DAMAGE DETECTION FROM QUICKBIRD HIGH-RESOLUTION SATELLITE IMAGES FOR THE 2003 BOUMERDES, ALGERIA EARTHQUAKE

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ABSTRACT: A strong earthquake of magnitude 6.8 struck the Mediterranean coast of Algeria on May 21, 2003 and the cities of Boumerdes and Zemmouri were most heavily damaged. QuickBird satellite observed these areas both before and after the earthquake. Using these images, the present authors performed visual damage detection of buildings. Using the post-event pan-sharpened image only, totally collapsed buildings, partially collapsed buildings, and buildings surrounded by debris were identified. Some buildings were difficult to judge their damage levels, and thus, the pre-event image was also employed as a reference to judge the damage status. By this visual inspection, a total 3,446 buildings were classified in Boumerdes and 1,399 in Zemmouri based on their damage grades. The locations of refugee tents in the two post-event images were also identified. These observations indicate that high-resolution satellite images can provide quite useful information to emergency management after natural disasters.

KEYWORDS: damage detection, remote sensing, high-resolution satellite image, the 2003 Algeria Earthquake.

1. INTRODUCTION

Recent advancements in remote sensing and its application technologies made it possible to use remotely sensed imagery for assessing vulnerability of urban areas and for capturing damage distribution due to natural disasters. Especially it is important for emergency management and recovery works to capture damage distribution immediately after an earthquake or other disasters. For example, through the experience of the 1995 Hyogoken-Nanbu (Kobe) earthquake, it was emphasized that the information about damages should be obtained at an early stage.

Since remote sensing data observed by various platforms have both advantage and disadvantage in immediacy and resolution, it is necessary to consider the characteristics of each platform and sensor and the quality of data when they are used. In order to examine the applicability of remote sensing technologies to emergency management after earthquakes, Hasegawa et al. (2000) performed visual damage detection using aerial images from high-definition television cameras, and Ogawa and Yamazaki (2000) performed visual detection using aerial photographs. These kinds of images can identify individual buildings but they cannot cover a wide area with one acquisition time. On the other hand, satellite images have an advantage to observe a large area at one time. Capability of optical/SAR satellite imagery has been demonstrated for damage detection in large-scale natural disasters. Matsuoka et al. (2001) investigated the characteristics of the pre- and post-event optical satellite images in the damaged areas due to the 1995 Kobe earthquake and Matsuoka and Yamazaki (2000) investigated the changes in the characteristics of SAR intensity images due to several recent earthquakes. However, the spatial resolution of these satellite images is from 20 m to 30 m. Hence, it is difficult to identify the damage of individual buildings and bridges from these images.

It is worth mentioning that QuickBird, a high-resolution commercial satellite with the maximum spatial resolution of 0.6 m, has been launched successfully on October 18, 2001 and it acquires optical images of urban areas, in which individual buildings can be identified. Hence, these images can be used to detect damages of individual buildings and infrastructures after natural disasters. Using the images obtained by QuickBird after the 21 May, 2003 Algeria earthquake, this paper presents the results of visual damage detection for the urban areas of Boumerdes and Zemmouri for the purpose of evaluating the capability of high-resolution optical satellite images.

2. THE 2003 ALGERIA EARTHQUAKE AND QUICKBIRD IMAGES

A strong earthquake of magnitude 6.8 struck the Mediterranean coast of Algeria on May 21, 2003. The epicenter was located at 36.90N, 3.71E (USGS), offshore of the province of Boumerdes, about 50 km east of the capital city, Algiers (Fig. 1). According to the last official report from National Earthquake Engineering Center of Algeria, 2,278 people were killed, more than 10,000 were injured and about 180,000 people were made homeless. The summary of the building damage assessment in the province of Algiers and Boumerdes, which were most heavily damaged areas, is shown in Table 1 (Belazougui et al., 2003).

QuickBird satellite observed the areas of Boumerdes City and Zemmouri City in the province of Boumerdes. The images of Boumerdes City were taken about one year before (April 22, 2002), two days after (May 23, 2003) and 28 days after the event (June 18, 2003), and those of Zemmouri City were obtained 8 days before (May 13, 2003), two days after (May 23, 2003) and 23 days (June 13, 2003) after the event. These images are considered to be the first sets of clear images acquired by civilian high-resolution satellites both before and after a severe earthquake disaster. In order to observe target areas in a short time interval, QuickBird can change the view angle of its sensors. Thus these three images have different off nadir view angles: 11.2, 24.3, and 7.8 degrees for Boumerdes images, 8.7,

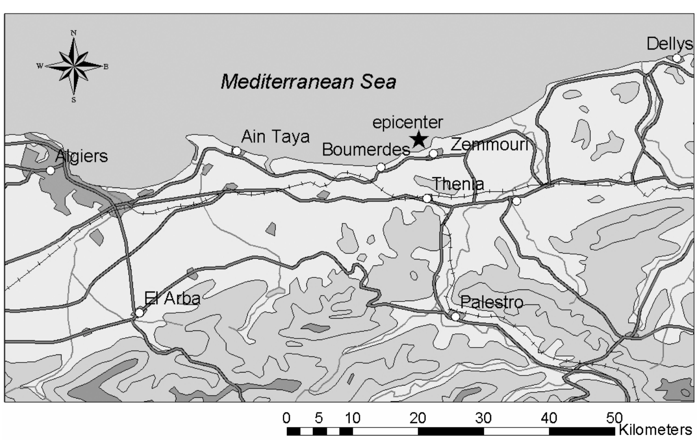


Figure 1. Epicenter and damaged cities in the north of Algeria.

Table 1. Building damage due to the earthquake (Belazougui et al. 2003)**.**

Province	Algiers	Boumerdes
Destroyed	about 8,500	about 7,400
Heavily Damaged	more than 20,000	about 7,000

24.4 and 15.7 degrees for Zemmouri images. Hence it is by no means easy to superpose these images exactly, especially in the areas where tall buildings are located, and to perform automated change detection. The difference in shadows of buildings on the different acquisition dates gives additional difficulty. Thus visual damage interpretation was performed as a first trial in this study.

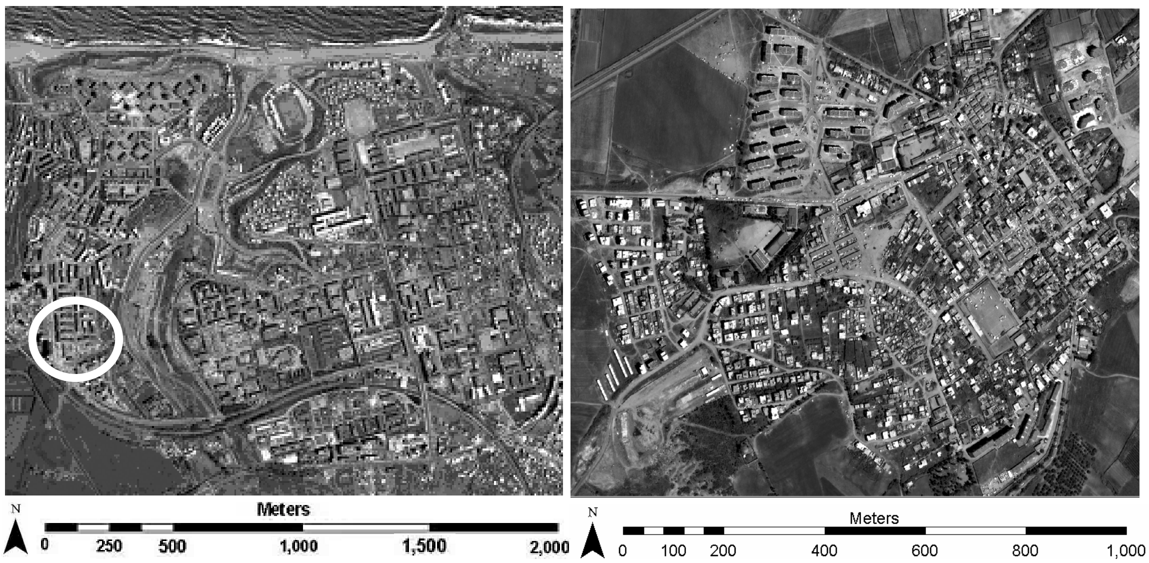


Figure 2. Pan-sharpened natural color QuickBird images acquired on May 23, 2003 (left: Boumerdes, right: Zemmouri).

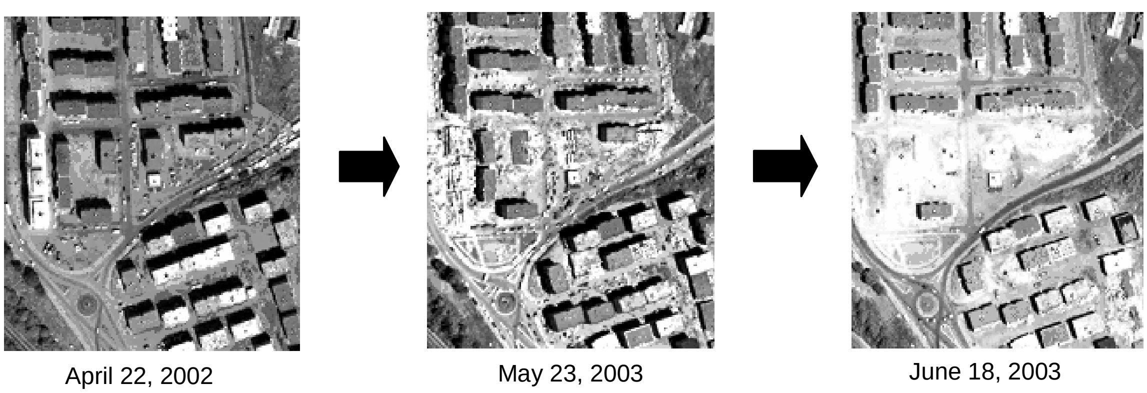


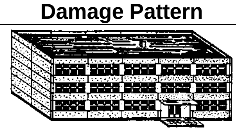
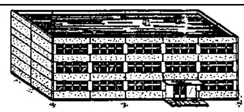
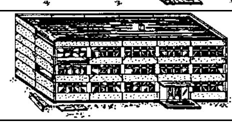
Figure 3. Example of time series images of a heavily damaged area (circled area in Fig. 2).

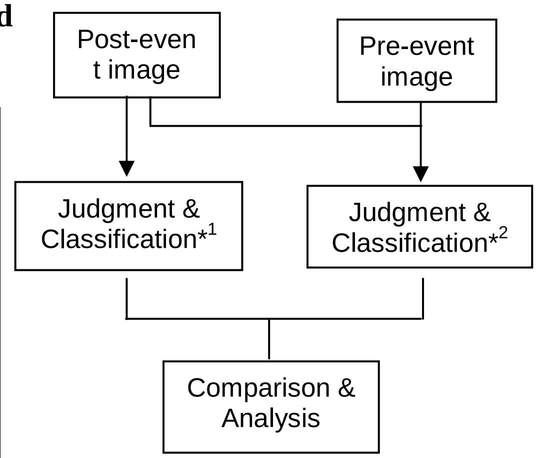
First, pan-sharpened images were produced by combining panchromatic images of 0.6 m resolution and multi-spectral images of 2.4 m resolution, as shown in Fig. 2. By this image enhancement, buildings, cars and debris can clearly be seen. Three pan-sharpened images (a pre-event, and two post-event images) were produced for each city and they were used in visual inspection of building damage. Figure 3 shows a typical area in Boumerdes where many collapsed buildings are observed in the post-event images. Debris of collapsed buildings can be seen in the image of two days after the event and cleaning-up of debris in the image of 28 days after the event.

3. VISUAL BUILDING DAMAGE DETECTION OF BOUMERDES CITY

Visual inspection of building damage was conducted based on the classification in the European Macroseismic Scale (EMS, 1998), shown in Table 2. Using only the post-event (May 23, 2003) image and using both the pre- and post-event images, buildings surrounded by debris (Grade 3), partially collapsed buildings (Grade 4) and totally collapsed buildings (Grade 5) were identified. According to the flowchart shown in Fig. 4, the damage levels of buildings were classified.

Table 2. Classification of damage to reinforced concrete buildings (EMS, 1998)**.**

Damage Pattern	Damage Level
	**Grade 1**: Negligible to slight damage (no structural damage, slight non-structural damage)
	**Grade 2**: Moderate damage (slight structural damage, moderate non-structural damage)
	**Grade 3**: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)
	**Grade 4**: Very heavy damage (heavy structural damage, very heavy non-structural damage)
	**Grade 5**: Destruction (very heavy structural damage)



*1: Classify into Unclear, Grade 1or 2, Grade 3, Grade 4 and Grade 5
*2: Classify into Grade 1 or 2, Grade 3, Grade 4 and Grade 5

Figure 4. Flowchart to classify building damage

Figure 5 shows the comparison between satellite images and on-site photographs. In the satellite images, circle symbol means "Grade 1 or 2", triangle "Grade 3", diamond "Grade 4" and star "Grade 5", respectively. The left satellite image in Fig. 5 shows an example of a highly damaged area. Buildings 'a' and 'b' are judged as Grade 4 based on visual interpretation. Compared with the ground photographs, it is observed that story collapses like these buildings are hardly judged with confidence from vertical images because the settlements are mostly to the vertical direction.

Furthermore, compared with the ground photographs, some buildings were judged incorrectly when little debris spreads or debris spreads in the shadow of buildings.

The right photographs in Fig. 5 show the buildings in the south campus of Boumerdes University. Building 'c' is judged as Grade 5 and Building 'd' as Grade 1 or 2 based on visual interpretation. The ground photograph verifies the accuracy of the judgment for Building c since their damages are apparent even from the vertical direction. Although Building 'd' was judged as no to moderate damage (Grade1 or 2), the ground photograph indicates that it suffered from some damage (Grade 2 or Grade 3), especially inside the building. The field observation revealed that the debris seen in the photographs were gathered between the buildings in the stage of clearing works. These examples show difficulty to identify damages less than Grade 3. In the area of ‘e’, refugee tents can also be seen.

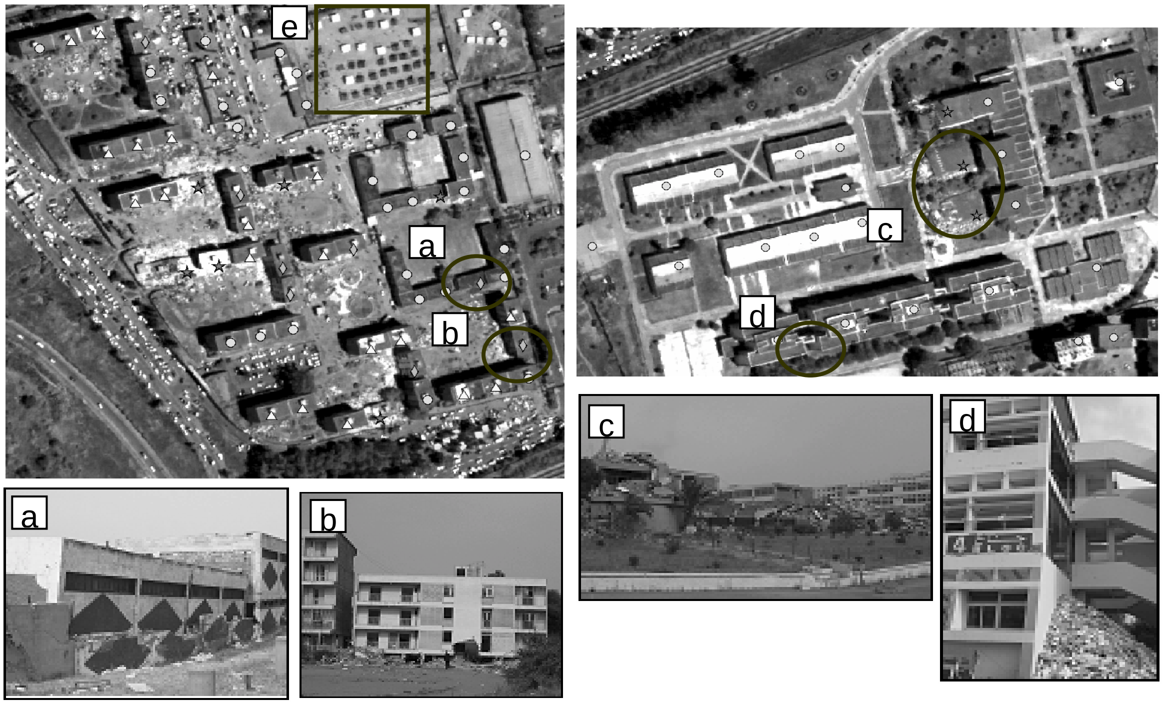


Figure 5. Comparison between the satellite images and the on-site photographs (the on-site photographs are by courtesy of Prof. K. Meguro of The University of Tokyo)**.**

By this visual interpretation, a total 3,446 buildings were classified based on their damage grades. The numbers of identified damaged buildings were 70, 29, 47, and 538 for Grades 3, 4, 5, and “Unclear”, respectively, based on only the post-event image of May 23. The numbers of identified damaged buildings were 261, 54 and 71 for Grades 3, 4 and 5, respectively, based on both the pre- and post-event images. The remaining buildings were identified as Grade 1 or 2. The numbers of identified damaged buildings using the pre- and post-event images are 3.7 times of that using only the post-event image for Grade 3, 1.9 times for Grade 4, and 1.5 times for Grade 5 (Fig. 6). Thus, the pre-event image was found to be more important for the detection of lower damage grades in visual interpretation.

Table 3. Damage levels of buildings used in the field survey by Algerian engineers

Level	Damage-Level	Description
1	N...	Only dis... ...niture and broken glasses.
2	L... w	Cracks ...d in ceilings; damage to water lines; non-stuctural and isolated ...
3	M... derate	Importa... ...-structural parts and weak damage to structural parts.
4	High / Important	...ctural damage and very extensive structural damage. Cracks ...s; rupture or hinging of beam-column joints.
5	Very High / Very Important	Condemned or collapsed buildings

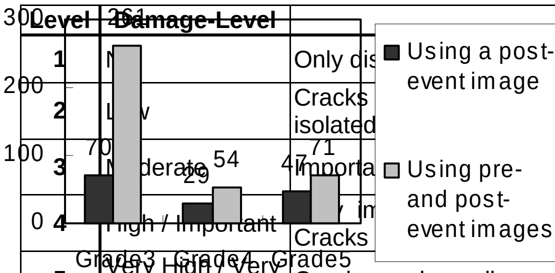


Figure 6. Number of damaged buildings by visual detection of Boumerdes

Table 4. Comparison of damaged building ratios between the field survey and the visual inspection of the satellite images

	Field survey	Visual detection
Grade/Level 1or2	1709 (54.9%)	3060 (88.8%)
Grade/Level 3	536 (17.2%)	261 (7.57%)
Grade/Level 4	301 (9.67%)	54 (1.57%)
Grade/Level 5	566 (18.2%)	71 (2.06%)
Total	3112 (100%)	3446 (100%)
Tents	2808	3150*

*: the number was counted based on June-18 image

Next, this result was compared with the data from a field survey, which started one week after the event by Algerian engineers. The number of damaged buildings was counted in almost the same area as that of the visual detection. The differences in the numbers of buildings and tents indicate that the area of the field survey is slightly smaller in size than that of our visual inspection. In the field survey, the damage assessment was conducted based on the classification shown in Table 3, which has 5 damage levels and is similar to EMS, 1998. Table 4 shows comparison of damaged building ratios between the field survey and the visual detection from the satellite images. The damage ratios based on the visual damage detection would be underestimated compared with those based on the field survey. In order to examine the difference between the damages identified the visual detection and the actual damages, more detailed ground truth data are required.

A total of 3,446 buildings were classified based on their damage grades as shown in Fig. 7(a). The ratio of damaged buildings to the total and that of Grade 5 buildings to the total in each city block (surrounded by major roads, total 31 blocks) were calculated and shown in Fig. 7(b) and 7(c), respectively. The blocks with high damage ratios were located along two rivers. This damage concentration may be explained by soft-soil condition and high site amplification in these areas (JSCE, 2004). Considering both the ratios of damaged buildings and the proportion of Grades 3 to 5 in each block, the damage states and characteristics can be grasped in more detail. The locations of refugee tents in the two post-event images were identified as shown in Figure 7(d). A total of 284 tents were observed in the May 23, 2003 image and the number increased to 3,150 in the June 18, 2003 image. Many tents can be seen in the open spaces of residential areas and in athletic fields. Thus it is said to be important to allocate open spaces, e.g. parks, properly in urban planning. These observations on building damage and refugee tents indicate that high-resolution satellite images can provide quite useful information to post-event disaster management.

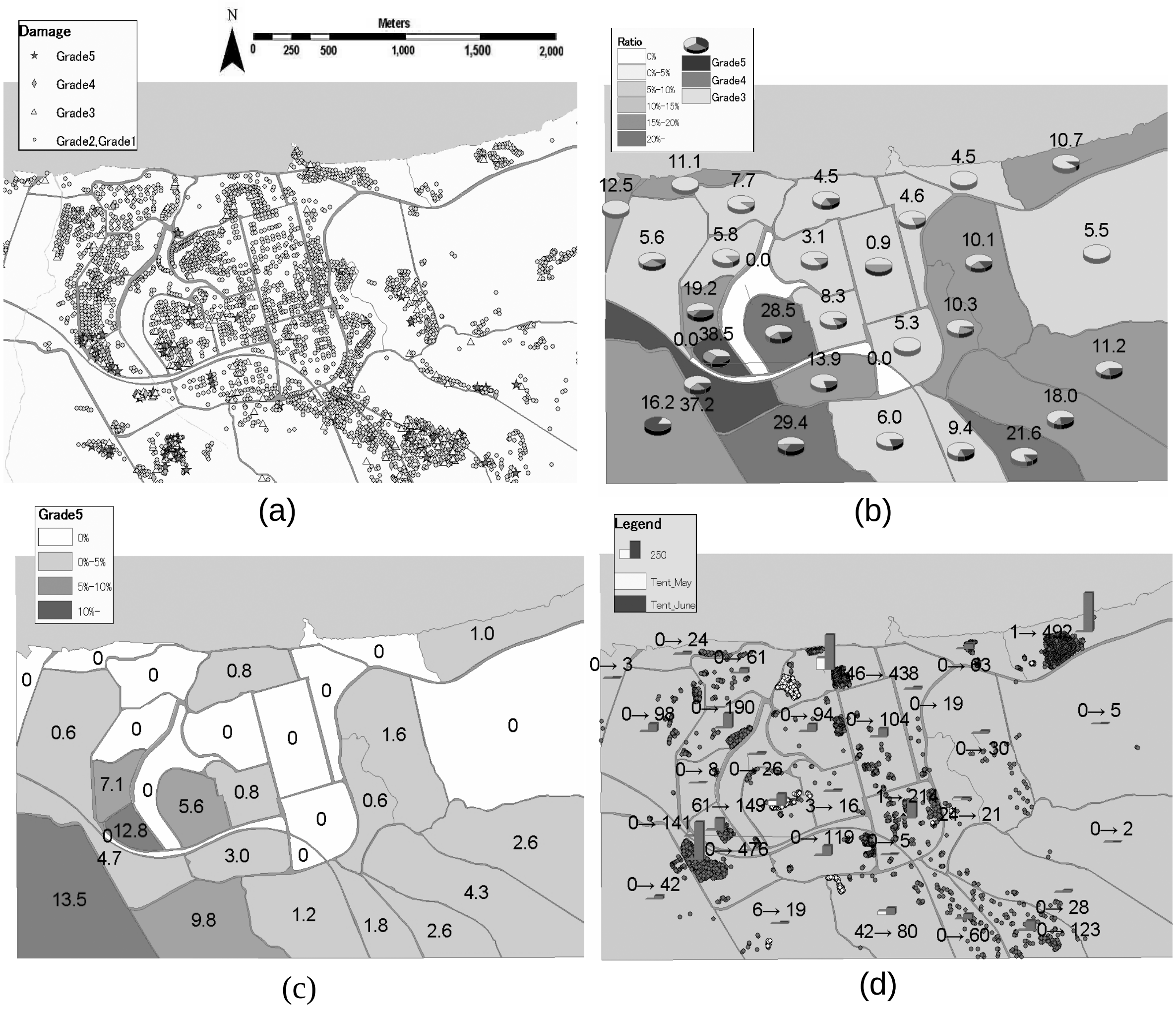


Figure 7. Damage and tent distribution map. (a) total 3,446 buildings classified based on their damage grads, (b) the ratio of damage buildings in each city block, (c) the ratio of Grade5 buildings in each city block, (d) the locations of tents in the two post-event images

4. VISUAL BUILDING DAMAGE DETECTION OF ZEMMOURI CITY

Using the images of Zemmouri City, the visual inspection of building damage was conducted based on the same classification as stated before (Fig. 4). For the purpose to obtain more confidence in the result of visual detection, five persons (actually the authors of this paper, who are researchers and graduate students in the fields of structural engineering) conducted visual inspection and the differences among their results were investigated.

Figure 8 shows the flowchart to determine “the majority damage level” from the individual detection results. First, comparing the number of persons who classified a building as “no damage” (Grade 1 or 2) with that as “damaged” (a total of Grades 3 to 5), if the former is majority, the damage level of the building is determined as “Grade 1 or 2”. If not, the damage level is determined in the next stage, by comparing between the numbers of persons who classified it as Grade 3, 4 or 5. Even after this procedure, the damage grade of some buildings cannot be determined. If the result by the five persons includes Grade 3 to 5, the damage level is classified as Grade 4. Otherwise the damage level is classified as the severer level.

The detection results of the five interpreters and the majority grade using both the pre- and post-event images are shown in Table 5. Figure 9(a) shows the breakdown of the buildings classified as Grades 1 or 2 to 5. The numbers of buildings classified to the majority damage levels were 35, 62, and 174 for Grades 3, 4, and 5, respectively, based on the pre- and post-event images. The other 1,128 buildings were classified as Grade 1 or 2 out of a total of 1,399 buildings. The interpreters #1 and #2 tend to judge the damage to severer levels than the others. Consequently, through the first majority decision rule, the interpreters #3, #4 and #5 became the majority in many cases.

The variations of the number of buildings identified as lower damage levels are large among the five interpreters. In the majority results, the number of buildings for lower levels is smaller than highest level (Grade 5). Based on the variations, it seems to be more difficult to determine the damage levels and to reach a consensus for smaller damaged levels.

The differences of the numbers of classified levels between using only the post-event image and using both the pre- and post-event images are shown in Fig. 9(b). In the results for Grades 3, 4 and 5, the difference for lower levels is seen to be larger. Especially the difference of the numbers of Grade 3 buildings is about one hundred for the interpreters #1, #4 and #5. Hence it may be difficult to identify buildings as Grade 3 by using only a post-event image.

The average number of interpreters who classify damage level same as the majority level is shown in Fig. 9(c). The numbers of Grade 1 or 2 and 5 are larger than those of Grade 3 and 4. The identifications of “collapse (Grade 5)” of “no or slight damage (Grade 1 or 2)” do not vary much and although it is necessary to evaluate the accuracy of the detection results based on ground truth

data. On the other hand it is difficult to reach a consensus for identifications of “moderate damage (Grade 3)” or “partially collapse (Grade 4)”. The average numbers in each grade based on the two images inspection are larger than those based on the one image inspection. Hence the detection results based on the two images can be said more stable than those based on the one image.

Figure 10 shows comparison between the satellite image and the on-site video pictures. In the satellite image, circle symbol means "Grade 1 or 2", triangle "Grade 3", diamond "Grade 4", star "Grade 5", respectively. The right-side pictures show a damaged low-rise house (the lower picture) and damaged/collapsed tall buildings (the upper one), which are examples that the detection results using satellite images are verified by ground photographs.

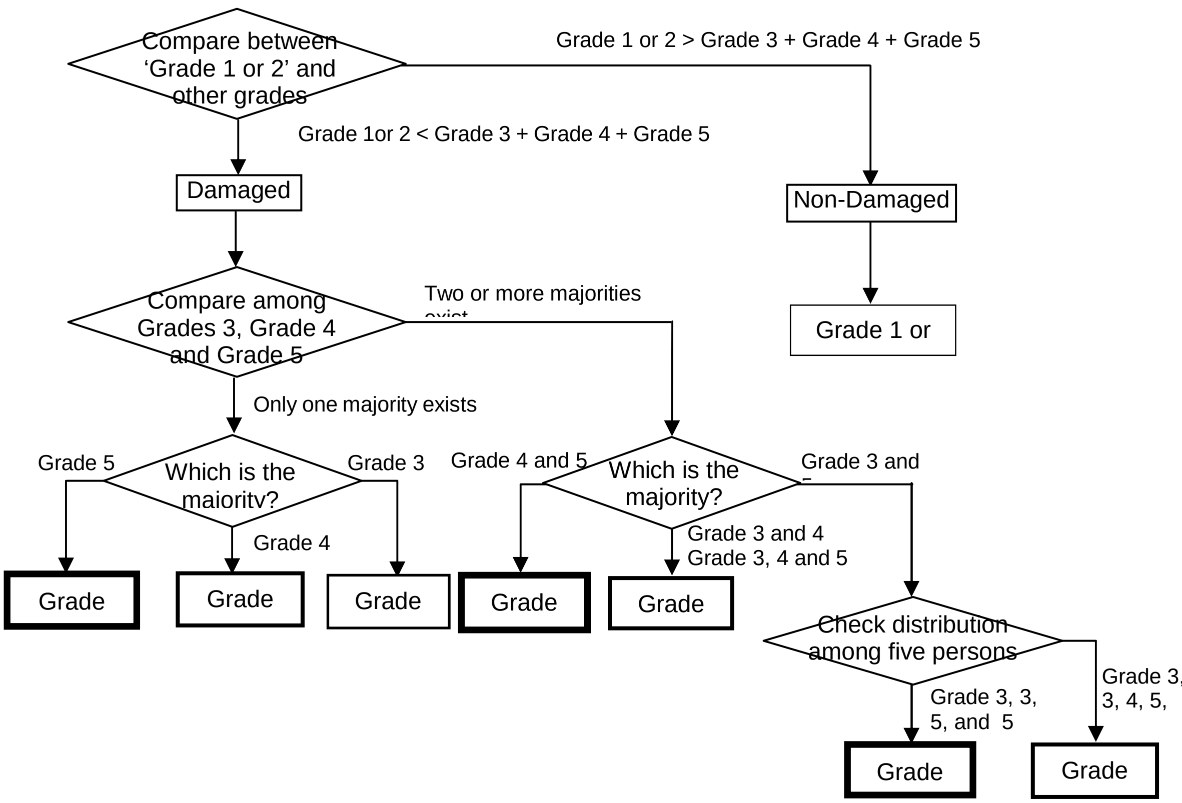


Figure 8. Flowchart to decide the majority damage level from the results by the five interpreters

Table 5. Comparison of the detection results of the five interpreters

Interpreter		#1	#2	#3	#4	#5	Majority
Grade 1 or 2		923	973	1168	1122	1120	1128
Grade 3		200	107	4	73	65	35
Grade 4		96	128	78	56	32	62
Grade 5		180	191	149	148	182	174
Total		1399	1399	1399	1399	1399	1399
Detection time (hours)	Using one image	2.5	4	3	4	2.5	-
	Using two images	5	3.5	4.5	5	2.5	-

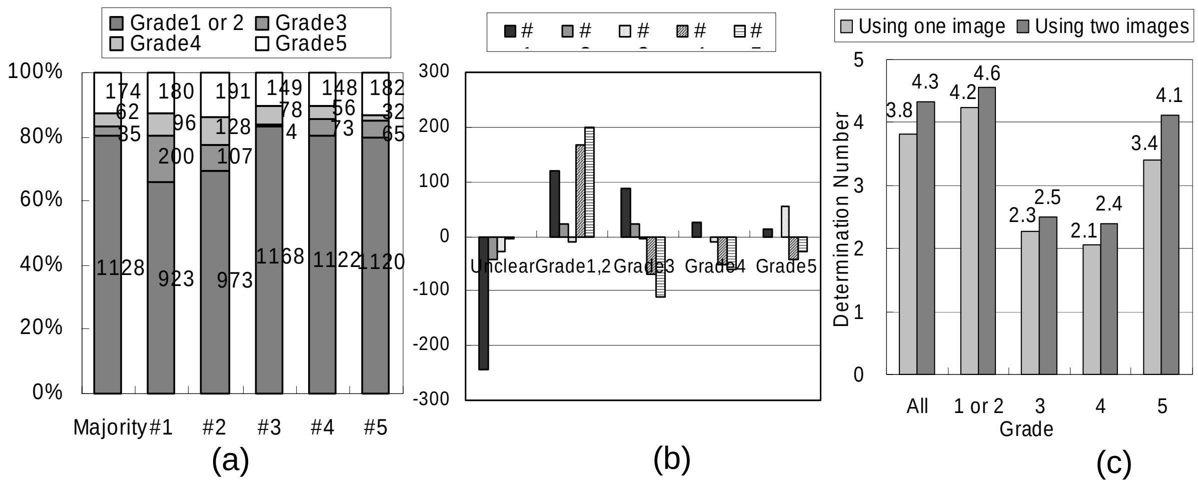


Figure 9. Comparison of the detection results of the five interpreters. (a) the number of classified levels using the pre- and post-event images, (b) difference of the numbers of classified levels between using only the post-event image and using the pre- and post-event images, (c) Average number of interpreters who determine damage level same as the majority level ("Determination Number").

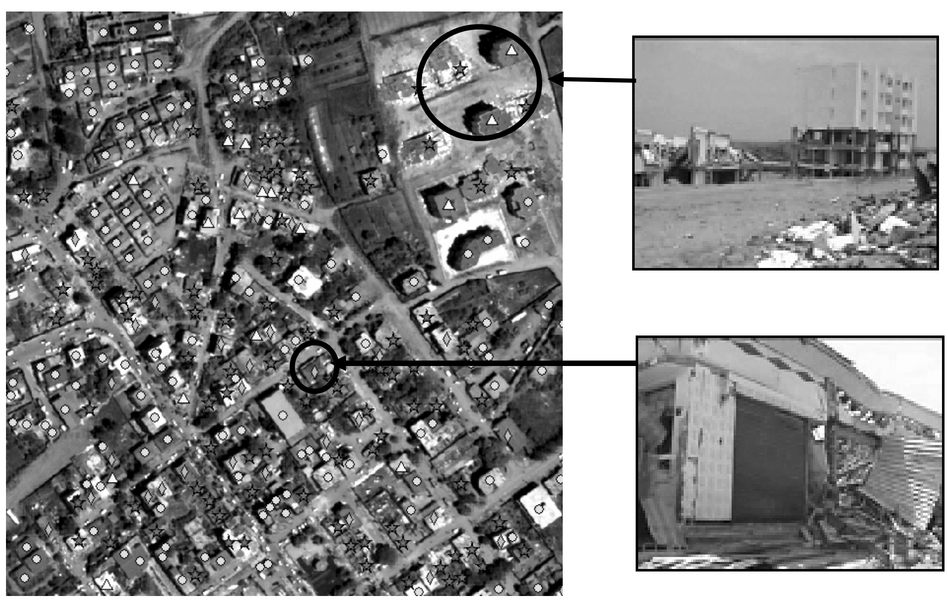


Figure 10. Comparison between the satellite images and on-site video pictures (the on-site video pictures are by courtesy of National Earthquake Engineering Center of Algeria)**.**

A total of 1,399 buildings in Zemmouri were classified based on their damage grades as shown in Figure 11(a). The damage ratios of buildings in each city block (a total 15 blocks) were calculated and shown in Figures 11(b) and 11(c). The locations of tents in the two post-event images were also identified (Figure 11(d)). The distribution of damaged buildings and tents can clearly be observed in QuickBird images of Zemmouri also.

Figure 12(a) and (b) show the damage map in Zemmouri evaluated by the United States Government, which is available on Internet (UN-OCHA, 2003), and the result of this study. We contacted UN-OCHA about the data source, but only reply we received is “It used a variety of
classified and unclassified aerial and satellite remote sensing images.” Although these two interpretation results are very close, there is possibility that they also used QuickBird images as a part of data source.

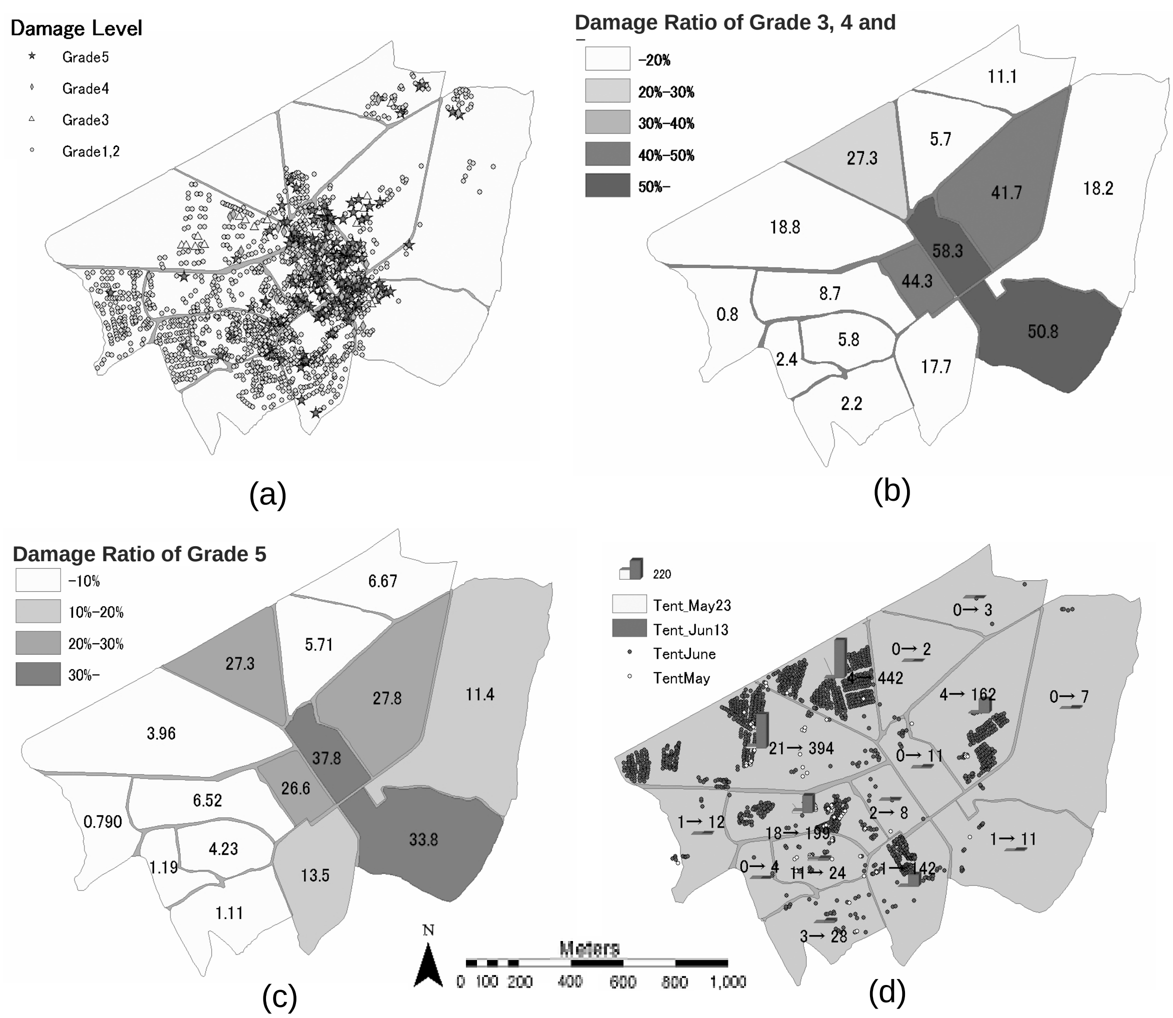


Figure 11. Building damage and tent distribution maps. (a) 1,399 buildings classified based on their damage grades, (b) the ratio of damaged buildings in each city block,

(c) the ratio of Grade5 buildings in each city block, (d) the location of tents in the two post-event images

Among the five interpreters, the interpreter #1 conducted visual detection for both Boumerdes and Zemmouri images. It should be pointed out that the damage ratio of buildings was different by the one-image and two-image interpretations. For Boumerdes, the difference in the ratios is 17.1% (of which the buildings identified as "Unclear" based on one image was 15.6%) and for Zemmouri 23.2% (of which 17.5% unclear). Hence, it is more difficult to classify damaged buildings in the post-event image of Zemmouri than that of Boumerdes. The satellite images of Zemmouri indicate that there are more low-rise buildings placed close together. This may explain the difference of difficulty into image interpretation.

Future research is suggested on the relationship between the damage ratio and building type, the accuracy of interpretation, and the application of automated damage detection.

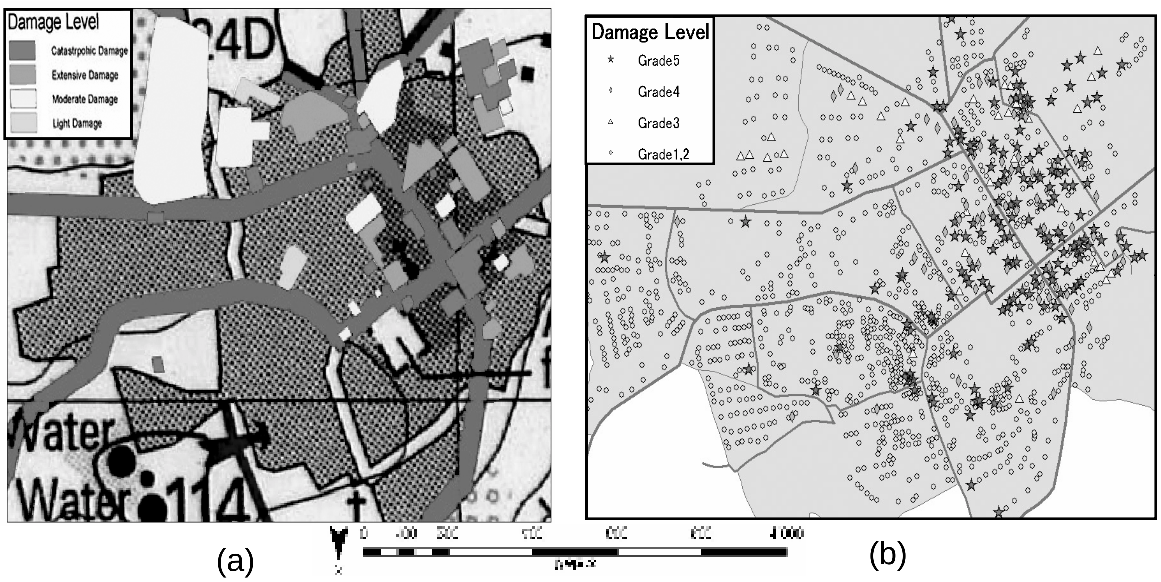


Figure 12. (a) Damage map for Zemmouri evaluated by the United States Government (UN-OCHA, 2003), (b) our detection result

5. CONCLUSIONS

Using the high-resolution satellite images of Boumerdes City and Zemmouri City acquired by QuickBird before and after the 21 May, 2003 Algeria earthquake, visual interpretation of building damage was conducted. Using only the post-event pan-sharpened image, buildings surrounded by debris (Grade 3), partially collapsed buildings (Grade 4), and totally collapsed buildings (Grade 5) were identified. Some buildings were difficult to judge their damage levels, and thus, the pre-event image was also employed as a reference to judge the damage levels. By this visual inspection, a total of 3,446 buildings were classified in Boumerdes and 1,399 in Zemmouri. The locations of refugee tents in the two post-event images were also detected. In case of Zemmouri, five persons conducted the visual damage detection, and all of them could classify at least 80 percent of the buildings as the same level as the majority damage level among the five. The detailed ground truth data are required in order to further evaluate the accuracy of the visual detection.

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