BUILDING DAMAGE DETECTION OF THE 2003 BAM, IRAN EARTHQUAKE USING QUICKBIRD IMAGES

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ABSTRACT: A strong earthquake with magnitude 6.5 struck the city of Bam in the southeast Iran on December 26, 2003. The earthquake brought massive destruction to the city and its surrounding rural areas. The earthquake caused the deaths of approximately more than 26,000 residents and injured about 30,000. QuickBird captured a clear image of Bam on January 3, 2004, eight days after the event. The city was also observed by QuickBird on September 30, 2003, about three months before the event. In this paper, using the pre-event image, the location of individual buildings was registered on GIS and the city blocks surrounded by major roads were assigned. Then, the visual damage inspection of buildings based on the European Macroseismic Scale was carried out building by building, comparing the pre-event and post-event images. 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 investigated.

1. INTRODUCTION

It is quite important for emergency management and recovery works to capture damage distribution immediately after the occurrence of natural disasters, e.g. earthquakes or floods. Through the experience of the 1995 Hyogoken-Nanbu (Kobe) earthquake, it has been emphasized in Japan that the information about damages should be obtained at an early stage.

In order to examine the applicability of remote sensing technologies to emergency management after earthquakes, the present authors have performed visual damage detection using aerial video images and aerial photographs (Hasegawa et al., 2000). These kinds of images can identify the damage status of 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 for damage detection has been demonstrated in large-scale natural disasters. Matsuoka and Yamazaki (2004) investigated the changes in the characteristics of SAR intensity images due to the 1995 Kobe earthquakes. They also performed change detection studies for several recent earthquakes using pre- and post-event SAR and

Landsat images. However, the spatial resolution of these satellite images is from 20m to 30m. 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 after natural disasters. The first such example is QuickBird images taken after the 21 May, 2003 Algeria earthquake and they were used in building damage detection (Yamazaki et al., 2004).

Eight days after the 26 December, 2003 Bam, Iran earthquake, QuickBird captured a good image of the hard-hit area as well as capturing a pre-event clear image on September 30, 2003. Using these images, this paper presents the results of visual damage inspection for the city of Bam for the purpose of evaluating the capability of high-resolution optical satellite images.

2. THE 2003 BAM EARTHQUAKE AND QUICKBIRD IMAGES

A strong earthquake of moment magnitude (Mw) 6.5 struck the southeastern part of Iran at 5:26:26 AM (local time) on December 26, 2003 (Eshghi and Zare, 2003). The epicenter is located at 29.004°N, 58.337°E (USGS, 2003), near the city of Bam in Kerman Province (Fig. 1). According to the report of Iranian authority in June 2004, 26,271 people lost their lives, mostly due to collapsed traditional mud-brick and clay houses, 30,000 people injured and up to 75,600 people left homeless (Relief Web, 2004). About 85 percent of the housing and infrastructure have been destroyed in Bam. The United Nations estimates that the number of people affected by the loss of economic activity and damage to property and infrastructure is counted as 200,000.

After the occurrence of the Bam earthquake, high-resolution commercial satellites observed the hard-hit areas, IKONOS on December 27, 2003 and QuickBird on January 3, 2004 (EERI, 2004). The image of Bam area was also captured by QuickBird on September 30, 2003 (Adams et al., 2004), about three months before the earthquake. The set of QuickBird images are considered to be the second case acquired by civilian high-resolution satellites both before and after a severe earthquake disaster. The first case is the May 21, 2003 Boumerdes, Algeria earthquake, and in this case, the images of Boumerdes City were taken about one year before, two days after and 28 days after the event, and those of Zemmouri City were obtained eight days before, two days after and 23 days after the event.

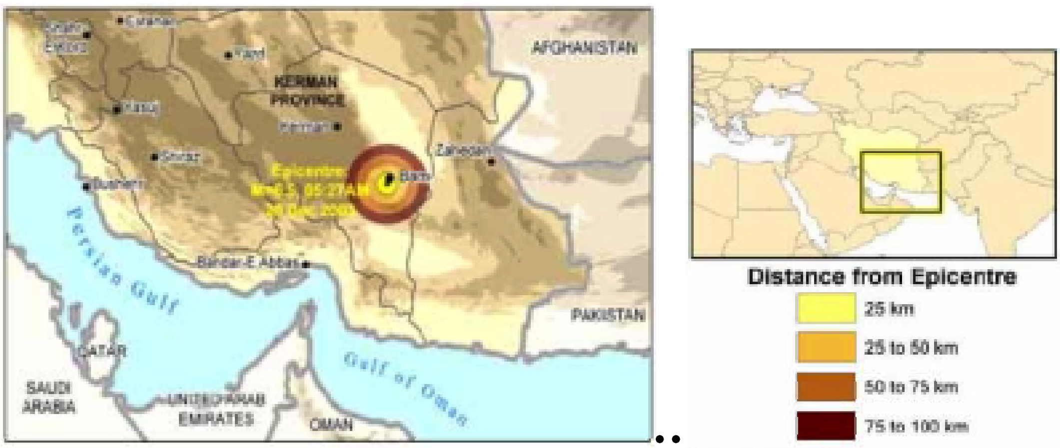


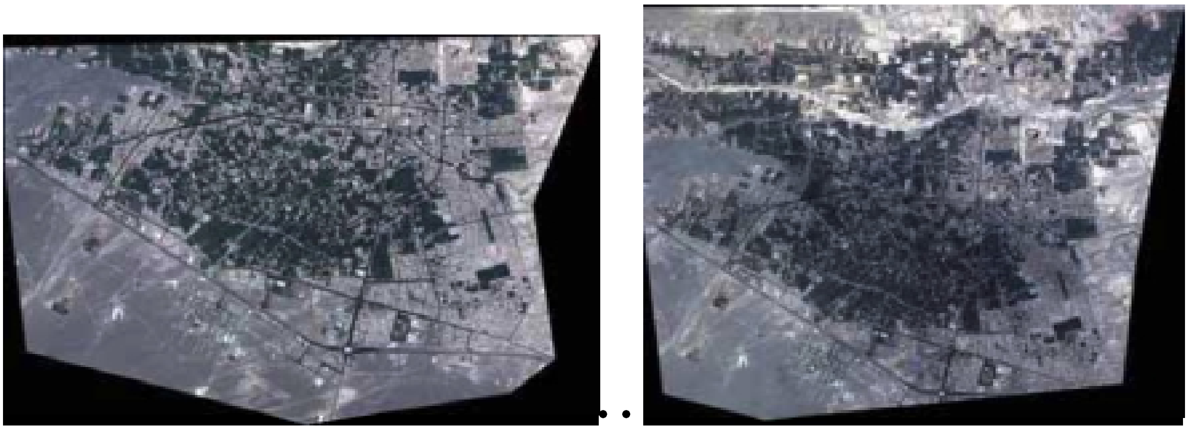
Figure 1 Epicenter of the Bam, Iran earthquake (Relief Web, 2004)

In order to observe target areas in a short time interval, QuickBird can change the view angle of its sensors. Thus the two images of Bam have different off nadir view angles: 10 degrees (pre-event) and 24 degrees (post-event). Hence it is not so easy to superpose these images exactly and to perform automated change detection. The difference in building shadow and vegetation in the different acquisition date images gives additional difficulty. Thus visual damage interpretation was performed as a first trial in this study.

First, pan-sharpened images were produced by combining panchromatic images of 0.6m resolution and multi-spectral images of 2.4m resolution as shown in Fig. 2. By this image enhancement, buildings, cars and debris can clearly be seen and they were used in visual inspection of building damage. Figure 3 shows a typical residential area in the south of Arg-e-Bam, the historical citadel that has collapsed completely due to the earthquake. The area consisted of mostly adobe (mud brick) houses, and hence most of them were reduced to rubble due to immense shaking.

3. VISUAL DAMAGE DETECTION OF BUILDINGS IN BAM CITY

First using the pre-event image, the location of individual buildings was registered on GIS and city blocks surrounded by major roads were assigned. Then visual inspection of building damage was conducted based on the classification in the European Macroseismic Scale (EMS, 1998), shown in Figure 4. Comparing the pre- and post-event images, buildings surrounded by debris



(a) September 30, 2003 (b) January 3, 2004

Figure 2 Pan-sharpened natural color QuickBird images of Bam City

(a) September 30, 2003 (b) January 3, 2004

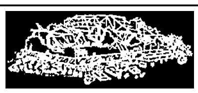
Figure 3 Comparison of pre- and post-event QuickBird images of a residential area in Bam

(Grade 3), partially collapsed buildings (Grade 4) and totally collapsed buildings (Grade 5) were identified.

In Figure 4, typical pre- and post event QuickBird images for houses classified as Grades 3, 4 and 5 by visual inspection are also shown. Because the spatial resolution is around 0.6m, it is almost impossible to detect damage equal to or less than Grade 2. It is rather easy to detect Grade 5 and in our experience, agreement among different interpreters was good in case of Grade 5 (Yamazaki et al., 2004). The effects of shadow and vegetation in damage classification become more serious for Grade 4 and damage detection becomes more difficult than that for Grade 5. Damage becomes further difficult to detect for Grade 3, especially from vertical images. If some deformation is located on the roof or some debris spreads around a building, Grade 3 damage can still be identified.

By this visual interpretation using the pre- and post-event images, a total 12,063 buildings were classified based on their damage grades. The numbers of identified damaged buildings are 1,597 (Grades 1 or 2), 3,815 (Grade 3), 1,700 (Grade 4), and 4,951 (Grade 5). In this case, we did not carry out damage interpretation using only the post-event image since the accuracy of single image interpretation was not so high in our previous experience for Bourmerdes and Zemmouri, in Algeria (Yamazaki et al., 2004). Especially in Bam, houses are generally small and brightness of the two images looks different due to different sunlight condition, thus damage detection was rather difficult even in the case using both the pre- and post-event images.

To examine the accuracy of our damage detection in Bam, the field survey data by Hisada et al. (2004) was employed. They used the same EMS-98 scale to describe the damage grade of each building near eight aftershock recording stations, established by International Institute of Engineering Earthquake and Seismology (IIEES). Figure 5 shows the satellite image and our visual inspection result around the aftershock station No.1 together with the cross table between

Classification of damage to masonry buildings	
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	**Grade 5: Destruction (very heavy structural damage)** Total or near total collapse.

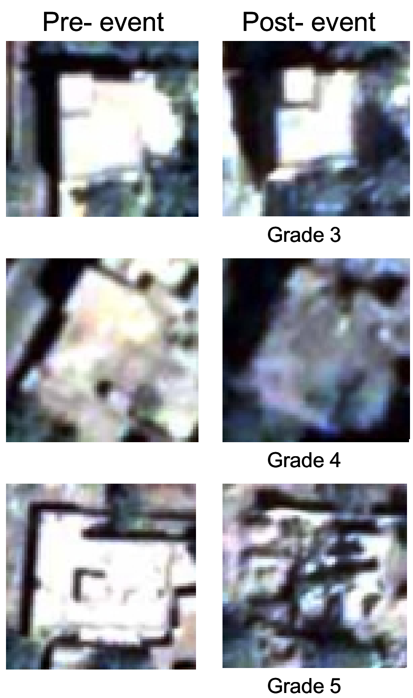


Figure 4 Classification of damage to masonry buildings (EMS, 1998) and typical pre- and post event QuickBird images for Grades 3, 4 and 5 houses • •

Hisada's survey and our result. This area is located in the south of Arg-e-Bam and 16 houses were made of mud brick (adobe) and 30 houses simple masonry construction. The damage ratio for Grade 5 is 72% by Hisada's survey while 64 % in our visual inspection. The coincidence of damage grade between the two data sets is quite high in this area. For lower damage areas, however, the coincidence becomes lower because lower damage grades are more difficult to detect from near-vertical satellite images.

Figure 6 compares the result of our visual interpretation (ratio of Grade 5 in each city block) from QuickBird image and the result of aerial photo interpretation (USAID, 2004). Some difference is observed between the two maps due to the difference of blocks to calculate the damage ratio although overall agreement is seen to be reasonably well. In obtaining the damage ratio, we counted the number of Grade 5 buildings out of all the buildings in each block although this is very time consuming. On the contrary, the air photo interpretation might be conducted rather in a macroscopic manner because the map was created rather at an early stage, within a week or so after the earthquake.

* Red : Grade 5
* Yellow : Grade 4
* Green : Grade 3
* Blue : Grade 2 & 1

QuickBird \ Field survey	G 1	G 2	G 3	G 4	G 5	sum
G 1&G 2	0	0	0	0	0	0
G 3	0	0	4	1	4	9
G 4	0	0	3	1	5	9
G 5	0	0	2	3	27	32
sum	0	0	9	5	36	50

Figure 5 Result of our visual interpretation compared with field survey data by Hisada et al., (2004) around aftershock recording station No. 1, located in the south of Arg-e-Bam

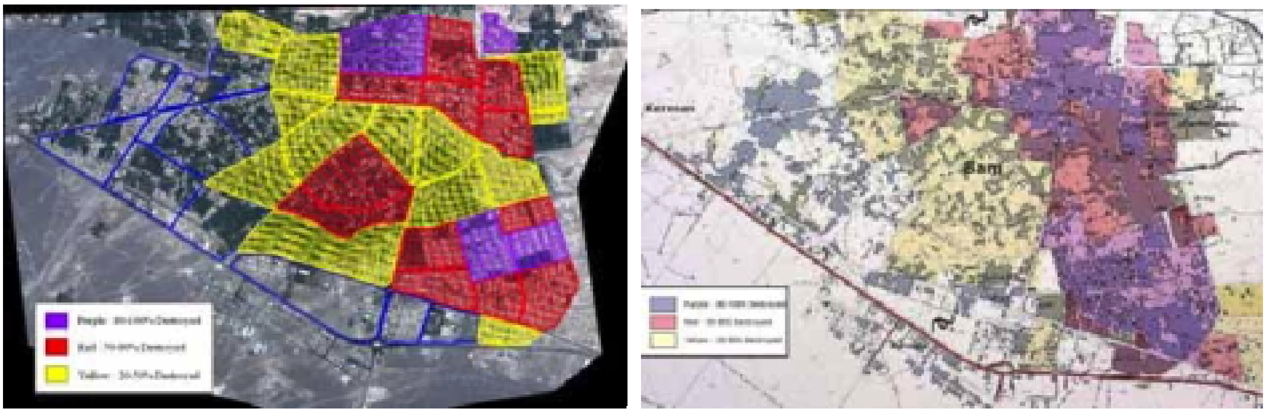


Figure 6 Result of our visual interpretation from QuickBird image (left) compared with the result of aerial photo interpretation (USAID, 2004)

4. CONCLUSIONS

Using the high-resolution satellite images of Bam City acquired by QuickBird before and after the 26 December, 2004 Iran earthquake, visual interpretation of building damage was conducted.

Comparing the pre-event and post-event pan-sharpened images, buildings surrounded by debris (Grade 3), partially collapsed buildings (Grade 4), and totally collapsed buildings (Grade 5) were identified based on EMS-98. A total of 12,063 buildings were classified; 4,951 as Grade 5 and 1,700 as Grade 4. The detailed ground truth data by Hisada et al. was employed to verify the accuracy of the interpretation for each building, and the result of aerial photo interpretation was used to compare the macroscopic damage distribution. By these comparisons, our visual damage inspection seems to give reasonable results. A further study on automated damage detection is going on and the result will be shown elsewhere.

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REFERENCES

Adams B. J. et al., 2004. The Bam (Iran) earthquake of December 26, 2003: Preliminary reconnaissance using remotely sensed data and the VIEWS system, MCEER Earthquake Reconnaissance Investigation Report, 10p. http://mceer.buffalo.edu/research/Bam/page1.asp

Earthquake Engineering Research Institute, 2004. Preliminary Observations on the Bam, Iran, Earthquake of December 26, 2003. EERI Newsletter, Vol. 38, No. 4. http://www.eeri.org/lfe/pdf/iran_bam_eeri_preliminary_report.pdf

Eshghi, S. and Zare, M., 2003. Bam (SE Iran) earthquake of 26 December 2003, Mw6.5: A Preliminary Reconnaissance Report, http://www.iiees.ac.ir/English/bam_report_english_recc.html

European Seismological Commission, 1998. European Seismic Scale 1998. http://www.gfz-potsdam.de/pb5/pb53/projekt/ems/

Hasegawa, H., Yamazaki F., Matsuoka M. and Sekimoto I., 2000. Determination of Building Damage due to Earthquakes Using Aerial Television Images. Proceedings of the 12th World Conference on Earthquake Engineering, CD-ROM, Paper ID 1722, 8p.

Hisada, Y., Shibayama, A., and Ghayamghamian, M.R., 2004. Building Damage and Seismic Intensity in Bam City from the 2003 Iran, Bam, Earthquake (paper in review)

Matsuoka M. and Yamazaki F., 2004. Use of Satellite SAR Intensity Imagery for Detecting Building Areas Damaged due to Earthquakes. Earthquake Spectra, EERI, Vol. 20, No. 3, 975-994.

Relief Web, 2004. http://www.reliefweb.int/w/map.nsf/Emergency?OpenForm&Query=Iran%3A +Earthquake+-+Dec+2003

United States Agency for International Development (USAID), 2004. http://www.usaid.gov/iran/

United States Geological Survey, 2003. http://earthquake.usgs.gov/recenteqsww/Quakes/uscvad.htm

Yamazaki, F., Kouchi, K., Matsuoka, M., Kohiyama, M., Muraoka, N., 2004. Damage Detection from High-Resolution Satellite Images for the 2003 Boumerdes, Algeria Earthquake. 13th World Conference on Earthquake Engineering, CD-ROM, Paper No. 2595, 13p.