Visual Damage Interpretation of Buildings in Bam City Using QuickBird Images Following the 2003 Bam, Iran, Earthquake

Fumio Yamazaki,[a] M.EERI, **Yoshihisa Yano,**[b] **and Masashi Matsuoka,**[c] M.EERI

A strong earthquake struck the city of Bam in southeast Iran on 26 December 2003. The earthquake brought massive destruction to the city and its surrounding rural areas. QuickBird, a high-resolution satellite, captured a clear image of Bam on 03 January 2004, eight days after the event. The city was also observed by QuickBird on 30 September 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 interpretation based on the European Macroseismic Scale (EMS-98) 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 demonstrated. [DOI: 10.1193/1.2101807]

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. In order to examine the applicability of remote sensing technologies to emergency management after earthquakes, the present authors performed visual damage detection using aerial video images and aerial photographs for the 1995 Kobe earthquake (Hasegawa et al. 2000). These kinds of aerial 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 the advantage of being capable of observing a large area at one time. However, the spatial resolution of conventional satellite images (e.g., Landsat, SPOT, ERS/SAR) is from 20m to 30m. Hence, it is difficult to identify the damage of individual buildings and bridges from these images.

Ikonos, the first commercial high-resolution satellite with maximum spatial resolution of 1.0 m, launched successfully on 25 September 1999. It captured a clear image of

[a] Professor, Department of Urban Environment Systems, Faculty of Engineering, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan
[b] Graduate Student, Department of Urban Environment Systems, Faculty of Engineering, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan
[c] Team Leader, Earthquake Disaster Mitigation Research Center, NIED, 1-5-2 Kaigandori, Wakinohama, Chuo-ku, Kobe 651-0073, Japan

Earthquake Spectra, Volume 21, No. S1, pages S329–S336, December 2005; © 2005, Earthquake Engineering Research Institute

Bhuj area after the 26 January 2001 Gujarat, India, earthquake, in which individual buildings can be identified. Saito et al. (2004) performed visual damage inspection using the post-event Ikonos image and pre-event other satellite images.

QuickBird, another high-resolution commercial satellite with a maximum spatial resolution of 0.6 m, launched on 18 October 2001 and has been acquiring optical images of urban areas, which can be used to detect damages of individual buildings after natural disasters. The first such image pairs (both pre-event and post-event) were taken for 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 30 September 2003. Using these images, this paper presents the results of visual damage inspection for all the buildings in Bam City for the purpose of demonstrating the capability of high-resolution optical satellite images.

QUICKBIRD IMAGES OF THE 2003 BAM, IRAN, EARTHQUAKE

After the occurrence of the Bam earthquake, high-resolution commercial satellites observed the hard-hit areas: Ikonos on 27 December 2003, and QuickBird on 03 January 2004 (EERI 2004). The image of the Bam area was also captured by QuickBird on 30 September 2003, 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 was the 21 May 2003 Boumerdes, Algeria earthquake, and, in that 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 (Yamazaki et al. 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 superimpose 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 0.6 m resolution and multi-spectral images of 2.4 m resolution, as shown in Figure 1. By this image enhancement, buildings, cars and debris can clearly be seen and these images were used in visual inspection of building damage.

VISUAL DAMAGE INTERPRETATION OF BUILDINGS

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 Mac-

Figure 1. Pan-sharpened natural color QuickBird images of Bam City captured on 30 September 2003 (left: pre-event) and on 03 January 2004 (right: post-event). *To see this figure in color*: see plates following p. xxx.

roseismic Scale (EMS 1998), shown in Figure 2. Comparing 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.

In Figure 2, 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 of

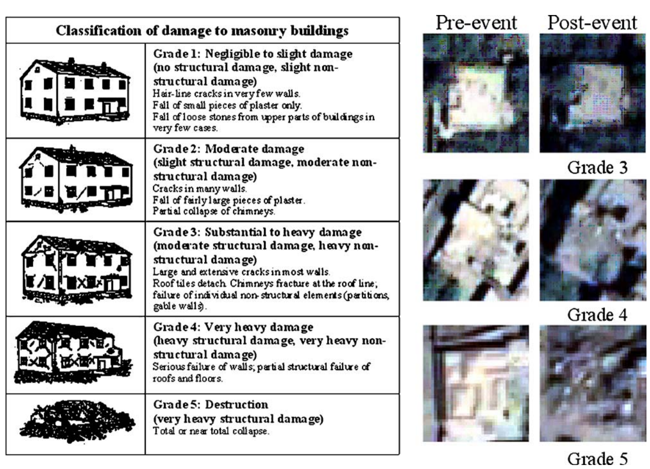


Figure 2. Classification of damage to masonry buildings (EMS 1998) and typical pre- and post event QuickBird images for Grades 3, 4 and 5 houses. *To see this figure in color*: see plates following p. xxx.

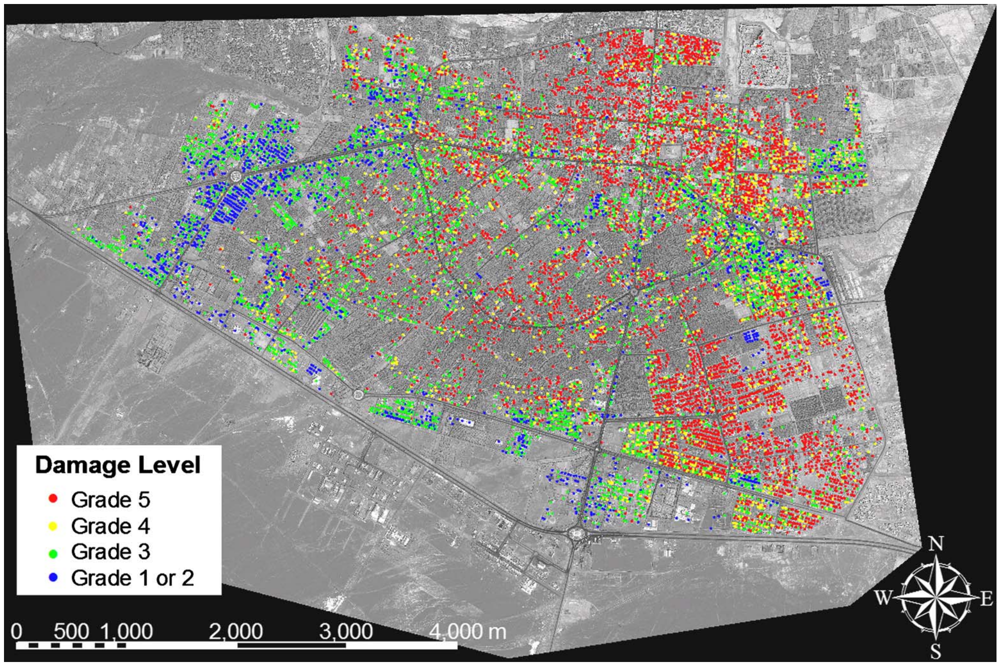


Figure 3. Result of visual damage interpretation using QuickBird images acquired on 30 September 2003 and 03 January 2004. Damage levels are based on EMS-98. *To see this figure in color*: see plates following p. xxx.

the image is around 0.6 m, it is almost impossible to detect damage equal to or less than Grade 2. It is rather easy to detect Grade 5 damage and 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 even more 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 building by building, based on their damage grades, as depicted in Figure 3. The numbers of identified damaged buildings are 1,597 (Grades 1 or 2: blue points), 3,815 (Grade 3: green), 1,700 (Grade 4: yellow), and 4,951 (Grade 5: red).

The time elapsed to register the location of individual buildings and city blocks using the pre-event image was around 30 hours, and judging and registering the damage grade of each building using the pre- and post-event images was around 20 hours. These

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	2	2	1	4	9
G 4	0	1	2	1	5	9
G 5	0	0	3	2	27	32
sum	0	3	7	4	36	50

Figure 4. Result of visual interpretation compared with field survey data by Hisada et al. (2005) around aftershock seismic station No. 1, located in the south of Arg-e-Bam. *To see this figure in color*: see plates following p. xxx.

elapsed times are considered to be highly dependent on the number of buildings, quality and resolution of images, and experience and efficiency of interpreters (Yamazaki et al. 2004).

To examine the accuracy of damage detection in Bam, the field survey data by Hisada et al. (2005) was employed. They used the same EMS-98 scale to describe the damage grade of each building near eight aftershock recording stations, which were established by International Institute of Engineering Earthquake and Seismology (IIEES). Figure 4 shows the satellite image and our visual inspection result around the aftershock seismic station No. 1, together with the cross table between Hisada's survey and our result. Each cell (row, column) in the table shows the number of buildings judged as Grade x(row) in visual interpretation and classified as Grade y (column) in field survey. This area is located in the south of Arg-e-Bam. Sixteen houses were made of mud brick (adobe), and 30 houses were of simple masonry construction. The damage ratio for Grade 5 is 72% by Hisada's survey, while it was 64% in our visual inspection. The coincidence of damage grade between the two data sets is quite high in this area.

Figure 5 shows another comparison for a lower damage area, around the aftershock seismic station No. 3. In the field survey, a total of 45 buildings were classified either as Grade 1 or 2; while in our visual interpretation, 47 buildings were judged as Grades 1 and 2. It is seen that omission errors (judging damage as lower grades than the field survey result) become significant for Grade 4 damage; out of 13 buildings identified as Grade 4 by the field survey, only one building was judged as Grade 4 by damage detection. This may be due to the fact that the houses in this area are rather new (mostly masonry, no adobe construction), and thus the damages are difficult to observe from the vertical image. However, the coincidence was very good for Grade 5; three buildings out of three were interpreted correctly.

Figure 6 summarizes the comparison of the result of the field survey around six aftershock observation sites (421 buildings total) in Bam City and that of the visual dam-

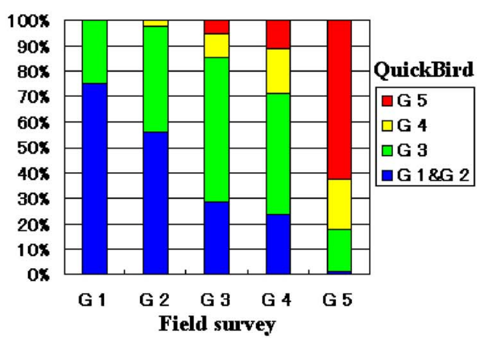
correct
omission error
commission error

Field survey / QuickBird	G 1	G 2	G 3	G 4	G 5	sum
G 1 & G 2	6	23	11	7	0	47
G 3	4	12	16	5	0	37
G 4	0	0	0	1	0	1
G 5	0	0	0	0	3	3
sum	10	35	27	13	3	88

Figure 5. Result of visual interpretation compared with field survey data by Hisada et al. (2005) around aftershock seismic station No. 3, located in the western part of Bam. *To see this figure in color*: see plates following p. xxx.

age interpretation. Commission errors (judging damage as higher grades than the field survey result): e.g., judging Grade 1 or 2 damage as Grade 3, and judging Grade 3 damage as Grade 4 or 5, are seen in the cross table. But only 16 buildings were interpreted as more than one grade higher. Thus, commission error can be judged as not so significant as for quick-look damage detection. Omission errors: judging Grade 4 damage as Grade 1-3, and judging Grade 5 damage as Grade 1-4, are also seen in the cross table. Forty-two buildings were interpreted as less than one grade lower. It may be concluded that we should expect some amount of omission error in damage detection from optical high-resolution satellite images, and thus we should consider this fact in estimating damage statistics at an early stage.

Figure 7 compares the result of the visual interpretation (the ratio of Grade 5 in each



correct
omission error
commission error

Field survey / QuickBird	G 1	G 2	G 3	G 4	G 5	sum
G 1 & G 2	12	50	29	15	2	108
G 3	4	37	57	30	25	153
G 4	0	2	10	11	30	53
G 5	0	0	10	7	95	107
sum	16	89	101	63	152	421

Figure 6. Comparison of the result of the field survey around 6 aftershock observation sites in Bam City and that of visual damage interpretation (field survey). *To see this figure in color*: see plates following p. xxx.

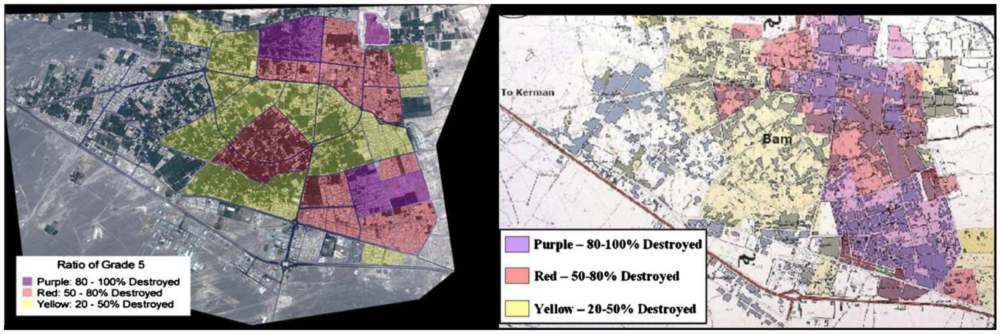


Figure 7. Result of our visual interpretation from QuickBird image (left) compared with the result of aerial photo interpretation (right: USAID 2004). *To see this figure in color*: see plates following p. xxx.

city block) from the 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 good. In obtaining the damage ratio, the number of Grade 5 buildings out of all the buildings in each block was counted, although this was very time-consuming.

CONCLUSIONS

Using the high-resolution satellite images of Bam City acquired by QuickBird before and after the 26 December 2004 Bam, Iran, earthquake, visual interpretation of building damage was carried out. 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 the European Macroseismic Scale (EMS-98). A total of 12,063 buildings were classified; 4,951 as Grade 5 and 1,700 as Grade 4. The detailed field survey data by Hisada et al. (2005) was employed to examine the accuracy of visual interpretation. By this comparison, the visual damage interpretation seems to give reasonably accurate results. However, some amount of omission error was observed due to the limitation of vertical images with 60 cm resolution, and hence this fact should be considered in estimating damage statistics at an early stage.

ACKNOWLEDGMENTS

The QuickBird images were provided from Earthquake Engineering Research Institute and the University of Southern California, and owned by DigitalGlobe, Inc. The field survey data was provided from Prof. Y. Hisada and Mr. A. Shibayama of Kogakuin University, Tokyo, Japan.

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(Received 23 November 2004; accepted 7 June 2005)

[1] Publication of this special issue on the Bam, Iran, earthquake was supported by the Learning from Earthquakes Program of the Earthquake Engineering Research Institute, with funding from the National Science Foundation under grant CMS-0131895. Any opinions, findings, conclusions, or recommendations expressed herein are the authors' and do not necessarily reflect the views of the National Science Foundation, the Earthquake Engineering Research Institute, or the authors' organizations.