PHOTO-INTERPRETATION OF BUILDING DAMAGE DUE TO EARTHQUAKES USING AERIAL PHOTOGRAPHS

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SUMMARY

Building damage due to the 1995 Kobe Earthquake was extracted using aerial photographs. The result was compared with that of ground surveys to examine the applicability of aerial photo-interpretation. It was recognized that damage interpretation using aerial photographs for an area of wooden buildings was effective for identifying "severe damage" and, in particular, "collapsed" buildings. The differences in the results due to different interpretation methods (single or stereoscopic) and due to different interpreters were small for the wooden collapsed buildings. In damage interpretation of "severely damage" buildings, it is recognized that the accuracy of stereoscopic photo-interpretation is higher than that of single photo-interpretation. However, in damage interpretation for an area of non-wooden buildings, "collapse" damage could be identified only to some extent. Since the rate of correct damage interpretation was low compared with that for the area of wooden buildings, it was recognized that damage identification using aerial photographs is difficult for areas of non-wooden buildings. Since the aerial photographs were taken at an right angle to the ground surface, the recognition of minor damage and damage to side walls and columns was difficult. Although there is some limitation, aerial photo-interpretation is considered to be an effective tool for detecting overall damage distribution in a large area after natural disasters.

INTRODUCTION

In the Hyogoken-Nanbu (Kobe) Earthquake on January 17, 1995, serious damage occurred over an extensive area of the Hanshin-Awaji region. We realized the importance of damage information at an early stage in order to carry out appropriate disaster countermeasures. Airborne and satellite remote sensing technologies are promising methods for gathering damage information from a large disaster area. However, the quality and quantity of the information required to initiate disaster countermeasures change with time. Platforms and sensors used in remote sensing should be selected considering the capability of identifying damage [Ogawa et al., 1999]. In this context, a preliminary study on the use of aerial photographs for damage identification of wooden buildings was carried out [Ogawa and Yamazaki, 1999].

For five days after the Kobe Earthquake, more than ten thousand aerial photographs were taken over the stricken area. These aerial photographs were used for mapping the damage caused by the earthquake, such as building collapse [Geographical Survey Institute of Japan, 1995], debris on roads, liquefaction and landslides. Building damage surveys from the ground were also carried out by various organizations and the extent of damage was determined. However, the relationship between the building damage interpreted from aerial photographs and the actual building damage has not been discussed in detail. In this paper, the building damage due to the Kobe earthquake was investigated using aerial photographs and the accuracy of aerial photo-interpretation was examined.

AREAS OF THE STUDY

For wooden buildings and non-wooden buildings (made of reinforced concrete, steel etc.), damage patterns differ and this difference may influence the result of photo-interpretation. Two areas in which the distribution of the

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structural type of buildings differs were selected as the areas of this study. The selected areas are seven blocks of Nishinomiya City (about 0.4 km^2) and eighteen blocks of Chuo Ward (about 1.0 km^2) in Kobe City, shown in Figure 1. The area of Nishinomiya City is located in a residential zone, which is occupied 94% by wooden buildings and is hereafter referred to as the "wooden building area". The area of Chuo Ward is located in a commercial zone, the city center of Kobe located in the south side of Sannomiya station, which is occupied 82% by non-wooden buildings, and it is hereafter referred to as the "non-wooden building area".

Photo-interpretation method and photographic scale were determined in accordance with the damage pattern of each structural type. The results of building damage interpretation using aerial photographs were evaluated in comparison with ground survey data. Together with the interpretation of aerial photographs, the interpretation of aerial high-definition television (HDTV) images taken from helicopters for the same areas was also conducted and its result is found in a companion paper [Hasegawa et al., 2000].

Wooden building area (Nishinomiya City)

In order to examine the difference in the accuracy of interpretation methods, building damage was interpreted using two methods, single photo-interpretation and stereoscopic photo-interpretation. The criteria of aerial photo-interpretation are shown in Table 1. The aerial photographs used were taken at an right angle to the ground surface from an altitude of 1,000 m on January 18, 1995 (one day after the earthquake) and were developed with a scale of 1/4,000 [Asia Air Survey Co., 1995]. Individual human difference in the result of aerial photo-interpretation was evaluated in this area. Since technical competence is needed for stereoscopic photo-interpretation, single photo method was used when examining the human difference.

Non-wooden building area (Kobe City)

The collapse of middle stories of many middle- to high-rise buildings was reported as the damage of non-wooden buildings due to the Kobe Earthquake. Therefore, the side views of buildings are important in the damage interpretation of non-wooden buildings, as compared with wooden buildings. In the scale of 1/4,000, used for the wooden building area, non-wooden buildings appear in the orthographic projection. Hence, photographs of a larger scale of 1/2,000 were used for damage interpretation of the non-wooden area. In photographs of this scale, although the objects near the center of a photograph appear in the orthographic projection, near the outer edges of the photograph, the side views of objects are visible. Photo-interpretation was carried out by single photo method for non-wooden buildings.

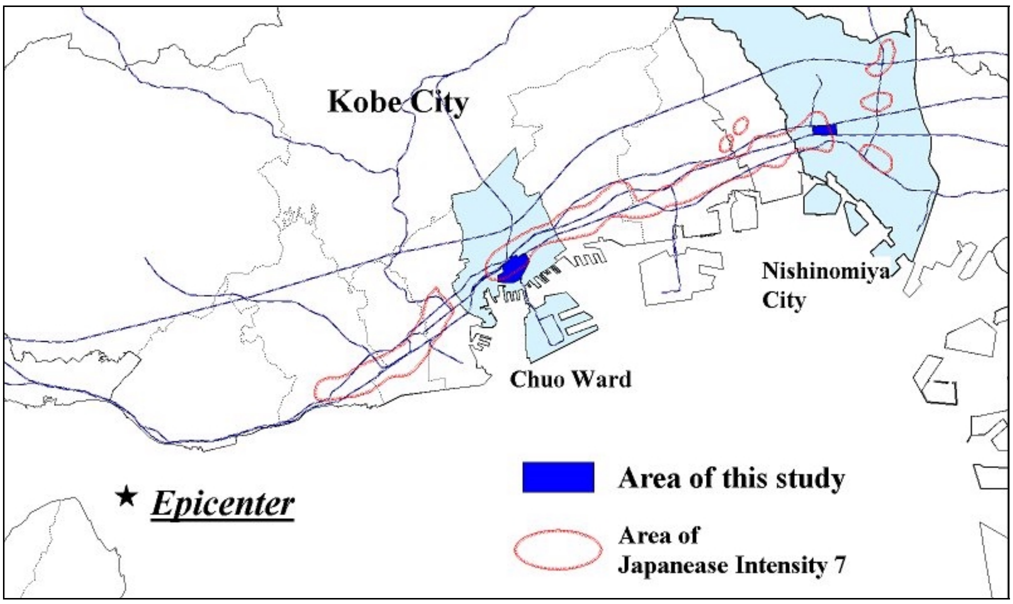


Figure 1: Areas of this study

Table 1: Criteria of aerial photo-interpretation

<table>
<tr><th colspan="2">Single photo-interpretation</th><th colspan="2">Stereoscopic photo-interpretation</th></tr>
<tr><th>Damage classification</th><th>Standard of interpretation</th><th>Damage classification</th><th>Standard of interpretation</th></tr>
<tr><td rowspan="2">Collapse</td><td rowspan="2">Collapsed, deformed, or severely leaning buildings</td><td>Collapse</td><td>Totally collapsed, buildings which reduced to rubble</td></tr>
<tr><td>Partial collapse</td><td>Partially collapsed, deformed, or severely leaning buildings</td></tr>
<tr><td>Falling of roof tiles</td><td colspan="3">Falling of roof tiles, damaged buildings other than those in the above category</td></tr>
<tr><td>No damage</td><td colspan="3">Buildings without visible damage or buildings whose damage state is difficult to identify from aerial photographs</td></tr>
</table>

RESULTS OF AERIAL PHOTO INTERPRETATION FOR THE WOODEN BUILDING AREA

Ground survey data for wooden buildings

The ground survey of 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 area affected by the Kobe Earthquake [AIJ & CPIJ, 1996]. The members of this survey mainly consisted of urban planners and architects. The damage levels of buildings were plotted on GIS by the Building Research Institute (BRI), Ministry of Construction, together with building plans [BRI, 1996]. This survey is hereafter referred to as Ground Survey 1.

In the building damage classification of this ground survey, the highest damage level, “severe damage”, includes buildings which cannot be repaired or reused. From this definition, we cannot distinguish “collapse” buildings, which may be responsible for human casualties, from “ordinary” severely damaged buildings, which may not. An example of an ordinary “severely damaged” building and a “collapsed” building is shown in Photo 1. For buildings whose photographs were taken at the time of Ground Survey 1 (hereafter referred to as “ground photographs”), we judged their damage levels based on the destructive pattern [Takai et al., 1997] seen in the photographs. The result of the judgement by the ground photographs was compared with that from photo-interpretation. The criteria of damage classification for wooden buildings in Ground Survey 1 and in the ground photographs are shown Table 2.

Relationship between the results of Ground Survey 1 and aerial photo-interpretation

Building damage was found in 472 (50%) of 946 buildings by single photo-interpretation. Among these, “collapse” applied to 227 buildings (24%) and “falling of roof tiles” to 244 buildings (26%). Building damage was detected in 528 (56%) of 946 buildings by stereoscopic photo-interpretation. Among these, “collapse” applied to 89 buildings (9%), “partial collapse” to 157 buildings (17%) and “falling of roof tiles” to 281 buildings (29%). The relationship between Ground Survey 1 and the aerial photo-interpretation is shown in Figure 2. Comparing the result of photo-interpretations with that of Ground Survey 1, single photo-interpretation and stereoscopic photo-interpretation showed almost the same tendency.

The percentage of buildings whose damage can be identified from the aerial photographs decreases as the damage level in Ground Survey 1 becomes low. The rate of damage detection for “severe damage” buildings in the ground survey data was comparatively high, 73% in single-photo interpretation and 88% in stereoscopic photo-interpretation. However, all the damage classifications in the photo-interpretation criteria were included in this damage detection. The side-view information for low-rise buildings can not be obtained for most cases from aerial photographs. Therefore, compared with Ground Survey 1, the damage level could not be distinguished into several classes; it was only classified as “collapse” and other visble damage to roofs. The rates of detection of damage smaller than “severe damage” by Ground Survey 1 were not much different between single and stereoscopic photo-interpretations.

Table 2: Criteria of damage classification for wooden buildings

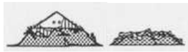
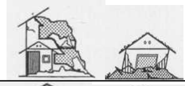
Building damage criteria by AIJ & CPIJ group			Destructive patterns for wooden building by Takai et al. [1997]		
Damage classification	**Criteria of damage classification**	**Examples of damage for wooden buildings**	**Damage classification**		**Destructive pattern**
Severe damage	Unusable buildings or buildings with very low possibility of reuse.	Totally collapsed, layer-collapse, severely leaning, or severe damage to foundation, columns and walls	**Collapse**	**D5+**	
				D5-	
			Severe damage	**D4**	
Moderate damage	Buildings may be reused after substantial repair.	Partially collapsed, extensive cracks on walls	**Moderate damage**	**D3**	
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	**Slight damage**	**D2** **D1**	
No damage	No damage in appearance		**No damage**	**D0**	

Photo 1: An example of ordinary "severely damaged" buildings and "collapsed" buildings

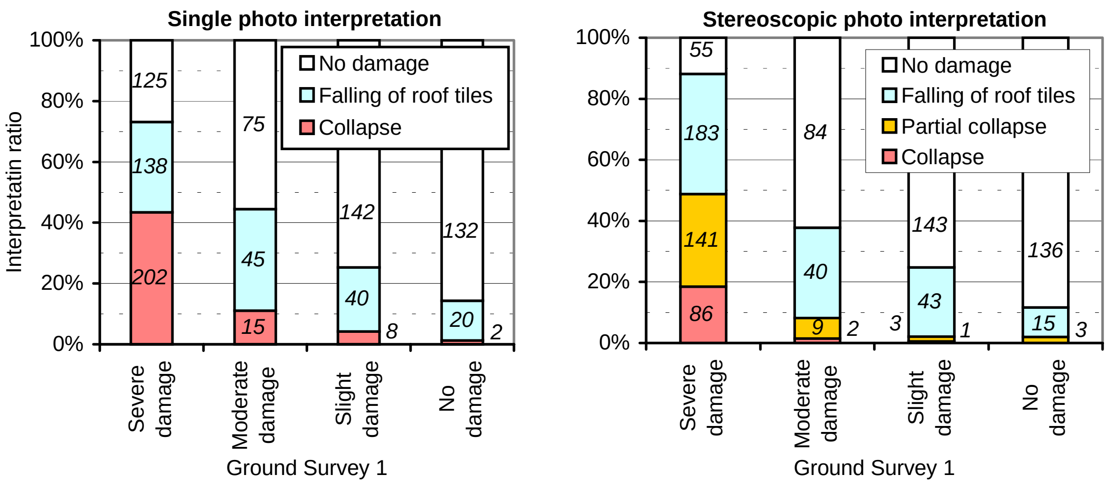


Figure 2: Relationship between the results of Ground Survey 1 and aerial photo-interpretations

Relationship between the interpretation results of ground photographs and aerial photographs

In order to evaluate the results of aerial photo-interpretation for collapsed buildings, a comparison with the ground photographs was conducted. The relationship between the results of interpretations from ground photographs and aerial photographs is shown in Table 3. The results of the ground photo-interpretation, divided into "collapse (D5)" and the other damage levels (D4-D1), were compared with the results of aerial photo-interpretations, as shown in Figure 3. For "collapse (D5)" by the ground photographs, "collapse" by single photo-interpretation and "collapse" and "partial collapse" by stereoscopic photo-interpretation are almost the same number. The rates of determination of "collapse (D5)" in both single and stereoscopic photo-interpretations are high at about 90%. For other damage levels (D4-D1), although about 10% of damage were mistaken as "collapse" for both single and stereoscopic photo-interpretations, most of the damage was identified as "falling of roof tiles". In summary, collapsed buildings could be correctly identified but less severely damaged buildings could not by aerial photo-interpretation.

Human difference in damage interpretation using aerial photographs

Similarly, the results of building damage interpreted by six people were compared with those of Ground Survey 1 and ground photographs as shown in Figure 4. In this figure, the comparison of the six interpreters for "severe damage" in Ground Survey 1 and "collapse (D5)" of the ground photographs are shown. These interpreters are civil/structural engineers having experience of more than a few years. Damage at least to same extent was detected from 50 to 70% of the buildings for "severe damage" in Ground Survey 1. However, for "collapse (D5)" buildings in the ground photographs, about 80-90% buildings were detected correctly by the six interpreters and little variation was seen in their results. Although not shown in this figure, for the other damage (D4-D1) categories in the ground photographs, the rate of damage detection was 40 to 70% and a large individual variation was observed.

Table 3: Relationship between the interpretation results of the ground photographs and the aerial photo-interpretation

Damage classification of aerial photo-interpretation		**Damage classification of "ground photographs"**			
		Collapse D5	Severe damage D4	Other damage D3-D1	No damage D0
Single photo-interpretation	Collapse	25	2	1	0
	Falling of roof tiles	3	7	3	0
	No damage	0	6	3	0
Stereoscopic photo-interpretation	Collapse	6	0	0	0
	Partial collapse	20	2	0	0
	Falling of roof tiles	2	11	5	0
	No damage	0	2	0	0

Unit: number of buildings

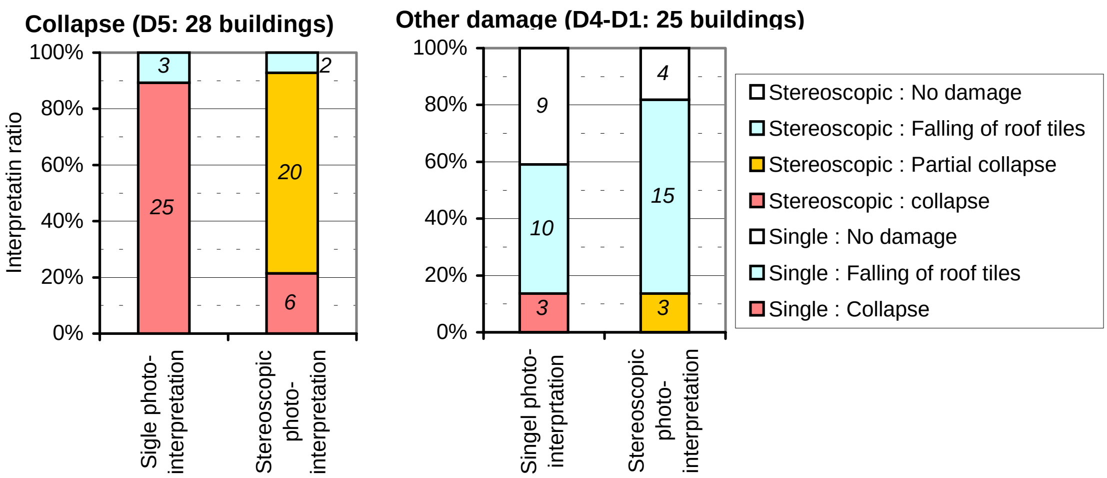


Figure 3: Comparison of the result of ground photo-interpretation, divided into "collapse (D5)" and the other damage levels (D4-D1), with that of aerial photo-interpretation

Next, the damage classification and the number of persons who determined that damage class are shown in Figure 5 for the 53 buildings with ground photographs. For "collapse (D5)", most buildings (25 out of 28) were correctly identified by 5-6 people, indicating that the identification of "collapse" does not vary much. For "collapse (D5)", only one building was interpreted as "no damage" by all the interpreters. For this building, it is clear in Photo 2 that the second story had almost no deformation while the first story was completely crushed. Since the side view of the building was not clearly visible in the aerial photograph, the building looked undamaged. This result demonstrates the limitation of building damage interpretation from aerial photographs. For the similar reason, the results of the aerial photo-interpretation also varied for other damage levels (D4-D1).

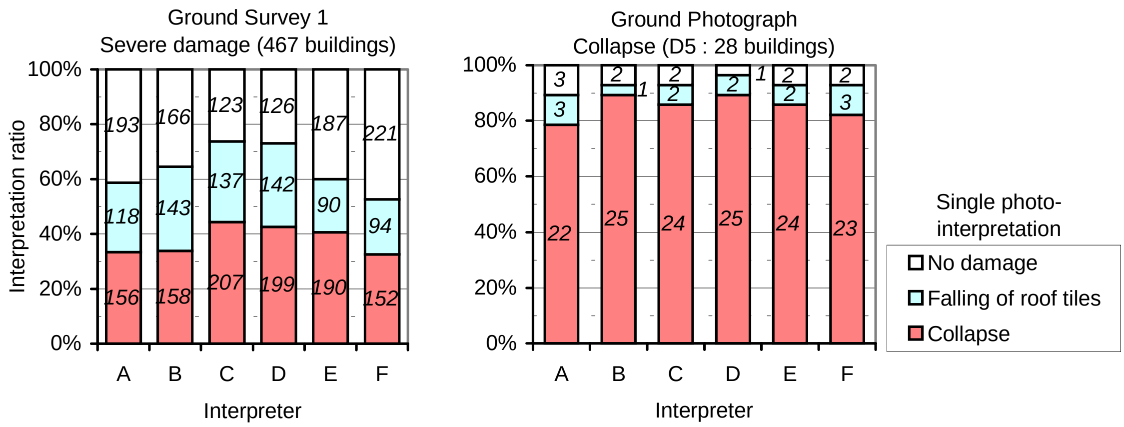


Figure 4: The results of building damage interpreted by six people were compared with those of Ground Survey 1 and ground photographs

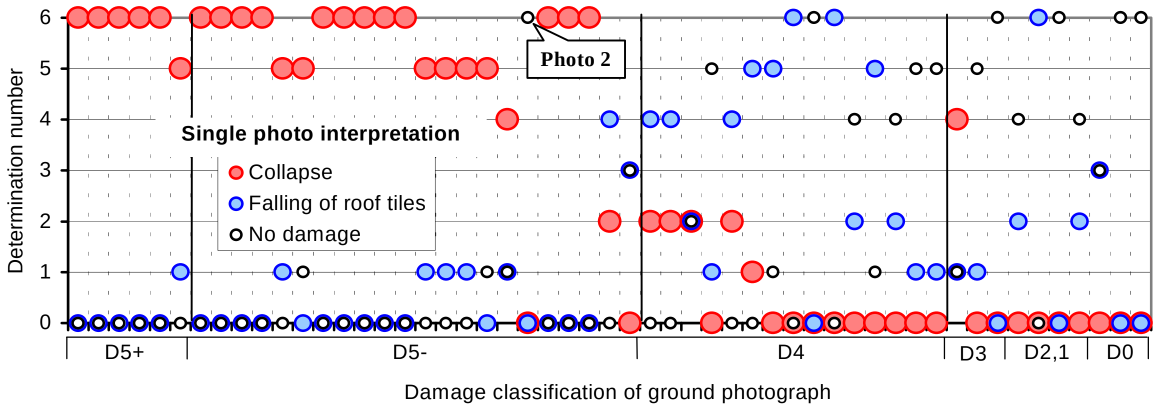


Figure 5: Damage classification and number of persons who determined that damage class

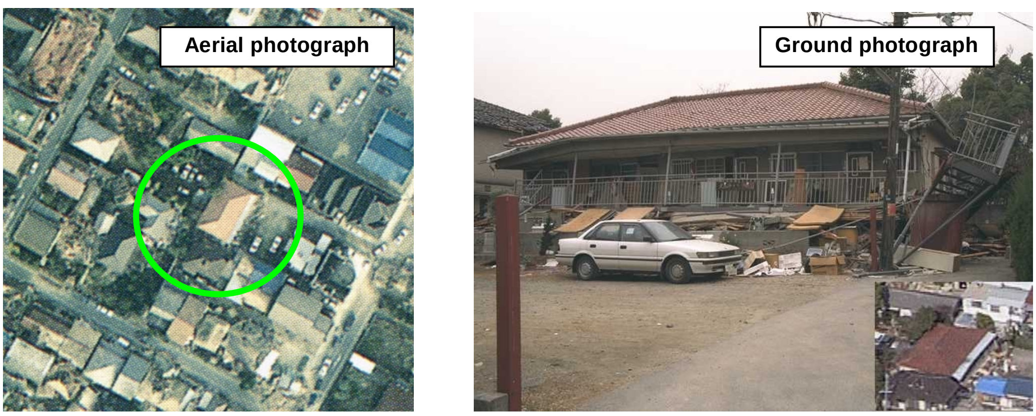


Photo 2: Comparison of an aerial photograph and a ground photograph (this building was not identified to be "collapsed" by all the interpreter since the first story was completely crushed.)

RESULTS OF AERIAL PHOTO INTERPRETATION FOR THE NON-WOODEN BUILDING AREA

The ground survey for building damage was conducted by the Kinki branch of the AIJ [AIJ, 1995]. The members of this survey were structural/construction engineers (hereafter referred to as Ground Survey 2), and its damage classification was more detailed than that of Ground Survey 1. The criteria of damage classification in Ground Survey 2 is shown in the companion paper by Hasegawa et al. [2000]. An example of aerial photographs for the non-wooden building area is shown in Photo 3.

Building damage was found in 100 (21%) out of 474 buildings by single photo-interpretation. Among those, “collapse” applied to 32 buildings (7%) and “damaged” to 68 buildings (14%). The relationship between the results of Ground Survey 2 and the aerial photo-interpretation is shown in Figure 6. In Ground Survey 2, although the rate of damage detection for “collapse” was comparatively highly as 74%, “severe damage” was 56% and damage classifications smaller than these were 40% or less. Most of “collapse” buildings interpreted from the aerial photographs were “collapse” and “severe damage” in Ground Survey 2. Those ratios of correct interpretation were low compared with those for “collapse” buildings in the wooden building area. Damage patterns differ significantly between non-wooden buildings and wooden buildings. For non-wooden buildings, complete collapse as seen in wooden buildings is rare while the collapse of a middle story and destruction of the lowest story are often observed for non-wooden buildings. In damage determination of non-wooden buildings, the side views of the buildings were important. Thus aerial photographs of a scale larger than that used for the damage interpretation of the wooden building area was used. However, information on the sides of buildings may not be obtained, depending on the position of buildings in photographs, the density of buildings, and the height of buildings. Hence, the rate of determination of damage was lower than that for wooden buildings.

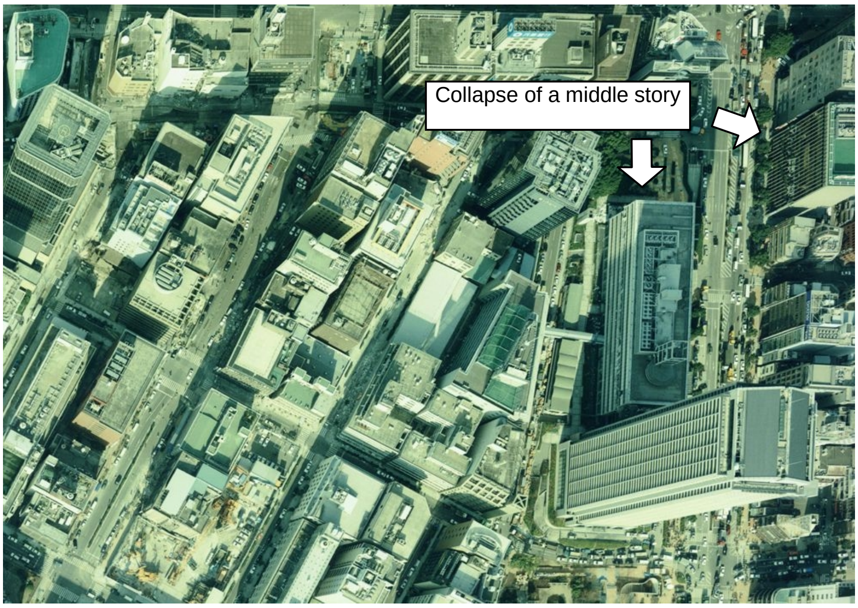


Photo 3: An example of aerial photographs for the non-wooden building area

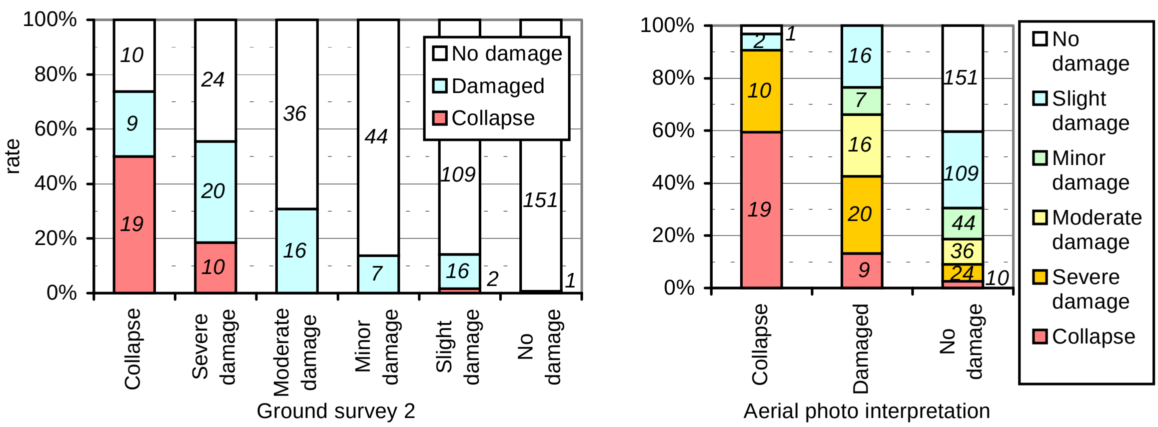


Figure 6: Relationship between the results of Ground Survey 2 and single photo-interpretation

CONCLUSIONS

Building damage due to the 1995 Kobe Earthquake was evaluated using aerial photographs. The results of the aerial photo-interpretation were compared with those of ground surveys to examine the accuracy of aerial photo-interpretation methods in detecting building damage. The damage interpretation using aerial photographs in a wooden building area was found to be effective for identifying “collapsed” and “severely damaged” buildings, in particular, “collapsed” buildings since the difference in the results due to different interpretation methods (single or stereoscopic) and that due to different interpreters were small. In damage interpretation of “severely damaged” buildings, the accuracy of stereoscopic photo-interpretation was higher than that of single photo-interpretation. In damage interpretation of a non-wooden area, “collapse” could be identified only to some extent. The rate of damage recognition was low compared with that forthe wooden building area and hence, the use of aerial photographs may be limited for damage detection of non-wooden buildings. The aerial photographs allow excellent recognition of the shape and location of objects. It is easy to compare the objects in a photograph with those on a map. However, since the current aerial photographs were taken at an right angle to the ground surface, the recognition of minor damage and damage to side walls and columns was difficult. Although there is some limitation, aerial photo-interpretation is considered to be an effective tool for determining overall damage distribution in a large area after natural disasters. In future research, in order to identify damage distribution promptly and objectively, we will employ an image processing technique for aerial photographs in damage detection.

ACKNOWLEDGEMENT

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