DETERMINATION OF BUILDING DAMAGE DUE TO EARTHQUAKES USING AERIAL TELEVISION IMAGES

Hirotada HASEGAWA[1], Fumio YAMAZAKI[2], Masashi MATSUOKA[3] And Izumi SEKIMOTO[4]

SUMMARY

Severe damage was incurred in a large urban area during the 1995 Hyogoken-Nanbu (Kobe) earthquake in Japan. In this study, the distribution of building damage due to the earthquake was examined using aerial television images taken by high-definition television (HDTV) cameras at an oblique angle. The distribution of damage for wooden buildings and nonwooden buildings was interpreted visually using aerial HDTV images. The accuracy of the interpretation for wooden building damage from aerial images was inspected by comparing the interpretation results obtained by different people. These results were compared with the results of the ground survey. For wooden buildings, severe and moderate damage was mostly recognized in the aerial HDTV images. Almost the same result was obtained, regardless of who performs the determination. It was found that damage level of nonwooden buildings extracted from the aerial images corresponded to collapsed and severe damage in the ground survey. Hence, although there is some limitation, aerial television images may be used to grasp overall damage distribution of urban areas due to earthquakes at an early stage.

INTRODUCTION

The 1995 Hyogoken-Nanbu (Kobe) earthquake in Japan demonstrated to us the importance of obtaining damage information at an early stage. The method of damage survey should be selected considering the balance between required accuracy and allowable time. It is very important to grasp the overall distribution of building damage within several hours to a few days of the event, for the purpose of emergency response and restoration planning. We examined the apprecability of airborne and satellite remote sensing technologies for gathering damage information [Yamazaki et al., 1998; Hasegawa et al., 1999]. In the later paper, the damage to each building was interpreted visually using aerial high-definition television (HDTV) images taken after the Kobe earthquake. These results were compared with those of a ground survey, and the accuracy of the aerial survey was discussed. Note that the highest damage level (severe damage) by the ground survey for all the buildings in the damaged areas due to the Kobe earthquake contains a wide range of damage degree, and that there is no other way to reclassify this damage level at the present time [Ogawa and Yamazaki, 2000]. Hence we cannot determine "collapse type" damage of buildings from the results of the ground survey after the earthquake. This paper intended to investigate the possibility of use of aerial television images for obtaining damage information at an early stage after earthquakes. Influences on the interpretation result due to the differences in structure type, building density and interpreter were examined. Adding to these objectives, we tried to extract the collapse type damage out of the severe damage using the HDTV images.

[1] *Research Engineer, Earthquake Disaster Mitigation Research Center, RIKEN, Japan, E-mail: hasegawa@miki.riken.go.jp*
[2] *Team Leader, Earthquake Disaster Mitigation Research Center, RIKEN, Japan, E-mail: yamazaki@miki.riken.go.jp*
[3] *Research Engineer, Earthquake Disaster Mitigation Research Center, RIKEN, Japan, E-mail: matsuoka@miki.riken.go.jp*
[4] *Chief Producer, Japan Broadcasting Corporation (NHK), Japan, Fax: +81-3-3465-6910*

ERIAL TELEVISION IMAGES AND INTERPRETATION METHOD

The aerial recording for all the damaged areas due to the Kobe earthquake was started shortly after the event by Japan Broadcasting Corporation (NHK). In this study, some of these images of Nishinomiya City and Kobe City were used. These images were taken at an angle inclined 30-45 degrees from the vertical direction, from a height of about 300m (Figure 1). Because these images were taken using NHK's high-definition television (HDTV) cameras and are of much higher quality compared with conventional television images, detailed damage information could be obtained. The HDTV images were converted to the data format (bitmap file of 1035×1920pixel) on a personal computer, and building damage was interpreted visually on the computer display. An example of the aerial HDTV images is shown in Figure 2.

The areas of this study were 7 blocks (about 0.37km^2) in Nishinomiya City and 18 blocks (about 0.97km^2) in Chuo-ku, Kobe City, as shown in Figure 3. The study area (Area 1) of Nishinomiya City is mainly residential and most of the buildings are wooden. In the area, many buildings suffered severe damage due to the earthquake as shown in Figure 4 (a). On the other hand, the study area (Area 2) of Kobe City is in a commercial zone located on the south side of Sannomiya Station, and most of the buildings are nonwooden (steel, reinforced concrete etc.) mid- to high-rise buildings. The classification of building damage due to the earthquake in this area is shown in Figure 4 (b). In this study, the damage to wooden buildings was extracted for Area 1 and that to nonwooden buildings was extracted for Area 2.

Because personal differences in interpretation of building damage were expected, the damage interpretation to wooden buildings in Area 1 was conducted by five people, such as three civil engineers, one remote sensing engineer and one female clerk. Nonwooden buildings in Area 2 were interpreted only by the first author of this paper. Detailed classification of the degree of damage was difficult using the aerial images, even for HDTV, because they were recorded from a height of 300 m. Therefore, building damage was classified into the three levels shown in Table 1. The building damage interpreted from the aerial HDTV images was digitized using GIS. The resulting digital maps were compared with those by ground surveys.

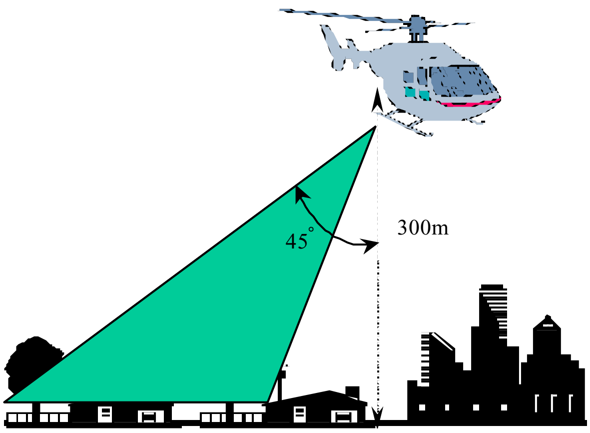


Figure 1: Schematic figure of helicopter loading the HDTV recording system by NHK

(a) Area 1 in Nishinomiya

(b) Area 2 in Kobe

Figure 2: Example of the aerial HDTV images taken by NHK

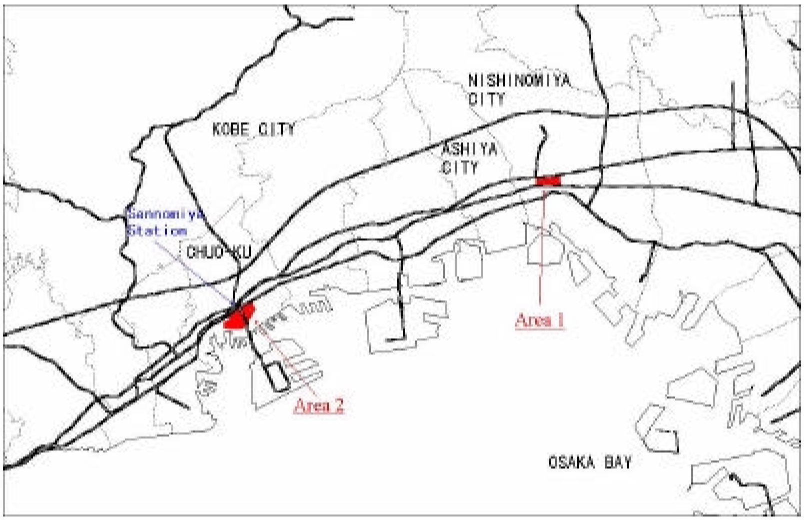


Figure 3: Residential area (Area 1) and commercial area (Area 2) selected in this study

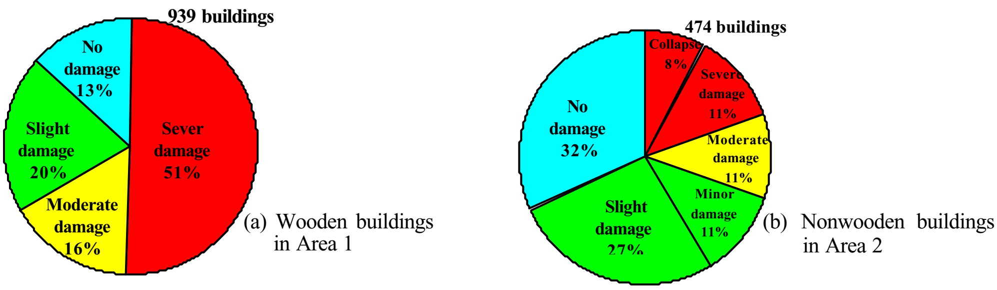


Figure 4: Damage levels based on the ground surveys: wooden buildings in Area 1 [AIJ and CPIJ , 1995] and nonwooden buildings in Area 2 [AIJ, 1995]

Table 1: Classification of building damage interpreted from the aerial HDTV images

Damage classification	Decipher standard
Collapsed	Collapsed, burned, or severely leaning buildings
Damaged	Damaged buildings other than those in the above category
No damage	Buildings without visible damage
Unclear	Buildings difficult to judge their damage states from HDTV images

RESULTS OF GROUND SURVEYS

The interpretation result for wooden building damage in Area 1 was compared with ground survey data. A ground survey on building damage was conducted by a group comprising members of the Architectural Institute of Japan (AIJ) and the City Planning Institute of Japan (CPIJ) for all the buildings in the areas affected by the Kobe earthquake [AIJ and CPIJ, 1995]. The damage levels of buildings were plotted on GIS by the Building Research Institute (BRI), Ministry of Construction, together with building plans [BRI, 1996]. The criteria of wooden building damage classification in the ground survey are shown in Table 2.

Damage to nonwooden building was surveyed principally by Kinki branch of AIJ, with the support from other branches [AIJ, 1995]. The criteria of building damage classification in this ground survey is shown in Table 3. The members of the AIJ and CPIJ group mainly consisted of urban planners and archtects while the members of Kinki branch of AIJ were mainly structural/construction engineers. Hence, the damage classification of Kinki branch of AIJ was more detailed than that of the AIJ and CPIJ group. We compared the interpretation results in Area 2 from aerial HDTV images with the ground survey result by Kinki branch of AIJ.

Table 2: Classification of wooden building damage in the ground survey by AIJ & CPIJ [1995]

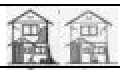
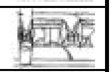
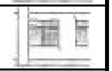
Damage classification	Criteria of damage classification	Examples of damage for wooden buildings	Sketch by Takai et al. [1997]
Severe damage	Unusable buildings or buildings with very low possibility of reuse.	Totally collapsed, layer-collapsed, severely leaning, or severe damage to foundation, columns and walls.	
Moderate damage	Buildings may be reused after substantial repair.	Partially collapsed, or extensive cracks on walls.	
Slight damage	Usable buildings with slight damage or buildings with possibility of use after little repair.	Falling of some roof tiles, or small cracks/peeling on walls.	
No damage	Not damaged in appearance.		
Burned	Buildings suffering from fires.		

Table 3: Classification of nonwooden building damage in the ground survey by AIJ [1995]

Damage classification	Description of damage	Sketch by AIJ
Collapse	Failure or overturning of the entire structure or complete failure of a single story.	
Severe damage	A large portion of the building frame is damaged, permanent deformation of the structure may cause imminent collapse.	
Moderate damage	Significant structural damage is visible. Permanent deformation between stories exists but with low possibility of collapse.	
Minor damage	Minor structural damage, although the structure may have significant architectural damage.	
Slight damage	No structural damage. Architectural damage may be noticeable.	
No damage	Not damaged in appearance.	

RELATIONSHIP BETWEEN THE RESULTS OF GROUND SURVEYS AND AERIAL HDTV INTERPRETATION

Possibility of Building Damage Interpretation using Aerial Images

In the study areas, the number of buildings whose degree of damage was evaluated from the ground surveys is 939 wooden buildings in Area 1 and 474 nonwooden buildings in Area 2. The distribution of building damage in Area 1 from the aerial HDTV images is shown in Figure 5 and that in Area 2 is shown in Figure 6. The result for the wooden buildings in Area 1 was given as the average of the results obtained by the five people, who engaged in the damage extraction. Interpretation of damage to most buildings was possible for Area 1 (97%). But the rate in Area 2 was lower (79%) than Area 1. The reason for this is that we used aerial images taken from an oblique angle in this study, and thus more buildings were blocked from view in Area 2 than in Area 1. Therefore, the extraction results for the both areas were evaluated without including the buildings for which damage extraction using the aerial images was impossible.

Results of Interpretation for Wooden Buildings

For the wooden buildings in Area 1, the relationship between the damage classifications in the ground survey and in the aerial HDTV image interpretation is shown in Figure 7 (a). In this figure, the result for the aerial survey is the average of the results obtained by the five people. The damage classification *burned* (2 buildings) in the ground survey was included in the *severe damage* classification. It is observed that 80 percent of *severely damaged* buildings in the ground survey corresponded to *collapsed* or *damaged* buildings in the aerial HDTV images. Furthermore, the 64 percent of *moderately damaged* buildings in the ground survey corresponded to *collapsed* or *damaged* buildings in the aerial HDTV images.

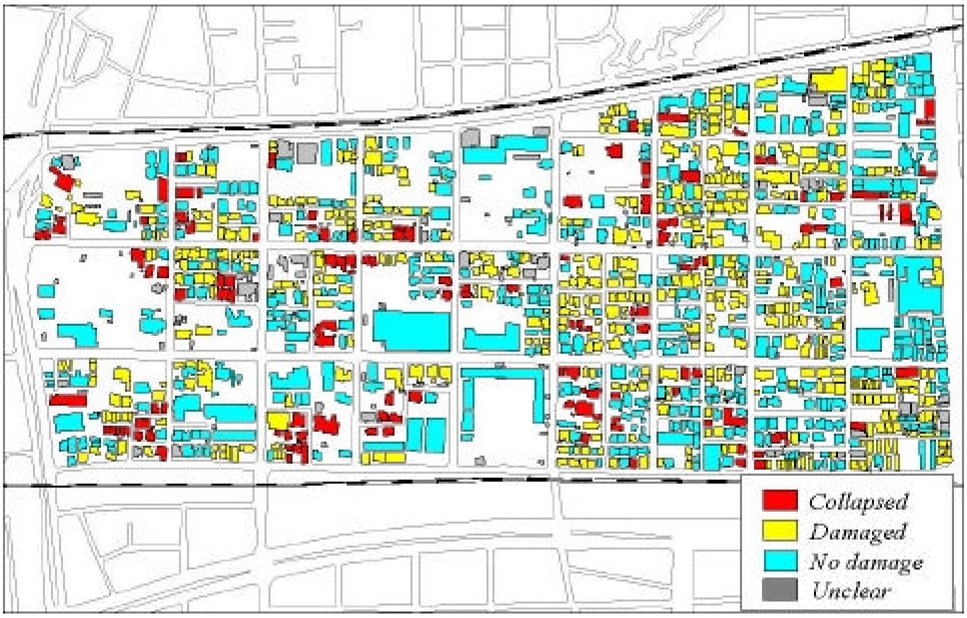
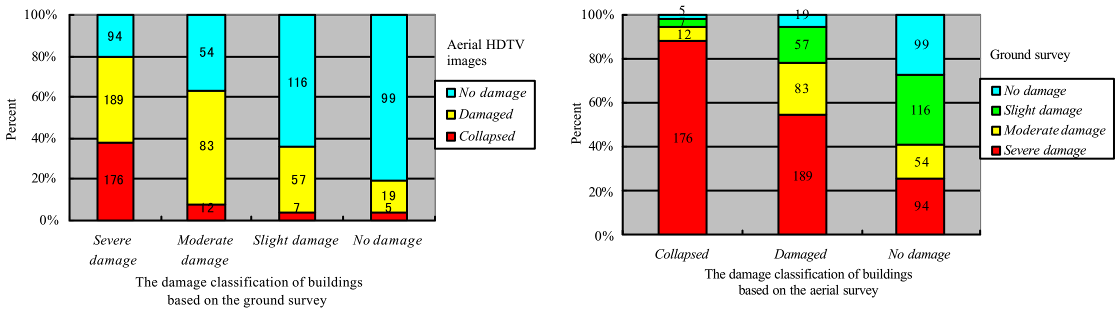


Figure 5: Distribution of building damage in Area 1 interpreted from the aerial HDTV images

Figure 6: Distribution of building damage in Area 2 interpreted from the aerial HDTV images

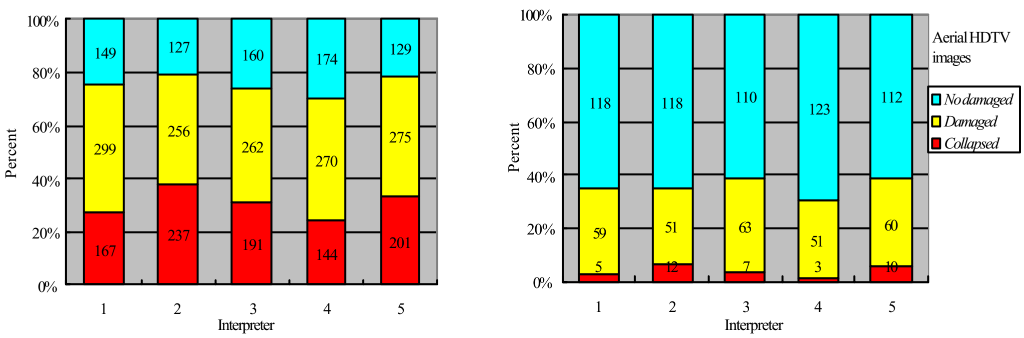
A similar plot by changing the reference from the ground survey to the aerial HDTV images is shown in Figure 7 (b). In this figure, 54 percent of *damaged* buildings based on the aerial HDTV images corresponded to *severe damage* by the ground survey, and 23 percent of *damaged* buildings based on the aerial HDTV images corresponded to *moderate damage* by the ground survey. *No damage* based on the aerial HDTV images almost corresponded to *slight damage* or *no damage* by the ground survey. It is pointed out that *slight damage* by the ground survey could not be interpreted using the aerial HDTV images due to the resolution.

The difference in the damage interpretation results between individual interpreters was examined. The relationship between the result of each person interpreting the aerial HDTV images and that by the ground survey is shown in Figure 8. It is found that *severely* or *moderately damaged* buildings could mostly be interpreted using the aerial HDTV images by all the interpreters while *slightly damaged* buildings could not be identified well.



(a) Ground survey and aerial survey (b) Aerial survey and ground survey

Figure 7: Relationship between the damage classifications for wooden buildings in Area 1 by two surveys



(a) *Severe* or *moderate damage* based on the ground survey (b) *Slight damage* based on the ground survey

Figure 8: Difference in the results of five interpreters of the aerial HDTV images for (a) *severe* and *moderate damage* and (b) *slight damage* in the ground survey

Table 4: Damage classification for wooden buildings in Area 1 using ground photographs

Damage classification	Collapsed	Damaged	No damage
The number of buildings	27	25	3

Figure 9: Example of a collapsed building from two different views: (a) a photograph taken from the ground and (b) a snapshot of HDTV images taken from the air

The 55 wooden buildings in Area 1 were classified into 3 damage level (*collapsed, damaged* and *no damage*) using photographs taken at the time of the damage survey (Table 4). Figure 9 shows an example of photographs and aerial HDTV images for a damaged building. Figure 10 plots the results of the five interpreters for the 27 collapsed buildings with photographs. It was found that the interpretation results for the collapse-type damage of buildings changed with interpreters. One factor for this fact might be time spent for interpretation; the time spent by Interpreter-4 was about 3 hours while other persons spent more than 5 hours. Furthermore, the criterion of interpretation of collapsed buildings from the aerial HDTV images was not very strict. Therefore, a further elaboration on the damage interpretation from aerial HDTV images may be necessary.

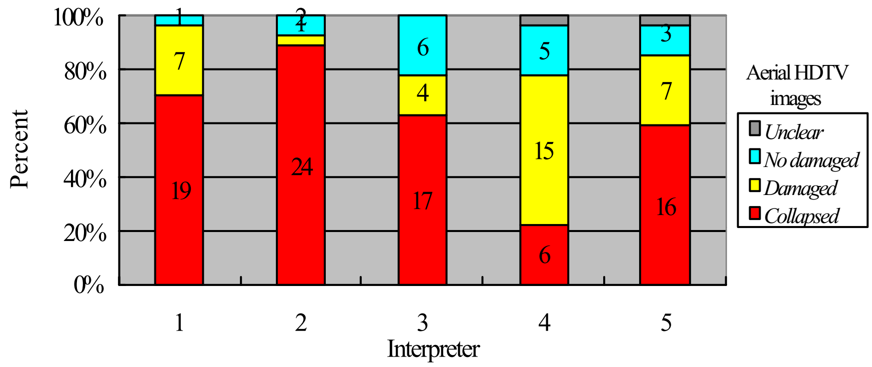


Figure 10: Difference in the results of five interpreters of the aerial HDTV images for the 27 collapsed buildings with photographs

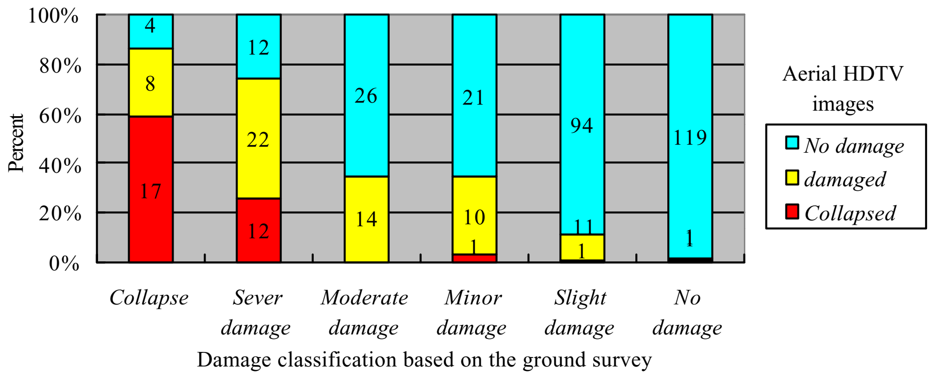


Figure 11: Relationship between the damage classifications for nonwooden buildings in Area 2 based on the ground survey and the aerial HDTV images

Results of Interpretation for Nonwooden Buildings

The relationship between the damage classifications in the ground survey and in the aerial HDTV image interpretation is shown in Figure 11. It is observed in the figure that 59 percent of *collapsed damage* in the ground survey was extracted as *collapsed* using the aerial HDTV images. Most (86%) of the *collapsed* buildings in the ground survey corresponded to *collapsed* or *damaged* in the aerial HDTV images. However, 14 percent of *collapsed* buildings in the ground survey could not be confirmed in the aerial HDTV images. The reason is that the damaged parts located in the blind spot of the aerial HDTV images, i.e., in a shadow of other buildings, or the damage position was different from the direction from which the image was shot. However, since the identifications of layer-collapsed type damage and damage to walls were mostly possible, the advantage of using the aerial images taken at an oblique angle was confirmed. It is observed in Figure 11 that 74 percent of *severely damaged* buildings in the ground survey corresponded to *collapsed* or *damaged* buildings in the aerial HDTV images. *Moderately damaged*, *minorly damaged*, and *slightly damaged* buildings in the ground survey could not be identified well using the aerial HDTV images. It was confirmed that damage classification of nonwooden buildings extracted from the aerial images corresponded to *collapsed damage* and *severe damage* based on the ground survey. Hence, the aerial HDTV images may be useful for the capture of hard-hit areas at an early stage.

CONCLUSIONS

Building damage due to the 1995 Kobe earthquake was visually determined using the high-definition television (HDTV) images taken from helicopters at a height of about 300 m The accuracy of the aerial survey was discussed comparing the result of the image interpretation with that of ground surveys.

In a residential area of Nishinomiya City with many low-rise buildings, wooden buildings classified as *severe damage* and *moderate damage* (both uninhabitable after the earthquake) in the ground survey were mostly corresponded to *collapsed* or *damaged* buildings in the aerial HDTV image survey. However, building damage other than these could not be identified well using the aerial HDTV images. Difference in the result of interpretation when the interpreter is different is slight.

In a commercial area of Kobe City with many mid- to high-rise buildings, nonwooden buildings classified as *collapse damage* and *severe damage* (both difficult to repair) in the ground survey were mostly corresponded to *collapsed* or *damaged* buildings in the aerial HDTV image survey. However, building damage other than these could not be identified well using the aerial HDTV images.

The aerial images taken at an oblique angle were effective for damage extraction since it is possible to identify the building damage of layer-collapsed type and damage to walls. However, in the densely built-up commercial area damage could not be extracted for many buildings since they were in the shadow of other buildings. However, the shooting-angle (inclined 30-45 degrees from the vertical direction) of the aerial images used in this study may give a good balance between the merits and demerits of the use of aerial images in building damage interpretation.

Aerial surveys from helicopters can be performed much more quickly than ground surveys and are suitable for covering large areas. Thus, HDTV images may be efficiently used at an early stage of natural disasters for the capture of an overall damage distribution. A future research topic of our HDTV image interpretation is automated interpretation using three-dimensional GIS and digital image processing.

REFFERENCES

Architectural Institute of Japan (1995), *Preliminary Reconnaissance Report the 1995 Hyogoken-Nanbu Earthquake.*

Architectural Institute of Japan and City Planning Institute of Japan (1995), *Report of Emergency Damage Survey of the 1995 Hyogoken-Nanbu Earthquake.*

Building Research Institute (1996), *Final Report of Damage Survey of the 1995 Hyogoken-Nanbu Earthquake* (in Japanese).

Editorial Committee for the report on the Hanshin-Awaji Earthquake Disaster (1997), *Report on the Hanshin-Awaji Earthquake Disaster*, Building Series Volume 1 (in Japanese).

Hasegawa, H., Yamazaki, F., Matsuoka, M. and Sekimoto, I. (1999), "Extraction of Building Damage due to the 1995 Hyogoken-Nanbu Earthquake from Aerial HDTV Images", *Proceedings of Asian-Pacific Symposium on Structural Reliability and its Applications*, NCREE, pp. 280-288.

Ogawa, N. and Yamazaki, F. (2000), "Photo-Interpretation of Building Damage due to Earthquakes Using Aerial Photographs", *Proceedings of 12th World Conference on Earthquake Engineering,* Auckland, New Zealand.

Takai, N., Okada, S. and Miyano, M. (1997), "Photographic Survey on Damage to Dwelling in Hokudan-cho in the 1995 Hyogoken-Nanbu Earthquake, Part 1 Building Damage and Building Collapse Pattern", *Papers of the Annual Conference of the Institute of Social Safety Science*, pp. 250-253 (in Japanese).

Yamazaki, F., Matsuoka, M., Ogawa, N., Hasegawa, H. and Aoki, H. (1998), "Airborne and Satellite Remote Sensing Technologies for Gathering Damage Information", *Proceedings of Multi-lateral Workshop on Development of Earthquake and Tsunami Disaster Mitigation Technologies and Their Integration for the Asia-Pacific Region*, Earthquake Disaster Mitigation Research Center, RIKEN, pp. 187-200.