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INTERPRETATION OF EXPRESSWAY DAMAGES IN THE 2004 MID NIIGATA EARTHQUAKE BASED ON AERIAL PHOTOGRAPHS

Yoshihisa MARUYAMA[1], Fumio YAMAZAKI[1], Hiroyuki YOGAI[2] and Yoshiyuki TSUCHIYA[2]

SUMMARY

In the Mid Niigata earthquake, which occurred on October 23, 2004, the expressways were closed just after the earthquake. Many major and minor damages were caused because of this earthquake. The traffic regulation was carried out just after the earthquake, and the expressway was tentatively re-opened on November 5. It took about a month to open the regular four-lane road. In Japan, it is anticipated that the Tokai earthquake is coming and many severe damages are caused in various infrastructures. The expressway network will be subjected to severe ground motion in the Tokai earthquake. From this viewpoint, it is important to grasp the damages of expressways at an early stage just after the earthquake so as to make an efficient traffic control and a rapid disaster response. The remotely sensed imagery data obtained from satellites and airborne platforms are effective to grasp damage distribution due to natural disasters. In this study, visual damage inspection is conducted using aerial photographs taken by Geographic Survey Institute, Japan. In addition that, image processing is performed to identify the damaged sections of the expressways. It is expected that this technique will be applied to the automated damage detection of the expressway networks.

1. INTRODUCTION

In order to gather the earthquake information and to make an effective traffic control just after an earthquake, the seismometer network is deployed along the expressways in Japan [Yamazaki *et al*., 2000]. The expressways are closed if the JMA (Japan Meteorological Agency) seismic intensity is larger than or equal to 4.5. In the Mid Niigata earthquake, which occurred on October 23, 2004, the expressways were closed just after the earthquake. Many major and minor damages were caused because of this earthquake. The traffic regulation was carried out, and the expressway was tentatively re-opened on November 5. It took about a month to open the regular four-lane road.

The remotely sensed imagery data obtained from satellites and airborne platforms are effective to grasp damage distribution due to natural disasters [Yamazaki, 2001]. In the 2004 Mid Niigata earthquake, various organizations have investigated the possibility to grasp the damage distribution based on remote sensing technology. The platforms and sensors of remote sensing should be selected considering the area to cover, urgency, weather and time conditions, and the resolution of images. It is worth mentioning that QuickBird, a high-resolution commercial satellite with the maximum spatial resolution 0.6 m, has been launched on October 18, 2001 [DigitalGlobe]. These images can be used to detect damages of individual buildings after natural disasters [Kouchi *et al*., 2004; Yano *et al*. 2004]. Airborne remote sensing is more suitable to collect the detailed damage distribution because aerial photographs have higher resolution than any other satellite images.

[1] Dept. of Urban Environment Systems, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba, Japan
Email : ymaruyam@tu.chiba-u.ac.jp, yamazaki@tu.chiba-u.ac.jp
[2] Expressway Research Institute, Central Nippon Expressway Co., Ltd., 1-4-1 Tadao, Machida-shi, Tokyo, Japan
Email: h.yogai.aa@c-nexco.co.jp, y.tsuchiya.aa@c-nexco.co.jp

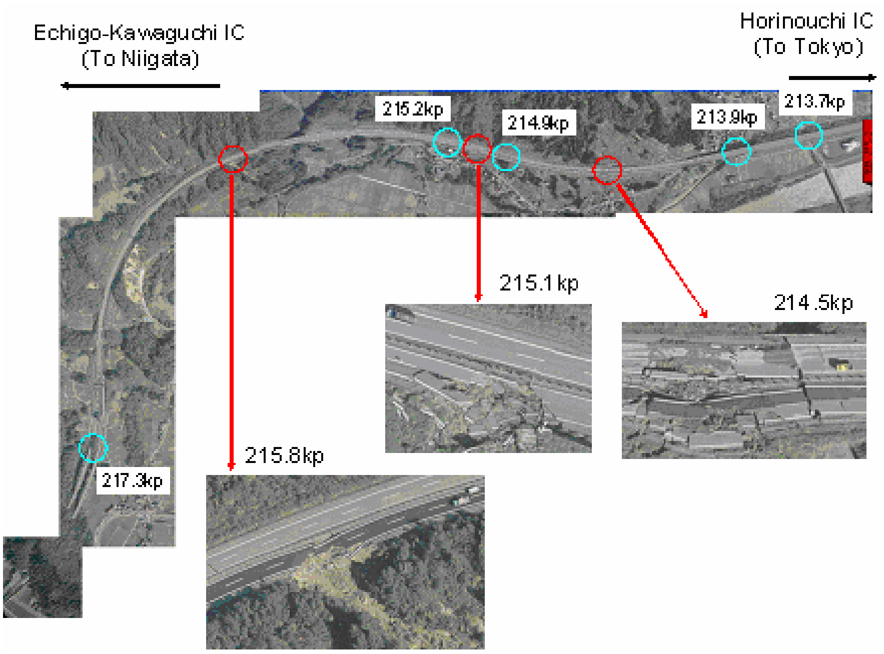


Figure 1: Aerial photograph of Kanetsu expressway between Horinouchi IC to Echigo-Kawaguchi IC

In this study, visual damage inspection is conducted using aerial photographs taken by Geographic Survey Institute, Japan. In addition that, image processing is performed to identify the damaged sections of the expressways. It is expected that this technique will be applied to the automated damage detection of the expressway networks.

2. EXPRESSWAY DAMAGES CAPTURED IN AERIAL PHOTOGRAPHS

Utilization of satellite images and aerial photographs is effective to grasp the damage distribution due to natural disasters [Bitelli *et al*., 2004]. The Geographic Survey Institute, Japan, has taken aerial photographs of heavily damaged areas on October 24 and 28, 2004. In some photographs, the expressways are captured. Therefore, it is possible to conduct the visual inspection and to compare the result of visual damage detection with that of the field investigation.

Figure 1 shows the aerial photograph which captures the expressway (between Horinouchi IC and Echigo-Kawaguchi IC). In this figure, the large-scale collapses of banks at 214.5kp (kilometer post), 215.1kp and 215.8kp are captured. These damages were easily interpreted from the aerial photograph. Some damages are also found from the figure where blue circles indicate. Figure 2 compares the damaged sections in the aerial photograph with those in the field photographs. The 20 cm gap of road surface can be identified from the aerial photo at 213.7kp. The gap of bridge joint was detected at 213.9kp. These damages are classified as severe damages. At 214.9kp, the depression of road shoulder with the length of 10 m was found, and it is reported that four sound insulating boards were fallen down. This depression of road shoulder is categorized as minor damage. The electric bulletin board was fallen down at 217.3kp, which can be identified from the aerial photograph.

Various platforms of remote sensing technology are available, and immediacy, coverage and resolution depend on the platforms. Table 1 shows the resolutions of imageries captured by some major high-resolution satellites. A high-resolution commercial satellite, QuickBird, was launched in 2001. QuickBird images have 0.6 m resolution [DigitalGlobe]. The IKONOS, which was launched in 1999, provide the image with the maximum resolution of 1.0 m [Space Imaging]. The SPOT-5 launched in 2002 can capture the image with the maximum resolution of 2.5 m and with the area of 3600 km^2 [Spot Image].

The aerial photographs used in this study have the 0.1 m resolution. The resolution of aerial photo was changed into 0.6 m, 1.0 m and 2.5 m. These images correspond to those of satellites shown in Table 1 from the viewpoint of the resolution. Figure 3 shows the images whose resolutions are changed as is mentioned before. According to the figure, the large-sized collapse of bank at 214.5kp can be detected by all four images. The crack of road surface at 215.2kp can be identified by the images with the resolution of 0.6 m and 1.0 m, which correspond to

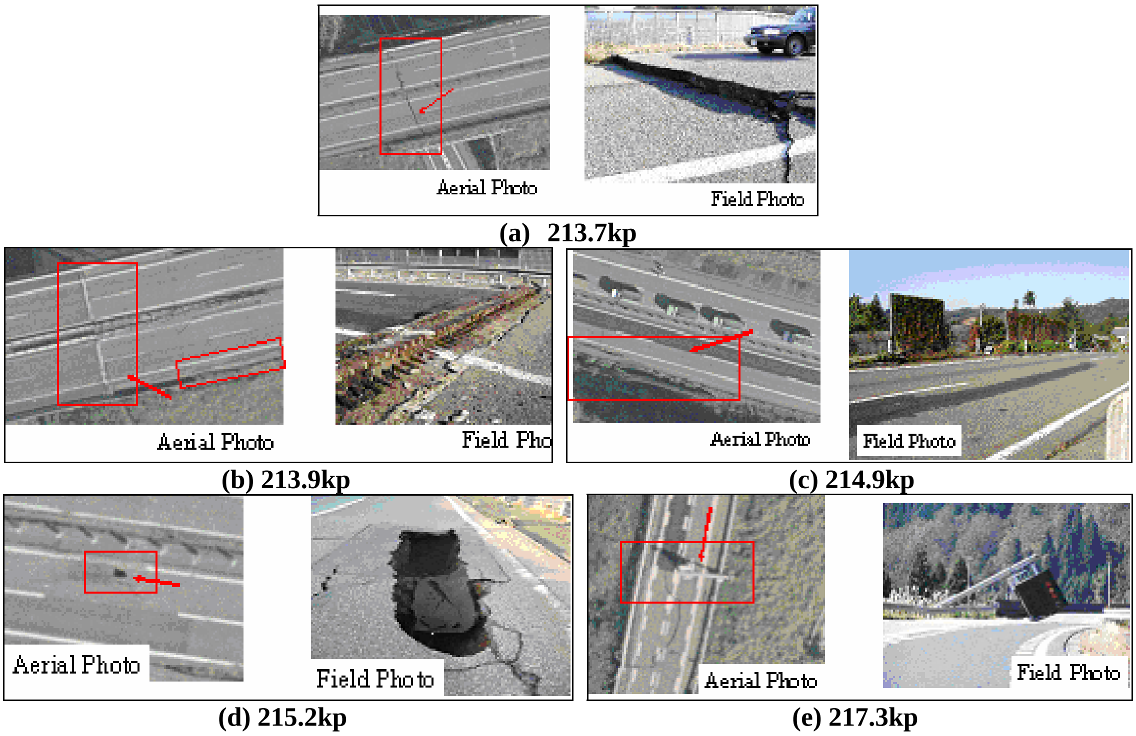


Figure 2: Comparison of damages detected from the aerial photograph with those from field photographs

Table 1: Resolutions of imageries taken from various satellites

Satellite	Spatial Resolution
QuickBird	0.6 m
IKONOS	1.0 m
SPOT-5	2.5 m

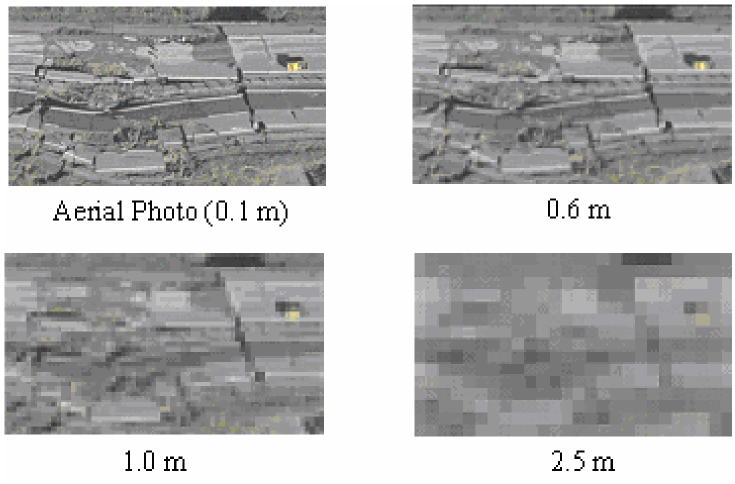
the QuickBird image and IKONOS image. It is impossible to detect the crack from the image with the resolution of 2.5 m. The depression of road shoulder at 215.2kp is observed in the aerial photograph. It can be detected by the image with the resolution of 0.6 m, but it may be difficult to be detected by the 1.0 m resolution image.

Based on the investigation, the aerial photographs and the high-resolution satellite images, e.g. QuickBird images and IKONOS images, are effective to detect the damages due to earthquakes, which affect the availableness of expressways. However, it takes time to conduct visual damage inspection for the entire area where is subjected to severe ground motion. In order to grasp the damage distribution in the expressway networks immediately, automated damage detection is more suitable than visual damage inspection.

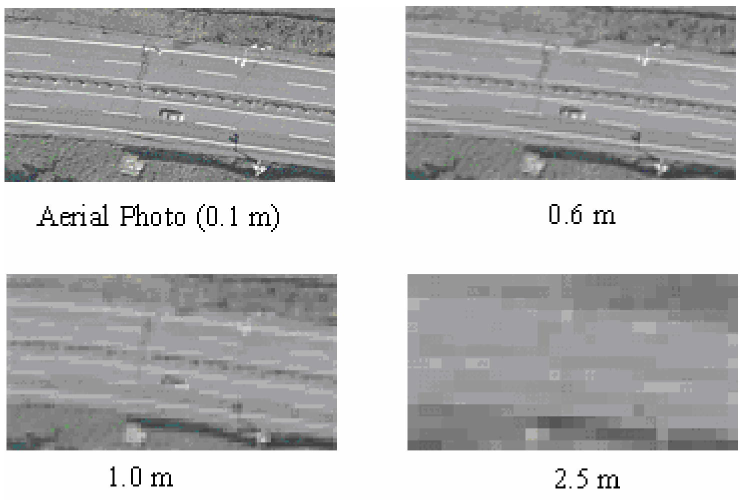
3. IMAGE PROCESSING OF AERIAL PHOTOGRAPHS TO DETECT DAMAGED SECTIONS OF EXPRESSWAYS

In this chapter, automated damage detection based on image processing is performed. Figure 4 shows the analytical flowchart of image processing to detect damaged sections of expressways. In this study, it is assumed that aerial photographs which focus on the expressway are available just after an earthquake. To detect the road areas from the high-resolution satellite image is currently under studied by some researches, but that is not considered in this study. This is because the expressway administrator can get aerial photos of expressways by using helicopters just after an earthquake.

First, the HSI transformation is performed on an aerial photograph [Mitomi *et al.*, 2001]. Generally speaking, the digital color image is drawn in RGB (Red, Green and Blue) color. The digital image can be also shown in three indices, Hue, Saturation and Intensity through HSI transformation. Because these characteristics are independent



(a) 214.5 kp



(b) 215.2 kp

Figure 3: Comparison of images which captured the damaged sections of the expressway with various resolutions

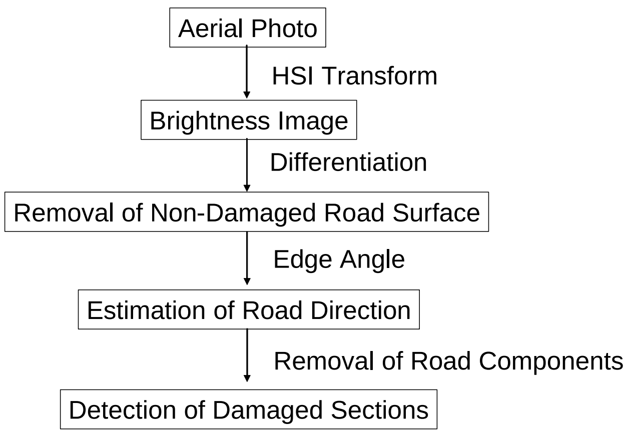
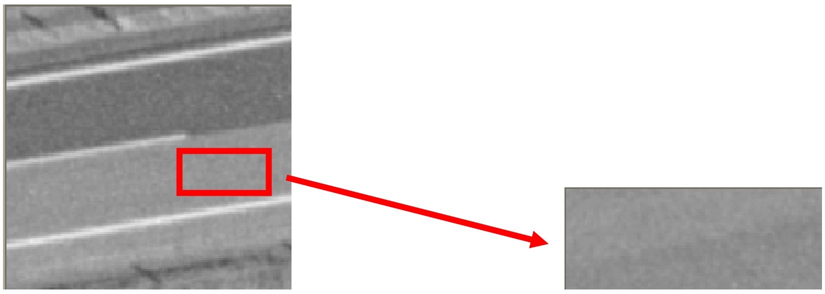


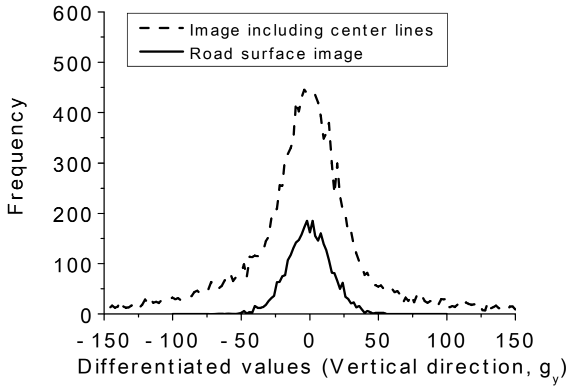
Figure 4 : Flowchart of image processing to detect the damaged sections of expressways

of each other, HSI is more suitable in image processing. In the image analysis, the brightness image obtained from HSI transformation is used in this study.

It is a fundamental and an important matter to detect the edge in the image processing. The edge is the border line in the aerial photo, and it is the area where the intensity of the image changes drastically. Hence, the



(a) Image including center lines **(b) Road surface image**



(c) Histogram of differentiated value

Figure 5: Differentiated images and obtained histogram

differential operation on images is performed to detect the edge. In this study, the spatial filtering by the Sobel filter [William, 1991] with a 3 x 3 pixel window is applied to the image in differential operation. The differential operation is performed on the images shown in Fig. 5(a) and (b). The images are parts of expressways. The center lines of the expressway are included in Fig. 5(a), and only the road surface is focused in Fig. 5(b). The histogram of obtained values by the spatial filtering on these images is shown in Fig. 5(c). The differentiated values from the image including center lines of expressway are in the wider range than those from the image focusing only the road surface. This is because the sudden change of intensity is not occurred in the road surface image. Based on these results, the road surface is identified through differentiated values of the image as shown in Eq. (1).

$$\left(|g_x| < c\right) \cap \left(|g_y| < c\right) \qquad (1)$$

where g_x and g_y are horizontally and vertically differentiated values, respectively. c is the threshold value to identify the road surface.

When the road surface is identified based on the above discussion, it was found that there remain some pixels that are not recognized as road surface. The spatial resolution of the aerial photograph used in this study is 0.1 m. Because the spatial resolution is very high, the salt-and-pepper noise is often observed in image processing. To avoid the noise, the median filter with a 3 x 3 pixel window was applied on the image before applying the Sobel filter (Eq. (2)).

$$g(x,y) = median\{f(x+m, y+n) \mid -1 \le m,n \le 1\} \qquad (2)$$

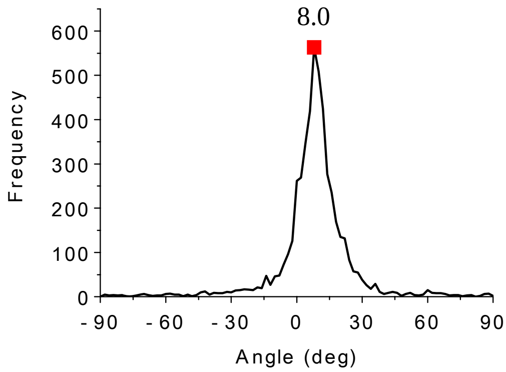
where $f(x,y)$ is the intensity of original image, and $g(x,y)$ is the smoothed value by applying the median filter. The median filter has an advantage that the image is smoothed with retaining the edge information.

Applying the median filter five times on the image, the road surface is identified using Eq. (1). Here, the threshold c was set to be 25. Due to the smoothing by the median filter, almost all the salt-and-pepper noise was eliminated (Fig. 6(a)).

Then, the pixels that are classified as road surface are removed in the estimation of road direction. The direction of road direction was estimated through the edge angle. The edge angle was calculated using the differentiated values by the Sobel filter (Eq. (3)).

$$\theta = \arctan(g_x / g_y) \qquad (3)$$

(a) Image to estimate the road direction



(b) Histogram of edge angle

Figure 6: Removal of road surface from the image and estimation of road direction

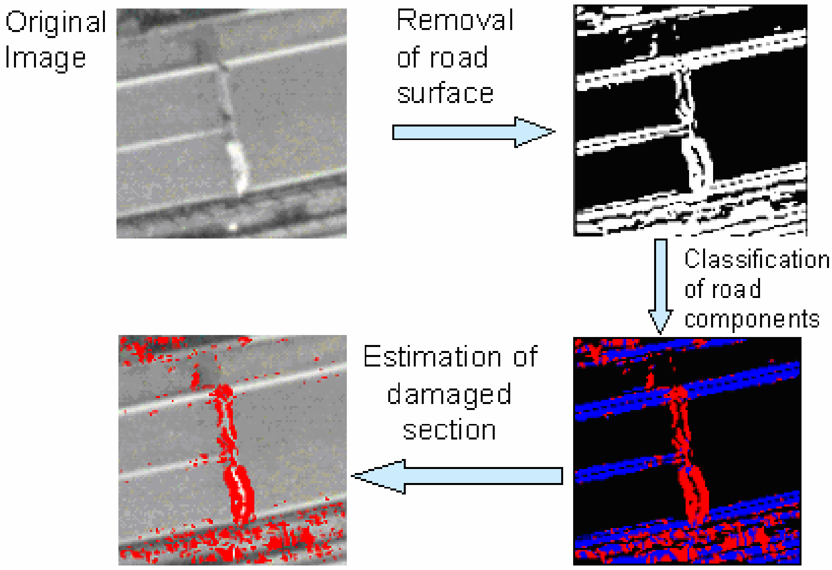


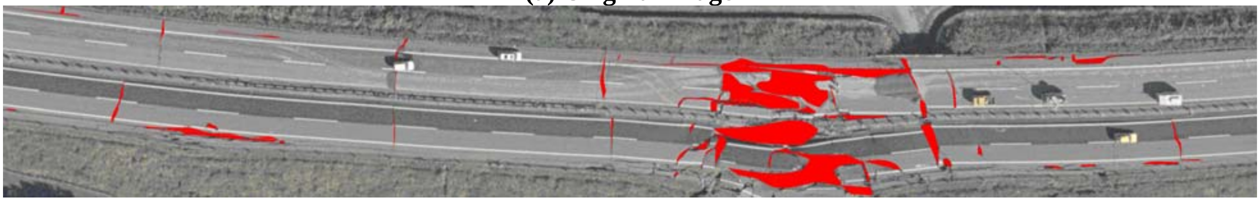
Figure 7: Example of analytical flow to detect damaged sections of expressways

Figure 6(b) shows the histogram of the edge angle obtained from the image in Fig. 6(a). The mode of the edge angle is seen at 8 degrees, and it coincides with the road direction.

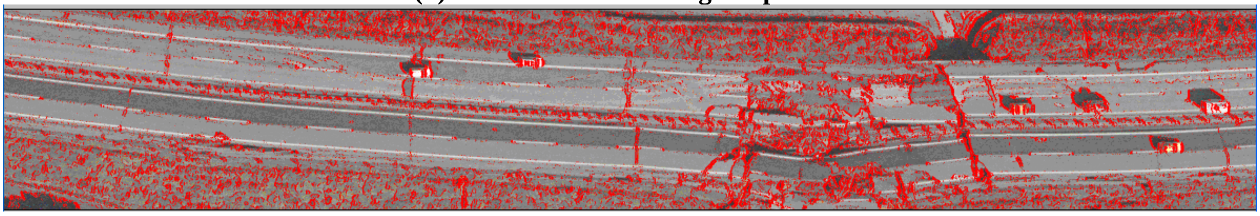
The pixels whose edge angle is in the range of 15 degrees centered at the mode are considered as those of road components, such as center lines. Because other pixels have different edge angles from the road direction, they are recognized as the damaged sections of expressways, such as cracks, depressions of road surface and so on. Figure 7 shows the example of the analytical flow to detect the damaged section of expressway using a small image. The original image captures the area where the gap of bridge joint was observed in the 2004 Mid Niigata earthquake. The damaged section in the original image was detected through the image processing as is expected.

Figure 8 compares the result of image processing conducted in this study (Fig. 8(c)) with that of visual damage inspection (Fig. 8(b)). The original aerial photograph which captures the expressway is shown in Fig. 8(a). In the image, the large-scale collapse of bank at 214.5 kp is observed. In the process of automated damage detection, the vegetation area is not considered. Therefore, the vegetation zone near the expressway is regarded as the damaged sections in Fig. 8(c). This is because the edge angles of these pixels show random values. However, it is easily found that these areas are apart from expressways. Hence, this does not matter in a practical use. The damaged sections detected through visual inspection are all extracted as damages based on the image processing. But, there remains salt-and-pepper noise in the result of automated damage detection.

(a) Original image



(b) Result of visual damage inspection



(c) Result of image processing

Figure 8: Comparison between the result of image processing and that of visual damage inspection

4. CONCLUSIONS

In order to grasp the damage distribution of expressway network just after an earthquake, visual damage inspection is conducted using aerial photographs taken on the next day of the 2004 Mid Niigata earthquake. In addition that, image processing is performed to identify the damaged sections of the expressways.

According to the visual inspection of damages of the expressways performed in this study, large-sized collapses of banks were easily detected from the aerial photographs. Other cracks of road surface, gaps of bridge joint and depressions of road shoulder that affect the serviceability of expressways were also identified from aerial photographs. To investigate the capability of visual inspection using satellite images, the images with the resolution of 0.6 m, 1.0 m and 2.5 m were produced from the aerial photograph. As the result, the images with 1.0 m and 0.6 m resolutions, which are correspondence to IKONOS and QuickBird images, may be helpful to grasp the damage distribution of expressways.

As a result of image processing, all damaged sections that are recognized visually were classified as damages. However, there remains salt-and-pepper noise in the result of automated damage detection. There are still some problems to be resolved, but it will be helpful to utilize the remote sensing technology in early earthquake disaster response.

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