Accuracy of Building Damage Detection from QuickBird Satellite Images in the 2003 Boumerdes, Algeria Earthquake

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ABSTRACT: Using the satellite images acquired by QuickBird for Boumerdes city following the 21 May, 2003 Algeria earthquake, this paper examined the capability of such high-resolution optical imagery in visual detection of building damage Grades, based on ground truth regarding the urban nature, typology of a total 2,794 buildings and the real damage they incurred. The results were presented as GIS damage mappings in buildings level created from field survey and from QuickBird images. In general, the comparison showed that totally collapsed buildings, partially collapsed buildings, and buildings surrounded by debris can be identified using only post-event pan-sharpened image. However, due to the nature of damage incurred, some buildings were judged incorrectly even with employing the pre-event image as a reference to judge the damage status. Hence, in this paper we have clarified the limitations regarding the applicability of QuickBird imagery in buildings level mapping.

1 INTRODUCTION

Recent advancements in remote sensing and its application technologies made it possible to use remotely sensed imagery for capturing damage distribution of urban areas due to natural disasters (Yamazaki, 2001). Especially it is important for emergency management and recovery works to capture damage distribution immediately after an earthquake or other disasters. The information about damages should be obtained at an early stage.

Following natural disaster events, damage sustained in urban environments has been identified through visual inspection of optical images by several researchers (Chiroiu et al. 2002, Chiroiu 2003, Huyck et al. 2002, Mitomi et al. 2002, Saito & Spence 2004). The QuickBird imagery was used for detecting damaged areas following the Bam (Iran) earthquakes in 2003, and Java (Indonesia) earthquake 2006. However, due to the lack of detailed GIS ground truth data the accuracy of damage detection for this category of image was not analyzed deeply. Beside truth damage Grades data from field survey, the examination of accuracy of identified or judged damage Grade might also depend on the nature of existing buildings, urban planning and environment of the zone.

Here, we introduce the results of visual damage Grades interpretation from high resolution satellite images for the 2003 Boumerdes, Algeria earthquake. The visual damage interpretation based on the European Macroseismic Scale EMS-98 was carried out building by building, comparing the pre-event and post-event images. The extraction of damage Grades is mainly based on geometry changes and debris. The result of the damage inspection was compared with field survey data, and the accuracy and usefulness of the high-resolution satellite images in damage detection was demonstrated by considering typology of buildings and urban environment.

(a) (b)

Figure 1. Pan-sharpened natural color QuickBird satellite images of Boumerdes City captured before and after the mainshock of the 2003 Algeria earthquake. (a) Image captured on June 22, 2002 (394 days before). (b) Image captured on May 23, 2003 (2 days after).

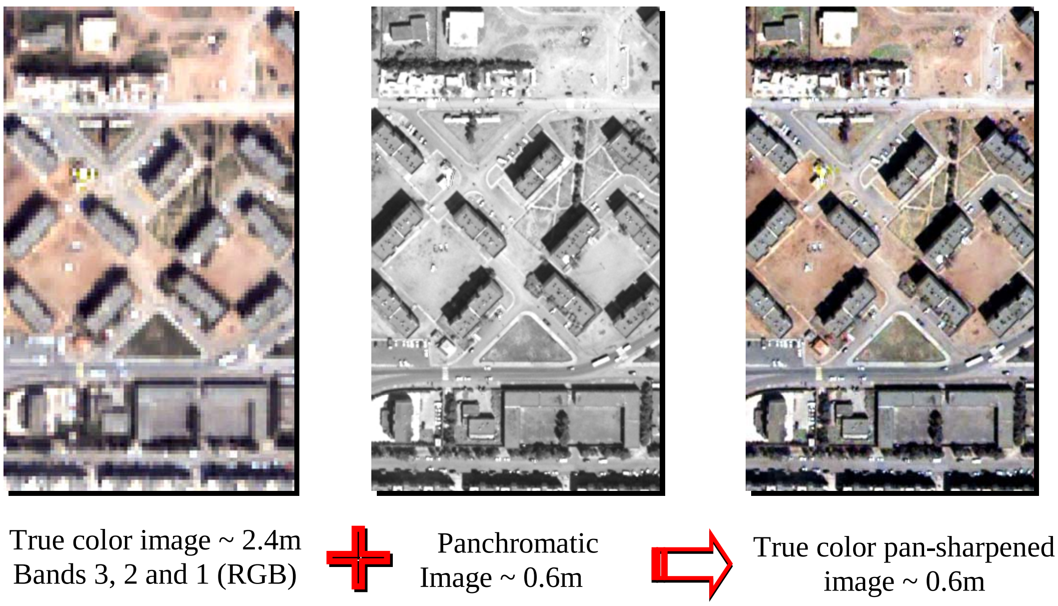


Figure 2. Pan-sharpened image produced by combining panchromatic image and multi-spectral image.

2 REMOTE SENSING IMAGERY FOR ASSESSING DAMAGE DISTRIBUTION IN URBAN AREA

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. (2000a, b) performed visual damage detection using aerial images from high definition television cameras, while Ogawa & Yamazaki (2000) performed visual detection using aerial photographs. These kinds of images can identify individual buildings but they cannot cover a large area with one acquisition time. Capability of optical satellite imagery has been examined for damage detection in large-scale natural disasters (Matsuoka & Yamazaki 1999, 2000a, 2000b, Mitomi et al. 2001). 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. Yamazaki et al. (2005) performed damage assessment using pre- and post-earthquake QuickBird images for Bam city, Iran. It has been found that more detailed ground truth data is needed to better evaluate the difference of damage ratios and examine the accuracy.

3 QUICKBIRD IMAGERY IN RESPONSE TO 2003 ALGERIA EARTHQUAKE

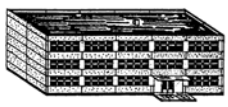
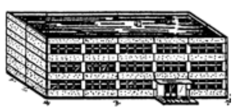
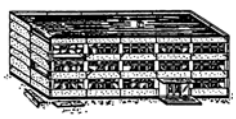
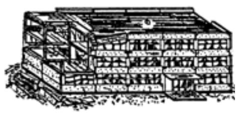
3.1 *QuickBird Imagery for Boumerdes City: Pre- and Post-Earthquake*

Following the 21 May, 2003 Algeria earthquake (Meslem et al. 2008) QuickBird satellite observed the area of Boumerdes City in the province of Boumerdes as shown by Figure 1. These 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 by Figure 2. The images were taken about one year before (April 22, 2002) and two days after (May 23, 2003) the event, with different off nadir view angles: 11.2 and 24.3 degrees respectively. These images are considered to be the first sets of clear images acquired by civilian high resolution satellite.

3.2 *Visual Building Damage Grades Detection and Comparison with Field Survey*

Field survey by engineers from Algerian Ministry of Housing was started one week after the earthquake event, covering all the affected areas in the provinces of Boumerdes and Algiers (Belazougui et al. 2008). This field survey mission, lasted until 30 June 2003, was conducted based on the scale of five damage Grades (Meslem et al. 2009), adopted by Algerian National Centre of Earthquake Engineering (CGS), and each of them corresponds very close to European Macroseismic Scale EMS-98 (Grünthal 2001) as shown by Table 1. According to the scale from EMS-98 no damage and slightly damage is classified as Grade 1, moderate damage as Grade 2, heavy damage as Grade 3, very heavy damage as Grade 4, and finally partial or total collapse as Grade 5.

Table 1. Damage grading for reinforced concrete and masonry buildings according to the European Macroseismic Scale (Grünthal 2001). This damage grading corresponds exactly to that adopted by CGS during field survey following the 2003 earthquake.

Damage Pattern		Description of damage level
Reinforce Concrete	Masonry	
		Grade 1: None or negligible-to-slight damage to non-structural elements, and no damage to structural elements
		Grade 2: Moderate to slight damage to non-structural elements, and slight damage to structural elements
		Grade 3: Heavy to slight damage to non-structural elements, and moderate damage to structural elements
		Grade 4: Very heavy to slight damage to non-structural elements, and heavy damage to structural elements
		Grade 5: Very heavy structural damage, with part of building collapsed, or total collapse

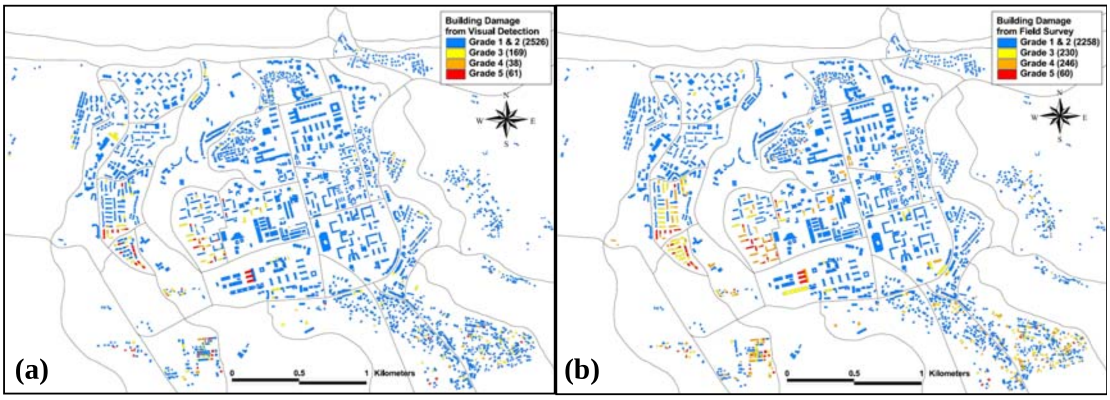


Figure 3. Comparison of GIS damage distribution map of existing buildings in Boumerdes during the 2003 Algeria earthquake. (a) Map made from visual detection using QuickBird images of pre- and post-event. (b) Map made from field survey mission.

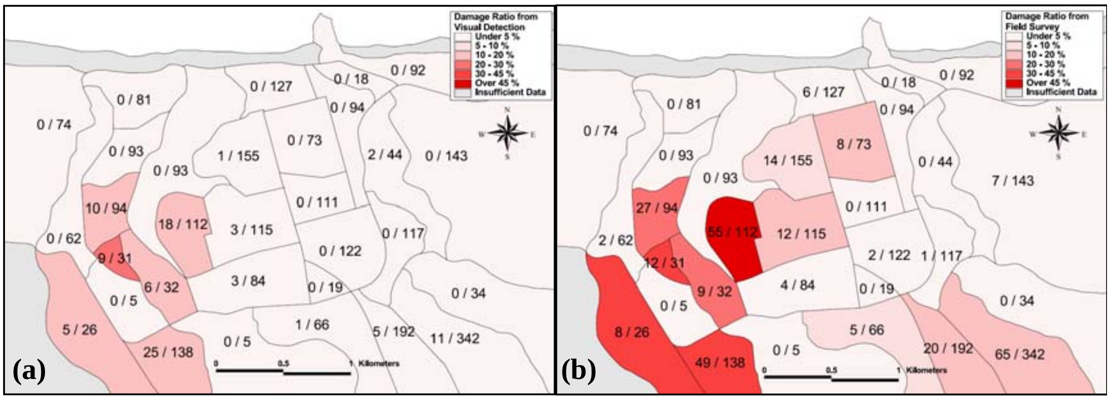


Figure 4. The Building damage ratios of very heavily damaged and collapsed (Grades 4 and 5). (a) Result by visual detection from QuickBird images. (b) Result by field survey.

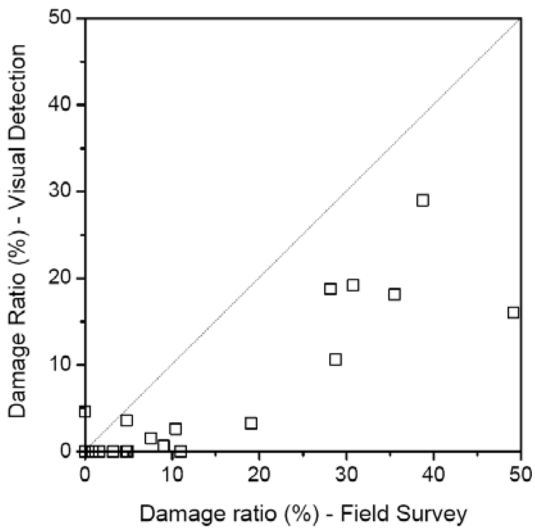
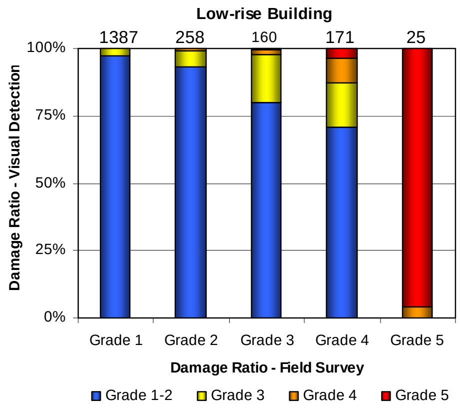


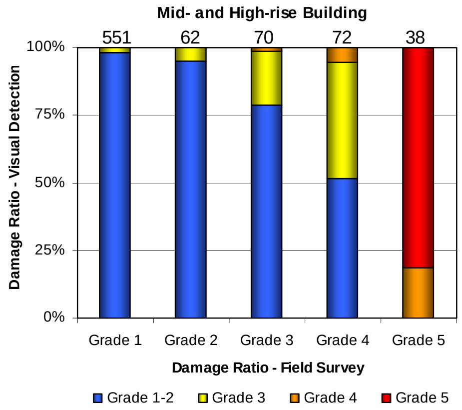
Figure 5. Comparison of damage ratios computed using damage data from mission of field survey with that computed using estimated damage data from QuickBird satellite images by visual detection.



Field survey / QuickBird	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Total
Grade 1 & 2	1346	240	128	121	0	1835
Grade 3	38	16	28	28	0	110
Grade 4	1	2	3	16	1	23
Grade 5	2	0	1	6	24	33
Total	1387	258	160	171	25	2001
Omission Error (%)	0	0	80	87.1	4	--
Commission error (%)	3	7	2.5	3.5	0	--
Accuracy (%)	97	93	17.5	9.4	96	--

Omission error
Accuracy
Commission error

a) Damage Grades accuracy for low-rise buildings.



Field survey / QuickBird	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Total
Grade 1 & 2	540	59	55	37	0	691
Grade 3	11	3	14	31	0	59
Grade 4	0	0	1	4	7	12
Grade 5	0	0	0	0	31	31
Total	551	62	70	72	38	793
Omission Error (%)	0	0	78.6	94.4	18.4	--
Commission error (%)	2	4.8	1.4	0	0	--
Accuracy (%)	98	95.2	20	5.6	81.6	--

Omission error
Accuracy
Commission error

b) Damage Grades accuracy for mid- and high-rise buildings.

Figure 6. Accuracy of distinguished building damage Grades from high resolution imagery in relation to building height classes.

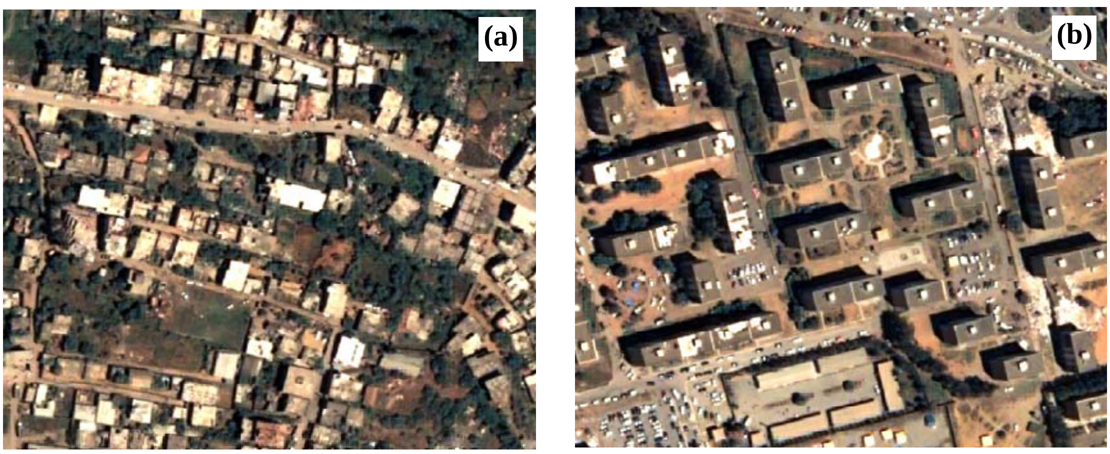


Figure 7. Views from post-event image of Boumerdes City: (a) Densely built-up area where the constructions are mostly low-storied, (b) Area of modern middle to high rise constructions.

Using both pre- and post-earthquake satellite images, a visual detection of building damage Grades was conducted based on the classification in the EMS-98, in order to compare with real damage data from field survey.

In this general, for visual detection from vertical image the damage can be detected by observing the absence of the decrease of shadows, geometric irregularities of contours, the heterogeneity of the roofs. Accordingly, totally collapsed buildings (Grade 5), partially collapsed buildings (Grade 4), and buildings surrounded by debris (Grade 3) could be identified using only post-event image. In addition, it is clearly understandable that Grade1, Grade 2, and a slighter part of Grade 3 can not be detected from QuickBird images. This is because non-structural damage (see Table 1) can not be identified from vertical images. However, severe damage than a slighter part of Grade 3 can be detected, and it is easier for Grade 4 and Grade 5. Accordingly, the judgment damage Grades of buildings were classified into four parts that is Grade 1-2, Grade 3, Grade 4, and Grade 5.

By this visual interpretation through QuickBird images, a total 2,794 buildings (existed RC buildings, masonry buildings etc, including houses) were classified based on their damage Grades. The numbers of different identified damage Grades were 2526, 169, 35, and 64 for Grade 1-2, Grade 3, Grade 4, and Grade 5, respectively. This result from satellite images was compared with ground truth data from which a field survey classified 2,258 buildings between Grade 1 and 2, 230 buildings as Grade 3, 243 buildings as Grade 4, and 63 buildings as Grade5.

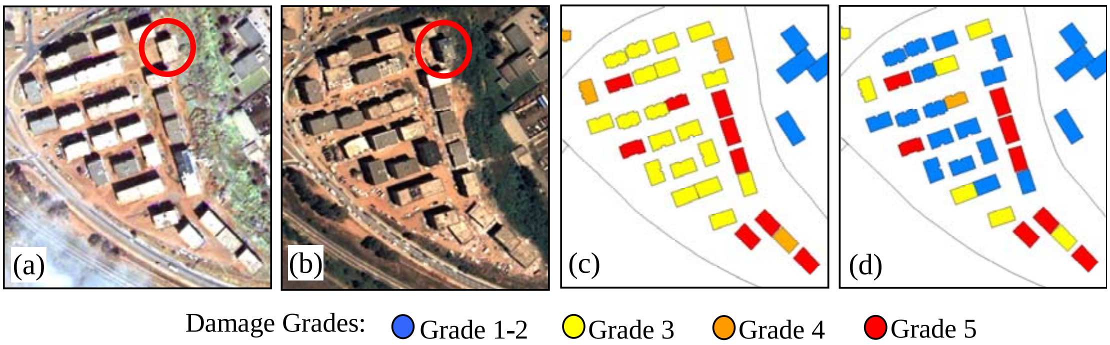


Figure 8. Example of accuracy for different damage Grades. (a) Pre-event QuickBird image, (b) Post-event QuickBird image, (c) Damage Grades distribution from field survey, (d) Damage Grades distribution from QuickBird images.

Figure 9. Example of 4-story building (shown by red circle in Fig. 8-a and -b) suffered from soft story damage corresponding to Grade 4, was incorrectly judged as Grade 1-2 through visual detection from QuickBird images.

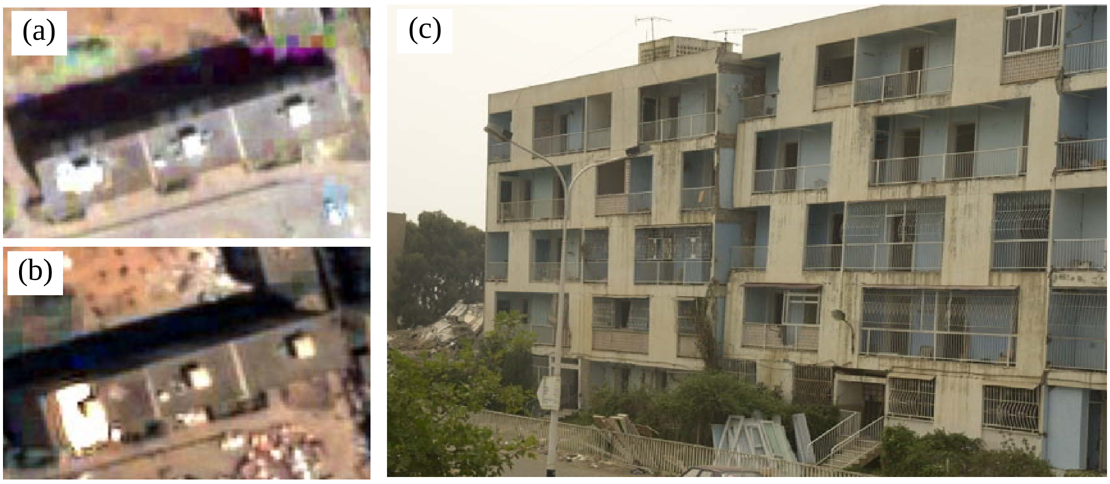


Figure 10. Damage detection accuracy for building slightly tilted, with no debris surrounded. (a) Pre-event QuickBird image, (b) Post-event QuickBird image, (c) Photograph of damaged building.

Table 2. Classification of observed damage patterns from field survey Grades 3, 4 and 5 and relationship to the visual detection accuracy.

Damage	Description
Grade 3-1	Slight damage in column/beam and walls, building surrounded by few debris.
Grade3-1(bis)	Slight damage in column/beam and walls, debris hidden by shadow through image.
Grade 3-2	Slight damage in column/beam and walls, building is not surrounded by debris.
Grade 4-3	Heavy damage in column/beam and walls, building surrounded by debris.
Grade 4-3(bis)	Heavy damage in column/beam and walls, debris hidden by shadow through image.
Grade 4-4	Heavy damage in column/beam and walls, building is not surrounded by debris; Presence of soft story and slight displacement; building slightly tilted; collapse of short column.
Grade 5-5	Totally collapsed building, massive debris surrounded.
Grade 5-6	Section of the building collapsed; building heavily tilted.
Grade 5-7	First storey collapse.

In this study, we have created two maps of GIS damage Grades distribution of buildings in Boumerdes city from two types of data: (a) data from the result of visual detection using QuickBird images, (b) data from the result of field survey. Figure 3 shows comparison of the two GIS damage mappings.

Basically, it is clearly seen that in zone level mapping the result of visual detection from QuickBird images is very close to that from ground truth data from field survey. In building level mapping, the very heavy damages seem to be well localized from satellites images through visual detection. Figures 4 and 5 show comparison of damaged building ratios of very heavily damaged and collapsed (Grades 4 and 5) 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. The buildings suffering from damage Grade 3 and also some buildings with damage Grade 4 were incorrectly judged from visual detection.

4 ACCURACY ANALYSIS AND DISCUSSION

We have examined the accuracy of using QuickBird images, for detecting damage Grades considering the nature of urban environment and building height classes. Figure 6 shows the comparison of damage Grades detection in relation to building height classes between low-rise buildings with mid- and high-rise buildings.

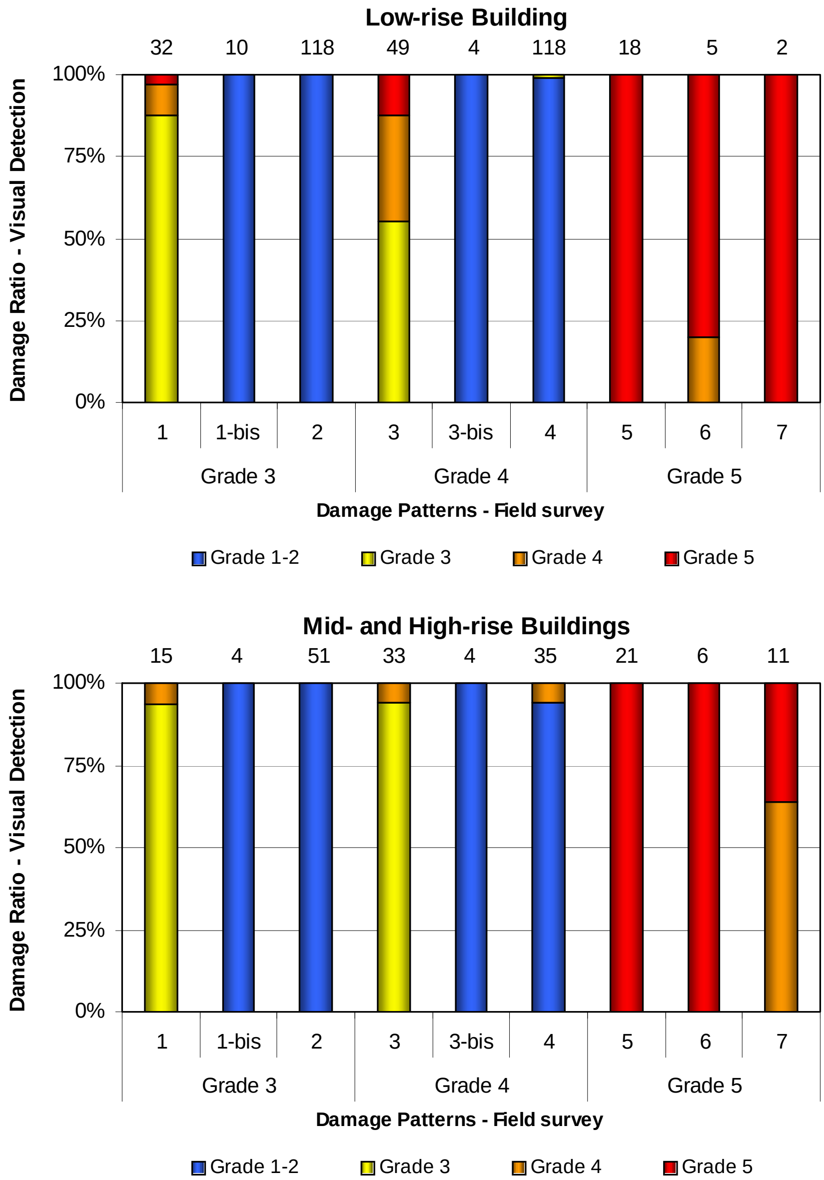


Figure 11. Accuracy of distinguished building damage Grades, from high resolution imagery, in relation to nature of damage patterns from field survey.

In general, In case of total collapse, the damage is easily detectable. However, for low-rise construction located in densely urban environment, sometimes there are difficulties for detecting damage even by using pre- and post-event images. Figure 7(a) shows an example of view, from post-earthquake, of densely built-up area. This image corresponds to the south-eastern part of the city, where almost all the existing constructions were single, non-engineered, 1-3 story private houses, and damage was incurred by only some houses.

Figure 7(b) shows an example of view, from post-earthquake, corresponding south-western part of the city where there are many modern mid-rise buildings. In this zone the damage was extensively concentrated which explains why the damage ratio is more important in the case of mid-rise buildings.

In addition, Figure 8 clearly shows that some of mid-rise buildings suffering from damage Grades 3 and 4 were incorrectly judged from visual detection through QuickBird images. This can be understood if we take a look to the Figure 9 showing 4-storied buildings suffering from soft storey damage (Grade 4) and incorrectly judged as Grade 1-2 in visual detection. This type of damage is difficult to be detected from vertical image, including the case of buildings suffering sever damage from inside. This observation explains why the percentage of incorrectly judged damage for buildings with Grades 3 and 4 is remarkable.

Figure 10 shows another example for 5-storied building slightly tilted (Grade 4) due to the earthquake, with no debris surrounded, and incorrectly judged as Grade 1-2 in visual detection. Table 2 presents a summary of results regarding the relationship between the observed buildings damage patterns from field survey to the visual detection accuracy for Grades 3, 4, and 5. Figure 11 shows the classification of damage patterns and comparison with results from visual detection for Grades 3, 4, and 5. It is well seen that for low-rise buildings as well as for mid- and high-rise ones the debris plays a predominant role in the accuracy of visual detection and also the nature of observed damage patterns.

5 CONCLUSIONS

Using the satellite images acquired by QuickBird for Boumerdes city following the 21 May, 2003 Algeria earthquake, we have examined the capability of such high-resolution optical imagery in visual detection of building damage Grades, based on ground truth regarding the urban nature, typology of a total 2,794 buildings and the real damage they incurred. The results were presented as GIS damage mappings in buildings level created from field survey and from QuickBird images.

In general, the comparison showed that totally collapsed buildings, partially collapsed buildings, and buildings surrounded by debris can be identified using only post-event pan-sharpened image. However, due to the nature of damage incurred, some heavily damaged buildings were judged incorrectly even with employing the pre-event image as a reference to judge the damage status.

The accuracy of identified or judged damage Grade might also depend on the building typologies (size and height classes), and the urban planning with environment of the zone. It has also found that there are difficulties in detecting damage for low-rise construction especially those located in dense area.

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