is generally difficult to collect damage distributions if transportation networks are paralyzed or the damage ranges over a wide area. Satellite images are considered to be a solution for such problems since those can observe wide areas quickly, and hence their utilization technologies have been studied by many researchers to provide damage information for emergency response after a disaster strikes.

By the advent of high-resolution satellite sensors with the resolution of 50-60 cm, it is more expected for satellite images to be utilized widely since those enable to understand the detailed geometries of buildings. Visual interpretation of optical satellite images have been widely used to in order to detect building damages after earthquakes. Accuracy of this approach has been demonstrated by various researchers for the 2003 Bam, Iran Earthquake (Yamazaki and Yano, 2005), the 2006 Central Java, Indonesia Earthquake, and the 2007 Pisco, Peru Earthquake (Matsuzaki et al, 2010). In the 2010 Haiti earthquake, UNOSAT (2010) have carried out visual damage inspection for high-resolution satellite images from GeoEye-1 and WorldView-2. However, it is recognized that the building damages such as mid-story collapse were often overlooked by optical satellite images because they are generally acquired from the vertical direction, in which only the upper surfaces of buildings can be seen and thus such types of damage modes are mostly invisible. But it is considered to be possible to detect such damage modes by measuring the building heights based on two stereoscopic satellite images taken from slightly different positions at the same time. However, this method requires a total of four images before and after the earthquake to measure the change of building heights, and thus is not practical in terms of cost efficiency.

Mitomi et al. (2002) proposed the use of high-resolution remote sensing images to detect debris areas automatically by image processing. Azmi et al. (2004) proposed an analysis method for extracting the three-dimensional information from shadows in aerial photographs to build a wide range of virtual cities. Miura et al. (2004) proposed an automatic detection method of buildings using high-resolution satellite images for the purpose of updating GIS data in urban areas, by which the shadow length of a building is used to measure the number of stories with high accuracy.

This paper estimates the difference in the building heights before and after the 2003 Boumerdes Earthquake by measuring the shadow lengths to detect large structural damages such as mid-story collapse. Then, the detected building damages are compared with field survey data to verify the accuracy of the method.

2. THE 2003 BOUMERDES, ALGERIA EARTHQUAKE AND QUICKBIRD IMAGES

A strong earthquake with moment magnitude (M_w) of 6.8 struck the northern part of Algeria at 19:44 in local time on May 21, 2003. The epicenter was located at 36.90° N, 3.71° E (USGS, 2003), Boumerdes County, about 7 km north of Zemmouri city. Maximum ground acceleration of 0.58 Gal was recorded at Keddara. In the city of Bourmerdes, at least 2,266 people were killed, 10,261 injured, 150,000 homeless, and more than 1,243 buildings were damaged or destroyed.

This paper analyzes building damages for the 2004 Boumerdes earthquake using pre-, and post-event QuickBird images acquired on April 22, 2002 (before) and May 23, 2003 (two days after the earthquake) to detect the change of building heights from shadow lengths in Boumerdes city. Then these results are compared with the field survey data and the results of visual image interpretation by Meslem et al. (2009).

3. CLASSIFICATION OF BUILDING DAMEGES

Figure 1 shows the buildings damage classification levels according to the European Macroseismic Scale (EMS, 1998). In EMS-98, building damages are classified into 5 levels from Grades 1 to 5 based on observed structural damages. Figure 2 shows the examples of damage levels based on the visual inspection of the QuickBird satellite images, which were determined based on the difference between the pre- and post-event images. It is noted that the structural damages are mainly evaluated from buildings' top views and hence uncertainties and limitations exit in the damage level classification.

Meslem et al. (2009) analyzed the building damage in Boumerdes city after the 2003 Boumerdes, Algeria earthquake by comparing field survey results with the QuickBird satellite images. In the study, due to the difficulty in classifying the damage levels from the vertical optical images, the damage extent was classified into 4 levels: such that totally collapsed (Grade 5), partially collapsed (Grade 4), surrounded by debris (Grade 3), and combined Grade 1 and 2. Meslem et al. (2009) also performed the detailed analysis on the characteristics of buildings based on the field survey to identify the major factors influencing the earthquake resistance of those structures.

Since these data are available with the detail descriptions of each damaged buildings, this study further investigates a type of total collapse, mid-story collapse or first-story collapse, which is difficult to detect only from the texture of optical satellite images. Using the satellite images of Boumerdes city captured on April 22, 2002 and May 23, 2003, the damage levels of buildings in a part of the city were reevaluated based on the measurements of shadow lengths of the buildings in the pre- and post-event images.

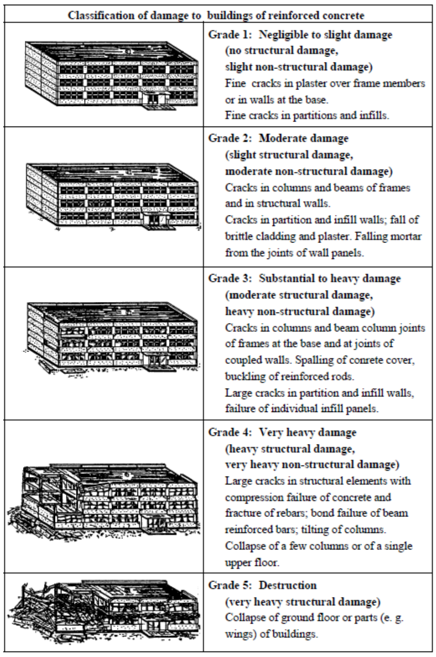

Figure 1 Classification of damage to masonry buildings (EMS, 1998)

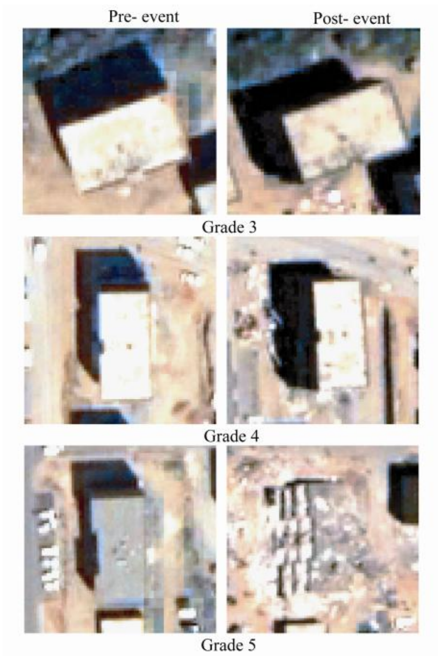

Figure 2 Typical pre- and post-event QuickBird images for Grades 3, 4 and 5 buildings

4. CALCULATION OF BUILDING HEIGHTS

The shadow length of a building in a satellite image differs depending on the view angle and position of the satellite sensor as well as the sun angle. Figure 3 shows the geometry of a 3D building and its cast shadow on the ground and the angles of sunlight and the satellite sensor. Table 1 shows the parameters of the pre- and post-event images, where λ, λ', α and α' are the satellite elevation angle, satellite azimuth, sun elevation angle and sun azimuth, respectively, as shown in Figure 3. Since the positions of the sun and the satellite are different for the pre- and post-event images, those parameters are also different, as listed in Table 1.

Figure 4 shows a sample 2D satellite image, showing the positions of a building's top, base and shadow. The top of the building is projected on position I in the 2D satellite image from the geometry in Figure 3 (Huang and Kwoh, 2007). This study measures the length between the top of a building and the corresponding point in the shadow projected onto the image, and calculates the actual building height using the azimuth and elevation angles of the sun and the satellite sensor.

By measuring the length of L_{is} in the image shown in Figure 4, the height of a building can be calculated by Equation (1). In this study, the length L_{is} was measured three times each to obtain the building heights before and after an earthquake. The change of the height of a building can easily obtained by subtracting the post-event height from the pre-event height.

$$H = \frac{L_{is}}{\sqrt{\frac{1}{\tan^2 \lambda'} + \frac{1}{\tan^2 \lambda} - \frac{2 \cdot \cos(\alpha - \alpha')}{\tan \lambda' \cdot \tan \lambda}}} \qquad (1)$$

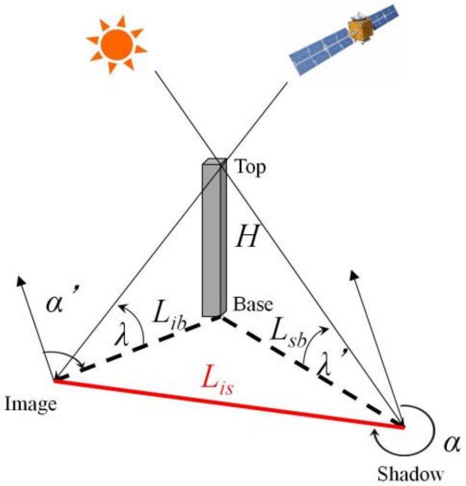

Figure 3. Schematic view of the sun, a satellite, a building, and its cast-shadow in a 3D space

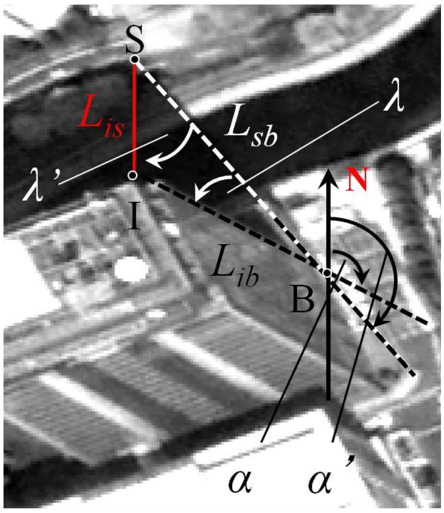

Figure 4. Geometric relationship and notations of the sun, a satellite, a building, and its shadow on a 2D image

Table 1. Parameters of the satellite images used in this study

	Before the EQ	After the EQ
Date and Time	2002/04/22 10:38	2003/05/23 10:36
Satellite Elevation λ	78.5°	64.2°
Satellite Azimuth α	352.6°	276.2°
Sun Elevation λ'	61.3°	68.2°
Sun Azimuth α'	144.2°	133.2°

5. DETECTION OF BUILDING COLLAPSE

It is expected that measurement errors of building heights effect on the result of building collapse detection. For example, the possible measurement error in a building height is approximately 1.57 m for the parameters in Table 1 if the errors in shadow length measurement are one pixel (0.6 m) each for the pre- and post-event images. If a mid-story collapse occurs for a building, the change of the building height is considered to be an order of 3 m, which corresponds to a typical story-height of ordinary residential buildings. Considering these, the threshold value of building-height reduction to judge as story-collapse was selected as 2 m in this study.

Figure 5 shows the results of damage classification based on the field survey (a) and visual inspection (b), and the change of building height (c) from the shadow length measurement. It is noted that the results of damage classification encircled in Figure 5 were underestimated in visual inspection compared with the field survey result. For these cases, the shadow-length measurement could reevaluate the damage level from Grade 4 to Grade 5.

Figure 6 shows the details of the buildings of satellite images classified as Grade 5 by field survey, but Grade 4 by visual inspection. It is noted that the classification of building damages between Grade 4 and Grade 5 is difficult if it only depends on the satellite images. However, with the use of estimated changes of building heights as shown in Figure 6, those classifications became much easier to distinguish Grade 5 damages from Grade 4. Note that the application of this method is limited to the cases such that shadow lengths are measurable. If buildings are surrounded by trees, cars, and other obstacles in measurement, the method cannot be used**.**

Misevaluation after measuring shadow lengths is also possible, as shown in Figure 7. This building was classified as Grade 4 in the field survey, but judged as Grade 5 after shadow-length measurement. In this case, the shadow length was measured shorter than the actual length because the shadow was casted over debris, which resulted in a larger change of the height for this building.

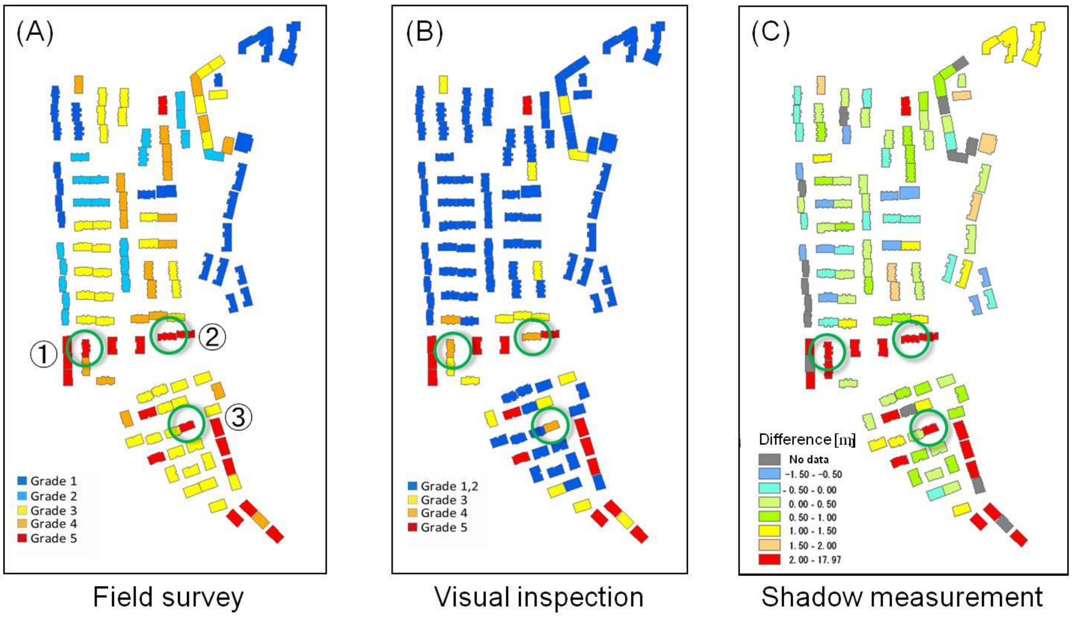

Figure 5 Comparison between the results from field survey, visual inspection, and shadow measurement

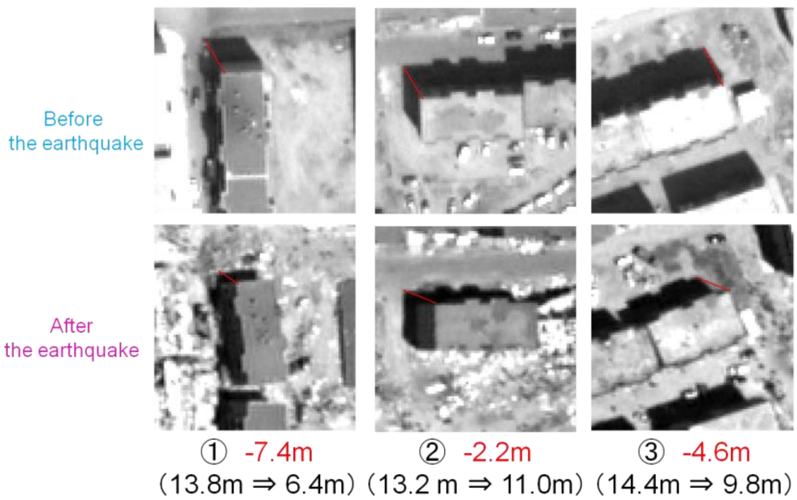

Figure 6 Comparison of the building heights before and after the earthquake for the buildings judged as Grade 4 by visual inspection

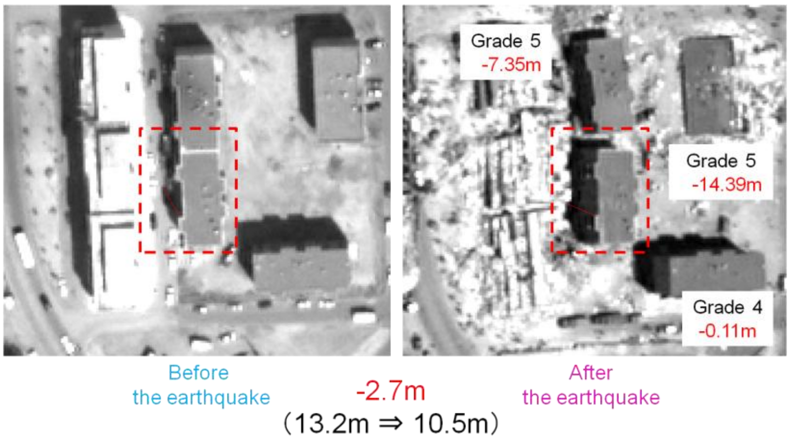

Figure 7 An example of error in shadow measurement

6. VERIFICATION OF ACCURACY

Table 2 shows an error matrix between visual inspection and field survey results while Table 3 reflects the shadow measurement result on Table 2. Comparing these tables, the producer accuracy increased from 83% to 100% for Grade 5 by introducing shadow-length measurement. However, the user accuracy for Grade 5 slightly decreased from 93.8% to 90.0% due to the misinterpretation of building damage in Figure 7. The proposed method has no effect on Grade1 to Grade3 because of no building height change for these damage levels.

Since the application of the proposed method is still limited to the small number of samples, these results should not be considered to be general. The applicability of the method is also affected by the surrounding conditions of a building, whether the shadow is measureable or not. In spite of these limitations, this method observes the physical changes of building height from the shadow length, and hence it will contribute to improve the accuracy of building damage extraction, especially for cases like mid-story collapse.

Table 2 Error matrix for the case of visual inspection of satellite images

QuickBird \ Field Survey	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Total	User's Accuracy
Grade 1,2	23	18	36	13	0	90	45.6%
Grade 3	0	1	7	8	0	16	43.8%
Grade 4	0	0	1	0	3	4	0.0%
Grade 5	0	0	0	0	15	16	93.8%
Total	23	19	44	21	18	126	
Producer's Accuracy	100.0%	94.7%	15.9%	0.0%	83.3%	Overall Accuracy	50.0%

Table 3 Error matrix for the case reflecting shadow measurement

QuickBird \ Field Survey	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Total	User's Accuracy
Grade 1,2	23	18	36	13	0	90	45.6%
Grade 3	0	1	7	7	0	15	46.7%
Grade 4	0	0	1	0	0	1	0.0%
Grade 5	0	0	0	1	18	20	90.0%
Total	23	19	44	21	18	126	
Producer's Accuracy	100.0%	94.7%	15.9%	0.0%	100.0%	Overall Accuracy	52.4%

7. CONCLUSIONS

This paper describes the methodology to detect large structural damages such as mid-story collapse by estimating the difference in building heights before and after an earthquake from shadow lengths. The method was applied to the building damages observed in Boumerdes city after the 2003 Boumerdes, Algeria earthquake, where a detail study on building damage is available from a field survey and visual interpretation of satellite images. The analysis results showed improvements of accuracy in damage detection for Grade 5 such as mid-story collapse, by differentiating those from Grade 4, which is not easy to detect from vertical satellite images. The proposed method is, however, still limited to favorable environmental conditions such that shadow lengths can be measureable without any obstacles. Since it takes time to measure shadow lengths manually from satellite image, a further study is suggested for automated extraction of shadow lengths.

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