Building Damage Detection Using Satellite SAR Intensity Images for the 2003 Algeria and Iran Earthquakes

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Abstract— **An earthquake occurred in the coast of Algeria on May 21, 2003. The cities of Boumerdes and Zemmouri were the most extensively damaged areas. Canadian SAR satellite, RADARSAT, observed Boumerdes area by the fine-beam mode, on 4 days after the event. European SAR satellite, ERS, also observed the same area on June 7, 2003. On December 26, 2003, another strong earthquake occurred beneath the city of Bam, Iran. Severely damaged areas were found widely being distributed in the city from high-resolution optical satellite images obtained after the event. ENVISAT also captured the hard-hit areas on January 7, 2004. In this paper, we investigated the characteristics of damaged areas in these SAR images by visual interpretation and clarified the effect of spatial resolution for the detection of damaged buildings. Then, we applied our automated damage detection technique, which was developed based on the data set of the 1995 Kobe earthquake, to the SAR images of Algeria and Iran.**

Keywords- SAR; damage detection; building; the 2003 Algeria earthquake; the 2003 Iran earthquake

I. INTRODUCTION

The recent earthquakes, such as the 1995 Kobe, the 1999 Turkey, and the 2001 India earthquakes, realized us the importance of grasping damage information of built-up areas at an early stage for recovery activities and restoration planning. High-resolution remote sensing using Synthetic Aperture Radar (SAR) is one of the most promising technologies for monitoring damaged areas under independence of weather condition and sun illumination. The complex coherence obtained from the interferometric analysis enables us to evaluate building areas with a small collapsed damage ratio due to earthquakes [1,2]. But it is sensitive to several parameters, such as satellite geometry, acquisition duration and wavelength of radar [3]. The backscattering coefficient of the earth's surface, having amplitude information (intensity), is less dependent on the above-mentioned conditions [4]. Hence, the backscattering coefficient derived from SAR intensity images may be used for developing a universal method to identify damaged areas in disasters. Detailed ground truth data with building damage due to the 1995 Kobe earthquake provided us the opportunity to investigate the relationship between the backscattering property and the degree of damage. From this analysis, we have already developed a method to detect areas of building damage [5].

An earthquake occurred at the coast of Algeria on May 21, 2003. RADARSAT and ERS satellites observed the damaged areas after the event. On December 26, 2003, another strong earthquake occurred beneath the city of Bam, Iran. Severely damaged areas were found widely being distributed in the city from IKONOS and QuickBird images obtained after the event. ENVISAT also captured the hard-hit areas on January 7, 2004. In this paper, we investigate the characteristics of damaged areas in these SAR images by visual interpretation and clarify the effect of spatial resolution for the detection of damaged buildings. Then, we apply our automated damage detection technique, which was developed based on the data set of the 1995 Kobe earthquake, to the SAR images of Algeria and Iran. Then the accuracy of the proposed method is examined by comparing the result of the analysis with the identified damaged buildings from QuickBird images.

II. CHARACTERISTICS OF SAR IMAGES

A. The 2003 Algeria and Iran earthquakes

A moment magnitude 6.8 earthquake shook the Mediterranean coast of Algeria on May 21, 2003. The epicenter is located offshore of the province of Boumerdes. Approximate numbers of collapsed and heavily damaged buildings were 7,400 and 7,000, respectively. Four days after the event, RADARSAT observed Boumerdes area by the fine-beam-mode, which captures the earth surface with approximately 8-meter resolution. ERS, whose resolution is approximately 30 meters, also observed the hard-hit area including Zemmouri on June 7, 2003. The both systems transmit the same C-band microwave signal and receive its reflection back to the sensors or antennas. However significant differences of the two SAR systems are the specifications of spatial resolution, incidence angle, and polarization.

The historic city of Bam, Iran, was strongly shaken by a magnitude 6.6 earthquake whose epicenter is located very close to the city, at 5:26 am on December 26. More than 49,000

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traditional mud-brick and clay houses were collapsed and more than 43,000 people, about one third of the population before the earthquake, were killed by this morning attack. After the earthquake, ENVISAT observed Bam and Baravat cities on January 7, 2004. SAR system specifications of ENVISAT used in this study are almost same as those of ERS.

B. Backscattering characteristics in damage areas

Figures 1 and 2 show the zoom-up images of pre- and post-event by RADARSAT and ERS, respectively, for a typical area in Boumerdes city, where totally collapsed buildings are identified in an image taken by Quickbird satellite on 2 days after the earthquake, as shown in Fig.3. The images acquired on February 20, 1998 by RADARSAT and July 27, 2002 by ERS were used for the data prior to the event. The locations of collapsed buildings determined by visual inspection using the QuickBird image are marked as small circles in these figures. As seen in Fig.1, it is found that the backscattering intensity of buildings circled by small solid line in the post-event image is smaller than that in the pre-event image. Generally, man-made structures show comparatively high reflection due to the cardinal effect of structures and ground. Open spaces or damaged buildings have comparatively low reflectance because microwaves are scattered in different directions (see in Fig.4) Buildings may be reduced to debris by an earthquake, and in some cases, the debris of buildings may be removed, leaving the ground exposed. Thus, the backscattering coefficient determined after collapse is likely to be lowered compared to that obtained prior to the event.

However, the reverse situations are occurred for the buildings marked by dot circles in Fig. 1. According to these appearances in high-resolution SAR images, several reasons are considered such as the relationship among the illumination direction of microwave transmitted from a satellite, the longitudinal direction of buildings, and the density of buildings. The area of refugee tents temporary placed in an open space in the post-event image shows brighter than that in the pre-event image. These kinds of complicated characteristics of backscattering echo are identified in high-resolution SAR images. Since the resolution of ERS images shown in Fig.2 is fairy coarse, it is relatively difficult to identify the backscattering characteristics of individual buildings.

Regarding the SAR images of Bam, Iran earthquake, we found that the above-mentioned reverse characteristics are dominant in some severely damaged areas in the southeast of Bam city. Figures 5 and 6 show the area of pre- and post-earthquake images by QuickBird and ENVISAT, respectively. The pre-event ENVISAT image was acquired on December 3, 2003. Many orderly houses with flat roof were densely located prior to the earthquake, but the most of them were damaged by the event. According to the ENVISAT images, the backscattered echoes became stronger in the post-earthquake image. When uniform buildings stand very close each other, specular bounces on the flat roofs cause the weak reflection. Then, if some buildings located in the near-range to a satellite were collapsed due to an earthquake, the cardinal effect against other buildings could cause strong reflection. The debris of collapsed buildings could also create relatively higher

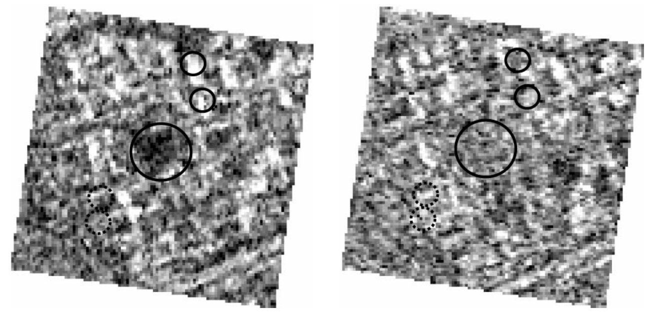

Figure 1. RADARSAT images of a part of Boumerdes city acquired before (left) and after (right) the Algeria Earthquake

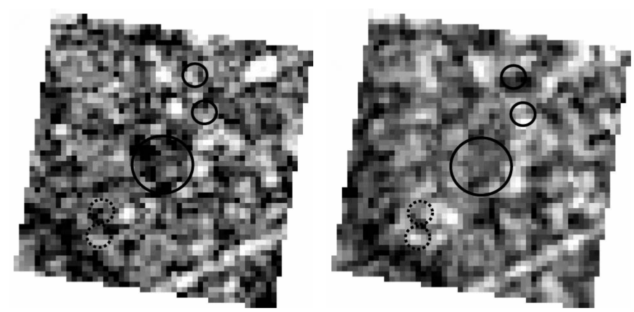

Figure 2. ERS images of a part of Boumerdes city acquired before (left) and after (right) the Algeria Earthquake

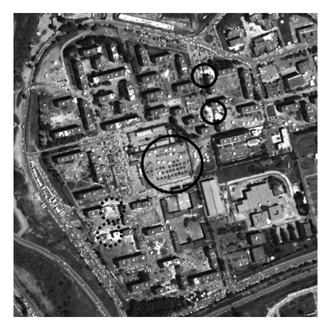

Figure 3. Panchromatic QuickBird image of a part of Boumerdes city acquired on May 23, 2003.

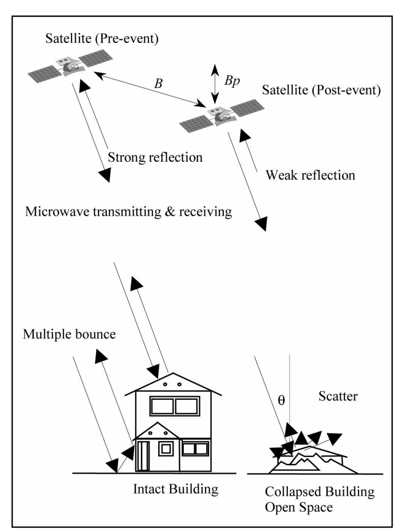

Figure 4. Schematic figure of the geometry of repeat pass satellite observation and backscattering characteristics of buildings

reflectance of microwave than the smooth/flat roof surfaces. A schematic figure is shown in Fig.7.

III. AUTOMATED DAMAGE DETECTION

A. Method

As we have already mentioned in the previous section, man-made structures show comparatively high reflection due to the cardinal effect of structures and ground (Fig.4). Based on this characteristic, we have already developed an automated method to detect the areas with severely damaged buildings using the time-series SAR dataset for the Kobe earthquake [5]. In this empirical method, we must prepare two multi-looked intensity images taken before and after an earthquake. It is desirable that the acquisition dates are close, as much as possible, to the earthquake occurrence day and the both observation conditions are similar. However, the method was successful in damage detection for the Kobe example, even though the image pair has quite different observation orbits before and after the earthquake. After co-registration for the pre- and post-event images, each image is filtered using Lee filter [6] with 21 x 21 pixel window. The difference in the backscattering coefficient, d, in (1) and the correlation coefficient, r, in (2) are derived from the two filtered images. Then, we calculate the discriminant score, z_1, based on (3).

$$d = 10 \cdot \log_{10} \bar{I}a_i - 10 \cdot \log_{10} \bar{I}b_i \tag{1}$$

$$r = \frac{N\sum_{i=1}^{N} Ia_i Ib_i - \sum_{i=1}^{N} Ia_i \sum_{i=1}^{N} Ib_i}{\sqrt{\left(N\sum_{i=1}^{N} Ia_i^{\,2} - \left(\sum_{i=1}^{N} Ia_i\right)^2\right) \cdot \left(N\sum_{i=1}^{N} Ib_i^{\,2} - \left(\sum_{i=1}^{N} Ib_i\right)^2\right)}} \tag{2}$$

$$z_1 = -2.140\, d - 12.465\, r + 4.183 \tag{3}$$

where i is the sample number, Ia_i and Ib_i are the digital numbers of the post- and pre-images, $\bar{I}a_i$ and $\bar{I}b_i$ are the corresponding averaged digital numbers over the surroundings of pixel i within a 13 x 13 pixel window, and the total number of pixels N within this window is 169 to compute the two indices.

In this study, we assumed and introduced a value z_2 to extract another type of damaged areas which are likely to be the situation shown in Fig.7.

$$z_2 = 2.140\, d - 12.465\, r + 4.183 \tag{4}$$

The z value is calculated as

$$z = \max(z_1,\ z_2) \tag{5}$$

The pixel whose value z is high is assigned as a severely damage area. Then, focusing on urbanized areas to detect building damage, the pixels whose backscattering coefficient is smaller than the assigned threshold value around –6dB is masked in the value z distribution.

Figure 5. QuickBird images of the southeast part of Bam city taken before (left) and after (right) the Iran earthquake

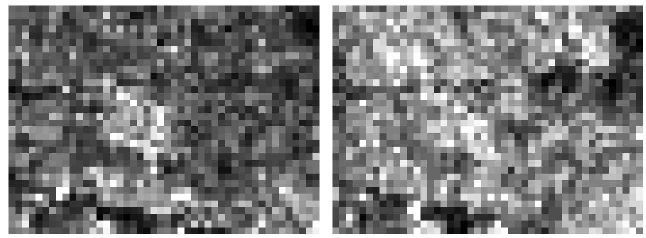

Figure 6. ENVISAT images of a southeast part of Bam city taken before (left) and after (right) the Iran earthquake

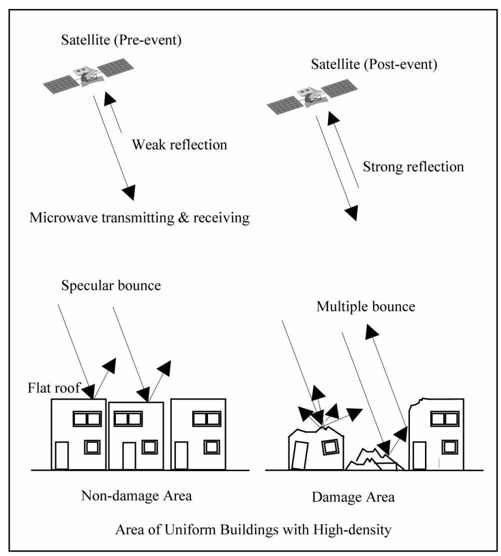

Figure 7. Schematic figure of the backscattering characteristics of orderly uniform buildings with flat roof and their damages

B. Detection of damage distribution

Using the above-mentioned procedure and the SAR images, we calculated the discriminant score z and estimated the damage distribution for the two earthquakes. In the result of the RADARSAT images of Boumerdes city, Algeria, it is difficult to extract any wide distribution of building damage. According to the visual inspection of building damage in Boumerdes city using QuickBird imagery, the maximum value of the collapsed building ratio is not so high (approx. 14%) [7]. By our previous examinations for the 1993 Hokkaido Nansei-oki, the 1995 Kobe, the 1999 Turkey, and the 2003 India earthquakes, the distribution of heavily damaged zone, empirically, the area where the collapsed building ratio is more than approximately

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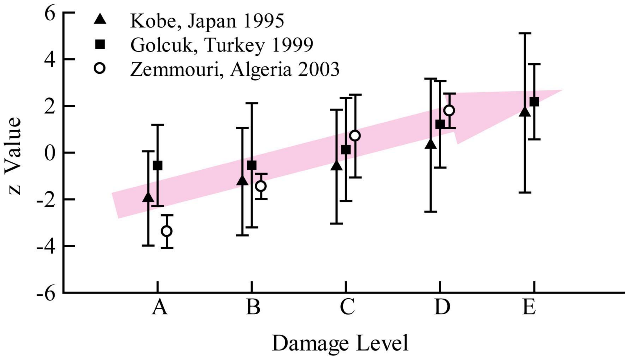

Figure 8. Relationship between *z* value and damage level for SAR images from the three earthquakes. The damage level classified into A, B, C, D, and E, corresponding to the collapsed building ratio of 0-6.25, 6.25-12.5, 12.5-25, 25-50, and 50-100%, respectively.

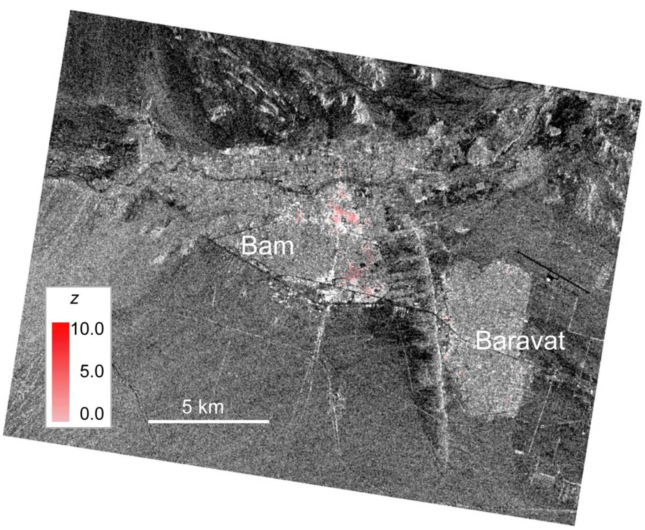

Figure 9. Distribution of the *z* value using the pre- and post-earthquake ENVISAT images overlaid on the SAR intensity image taken over the cities of Bam and Baravat

25%, should be detected [8]. Therefore, this result shows good agreement with our previous experiences for other earthquakes. By using ERS images of the Algeria earthquake, damaged areas are clearly detected in the city of Zemmouri and not in other cities. The relationship between the damage level [7] and *z* value in Zemmouri city is shown in Fig.8. As observed in the Kobe and the Turkey studies, the *z* value in the Algeria case is also seen to increase as the damage level increases.

For the cities of Bam and Baravat by the Iran earthquake, the distribution of *z* value using the pre- and post-event ENVISAT images is shown in Fig.9. The damaged areas, which are widely detected in Bam city, well correspond to those interpreted by aerial photographs [9] and QuickBird images [10].

IV. CONCLUSIONS

This paper reported on visual and quantitative evaluation on the backscattering characteristics of damaged areas due to the 2003 Algeria and Iran earthquakes using SAR images. We applied an automated technique for detecting areas with building damage, which was developed from the experiences from the 1995 Kobe earthquake using SAR intensity images, to the pre- and post-event images of the two earthquakes. As a result, the damaged areas detected based on the compound variable that uses the difference value and correlation coefficient of the backscattering coefficient as explanatory variables roughly corresponded to the distribution of severely damaged areas obtained by visual interpretation of high-resolution optical satellite images.

ACKNOWLEDGMENT

The present authors would like to express their gratitude to the organizations concerned. ERS and ENVISAT are owned by European Space Agency; RADARSAT is owned by Canadian Space Agency; and QuickBird is owned by DigitalGlobe Co., Ltd. QuickBird images used in this study were licensed and provided by Earthquake Engineering Research Institute (EERI), Oakland California, USA.

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