Application of Image Processing to Detect Infrastructure Damage Caused by Earthquakes

by

Takaaki Kusakabe[1], Akihiro Sanada[2]

ABSTRACT

At a serious earthquake, it takes longer time to grasp damage, even if serious damages are focused on. In such a situation, remote sensing technology can play crucial roles.
Because it is time-consuming to detect damage by human eyes, it is effective to apply image processing. This paper presents applicability of image processing to detect various types of damage. For areal-type damage, 1)edge extraction, 2)unsupervised classification, 3)texture analysis, and 4)edge enhancement is appropriate to detect damaged area. For liner-type damage, it is difficult to improve visibility of damage portion by image processing. In addition, effect of overlaying facility-data to help staff to find damage at an extraction by human is descrived in this paper.

KEYWORDS: Earthquake, Image processing, Remote sensing

1. INTRODUCTION

The Ministry of Land, Infrastructure and Transport supervises facilities such as rivers, embankments, and roads that play important roles when a disaster occurs and could themselves become, in some cases, disaster sites.
Thus, when there is unusual weather or an earthquake occurs, appropriate crisis management is required, including making information available by detecting and seizing the disaster situations (Fig.1). For example, a road administrator must quickly grasp a road disaster and, based on the presence/absence of disaster, make passable routes in the disaster area to the public to provide assistance for the damaged area, secure traffic safety for road users, and make suitable emergency repairs on important routes to quickly reopen the roads by removing obstacles.

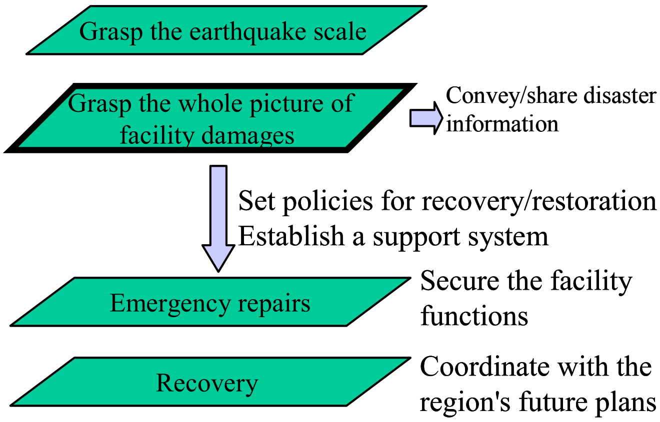


Fig.1 Disaster response by facility administrator

At a serious earthquake, it takes longer time to grasp damage by facility inspection patroll, even if you ignore small damage and focus on serious damage. In such a situation, remote sensing technology can play crucial roles. In this paper, after presenting consideration matters of using remote sensing technologies, methods to get damage information from images are discussed. To put it concretely, first, applicability of image processing in order to detect damage from images is presented. Next, information extraction by human is discussed. Each image processing has its area of strength (applicability). It means that several image processings should be applied to detect various types of damage. Extraction by human has an advantage that it can apply to all types of damage. However, a disadvantage is that it is time-consuming to check all over the images by human eyes. Therefore, method to help personnel to examine images by using facility data is developed in our research.

---

1 Head, Earthquake Disaster Prevention Division, National Institute for Land and Infrastructure Management, Tsukuba-shi, Ibaraki-ken 305-0804 Japan
2 Senior Researcher, ditto

2. CONSIDERATION MATTER IN USING REMOTE SENSING TECHNOLOGIES

There are restrictions considered in using remote sensing technologies [1]. Lead-time, weather/time and resolution are discussed in this part. Furthermore, by considering restrictions, possible procedures of remote sensing systems to detect damaged facilities are simulated (Fig.2).

2.1 Lead-time & Weather/time

Lead-time from occurrence of an earthquake to staff's acquiring damage information based on remotely sensed data should be considered when remote sensing systems are applied to disaster response. Lead-time depends on platform-type. Below shows the each platform's present situation.

2.1.1 High Resolution Artificial Satellite

Most of high- resolution artificial satellites get images at around 10:30A.M. If a disaster occurs just after satellite's getting images (10:30A.M.), it takes more than 24 hours to get images of damage distribution. In this case, remote sensing images is not so effective for understanding disaster situations, because field staff can reach damage sites and get detail by then. If a disaster happens before 10:30A.M. images can be reached on staff in 5-6 hours(Fig.2).

Concerning weather/time, high-resolution satellites equip optical sensors generally. Therefore, it is difficult to grapes the ground surface information under the bad weather conditions and night time.

2.1.2 Aircraft & Helicopter

In using aircraft or helicopter, restriction related to needed operation time is short if they are compared with satellites. However, they have a restriction that they cannot fly during bad weather or the time that visible distance does not fill regulation for secure flight. Moreover, they have same restriction as satellites caused by sensors that are equipped.

2.2 Resolution

Possibility to detect damage from images depends on the ability of sensor. The relation between visibility and resolution is examined based on the simulated images of damage at Hyogoken-Nanbu Earthquake. Resolution is set up in three stages. Summarized results of this examination is shown below:

In the case of resolution 0.2 to 0.5m, almost all types of damage can be detected. Even damage on road surface like major cracks can be grasped.

In the case of resolution 1 to 2m, it becomes difficult to find small damage like horizontal and vertical difference.

In the case of resolution 10m, most of damage cannot be detected. Only widely spread areal-type damage such as liquefaction and slope failure can be found.

3. APPLICABILITY OF IMAGE PROCESSING

In detecting damaged facilities based on the remote sensing images, one of factors how accurately and rapidly damaged facilities are detected is the applicability of image processing. Damage types influence applicability. The types are mainly divided into two categories. One is liner-type damage. Another is areal-type damage.

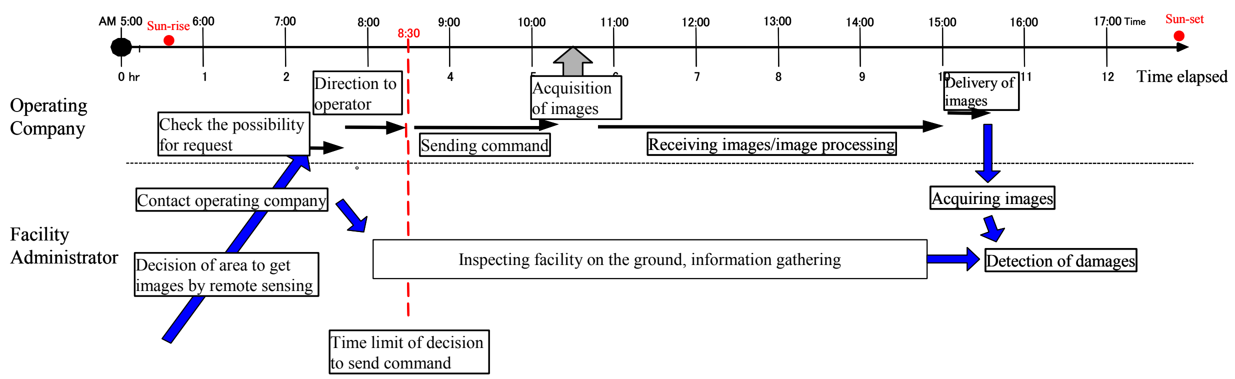


Fig.2 Simulated procedures of remote sensing technologies for disaster detection

In this section, applicability of image processing for each damage-type is presented, first. Next, sample processed results are shown.

3.1 Liner-type damage (Table 1)
Examples of liner-type damage are collapsed bridge and slope failure on embankment. For these kinds of damage, edge extraction is good to detect them from images. If damage does not exist, extracted edge is straight. On the contrary, if there is damage, extracted edge has blurs. The problem to overcome is that not only damage but also shadows are also extracted. In order to remove extraction of non-damage objects, combination of two image- processings; edge extraction and line-thinning, are tried. Its result is shown in Fig.3. Some of extracted edge of non-damage objects can be removed. Though, it is still difficult to find edge of damage.

3.2 Areal-type damage (Table 1)
Damage such as liquefaction and slope failure on mountains have the character that damage spread widely. In these cases, it is efficient to apply operations between images using spectral and color classification.
Some kinds of damage such as collapsed buildings in a wide area have characteristics of both liner and areal-type damage. In this case, it is effective to extract damage area based on the texture of damaged area. It is also possible for edge enhancement to grasp the boundary of widely spread damage.

By comparing pre- and post-disaster images, difference of brightness can be extracted. This method is efficient to detect both types of damage. At this processing, comparison can be done by two ways. One is comparison of original images of pre- and post- disasters. Another is comparison after applying image processing mentioned at 3.1 and 3.2 such as edge-extraction and color classification.

3.3 Trial to detect damage by image processing
Easiness and rapidness are important factors when you select image processing to detect damage, because it is necessary to grasp disaster situation as soon as possible. Thus, in our study, only simple image processings are examined. Table2 shows the results. Among these results, two of the trials are presented in detail at 3.3.1 & 3.3.2.

3.3.1 Horizontal difference at a viaduct (Liner-type damage)
In the case of liner facilities, damage appears as blurs. To grasp this blurs, 1) edge extraction, 2) texture analysis, and 3) edge enhancement are applied in this trial. Target damage is horizontal difference at a viaduct. The size of difference is

Table 1 Applicability of image processing for various types of damage

Damage Type		Image Processing		Extracted Image	Example
Linear-type Damage	Damage on a road, bridge and embankment	Feature Extraction	Geometric Feature Extraction	Line	Filtering（Edge Enhancement）
Areal-type damage	Collapsed Buildings Sinking road	Feature Extraction	Geometric Feature Extraction	Line	Filtering（Edge Enhancement）
			Spectral Extraction	Area	Principal Component Analysis Supervised Classification
			Textural Feature Extraction		Statistical Feature Extraction Fourier Analysis
	Liquefaction、 Slope failure		Geometric Feature Extraction	Outline	Filtering（Edge Enhancement）
			Spectral Extraction	Area	Principal Component Analysis Supervised Classification
		Classification			Unsupervised Classification

about dozens of cm. Resolution of processed images is 50 cm (Fig.4). Results show that it seems difficult to find damage, because blurs caused by shadow and non-damaged facility are also extracted.
In addition, operations between images (image overlay) are applied. The difference of time and season when images are acquired and the difference of two images' exact positions causes the extraction of non-damaged parts. These two factors become reason to make incorrect detection.

3.3.2 Slope failure (Areal-type damage)
One of typical areal-type damage is slope failure. After a disaster, bare ground appears instead of the area covered by trees. Therefore, the change of color at the surface gives us the information to detect and specify the spread of slope failure(Fig.5). To extract damage, in this trial, 1) edge extraction, 2) unsupervised classification, texture analysis, 3) edge enhancement and 4) fourier transformation are applied. In addition, 5) operations between images, 6) image overlay and 7) principal component analysis are also applied. Trial applications of these image processing are done for the slope failures at the Kohzu Shima island, Tokyo. Damage size is dozens of meter height and width. Resolution used in this trial is 1m, similar to the resolution of Ikonos. Result is described as following:
1) Applied all image processing except fourier transformation can extract the slope failure area.

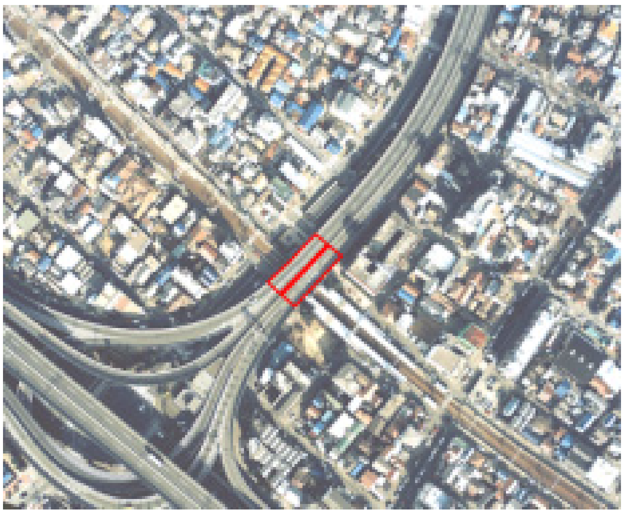


Fig.6 Method to designate particular facilities

2) Especially, in the cases of image overlay and principal component analysis, by using images both pre- and post- slope failure, bare ground area is clearly detected. However, not only areas of slope failure but also changing area by other factors like aging are detected. The thickness of growing trees and grasses are different in season. Shadow is also different in weather and time. In addition, difference of location between pre and post disaster occurs. These are the factors to judge by mistake.
The summary of applicability of image processing to various types of damage is presented at Table 2. In many cases, it is difficult to extract damage portion. Among trials, comparatively, to detect slope failure is executed well.

4.SUPPORT SYSTEM FOR INFORMATION EXTRACTION BY HUMAN

As mentioned above, disadvantage of information extraction by human eyes is that it takes longer time to complete extract facility damage. Furthermore, in some cases, staff might fail to find damage facilities. It seems difficult to focus on the target facilities from images of wide area.
To improve these situations, we conducted technology development to overlay data related to facility on remote sensing image data to support extraction by human. In this section, some examples are presented below.

4.1 Method to designate particular facilities
Digital register data about facilities is under developing for maintenance. For example, Road Bureau, Ministry of Land, Infrastructure and Transport is now developing road GIS data. This data includes polygon of structures like bridge. If you highlight particular facility on the remote sensing images based on the road GIS data, you can focus on the target facility quickly among images of wide area. In result, you can easily and rapidly find whether there is damage on the particular facility (Fig.6).
Another method is to use line data instead of polygon data. This is proper to liner-type facilities such as roads and embankments. You can check along the line.

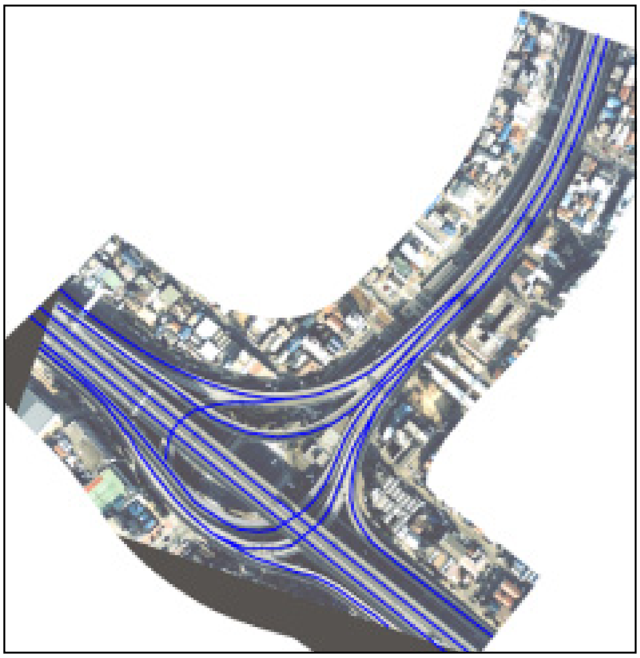


Fig.7 Method to mask some parts

Fig.8 Method to zoom in a target point

4.2 Method to mask some parts

This is the method to mask parts that you do not need to watch in a remote sensing image. You can easily focus on only what you have to check. Fig.7 is sample image. Road center is used as base line. The area without 50m from this road center line is masked (white area in Fig.7). Distance of buffering should be adjust according to what damage is detected.

4.3 Method to zoom in a target point

This method is not data-overlaying. GIS software has the function to zoom in an object. If you use this function when you read images, it becomes easy to find facility damage/blurs from images. Fig.8 is sample to apply this method. You move your mouse to where you want to check the existence of facility damage. This is also applied after image processing.

5. CONCLUSIONS

For areal-type damage like slope failure, 1) edge extraction, 2) unsupervised classification, 3) texture analysis, 4) edge enhancement and 5) operations between images are suitable to detect damaged area. In this way, it is possible to find areal-type damage. However, for liner-type damage such as horizontal difference, it is comparatively difficult to detect damage. In this case, extraction by human should be applied and in order to help staff to extract, it is effective to overlay other data to focus on specific area/facility to check.

6. REFERENCE

1. KUSAKABE, T. and SANADA, A.: Draft Manual for the application of remote sensing technologies to detect facilities damage, Technical note of National Institute for land and infrastructure management, 2004.

Table 2 Applicability of image processing to various types of damage

		Use only Post-disaster Images					Use Images of Pre & Post-disaster		
Facility Type	Damage Type	Edge Extra-ction	Unsupervised Classification	Texture Analysis	Edge Enhance-ment	Fourier transformation	Operation between Images	Image overlay	Principal Component Analysis
Bridge	Collapsed bridge (Road)	□		□	□		△	△	
		□		□	□		□	×	
	Collapsed bridge (Railroad)	□		□	□		△	△	
		□		□	□		□	×	
	Vertical Offset	△		×			□	□	
		×		×	□		□	×	
	Horizontal Offset	□		□	□		□	×	
		□		□	□		□	×	
Road	Crack	□		□	△				
		□		□	□				
	Deformation	□		□	△				
		□		□	□				
	Obstacle on road	□	△	□	□	×	△	△	△
		×	×	×	□	×	×	×	×
Buildings	Collapsed Buildings	□	×	□	□	×	△	△	×
		×	×	×	□	×	×	×	×
River/Port	Subsidence of Embankment	□		□	□		□	□	
		□		□	□		□	○	
	Liquefaction	△	□	△	□				
		×	□	×	×				
	Out flowing	△	□	△	□				
		×	□	×	□				
	Crack	△		△	□				
		×		×	□				
Sediment Disaster	landslide	□	□	□	□	×	□	○	○
		□	□	□	□	×	□	○	○

(Legend)

Upper row: Evaluation of visibility of damage in the image.

○:Detect damage clearly □:Detect not only damage but also other parts △:Detect damage, but not clear ×:Not detect damage

Lower row: Evaluation how visibility is improved on processed image in comparison with original image

○ :More visible than original image □:Similar visibility to original image ×:Less visible than original image

(grey) :Impossible to do trial because pre-disaster image can not get in this research.

(black) :No trial because damage type and image processing does not match.

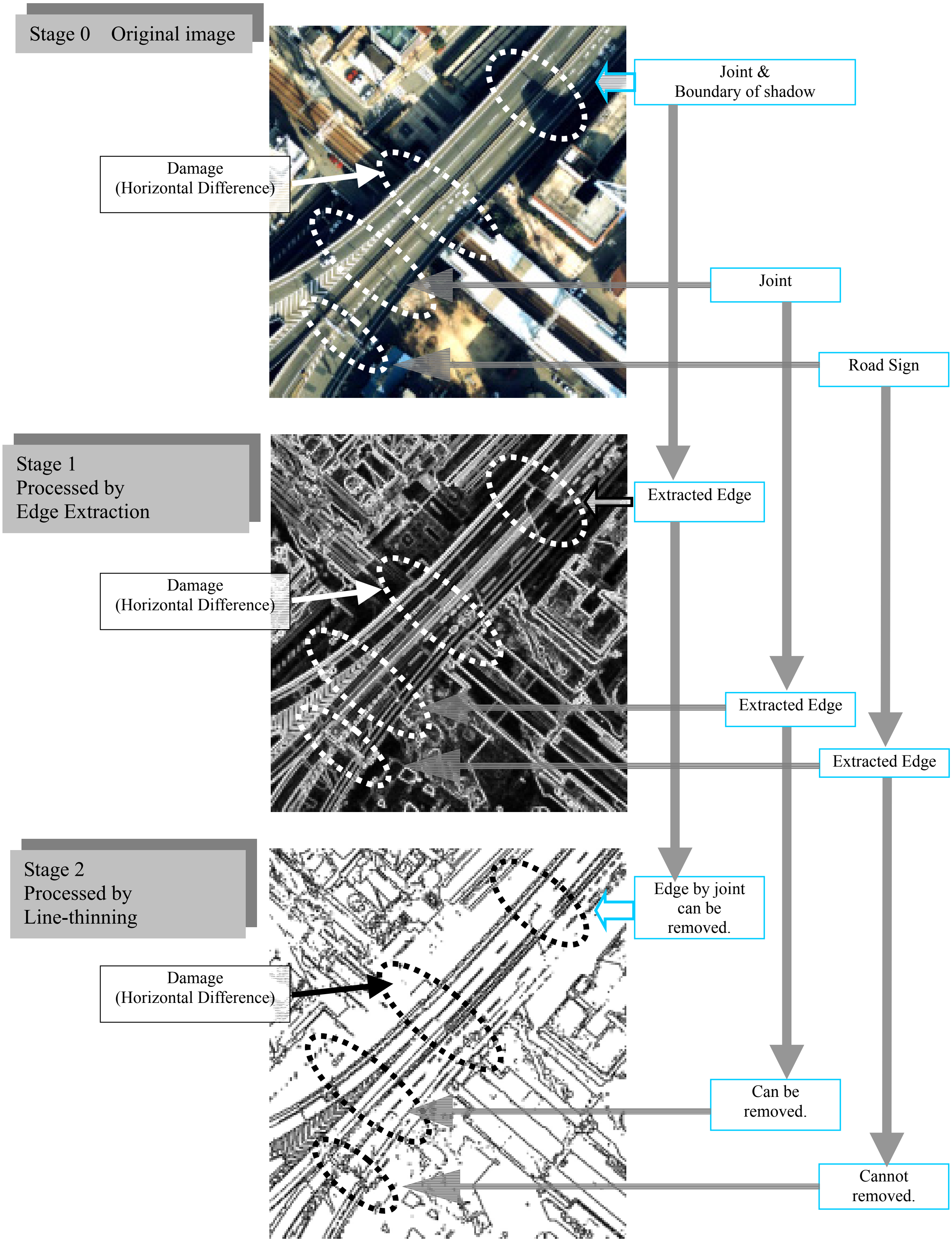


Fig.3 Combination of image processing to improve visibility of damage

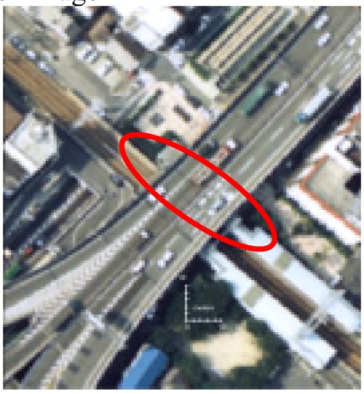
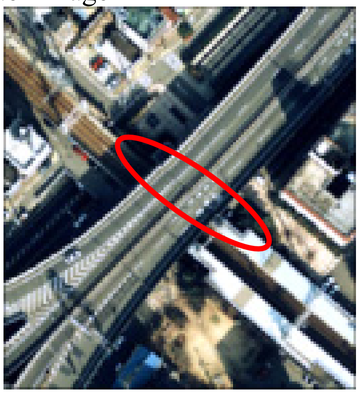
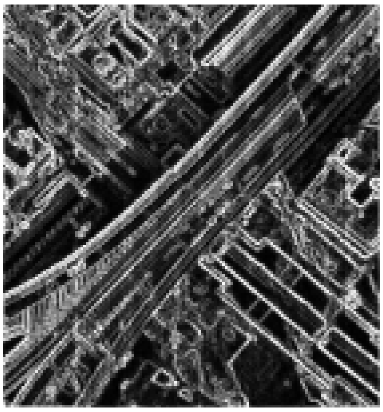
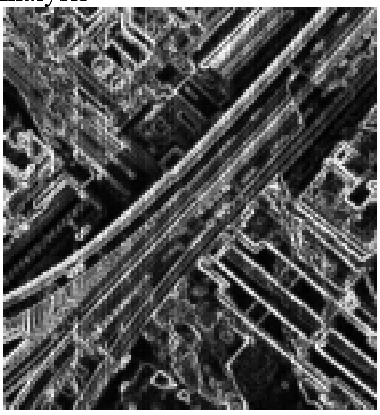
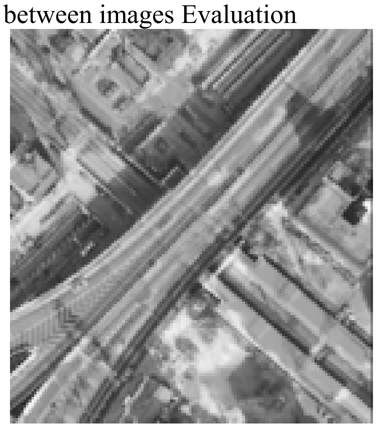
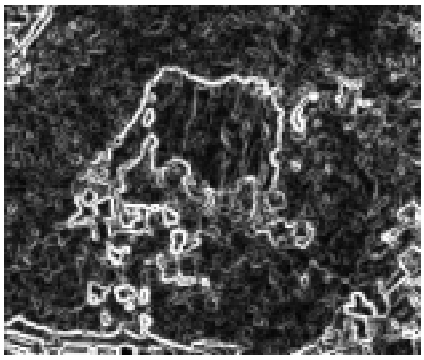
Pre-disaster Image 	Post-disaster Image 
Edge extraction  In the post-disaster image, pixels whose intensity value is very different from adjacent pixels' are expressed light, and vice versa. By edge extraction, information that has no relation with damage such as shadow cannot remove.	Texture Analysis  In the post-disaster image, if the distribution of the intensity value of a pixel and its adjacent ones is large, the pixel is shown as light, and vice versa.
Edge enhancement  In the post-disaster image, extracted edge is expressed light.	Operation between images Evaluation  In comparison with pre- and post images, pixels that become light after damage are expressed light, and vice versa.

Fig.4 Result to apply image processing to liner-type damage

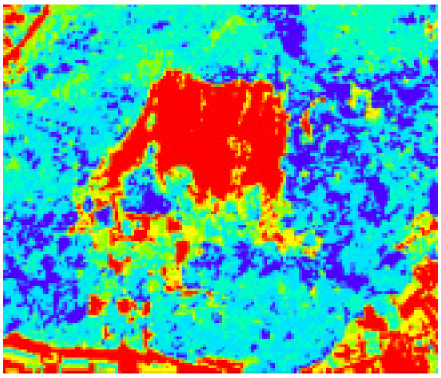
Post-disaster Image

Edge extraction



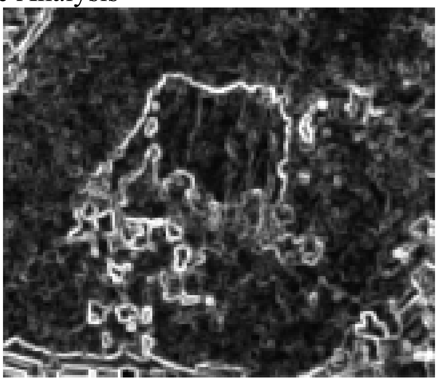
In the post-disaster image, pixels whose intensity value is very different from adjacent pixels' express white, and vice versar.

Unsupervised classification



In the post-disaster image, based on the similarity of color, pixels are divided into six categories. Bare ground is extracted.

Texture Analysis

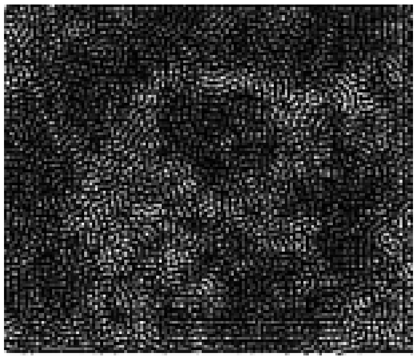


In the post-disaster image, if the distribution of the intensity value of a pixel and its adjacent ones is large, the pixel is shown as light, and vice versa.

Edge enhancement

In the post-disaster image, extracted edge is expressed light.

Fourier transformation



Distinctive texture; pixels of middle frequency image data, is expressed light. Because areas of slope failure and non-failure have similar frequency, damage area is not clear.

Fig.5 Result to apply image processing to areal-type damage