Characteristics of Satellite SAR Images in the Areas Damaged by Earthquakes

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ABSTRACT

The 1995 Kobe and the 1994 Northridge earthquakes realized us the importance of grasping damage distribution at an early stage for recovery activities and restoration planning. Satellite remote sensing using SAR is one of the most promising technologies for this objective. In this paper, we investigated the scattering characteristics of microwaves for the areas hit by the 1999 Kocaeli, Turkey earthquake, using satellite SAR images. From the difference in backscattered intensity and coherence from an interferometric analysis of SAR images taken at different acquisitions, we found that the backscattering property in heavily damaged areas showed significant change, compared with that in minor damage areas. The relationship between building damage and difference of pre- and post-event SAR images was found to relate to the damage level. This trend in the hard-hit areas was due to the fact that the backscattered intensity and the intensity correlation of two images became low. The degree of coherence was found to be a good index to distinguish slight to moderate damage levels. The microwave reflection is considered to decrease in hard-hit areas due to the reduction of the cardinal effect. The decorrelation of the phase can also occur due to the existence of collapsed buildings. Thus, the images obtained by satellite SAR may be a powerful tool for the post-disaster damage assessment.

INTRODUCTION

Satellite remote sensing, which can monitor a large area, may provide effective information on determining damage distribution for recovery activities and restoration planning. The present authors have already reported spectral characteristics of the damaged area by comparing satellite optical images [1] with the detailed damage survey results on the 1995 Hyogoken-Nanbu (Kobe) earthquake, and have attempted to identify the damage distribution from the satellite optical images.

Synthetic aperture radar (SAR) observations can be performed in both day and night time without influence of weather condition. This feature can be useful for effective post-disaster damage assessment, especially when optical remote sensing or a field survey for a large area is difficult. Several researchers reported the interpretation of the building damage distribution using SAR amplitude information [2, 3] and phase information [4, 5]. Using the phase approach, which has higher sensitivity than the intensity approach, crustal deformation due to seismic events was successfully identified [6].

In this paper, a brief summary on the result from the Kobe earthquake is given. Then the backscattering characteristics for the damaged areas due to the 1999 Kocaeli, Turkey earthquake were investigated using ERS/SAR data and field survey results.

INTERFEROMETRIC APPROACH FOR BUILDING DAMAGE DETECTION

Generally, artificial structures show comparatively high reflection due to specular characteristics of structures and ground. Open spaces or damaged buildings have comparatively low reflectance because microwaves are scattered to different directions. A schematic diagram of a surface object and its backscattering property are shown in Fig. 1. Buildings may be reduced to debris by an earthquake, and in some cases, the debris of the buildings may be cleared leaving the ground exposed. Thus, the backscattered intensity determined after a damaging earthquake may become low compared with that obtained before the event.

The complex coherence derived from an interferometric analysis is also a suitable and sensitive parameter for detecting superficial changes and land classification. Because collapsed buildings exert an influence on phase, the degree of coherence becomes small between pre- and post-event images.

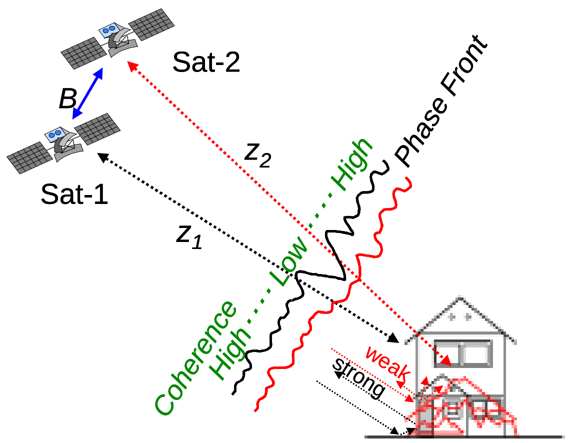

Fig. 1 Schematic diagram for detecting building damage using repeat-pass radar observations

Building damage survey data after the 1995 Kobe earthquake [7] provide a good opportunity to investigate on the relationship between the building damage level and the backscattering property from satellite SAR images. The JERS/SAR image, which was taken over the affected area twenty days after the event, was employed [5]. Five images from the pre-event period were also chosen, and four pairs consisting of pre- and post-event images with 260 to 880 days acquisition time difference and baseline distance (*B*) of 250 to 6,500 meters were selected. The results showed that the mean value of the backscattered intensity and the coherence between the pre- and post-event images became low in heavily damaged areas, in spite of the line-noise included in most of the images.

THE 1999 KOCAELI, TURKEY EARTHQUAKE

On August 17, 1999, a magnitude (Mw) 7.4 earthquake struck the northwestern region of Turkey as shown in Fig. 2 and caused immense destruction to man-made structures with over confirmed 14,000 deaths. The total numbers of collapsed and moderately damaged buildings are approximately 66,000 and 67,000, respectively. Approximately 67,000 house units are classified as slightly damaged. A detailed and systematic field survey on building damage was conducted by a Japanese team [8] in Golcuk and Degirmendere. Using the survey data, the damage ratios of buildings in the city-block level were calculated.

Figure 3 shows the collapse ratio of the buildings evaluated for each block in Golcuk, defined as the ratio of the number of buildings classified as collapse and the total number of buildings in each block. The damage rank was classified into the five categories as rank A, B, C, D, and E, which correspond to the collapse ratios of 0-6.25, 6.25-12.5, 12.5-25, 25-50, and 50-100%, respectively.

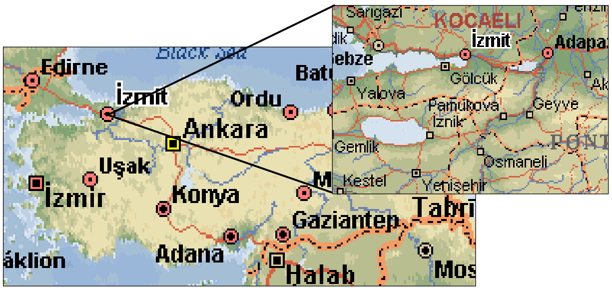

Fig. 2 Northwestern region of Turkey

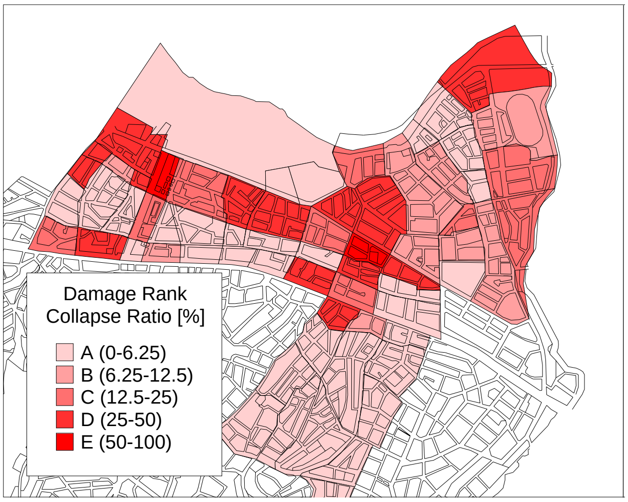

Fig. 3 Distribution of building collapse ratio in Golcuk by the field survey of AIJ

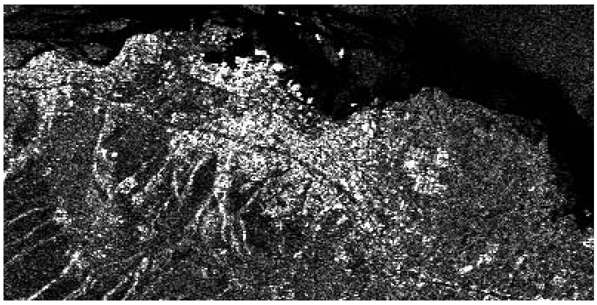

Fig. 4 ERS/SAR amplitude image of Gulcuk (September 17, 1999)

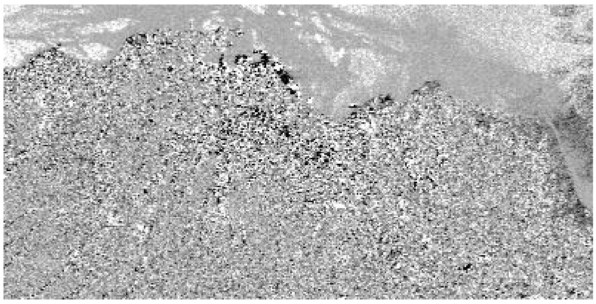

Fig. 5 Intensity difference image for the pair 8/13-9/17: the intensity of 8/13 subtracted from that of 9/17.

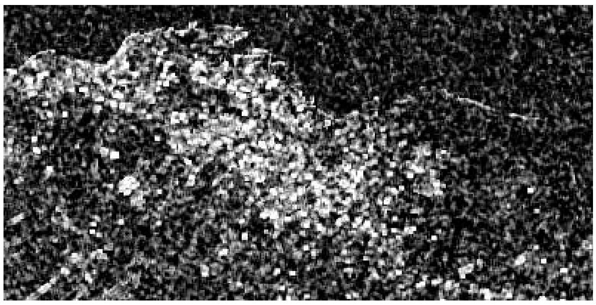

Fig. 6 Intensity correlation image for the pair 8/13-9/17

ERS/SAR DATA AND IMAGE PROCESSING

Series of radar observations including tandem flights using ERS-1 and ERS-2 was conducted over the affected area before and after the earthquake. The image pair, which consists of August 13 and September 17, 1999 (pair 8/13-9/17), with 34-day difference and 80m baseline distance, and the pair of August 12 and August 13, 1999 (pair 8/12-8/13), with 1-day difference and 240m baseline distance, were used to investigate the variation of backscattering property in the damaged areas. All the images were registered to the 99/08/13 data by the nearest neighbor method, using tie points derived from the optimum pixel pair determination, by searching pixel by pixel, at the position that yields the highest correlation between two single-look amplitude images.

Figure 4 shows a pseudo multi-look amplitude image created by averaging 5 azimuths and one range pixels to single-look one, which observed Golcuk on September 17, 1999. The amplitude difference value was calculated for each pair, and then the intensity difference images were generated. The image for the pair 8/13-9/17 is shown in Fig. 5.

The correlation coefficient between two single-look amplitude images was calculated within a small corresponding window, with pixel sizes of 15 for the azimuth and 3 for the range direction. Following this procedure, we created the correlation images that have the same size as described using a spatial averaging. The correlation image from the pair 8/13-9/17 is shown in Fig. 6. The degree of coherence, which indicates the correlation between two co-registered complex SAR images by calculating the phase of the backscattering echo, was also used as an index to indicate the changes in the affected area. The window sizes for the coherence calculation and the averaging were same as those for the intensity correlation calculation.

BACKSCATTERING CHARACTERISTICS OF DAMAGED AREAS

The pixels that correspond to the area of each damage rank shown in Fig. 3 were selected from the SAR images in order to examine the characteristics of the intensity difference, the intensity correlation, and the degree of complex coherence in the damaged areas. The numbers of selected pixels were approximately 1,800, 840, 720, 1,000, and 80 for the damage ranks A, B, C, D, and E, respectively.

The characteristics of the mean value and the standard deviation of the intensity difference in each damage rank for the two pairs are shown in Fig. 7. Although there is a scatter in the intensity difference for each damage rank, the mean value in each rank decreases as the damage rank increases, for the pair 8/13-9/17. This trend is remarkable in the severe damage ratios (D and E). In the pre-event images' pair of 8/12-8/13, this trend cannot be observed because they are not affected by the destruction due to the earthquake.

The same behavior in case of the intensity correlation and the complex coherence are shown in Figs. 8 and 9, respectively. As the damage level increases the intensity correlation decreases gradually for the pair 8/13-9/17, which agrees with the results of the Kobe study [2]. As shown in Fig. 8, the degrees of coherence in the slight damage area (A) are relatively high in comparison with those in the moderate (B, C) or heavy damaged areas (D, E) for the pair 8/13-9/17 although the standard deviations are quite large. For the

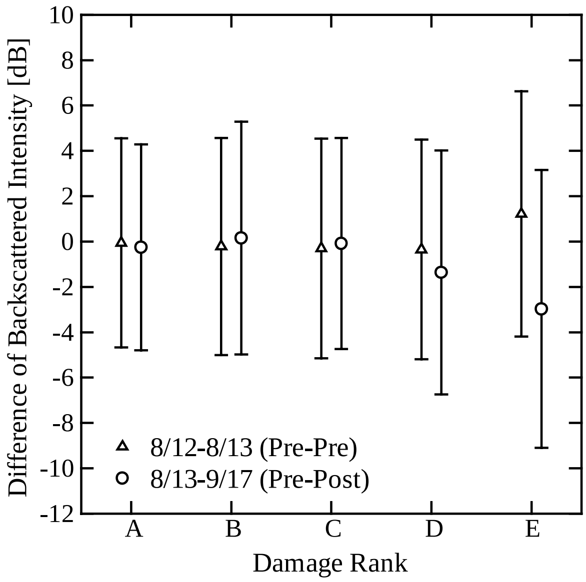

Fig. 7 Difference in backscattered intensities from two time instants for different damage rank

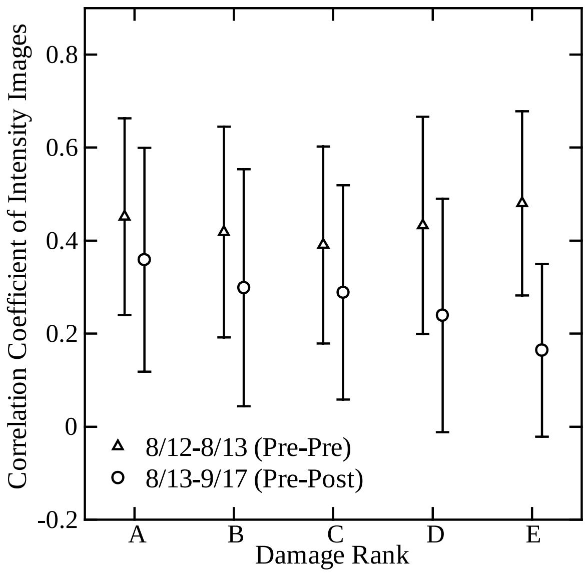

Fig. 8 Correlation coefficient of intensity images between two time instants for different damage rank

pre-event pair 8/12-8/13, the backscattering property and the damage level are seen to have no relationship. A similar tendency for the two pairs is observed in the complex coherence shown in Fig. 9.

According to the results obtained in this study, it is found that the intensity difference can identify large surface changes, and that the intensity correlation is sensitive to a wide range of earth surface changes while the degree of coherence is sensitive to only slight surface changes. However, since these results were derived from the pairs with short baseline distances and using C-band microwaves, a further study based on SAR images with different acquisitions and satellites should be necessary to reach a general conclusion on grasping damage distribution from the space.

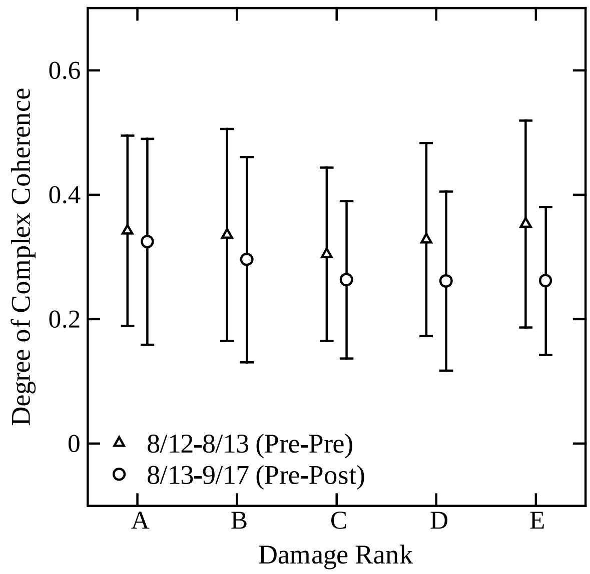

Fig. 9 Degree of complex coherence between two time instants for different damage rank

CONCLUSIONS

This paper demonstrated a quantitative evaluation on the backscattering properties of SAR images, such as the difference of intensities, intensity correlation, and complex coherence between different acquisitions for the areas hit by the 1999 Kocaeli, Turkey earthquake. ERS/SAR images taken before and after the event and detailed field survey data were employed to examine the possibility of capturing the damage distribution. The building damage ratio for city blocks obtained by the field survey and the backscattering properties derived from the SAR images were compared.

In the areas of heavy building damage, the backscattered intensity and the intensity correlation between pre- and post-event images were found to become low. The degree of complex coherence was found to be useful to classify small damage levels. In spite of these results regarding the mean characteristics of SAR images, a large degree of randomness exists in the backscattering properties for each damage classification. A further study is suggested till a general statement for the earthquake damage survey in urban areas using satellite SAR is made.

ACKNOWLEDGMENT

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