EXTRACTION OF COLLAPSED BRIDGES DUE TO TSUNAMIS USING A POST-EVENT AIRBORNE FULL-POLARIMETRIC SAR IMAGE

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ABSTRACT: This study attempted to extract bridge damages due to tsunamis by visual inspection from a post-event X-band airborne full-polarimetric SAR image, by decomposing it into 4-component scattering power. The 12 damaged bridges due to the 2011 Tohoku earthquake and tsunami were inspected by comparing post-event airborne SAR images, optical images before the disaster and aerial photographs soon after the disaster. From the results, it is found that the visual inspection of bridges from a post-event airborne SAR image can extract the washed-away of whole or a part of superstructure, both the superstructure and the substructure, the accumulation of debris on a bridge deck.

KEY WORDS: Pi-SAR-X2, full-polarimetric SAR image, bridges, tsunami

1. INTRODUCTION

Many highway bridges were damaged or collapsed/washed away due to the 2011 Tohoku earthquake and tsunami (NILIM, 2014; Tamakoshi et al. 2015). Traffic networks were suspended at the collapsed sections of bridges and the delay of emergency operations was followed. The emergency response for road systems reaches the maximum within 24 hours after a disaster strikes (Kaneko and Matsuoka, 2013). Therefore, it is important for the emergency response to grasp the situation of damaged bridges soon after a disaster strikes.

Synthetic aperture radar (SAR), which can observe the ground surface in all whether conditions and in 24 hours, is useful to grasp the situation of affected areas. Modern airborne SAR is suitable for grasping damage situations since it is possible to perform emergency observation with high-resolution of 30 cm and by the full-polarization (HH/HV/VH/VV) mode. However, it is difficult to compare the airborne SAR data before and after a disaster because airborne SAR cannot observe the same area in the same acquisition condition twice unlike satellite SAR. Thus, it is important to extract damaged bridges only from a post-event airborne SAR image.

There are several researches about bridges using SAR images. Soergel et al. (2006) tried to detect layover, double-bounce and triple-bounce of the bridges over water areas from airborne SAR data. Liu et al. (2017) clarified that layover, double-bounce and triple-bounce of small bridges are overlapped one another and the backscattering of bridges changes according to the angle between the bridge-axis and the range direction using high-resolution X-band satellite SAR images. Yamazaki et al. (2016) attempted to extract damaged bridges due to tsunami using the changes of the backscattering coefficient before and after a disaster from two high-resolution X-band satellite SAR images.

This study tries to extract the collapsed/washed-away bridges due to the 2011 Tohoku earthquake and tsunami using a post-event airborne full-polarimetric SAR image. We discuss the effectiveness of visual inspection from a post-event airborne SAR image by comparing with pre-event optical satellite images and aerial photographs soon after that for each damage type.

2. STUDY AREA AND IMAGE DATA

The study area focused on the Pacific coast of the Tohoku District, Japan, which was damaged by the 2011 Tohoku earthquake and tsunami. The data observed soon after the disaster strikes by the second-generation X-band polarimetric and interferometric SAR (Pi-SAR-X2), which was developed by the National Institute of Information and Communications Technology (NICT), were used in this study. The Pi-SAR-X2 can perform emergency observation with high-resolution of 30 cm and full-polarization. **Figure 1** shows the Pi-SAR-X2 images in the study area and **Table 1** shows the data acquisition conditions. The used data are in the MGP (Multi look Ground range Product), which has power and phase information.

First, the Pi-SAR-X2 images were decomposed into 4-component scattering power using the PolSARpro_v5.1 software, which was developed by the European Space Agency (ESA). After the geocoding process of the SAR images, these data were resampled into 0.3 m/pixel in both the azimuth and range directions. After that, the SAR images were transformed from the digital number to the backscattering coefficient (sigma naught). Any speckle filter process is not applied to the data so that we can clearly recognize bridge outlines.

The 12 damaged bridges due to tsunami were adopted as subjects based on the reports of the National Institute for Land and Infrastructure Management (NILIM, 2014;

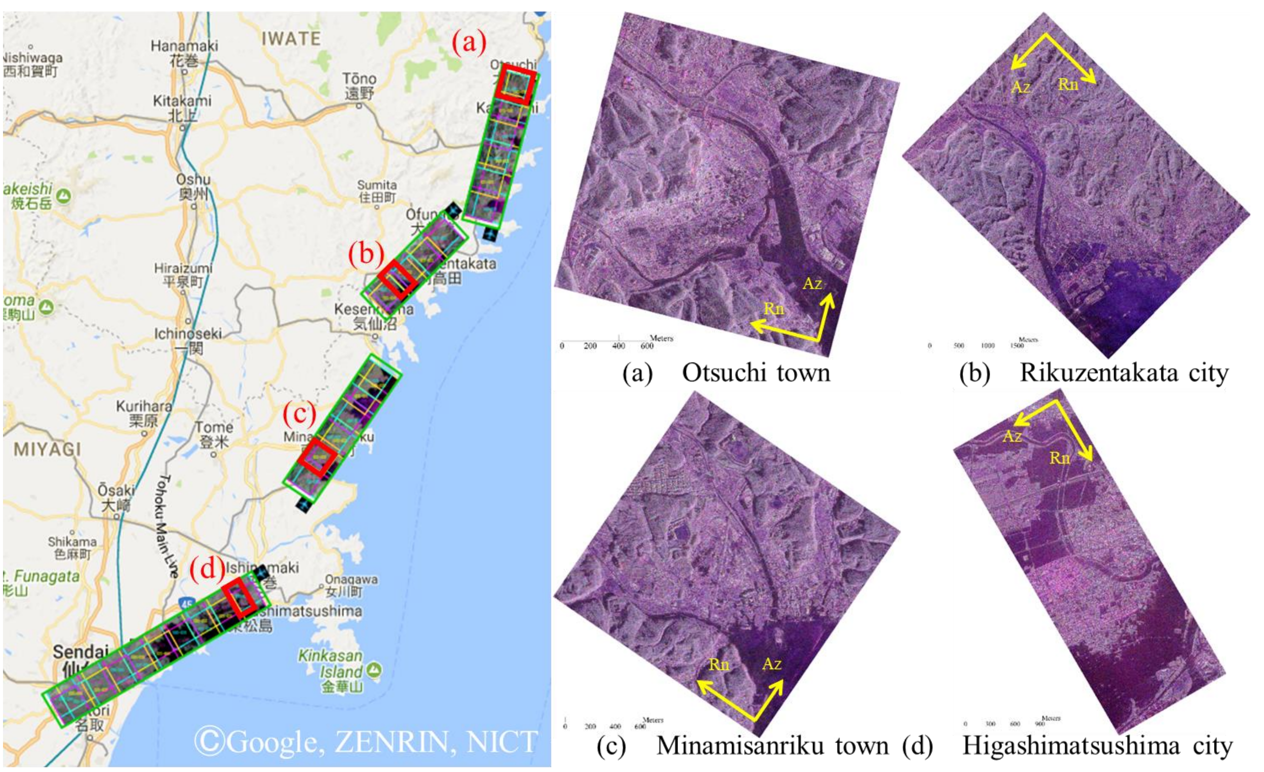

Figure 1 Pi-SAR-X2 images (R : HH, G : HV, B : VV) in the study area

Table 1 The SAR data acquisition conditions

area	(a)	(b)	(c)	(d)
date	March 18, 2011	March 18, 2011	March 18, 2011	March 12, 2011
azimuth (°)	15	225	35	240
incident angle (°)	44.6	43.1	45.3	36.2

Tamakoshi et al. 2015). The subjected bridges include 8 bridges whose superstructure and/or substructure were washed away and 4 bridges which were damaged such as accumulation of debris on bridge decks and the deformation of handrails.

3. METHODOLOGY

The Pi-SAR-X2 data were decomposed into 4-component scattering power to investigate the backscattering mechanism of bridges (Singh et al., 2013). The 4-component scattering power decomposition is a method, in which we can more clearly recognize objects by fitting measured data to the scattering matrix. Each scattering power is defined as the surface scattering power (Ps), the double-bounce scattering power (Pd), the volume scattering power (Pv), and the Helix scattering power (Pc) as proposed by Yamaguchi et al. (2005). The Ps shows odd times scattering caused at the ground surface. The Pd shows even times scattering caused at corners. The Pv shows scattering caused at random linear objects. The Pc shows scattering power, which is transformed from the co-polarization to the circular polarization. This decomposition method leads to more clearly distinguish objects such as bridges, vegetation and water surfaces. We discuss the effectiveness of visual inspection from color composite images of the 4-component scattering power.

4. RESULTS AND DISCUSSION

Figure 2 shows the color composite images of the 4-component scattering power, the optical images before the disaster, cited from Google Earth and the aerial photographs soon after the disaster (March 13, 2011), cited from the Geospatial Information Authority of Japan (GSI) map. **Table 2** shows the extraction results of collapsed bridges due to tsunami. The bridge numbers and the damage types are based on the reports (NILIM, 2014; Tamakoshi et al. 2015).

For the bridges Nos. 61 and 126, both the superstructure and substructure were washed away. In such cases, the bridge cannot be confirmed in the SAR image because specular reflection occurs just like the water surface. We can extract the washed-away of both the superstructure and substructure from a post-event airborne SAR image if we know the positions of the bridges beforehand.

For the bridges Nos. 90, 101 and 103, the whole superstructure was washed away. It is possible to extract the collapsed bridges from a post-event airborne SAR image when the superstructure is washed away and the substructure remains since the double-bounce scattering can be recognized from piers. We can also observe several double-bounce scattering, volume scattering and surface scattering. It is considered to be the influence of the side block, driftwood and steel bridge bearings etc.

For the bridges Nos. 94, 128 and 159, a part of superstructure was washed away. The washed-away part shows the specular reflection. It is possible to recognize a part of washed-away superstructure from the post-event airborne SAR image since the bridge outline was terminated suddenly.

For the bridges Nos. 59 and 125, handrails were deformed. The surface scattering and volume scattering occur along the side face of the bridges. It is unknown whether or not this complexity of backscattering indicates the deformation of handrails because the size of handrails may be smaller than the resolution of the image.

For the bridges No. 96 and 124, the debris carried by tsunami was accumulated on the deck of the bridges. The volume scattering and surface scattering can be recognized on the bridge deck. It should be shown as dark due to weak backscattering when no objects on the deck of the bridges. Therefore, debris might be accumulated when the strong backscattering was confirmed on the bridge deck.

From **Table 2**, we could extract the washed-away of the whole superstructure when the bridge outline was not confirmed but piers could be. In addition, we could recognize the washed-away of both the superstructure and substructure when we could not observe both the bridge outline and piers. However, piers could not be confirmed due to radar shadow when we could observe the bridge outline. Although this paper focuses on damaged bridges that we can observe the bridge outline, it is difficult to extract bridge damages when we cannot recognize the bridge outline.

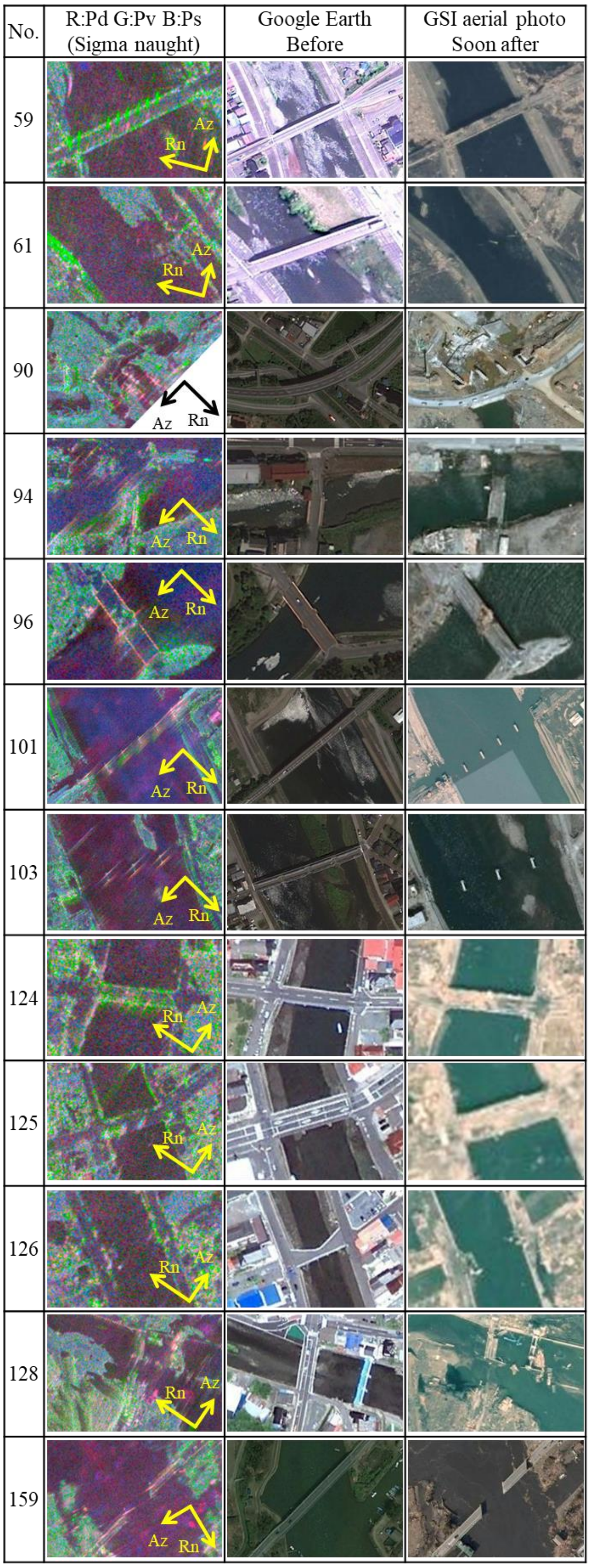

Figure 2 Twelve collapsed bridges used in this study. Pi-SAR-X2 images of 4-component scattering power (left), optical images from Google Earth (center), and aerial photographs from GSI map (right).

Table 2 Extraction results of the 12 collapsed bridges due to tsunami

No.	Main damage type	Bridge outline	Piers	Extraction of collapsed bridges
59	deformation of handrails	○	-	○
61	washed away (superstructure and substructure)	×	×	○
90	washed away (whole superstructure)	×	○	○
94	washed away (a part of superstructure)	○	-	○
96	accumulation of debris	○	-	○
101	washed away (whole superstructure)	×	○	○
103	washed away (whole superstructure)	×	○	○
124	accumulation of debris	○	-	○
125	deformation of handrails	○	-	○
126	washed away (superstructure and substructure)	×	×	○
128	washed away (a part of superstructure)	○	-	○
159	washed away (a part of superstructure)	○	-	○

5. CONCLUSIONS

This study attempted to extract the collapsed bridges due to the 2011 Tohoku earthquake and tsunami by visual inspection from a post-event X-band airborne full-polarimetric SAR image, which was decomposed into 4-component scattering power.

It was found that the visual inspection of bridges from a post-event airborne SAR image can extract the washed-away of whole or a part of superstructure, both the superstructure and substructure. The accumulation of debris carried by tsunami on bridge decks could also be detected. However, it was difficult to recognize the deformation of handrails. Quantifying parameters for collapsed bridges will be discussed in a future work since the result of visual inspection depends on individuals.

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