

DISASTER RISK EVALUATION AND DAMAGE DETECTION USING REMOTE SENSING DATA FOR GLOBAL RESCUE OPERATIONS

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ABSTRACT:

In this study, for supporting global rescue operations, we will propose a new earthquake damage detection method, based on a combination of earthquake damage estimation using earthquake information (magnitude, location of source, detailed ground condition, and attenuation equation for distance) and change detection by means of remote sensing data. First, to find collapsed buildings and houses on the earth's surface, we adopt a coherence or difference image calculated from multi-temporal SAR images observed before and after the earthquake. Next, to estimate seismic intensity and probability of destruction caused by the earthquake, we applied an earthquake engineering model. Finally, damaged area is calculated from a logical AND of the coherence or difference image and destruction probability. As a result of our simulation, we were able to obtain a damage detection map that corresponds with the actual damage of houses. The detection map has less noise than the coherence or difference image, which indicates that the proposed method has better detection ability than that of using only the change observed by SAR.

1. INTRODUCTION

A strong earthquake can cause tremendous destruction in an urban area such as structure collapse and conflagration. When the disaster is too serious, rescue and medical activity cannot be carried out by individual countries acting alone. Accordingly, cross-border cooperation on countermeasures against disasters is very important. Many relief teams were dispatched to large disaster sites from many countries in the world, for example after the 2004 Indian ocean tsunami and the 2005 Pakistan earthquake. It is necessary to resolve the following issues so that the above mentioned operations are carried out effectively.

1. The relief operation plan and its logistics must be drawn up based on disaster risk evaluation beforehand. Therefore, it is required that the risk evaluation simulation of earthquakes is workable for the entire world.
2. Actual damage information of a struck area is absolutely necessary for rapid countermeasures against the disaster. This information is very useful for decision-making to determine where rescue teams are dispatched.
3. It is necessary to build a communication system for information sharing between the headquarters and disaster site.

In this study, for supporting global rescue operations, we propose a new earthquake damage detection method, based on a combination of earthquake damage estimation using earthquake information (magnitude, location of source, detailed ground condition, and attenuation equation for distance) and change detection by means of remote sensing data. First, to find collapsed buildings and houses on the earth's surface, we adopt a coherence or difference image calculated from multi-temporal SAR images observed before and after the earthquake. Next, to estimate seismic intensity and probability of destruction caused by the earthquake, we applied an earthquake engineering model. Finally, damaged area is calculated using a logical AND of

difference image and the destruction probability. In order to show that we can obtain a damage detection map which corresponds with the actual damage of houses, we applied the method to simulations of the 1995 Hyogoken Nanbu earthquake in Japan and the 2007 Pisco earthquake in Peru.

2. INTERNATIONAL RESCUE TEAM OF JAPAN

The Japanese government dispatches the International Rescue Team of Japanese Fire-Service (IRT-JF) to a disaster stricken country as a team specialized in rescue operations of the Japan Disaster Relief Team. The IRT-JF consist of 599 rescue specialists selected from 62 fire departments throughout the country. They are specialists with abundant field experience and have the ability to judge and act reliably under any circumstances. They are called up and dispatched within 24 hours to areas stricken by a large-scale disaster somewhere in the world.



Figure 1. The IRT-JF operating in the Islamic Republic of Pakistan (2005)

The IRT-JF was dispatched 14 times since 1986, for example after the 2004 great Sumatra earthquake, the IRT-JF consisting

of 11 specialists carried out a rescue operation in the Kingdom of Thailand.

3. PROPOSED METHOD

3.1 Outline

The government needs actual damage information of the struck area to determine where rescue teams must be dispatched, and a communication system of information sharing between the headquarters and disaster site, for an effective rescue operation. In our study, we are planning to use data from two remote sensing satellites (ALOS-PALSAR and Terra-ASTER) and a communication satellite (WIND) according to following operation periods as shown in Figure 2.

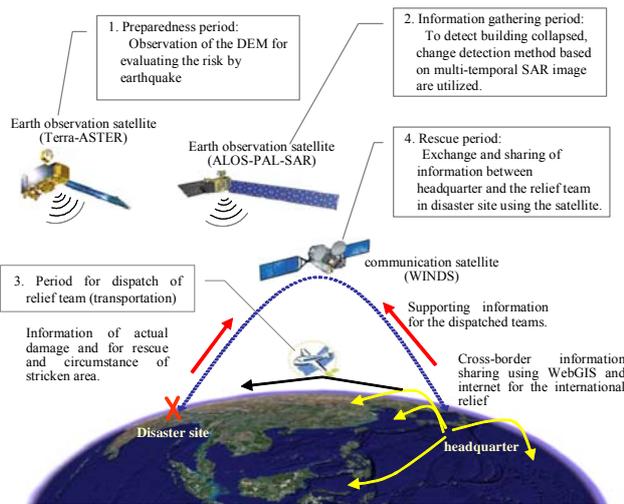


Figure 2 .Satellites for the proposed method to support the IRT-JF

3.2 Change detection using remote sensing data

It is necessary to gather actual damage information from areas struck by earthquakes to allow for rapid countermeasures against disasters. Since the telecommunication system may be damaged by the shock of an earthquake, it is difficult to get actual damage information from a seriously damaged region. Therefore, Ito (2003) proposed remote sensing appropriate for detecting earthquake damage, by using multi-temporal remote sensing image data. In this paper, to find collapsed buildings and houses on the earth's surface, we calculate a coherence or difference image using multi-temporal SAR images observed before and after the earthquake.

3.3 Risk evaluation using an earthquake engineering model

Earthquake intensity can be evaluated by means of magnitude and by an attenuation equation for distance as shown in Figure 3. Seismic intensity is calculated by means of the following equations.

$$\log V_h = p - \log(X+q) - 0.002X \quad (1)$$

$$p = 0.52M_w - 0.918$$

$$q = 0.0164 \cdot 10^{0.382M_w}$$

$$V_{max} = V_h \cdot R \quad (2)$$

V_h is velocity of ground motion in the rock bed, V_{max} is peak velocity on the surface, and R is amplification factor due to soft ground surface. R is calculated for typical landform types - hill, plateau, fan, reclaimed land, etc., using the following relationship (Matsuoka, 1994).

$\log V_h = p - \log(X+q) - 0.002X$ $p = 0.52M_w - 0.918$ $q = 0.0164 \cdot 10^{0.382M_w}$ <p>M_w : moment magnitude X (km) : distance from the fault</p>	$\log R = 1.98 - 0.71 \log V_s$ $\log V_s = a + b \log h + c \log D$ <p>h is height above sea level, D is distance from a main river $a, b,$ and c are empirical parameters defined for each landform</p>
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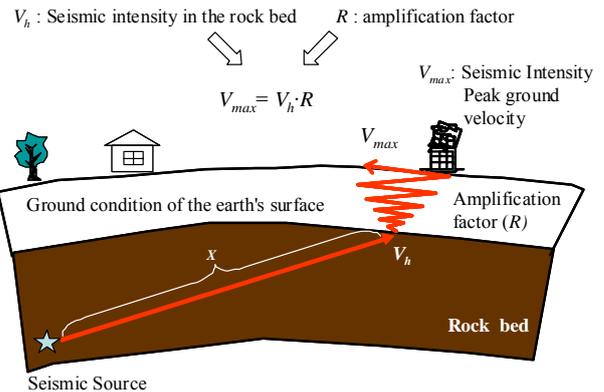


Figure 3 .Method to calculate seismic intensity on ground surface

The probability of destruction in Japan caused by an earthquake can be estimated using an empirical relationship between V_{max} and the number of collapsed wooden houses damaged by past earthquakes. We can calculate the estimated number of collapsed wooden houses for the stricken area from

$$D = N \cdot r \quad (3)$$

$$SI = 1.18 \cdot V_{max}$$

$$r = 1.21 \cdot 10^{-4} (SI - 30)^{1.51}, \quad (SI > 30)$$

$$r = 0, \quad (SI \leq 30) \quad (\text{Miyakoshi, 1997}).$$

Where, r is damage rate of wooden houses, N is number of wooden houses in the each mesh. The number of collapsed wooden houses (D) is calculated by multiplying N by r . The result of the earthquake risk evaluation is utilized as useful information to determine disaster prevention planning and fire fighting tactics in Japan. By using the estimation relation described above, the Early Estimation System (EES) is utilized in the Cabinet Office of the Japanese government. This system provides useful information for urgent response activities of the headquarters offices which have responsibility for countermeasures against disasters.

In order to evaluate earthquake intensity and damage, we need much data, such as ground condition (amplification factor: R), population, structures, etc., which are stored as two or three dimensional mesh data by means of a Geographical Information System (GIS). In particular, the amplification factor (R) for the each landform is very important information needed to calculate ground motion of the ground surface. However, detailed investigation of the ground conditions is costly. Therefore, such work is not performed everywhere in the world. Even if detailed data for an area exists, it is not always open to the public. Therefore, we will use a landform classification method using a high resolution Digital Elevation Model (DEM) made from satellite observations to obtain typical landform types - hill, plateau, fan, reclaimed land, etc. anywhere in the world.

3.4 Damage detection map

However, change detection using SAR has the problem that no damaged region is identified as a structure collapse region because of the changes of the earth's surface that do not relate to an earthquake. An improvement of damage estimation accuracy is needed in order to apply remote sensing data to detect damage caused by earthquake disasters. Therefore, we adopt the following data process to create the damage detection map with high accuracy. Figure 4 shows data process flow of the proposed method, based on a combination of both earthquake information provided by the seismometer network and the SAR images observed by satellite.

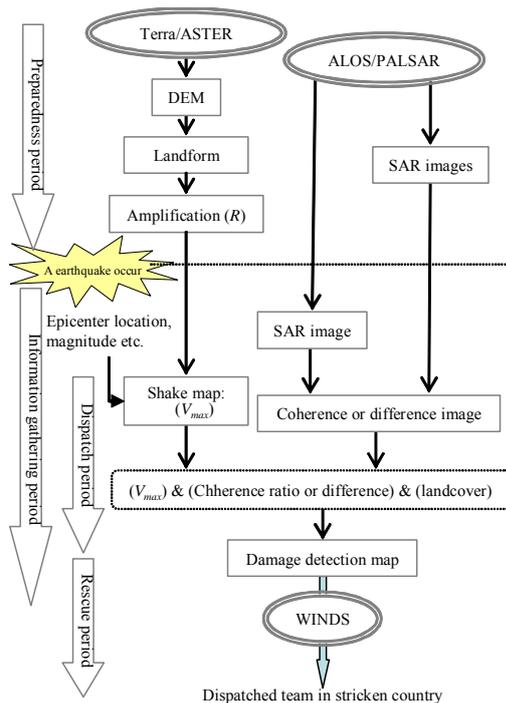


Figure 4. Data process flow

4. SIMULATION RESULTS

4.1 The 1995 Hyogoken Nanbu earthquake in Kobe, Japan

The 1995 Hyogoken Nanbu earthquake was an earthquake in Japan that measured 6.8 on the moment magnitude scale. It occurred on Tuesday January 17, 1995 at 5:46 a.m. JST in the southern part of Hyōgo Prefecture. Approximately 6,434 people, mainly in Kobe, lost their lives as a result of the earthquake. Because Kobe was the closest major city to the epicenter of the earthquake, it was hit by the strongest shock waves. More than 200,000 buildings and houses collapsed in the southern part of Hyōgo Prefecture. In order to demonstrate the efficacy of the proposed method, we used a simulation of the 1995 Hyogoken Nanbu earthquake in Kobe to detect earthquake damage.

In this case, using a neural network classification method and a 50m² resolution Digital Elevation Model (DEM) provided by the Geographical Survey Institute of Japan, four typical landform types (hill, plateau, fan and reclaimed land) were obtained for Kobe. The empirical parameters a, b, and c for each classified landform are specified, to evaluate seismic intensity (Hosokawa, 2001).

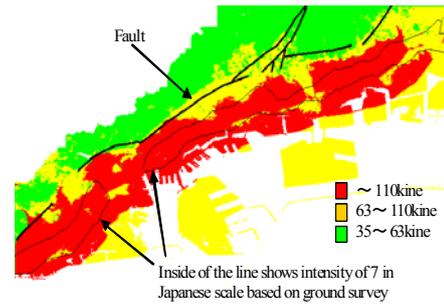


Figure 5. This shows an estimated seismic intensity for the 1995 Hyogoken Nanbu earthquake in Kobe, Japan

To extract temporal changes of the earth's surface, we used a coherence ratio image calculated from the two SAR coherence images. These coherence images are calculated from three pre-earthquake SAR images and one post-earthquake SAR image as shown in Figure 6. Next, to calculate the number of collapsed wooden houses, we applied an empirical relationship for the pixels where coherence ratio decreases. From our simulation, we were able to obtain a damage detection map that corresponds with actual damage of wooden houses as shown in Figure 6.

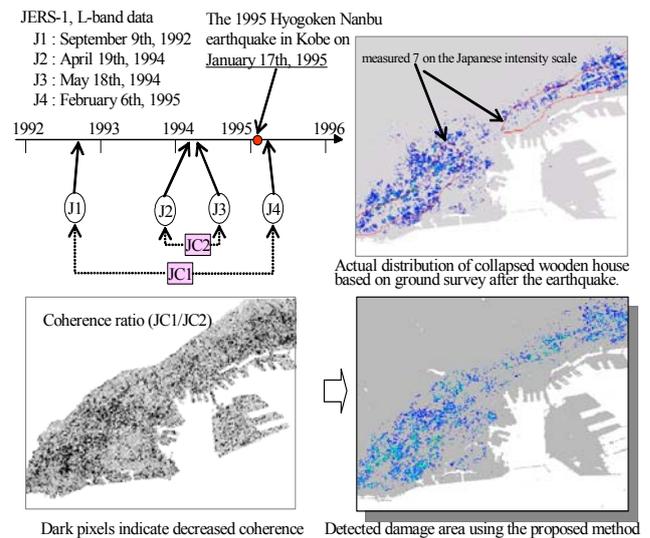


Figure 6. SAR data description and simulation results for the 1995 Hyogoken Nanbu Earthquake.

As can be seen, the detection map has less noise than the coherence ratio image, which indicates that the proposed method has better detection ability than that of using only the change of coherence value.

4.2 The 2007 Peru earthquake

The 2007 Peru earthquake was an earthquake measuring 8.0 on the moment magnitude scale that hit the central coast of Peru on Wednesday August 15, 2007, at 23:40:58 UTC. The epicenter was 150 kilometres south-southeast of Lima at a depth of 39 kilometres. More than 58,000 homes were destroyed. The city of Pisco, which is 260 km southeast of Lima, was about 80% destroyed, and as many as 430 Pisco residents died.

In order to demonstrate the efficacy of the proposed method, we tried to simulate damage detection and earthquake intensity

evaluation for the 2007 Peru earthquake. For this paper, we used the following remote sensing data.

ALOS/ PALSAR : Level 1.5	
Observation date	2007/7/12(before), 2007/8/27(after)
Pixel spacing	12.5m
Polarization	HH
Terra/ASTER	
Observation date	2006/4/11
Pixel spacing	15m
Sensor	VNIR

Table 1. Remote sensing data description

The Terra/ASTER VNIR and DEM data are provided by the National Institute of Advanced Industrial Science and Technology (AIST), we can obtain the DEM data processed by the GEO Grid on demand using internet access. (URL for reference : <http://www.geogrid.org/en/>)

First, to find change on the earth's surface, we calculated differences of the backscattering coefficients from multi-temporal SAR images observed before and after the earthquake using equation (4).

$$Diferrence\ image = \frac{\sum_{i=-n}^n \sum_{j=-n}^n \sqrt{(b_{i,j} - a_{i,j})^2}}{N} \quad (4)$$

$a_{i,j}$ and $b_{i,j}$ are backscattering coefficients of the SAR data observed after and before the earthquake respectively. N is the number of pixels in the window operator of $(2n+1)^2$. In this simulation, we adopted that $n=2$ and $N=25$. Next, to estimate seismic intensity (V_{max}), we applied the model described in Eq. (1) and (2). Finally, the damaged area is found from a logical AND of the difference ($>2,000$), the seismic intensity ($V_{max}>20cm/sec$), and land cover processed from the VNIR data (excluding vegetation regions). As a result of this simulation, we were able to obtain the damage detection map shown in Figure 7(d).

5. CONCLUSION

In our simulation of the 1995 Hyogoken Nanbu earthquake in Japan and the 2007 Pisco earthquake in Peru, we were able to obtain damage detection maps that correspond with the actual damage of houses. The map has less noise than the coherence ratio image, which indicates that the proposed method has better detection ability than that of using only the change observed by SAR. It is expected that the proposed method can provide early and highly accurate information to headquarters for countermeasures against earthquake disaster, and can enable quick and effective relief and rescue operations.

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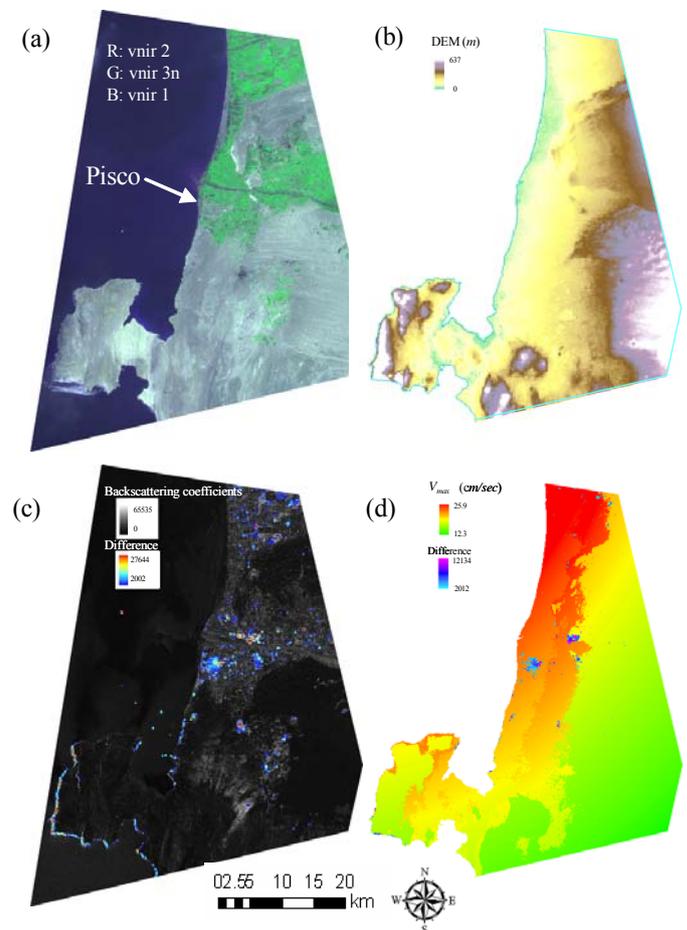


Figure 7. (a)Terra/ASTER (VNIR) natural color image. (b)ASTER DEM processed by the GEO Grid. (c)The difference image superimposed on ALOS/PALSAR power image. (d)Detected damage area superimposed on a shake map (V_{max}) estimated by the epicenter information and the ASTER DEM.