Post-earthquake damage assessment using satellite and aerial video imagery

by

Derya OZISIK

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of **Master of Science in Urban Planning and Land Administration.**

Degree Assessment Board

Prof. Dr. Douglas R. WEBSTER (Chairman)
Dr. Stan C.M. GEERTMAN (External Examiner)
Dr. Norman KERLE (First Supervisor)
Drs. Paul HOFSTEE (Second Supervisor)

ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.

Signed : ....

Disclaimer

....dedicated to my mom,
Aysel , who always encourage
and gave me strength to go on.....

ABSTRACT

To date, prevention of natural disasters is only rarely achieved, and such events continue to pose an increasing threat to life and property. Especially following earthquakes, typically unheralded events associated with widespread destruction and high mortality, there is a need for rapid, accurate and reliable damage information in the critical post-event hours to guide response activities. In reality, it is still difficult to obtain that information rapidly, because of interruptions in communication systems and access difficulties in remote areas. Moreover, in the time of emergency, data coming from different sources create confusion and decrease the reliability of information. Remote sensing systems can provide valuable information for response activities. However, the use of remote sensing technology in post-earthquake urban damage assessment is still limited, since it requires not only high spatial-temporal resolution and rapid response but also a 3D view to assess structural damage. Besides these technical limitations, there is also a gap between emergency managers and remote sensing technology, especially in developing countries. Information derived from remote sensing technology, however, is only valuable if it fulfils the requirements of the user.

This work aims at integrating vertical satellite and oblique airborne imagery to improve damage assessment, not in a sense of image fusion, but of synergy. Moderate-resolution satellite imagery was used to detect damaged areas at the regional level. Since vertical satellite imagery (even of high spatial resolution) has limitations in detecting structural damage, in particular pancake damage, airborne oblique imagery was used to improve the damage information at the local level. Those data can provide critical façade information that gives more meaningful insight into the state of damage than vertical data can provide. Moreover, vector data were used as an additional data source to enhance the utility of the image data and to aid in the data registration process. On the other hand, to determine the effectiveness of the use of remote sensing technology in emergency activities and to create a link between academic research and real life problems, user information requirements were investigated by interviewing emergency organizations in Turkey, where the case study area is located.

Pre and post-earthquake Spot XS/PAN and post-earthquake aerial video imagery were used in the case of the 1999 Marmara earthquake, Turkey. Pixel-based change detection methodology was applied to derive damaged areas. Detectable damage at the regional scale (urban and rural areas) was investigated. Aerial video imagery of Golcuk, taken by a Turkish media agency, was used to derive digital image frames. The information content of the video frames was enhanced using Astrostack, which integrates a sequence of frames to improve the image quality. Damage detection analysis of video frames was carried out at three levels: (i) visual interpretation, (ii) digital analysis, (iii) further experiments on methodology. Color indices, edge elements and their variance were used as feature layers for threshold based classification in digital analysis of video imagery. Further experiments were carried out by line detection, conditional unidirectional local variance and local binary patterns.

The results indicate significant limitations of moderate-resolution optical satellite imagery for post-earthquake damage assessment. Vector data integration has valuable contribution for the evaluation and visualization of the results. Despite substantial processing, registration and integration challenges of video imagery, it can improve damage assessment at the local level, since it provides information about damage, which can be seen from the building facades. Digital analysis of video imagery can overcome time requirement and subjectivity problems of visual interpretation. Although the meth-

odology applied in this research is threshold based, it is promising, as it improves damage assessment compared with Spot imagery analysis. Further experiments, which aims to find a generic methodology based on geometry and texture characteristic of the objects, was not successful due to poor spatial resolution, high oblique characteristic and texture characteristics of the urban scene. Further research on finding a generic methodology, registration and mosacing of highly oblique video imagery will improve the damage assessment result.

On the other hand, even using video imagery cannot fulfill the information requirements of the user, as most of the information requires integration of GIS and RS data. For effective use of information between different, there is a need for organizational improvements in terms of data network, technical infrastructure and expertise.

ACKNOWLEDGEMENTS

I would like to express my gratitude to *ITC* and *Dutch government* for giving me the opportunity to complete my MSc. thesis. Without a fellowship from *Netherlands Fellowship Program (NFP)*, this research could not have been done. Besides improvement in my scientific knowledge, being in an international environment also enriched my personal and professional life. I am also grateful to my office, *Bank of Provinces*, for giving me the chance to study in ITC.

I wish to express my sincere thanks and appreciation to my first supervisor, *Dr. Norman KERLE* for his support, scientific guidance and critical reviews during the research. Working with Norman over the past six months has been a pleasure. I also want to thank to my second supervisor, *Drs. Paul HOFSTEE*, for providing me additional insight. I am also grateful to *Mr. Rob STEKELENBURG* for sharing his knowledge and skills during the research.

Special thanks go to *Dr. Lorena MONTOYA* for not only helping me to construct my proposal formulation at the beginning stage of the research, but also her friendly support in every subject. I also would like to thank the entire *staff of the Department of Urban Planning and Land Administration* for the knowledge and skills I have acquired. I wish to thank programme director of UPLA Department, *Mr. Marc BRUSSELS*, for helping me when I needed.

I am grateful to *Mr. Gerard REININK* and *Mr. Boudewijn van LEEUWEN* for helping me deal with difficulties in data analysis and processing. I also would like to express my thanks to *Mr. Boudewijn van VEEN* for helping me to convert analogue video images to digital ones. And the other *ITC staff* whose names have not been mentioned, thank you very much for your patience and help.

I wish to acknowledge my classmates; *Jayaweera SOMASEKERA, Md Ahsanul KABIR, Jimmy Ernesto AVENDANO CASTILLO, Kithsiri TENNAKOON, Sharon AFRICANO*, who were always ready to help in any time during the MSc. research. My special thanks go to *Ronald Roy BROWN*, my Jamaican friend, for his moral support.

I am also grateful to my colleagues and friends, *Elif Gulay ONEL, Ali Riza ILHAN, Abdulvahit TORUN, Selma BINGOL, Sibel ALKAN, Birgul EKSI, Ozlem ASIK*, who not only helped me in the field work and data collection, but also encouraged me during my stay and study in the Netherland.

I want to thank the *Golcuk Municipality, Kocaeli Governorship, Show TV, Marmara Research Centre (MAM), AKUT, General Directorate of Disaster Affairs, Turkish Red Crescent (AFOM), and General Directorate of Civil Defence* for providing data and giving me time to answer my interview questions.

My special thanks go to *Umut DESTEGUL*, my country mate, for being with me in good times and bad times during the 18 months in Enschede.

Derya OZISIK
February, 2004, Enschede

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDIX

1. Introduction

1.1. Background

Natural disasters can be described as rapid and extreme events within the geophysical system (lithosphere, hydrosphere, biosphere or atmosphere), which create potential danger to life and property (Alexander, 1993). Another characteristic of the disasters is that the affect of the disasters exceeds the ability of affected society to cope using its own resources (http://www.unisdr.org visited on 03.November.2003). Kerle and Oppenheimer (2002) describe natural disasters as "events that result in mortality and damage, which exceed the response and recovery capabilities of the affected areas, creating the need for outside assistance". Natural disasters are dynamic and uncertain processes as they can trigger other disasters, and it is difficult to forecast them (Montoya, 2002b). As the world population has doubled in size from 3 billion in the 1960's to 6 billion in 2.000, the number of population under the risk of natural disaster has been increasing. Increased vulnerability of global society because of concentration of the population in the hazardous areas, urbanization, poor urban planning, increase in the number of weather related disaster has resulted in an eight times increase in economic loss over the past four decades (Van Westen, 2002). On the other hand, less developed countries, where more than 4.200 million people live, have suffered 95 percent of the disaster casualties (Van Westen, 2002).

Prevention of disasters is only rarely achieved with today's technology and knowledge. One way of dealing with disasters is simply to ignore them. In many part of the world, society and authorities do not always take disasters into serious account (Van Westen, 2002). Adequate and comprehensive disaster management is another way of dealing with disasters. Disaster management is the collection of policies, administrative decisions and operational activities, which are related to the various stages of a disaster (http://www.unisdr.org visited on 3 November 2003). With effective disaster management strategies it is possible to avoid or to diminish the impact of the disasters (Montoya, 2002b). The main objective of disaster management is to increase preparedness, provide early warning, monitor the hazard in real time, assess the damage and organize relief activities (Ayanz *et al.*, 1997).

Montoya (2002b) examined disaster management in four phases: mitigation, preparedness, response and recovery (Figure 1.1). ***Mitigation*** activities include activities taken in advance, which aim at reducing or eliminating effects of disasters, like land use regulations, engineering works, building codes, insurance programs. ***Preparedness*** covers the planning activities for effective response. These activities are designed to minimize the loss of life and damage, to organise the temporary removal of people and property from a threatened location and facilitate timely and effective rescue, relief and rehabilitation. ***Response*** activities take a role after disaster to meet the life preservation and basic subsistence needs. Search and rescue activities are important part of the response stage, as it aims to locate and recover disaster victims. Evacuation, emergency medical services and fire fighting are the other main activities in the response stage. ***Recovery*** includes the activities, which is required to return normal situation of social life. Construction of permanent housing, full restoration of all services and complete resumption of pre-disaster state are the major response activities.

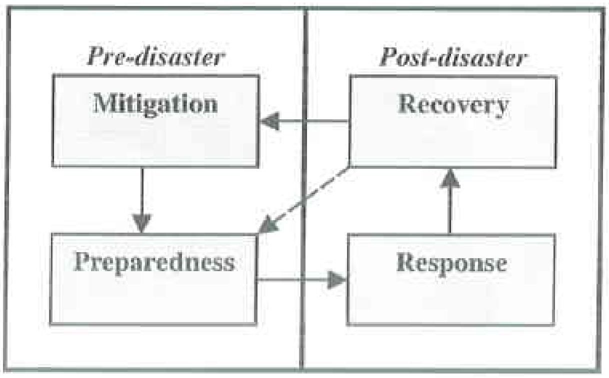


Figure 1.1. Disaster management cycles
(Montoya, 2002b)

1.2. Geo- information science and disaster management

In disaster management, there is a need for a variety of geo-spatial information at different scale, such as topographic, geologic and soil maps, vegetation cover, road network, location and type of buildings, aerial photography, satellite imagery, and global positioning system data (GPS). The volume of the data required for disaster management is too much to be handled by manual methods in a timely and effective way (Van Westen, 2002). Geo-information science is a way of computerized handling spatial data, which includes geographic information system (GIS), remote sensing (RS), and global positioning system (GPS). Geo-information science can provide concrete support for disaster management activities in terms of efficiency and speed up the data management, manipulation, analysis, output and value of better decisions (Montoya, 2002a).

In the preparedness phase of disaster management, GIS and RS can be used in derivation of hazard zonation maps and identification of area of risk. Modelling and analysing the phenomena can provide better understanding of the nature of disaster. In the response phase, integration of GIS and RS technologies can be used not only in monitoring the occurrence of the disaster, but also in emergency activities. GIS can be helpful for loss estimation after disaster. GPS can be used for ground observations of the building characteristics leading to loss estimation (Montoya, 2002a). Integration with GPS, GIS can provide important information for search and rescue operations (Van Westen, 2002). The 11th September 2001 terrorist event showed the value of geo-information science in emergency management. Applications ranged from the positioning of logistical support and resources to public maps of damage (Cutter, 2003). In the recovery phase, GIS can be utilized in organizing damage information, post disaster census information, and site selection of reconstruction.

1.3. Role of remote sensing in disaster management

Remotely sensed data can provide valuable information for disaster management studies. Using remotely sensed data allows continuous monitoring[1] of atmospheric as well as surface related natural disasters (Rao, 2000). Comprehensive, synoptic and multi temporal coverage of large areas in real time and at frequent intervals are the main advantages of using remotely sensed data in disaster man-

[1] System that permits the continuous observation, measurement and a valuation of the progress of a process or phenomenon with a view to taking corrective measures (http://www.unisdr.org visited on 3 November 2003).

agement. Rao (2000) examines the use of remotely sensed data in 3 different phases of disaster management for different disasters.

Disaster	Mitigation	Preparedness (Warning)	Recovery / Response
Earthquakes	Mapping geological lineaments and faults, the study of tectonic setting of an area and Neo tectonic studies, land use	Geodynamic measurements ofstrain accumulation	Locating stricken areas, damage map
Volcanic Eruptions	Topography and land use maps, identification of potentially dangerous volcanoes especially in remote areas, mapping volcanic landforms and deposits	Detection/measurement of gase-ous emissions, detecting and monitoring volcanic eruptions, measurement of heat increase	Mapping lava flows, ash falls and lahars, damage map
Landslides	Topographic and land use maps, mapping the factors related to the occurrence of landslides, landslide inventory	Rainfall, slope stability	Mapping slide area
Floods	Land use maps, flood plain maps; numerical weather prediction models to assess hydrological and hydro –geological risk, mapping of historical floods, detailed geo-morphological terrain mapping	Local rainfall measurements, regional rainfall	Flood damage map
Storm surge	Land use and land cover maps	Sea state; ocean surface wind velocities	Mapping extent of damage
Hurricanes	Tracking	Synoptic weather forecasts	Mapping extent of damage
Fires	Mapping vegetation type and stress	Monitoring fires, monitoring fires smoke	Detecting burned areas
Drought	Soil moisture, vegetation type	Long ranged climate models	Monitoring vegetative biomass

Figure 1.2. Application of remote sensing in disaster management
(Modified from Rao, 2000)

Within the disaster management cycle, possibly the most important and challenging phase is the response phase, since the situation after the event is usually not clear, little is known about what happened exactly, where it happened and how many people were affected (Steinle *et al.*, 2001). On the other hand, to deal with the situation requires well organized and effective emergency planning. How quickly the event is responded and how efficiently response activities are managed are the main determinants of the overall cost of a disaster, both in terms of economic damage and fatalities (Kerle & Oppenheimer, 2002). For effective allocation of limited resources, there is a need for information about the extent and the concentration of damaged area in critical hours following a disaster. Moreover, this information needs to be accurate, reliable and provided in a timely and appropriate manner.

On the other hand, in the time of the emergency, to get this information is typically difficult. After a natural disaster, damage to critical lifelines, in particular telecommunication, roads, and power supply systems, creates limitations for the communication with the emergency agencies to get information about the current situation (Kerle & Oppenheimer, 2002). Therefore, there is a strong need for information, which does not depend on actual access to the disaster area (Ayanz *et al.*, 1997). In the case of the 2001 Gujurat earthquake, identification of affected villages took three days (Economic & Political Weekly, 2001). On the other hand, information coming from the field may not be reliable and accurate due to the stress and confusion in disaster area. The emergency situation itself can lead to exaggerated or distorted information.

Following a disaster, potential high-speed acquisition and dissemination of air and space-borne data allows the event to be detected and monitored (Van Westen, 2002). The use of remote sensing technology provides quantitative base information about damage and aftermath monitoring to assist response operations (Van Westen, 2002), and helps response and relief specialist in the decision making (Walter, 1990). Overall damage information of large areas derived from moderate spatial resolution remotely sensed data can be valuable for assessing the extend of damage (Walter, 1990).

1.4. Earthquakes as one of the major disasters

FEMA (Federal Emergency Management Agency, U.S. Department of Homeland Security) describes an earthquake as "a sudden, rapid shaking of the earth caused by the breaking and shifting of rock beneath the Earth's surface. This shaking can cause buildings and bridges to collapse; disrupt gas, electric, and phone service; and sometimes trigger landslides, avalanches, flash floods, fires, and huge, destructive ocean waves (tsunamis). On a yearly basis, 70 to 75 damaging earthquakes occur throughout the world" (FEMA, 2003).

Earthquakes are one of the major natural disasters with a high mortality rate and very wide-spread destruction (Alexander, 1993). According to the statistics:

- The largest amount of economic losses (35 percentage of total losses has been caused by earthquakes ahead of floods (29%), windstorms (29%) and others (7%; Van Westen, 2002).
- The largest amount of fatalities (48 percentages of total fatalities has been caused by earthquakes, which is followed by windstorms (44%) and floods (8%; Van Westen, 2002).
- Total 158.551 deaths were associated with earthquakes around the world between 1980 and 2000 (see Figure 1.3;(UN, 2004)
- About 130 million people were found to be exposed on average every year to earthquake risk (UN, 2004).

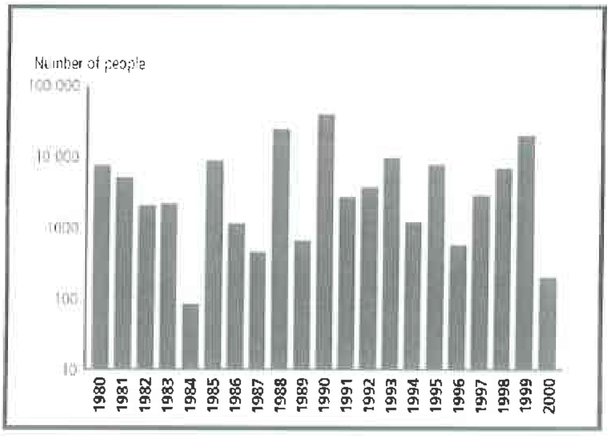


Figure 1.3. People killed by earthquakes, 1980 -2000 (UN, 2004)

Furthermore, earthquakes differ from other natural disasters in several aspects. Unpredictability and rapid affects are the major characteristics of earthquakes, which can occur at any time of the year and at any time of the day or night. Another important characteristic of earthquakes is that they can trigger secondary disasters[2], such as fire, hazardous material release or dam failure. Landslides caused by earthquake can involve rock falls and slides of rock fragments on steep slopes. Tsunamis

[2] Those hazards that occur as a result of another hazard or disaster, i.e., fires or landslides following earthquakes, epidemics following famines, food shortages following drought or floods (http://www.unisdr.org visited on 3rd November 2003)

produced by a submarine earthquake, can reach 80 feet and can devastate coastal cities and low-lying coastal areas (FEMA, 1996). These characteristics of earthquakes create difficulties to deal with them.

Moreover, vulnerability to seismic hazards is not the same all around the world. Urban areas are the most vulnerable with their concentration of buildings, infrastructure and population. That is why losses in urban areas are much higher, and the effects of earthquakes are more severe than in rural areas (Montoya, 2002b). Moreover, all over the world it has been estimated that rapid urban growth will take place in the next 10-20 years. According to one estimation, the urban population by 2025 will reach 5 billion people and the number of mega cities will be 64, with additional 23 new mega cities[3] (Masser, 2001). Therefore, disaster management for urban areas is becoming increasingly important.

On the other hand, according to the United Nations (2004), Turkey is the one of the countries having the highest average annual deaths due to earthquakes. Conversely average population exposed to earthquakes in Turkey is lower compared to Japan, Indonesia, Philippines, Taiwan, United States, Mexico (see Figure 1.4). Iran has the highest toll of death, with 47,267 people killed in earthquakes. After Iran and Armenia, Turkey takes third place in average annual deaths. Figure 1.5 shows the descriptive figures per disaster in Turkey. High causality rate due to earthquakes (949.9 killed/year) can be observed from the figure.

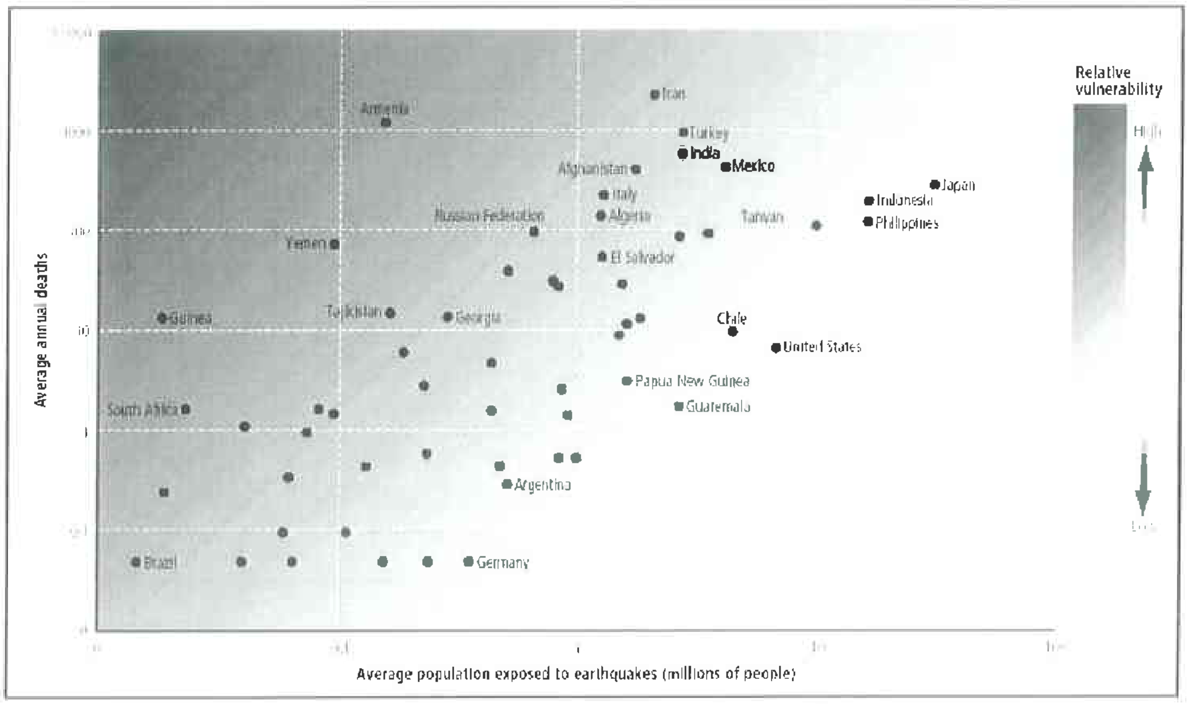


Figure 1.4. Relative vulnerability for earthquakes
(UN, 2004)

[3] Although there is no exact figure to define a mega city, the United Nations, Department of International Economic and Social Affairs defines mega-cities as cities that are expected to have populations of at least eight million inhabitants.

	Disasters per year [nb/year]	Casualities [killed/year]	Physical exposure [nb/year]	Relative vulnerability [killed/mio. exp.]
Droughts	x	x	x	x
Earthquakes	0.76	949.9	2'745'757	345.9
Floods	0.67	20.9	1'883'782	11.1
Tropical Cyclones	x	x	x	x

Figure 1.5. Descriptive figures per disaster types

(http://www.undp.org/bcpr/disred/rdr.htm visited on 17 February 2004)

1.5. Post-earthquake damage assessment using remote sensing data

After an earthquake, getting information about the damaged area is essential for effective emergency management and allocation of limited resources. On the other hand, to collect information about damaged structures in an urban area is a challenging task. Even though, the field survey has a high accuracy (Estrada *et al.*, 2000), getting information through ground survey requires extensive time and man power, especially when the extent of the affected area by the earthquake is large. Moreover, in time of emergency[4], because of the interruptions of communication and confusions of information coming from different sources (like, rescue teams, inhabitants or international press; (Steinle *et al.*, 2001), to get timely, accurate and detailed information about the disaster situation is difficult. So it is possible that relief actions would concentrate to only a few media reported areas, which may have less damage than other areas (EDM, 2000). For quick mobilization of response and relief communities, it is necessary to identify the exact location of impacted areas in the first 72 hours after disaster, which is important for survival of people injured or exposed by the disaster. This information is valuable for response activities, which includes search and rescue operations, access control and re-entry to the impacted area, debris clearance, restoration of utilities and lifeline repairs and inspection, condemnation and/or demolition of buildings and other structures (FEMA, 1996).

Here remote sensing technology can be an important tool to get the required information, as it can overcome access problems. Using remote sensing technology, damage concentration in urban areas can be located in a shorter time compared to conventional ground survey method (Rao, 2000). Post-earthquake urban damage assessment[5] using satellite imagery is one of the more recent applications, which parallel new improvements in spatial resolution of the images. The result of damage assessment using remote sensing data is a damage map, which shows the distribution of the damage in the urban area. This information can be used not only in search and rescue operations (SAR) and emergency actions, such as identification of damage areas, escape routes and estimation of causalities, but also in developing and implementing strategies for recovery and restoration activities, such as defining locations for temporary housing (Rejaic & Shinozoka, 2003).

[4] A sudden and usually unforeseen event that calls for immediate measures to minimize its adverse consequences (http://www.unisdr.org visited on 3rd November 2003).

[5] Described as a survey of a real or potential disaster to estimate the actual or expected damages and to make recommendations for prevention, preparedness and response (http://www.unisdr.org visited on 3rd November 2003).

1.6. Research problem statement and justification

According to literature review, substantial research on the post-earthquake damage assessment has been already carried out (17 case studies reviewed, see Appendix 1). While their contribution to knowledge is worthwhile, there are still some limitations for the application of post-earthquake damage assessment to practical life. In this part, there will be evaluation of the previous research to identify the main gaps in existing knowledge. Problem definition will be carried out according to this evaluation.

Post-earthquake damage assessment using remotely sensed data can be carried out in several ways. One of them is a multi-temporal approach, which requires two images (pre and post-earthquake) of the affected area that are compared to identify changes. The literature review has shown that change detection is the major methodology to assess the post-earthquake damage. However, change detection analysis has very rigid assumptions, which create limitations in the practical application of damage assessment for real time response. The main principal assumption is that the time gap between pre and post-earthquake images should be as short as possible to eliminate and substantially reduce to occurrence of non-disaster related changes. In reality, however, urban areas are dynamic structures and changes occur rapidly, leading to reduced accuracy with an increasing time gap. Chiroiu and Andre (2001) used KVR 1000 and Ikonos images acquired in 1998 and 2001, respectively, to detect earthquake damage. Because of the time gap between the two images, change detection analysis failed to detect earthquake damage in the city of Bhuj, India. The second assumption of the change detection analysis is that changes in land cover result in changes in radiance values. However, the case study by Turker and San (2003) shows that this assumption is not always true. Due to lack of change in reflectance values, one totally collapsed building block was classified as non-damaged. Even though the percentage of such cases is low, this shows that the assumption should be examined critically. On the other hand, type of damage, such as pancake collapse or soft story collapse, does not create a change in the building roofs. So, lack of change in the reflectance value of the structure creates difficulties to assess the all types of damages to buildings by change detection methodology. Lastly, having a pre and post-earthquake imagery of the affected area is the major pre-requisite for change detection analysis. Nevertheless, it is not always the case to have pre-earthquake images for every part of the world within the specific time period and under restriction of weather condition. Although the use of radar imagery can overcome the weather restrictions at some level, radar applications for urban areas are limited by side looking characteristic of the system (Stilla *et al.*, 2003). All these limitations create difficulties for the practical solutions of the real life problems. As a result, there is a need for more practical and flexible solutions for earthquake damage assessment.

The second methodology for damage assessment is to use post-earthquake images for visual interpretation (Chiroiu & Andre, 2001) or texture analysis (Mitomi *et al.*, 2000). These methodologies provide much more flexible and practical solution, as they do not depend on the availability of pre-disaster imagery.

There are several data resources for getting information about the damaged area, such as optical and microwave satellite imagery, aerial photography, and video imagery (Mitomi *et al.*, 2000). One of the major limitations of using satellite imagery is revisit time of the sensors, as emergency activities require rapid response. Another restriction is cloud coverage, which creates limitations for optical satellite imagery for post-earthquake damage assessment applications. After the 1988 Armenian earthquake, image acquisition at a desirable level was not possible, due to cloud coverage for several weeks (Walter, 1990). Besides, 3D characteristic of the structural damage is another restriction for damage assessment using the remotely sensed data with vertical view. Even using high spatial resolution imagery, such as Ikonos or Quickbird, may not be helpful for detecting damage in the case of pancake collapse with intact roof. The cost of the high spatial resolution imagery is another limitation for the applications. Medium resolution imagery like Spot can play an important role in identification damage at regional level. But structural damage on buildings may not be possible at local level.

Night-time imagery can be an alternative for real time damage assessment, as it has high revisit time (twice a day), e.g. captured by DMSP/OLS. However, the main shortcoming of nighttime imagery is low spatial resolution (2.7 km), which does not allow detailed damaged assessment. Furthermore, the main assumption behind the idea of using night-time imagery is that there will be the reduction in the night-light, because of the earthquake damage. Nevertheless, there are other extraneous effects like fires, which increase the light occurrence.

Airborne laser (Light Amplification by Stimulated Emission of Radiation) scanners have significant advantages, such as high positional accuracy, possibility of creating digital surface model (DSM), capability of image acquisition in any time. Using DSMs derived from laser imagery can be valuable information for damage assessment, as they can give information about building height changes. Although it has blind characteristic, it can be overcome by integration with other data sources, such as airborne scanner or photography. On the other hand, the high cost and complex image processing are the main disadvantages of laser imagery.

Aerial imagery as another data source can be examined in two categories: standard vertical aerial photography versus small format, uncalibrated aerial photos and video imagery. Standard vertical aerial photography has the advantage of high spatial resolution, but the cost of data acquisition and time requirement for the processing is high enough to create limitations for damage assessment. On the other hand, the second category could be available alternative to satellite imagery, as their response time is much more flexible than space-borne sensors. Another advantage of small format aerial photography and video imagery is an oblique view of the disaster area can give information about the facades of the building, which can improve damage assessment. To be able to see the facades of the structures can help to assess the different types of damages and collapse, such as pancake collapse, intermediate floor collapse, which is not possible to detect using images with vertical viewing. Main difference between standard vertical aerial photography and small format aerial photography is the geometric characteristic of the images. Geometric characteristic of images with oblique view is much more complex to solve compared with the standard vertical aerial photography.

Another point is the coverage area characteristics of sensor systems. Airborne and space-borne imagery can provide different scale of the coverage area. Data selection is dependent on the scale of the disaster (regional or local). Although space imagery has a number of restrictions, it can provide synoptic data for early identification of damaged areas at regional scale, which can guide airborne image acquisition for more detailed images to be used in disaster relief activities (Walter, 1990). For local level, video imagery and oblique aerial photo taken by helicopter can be alternative, in terms of lower cost and shorter time requirement for data acquisition.

In conclusion, even though each of the data acquisition alternatives has some limitations, remote sensing technology still can be an important technological tool, which can speed up the rescue operations. None of the strategies can fulfil all requirements; however, limitations can be overcome by integration of different data sources. Integration of moderate resolution space-borne and airborne imagery can complement each other at regional and local level to improve the damage information.

Another shortcoming in post-earthquake damage assessment researches is the gap between research and user requirement. It is still not clear whether these modern digital remote sensing technologies offer practical techniques to meet the requirement of the user. Without defining the real life problems and requirements, it is difficult to find practical solutions. Therefore, there is a need for an improved understanding of relation between research and user. This is the only way to use technology as a tool for improvement of the social life. User needs assessment should be the base for the further development of the research.

The major current requirement for remote sensing data to be useful for post-earthquake damage assessment is improved spatial and temporal resolution (Rao, 2000). High temporal resolution is important for getting information as soon as possible in the time of emergency, while higher spatial resolution can provide damage information at building level. Structural characteristics of the settlements are the main determinant of the selection of resolution for urban remote sensing studies. On the other hand, it is not possible to say exactly what resolution is required for every application, as the size, densities and the contrasts of urban areas around the world are not the same. Narrow streets and compact structures require higher spatial resolution (Welch, 1982). Although there is a need for high spatial resolution for urban damage assessment (Rao, 2000), in the case of large extended earthquakes, damage at regional level can be derived from moderate spatial resolution imagery. Therefore, it is also important to know the effectiveness of detecting damage at regional level in the case of large extend disasters by using moderate spatial resolution imagery.

1.7. Brief description of case study area

Research was carried out on the case of the 1999 Kocaeli earthquake, Turkey. Kocaeli is situated in the Marmara region of Turkey, lying within the North Anatolian Fault Zone (NAFZ: Olgun, 2000). Industrialization and high population density are the major characteristics of the region. It is the industrial heartland of Turkey. One third of Turkey's overall output is produced in this area and 23% of total population lives in this region.

The 1999 Kocaeli earthquake (M 7.4) resulted in widespread and extensive damage, affecting 4 provinces in the region; Adapazari, Kocaeli, Bolu, Yalova. Three additional provinces, Istanbul, Eskisehir, and Bursa, were affected indirectly. Over 15.000 people are estimated to have died and 23.000 were injured (Government Crisis Center). Golcuk is the case study area, which is located approximately 15 km southeast of Kocaeli. The epicentre of the earthquake was located 15 km south-east of Golcuk (Kabeyasawa *et al.*, 2000). Golcuk was one of the most damaged areas with a death toll of 5.384. Because of the affect on the large area, to assess the damage for the relief works was challenging task in the time of emergency after disaster.

1.8. Research objectives

1.8.1. Main objective

The principle objective of this study is to integrate, not in a sense of image fusion, but of synergy, space-borne and airborne imagery to improve the damage assessment at regional and local level. As none of the sensor, space-borne or airborne, can fulfil the requirement for damage assessment, use of data acquired from different sensor can improve the damage assessment. While satellite imagery can provide information at regional level, airborne imagery can complement it at local level with more detailed information.

1.8.2. Sub-objectives

- To define the end user information requirements at different levels in emergency planning for the end product of the damage assessment;
- To determine the level of damage information, which can be derived from space-borne and airborne imagery.

1.9. Research questions

- What are the user information requirements for post-disaster response operations in Turkey?
- What kind of damage information is valuable for disaster response?
- How can air (oblique), space-borne (vertical) imagery and vector data be integrated?
- What are the damage levels that can be derived from different remotely sensed data?
- How can the quality of video images be improved?

1.10. Research and study design

The main conceptual frame of the research will be to establish a link between the natural disaster, remote sensing technology and the end user. As it was mentioned before, in previous studies the connection between remote sensing technology and natural disaster was investigated in many ways. The lacking part was the consideration of the end user. End user requirements will be valuable in testing the usefulness of remote sensing data in the post-earthquake damage assessment.

Figure 1.6 shows the correlation between the main components; natural disaster, remote sensing and end user. The elements of each entity play an important role, as they are the determinant of each other. So it can be said that all concepts should be considered as a whole. For example, the scale of the disaster determines the data requirement for the damage assessment. If the disaster is in the large scale, first of all there is a need for determination of the extent of the affected area at the regional scale. After that, the local damage investigation would be meaningful. Therefore, the research will be carried out mainly in three basic issues at the conceptual level: the characteristic of the 1999 Kocaeli earthquake and its affects, end user information requirements of Turkish emergency agencies and analysis of remote sensing data for post-earthquake damage assessment.

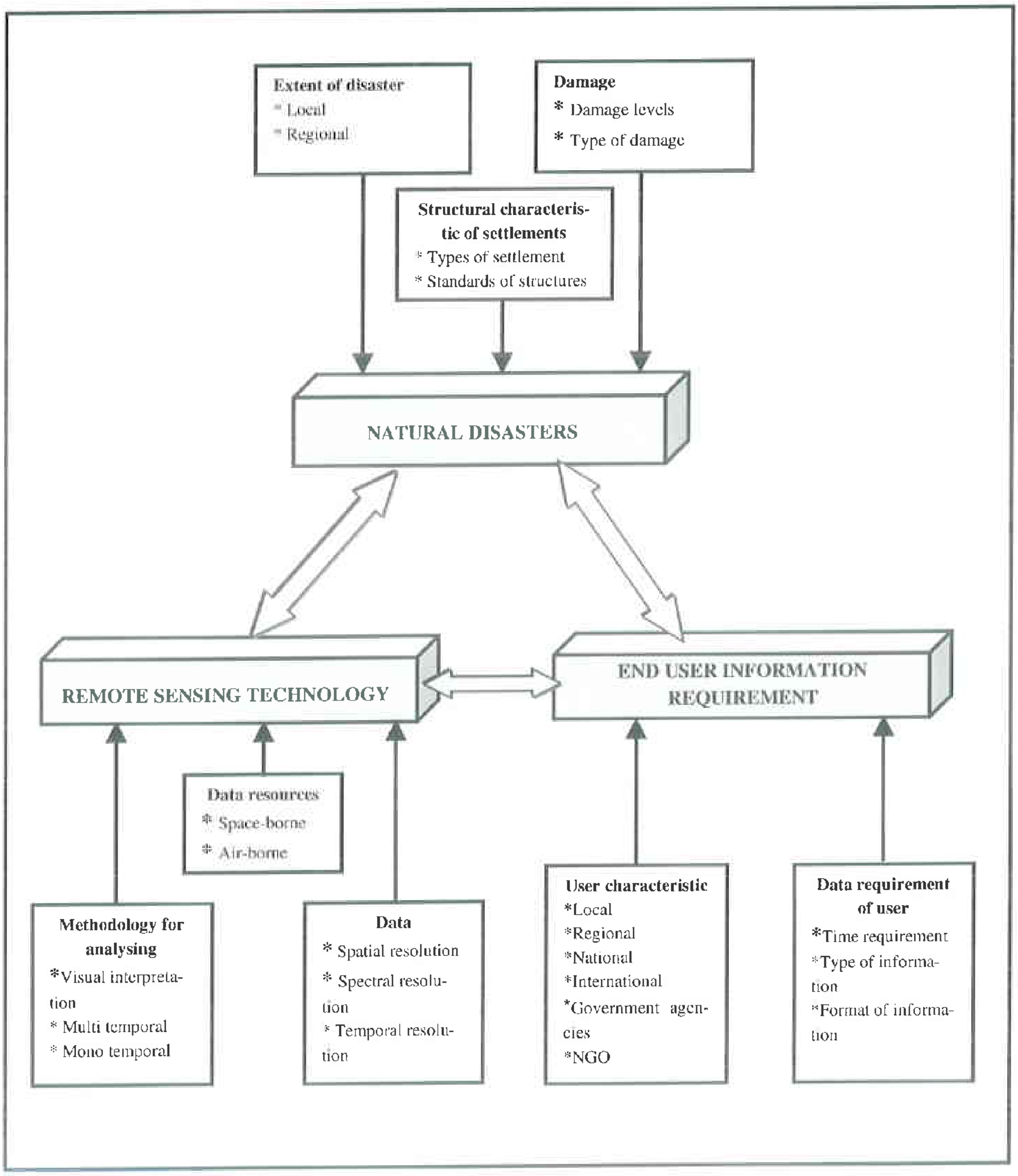


Figure 1.6. Conceptual framework of the research

The study design has four parts. In the first part, user information requirements in the case of Turkey will be investigated. In the second part, regional damage assessment will be examined by using satellite imagery, which has large coverage area relative to airborne remote sensing. In the third part, local damage assessment will be investigated by using airborne remote sensing. This will allow investigating improvement in the damage assessment by using different data sources. In the last part of the research, the results of the remote sensing data analysis will be evaluated according to user information requirements. The study design of the research is shown in Figure 1.7.

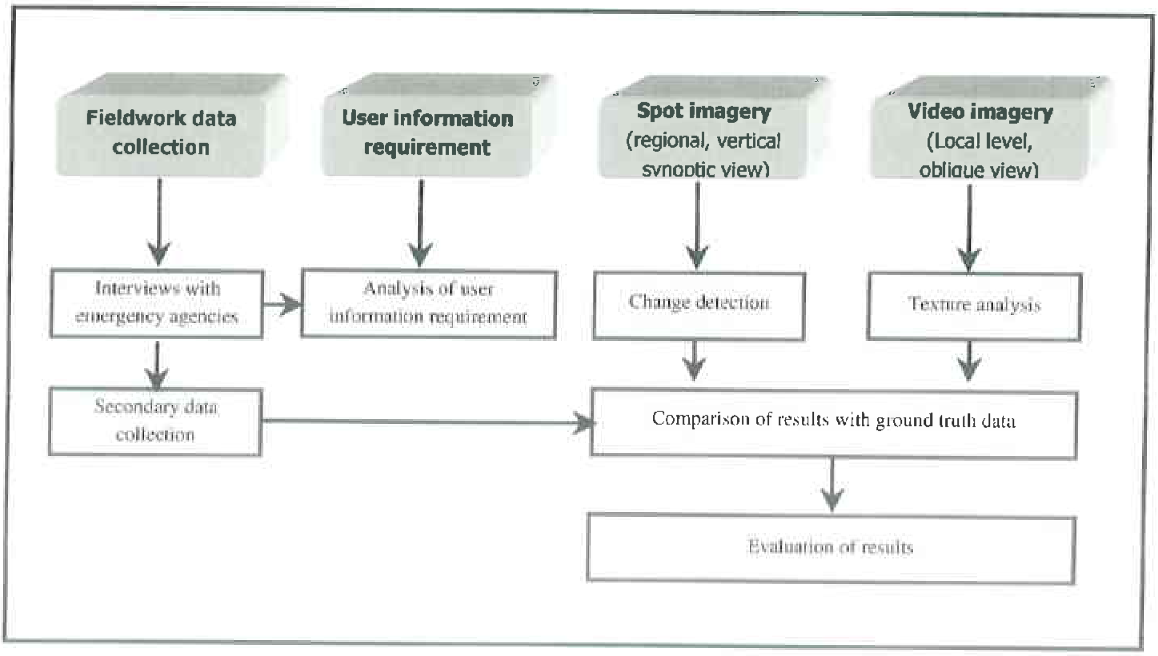


Figure 1.7. Study design

1.11. Organization of the thesis

Chapter one describes the research topic, justifies the statement of the problem, research objectives and research questions. It also includes the research and study design of the research.

Chapter two provides literature review about post-earthquake damage assessment, in terms of previous studies, data requirements, and methodology. It discusses the advantages, disadvantages and limitations of different data and methodologies.

Chapter three introduces the case study area. A broad overview on location and geological formation of the area is given. It presents the information about the 1999 Kocaeli earthquake and its affects on the region.

Chapter four describes the data and methodology used in the research.

Chapter five presents a overall aspects of the information requirements of the emergency agencies and explore the specific information requirements of the user in the case of Turkey.

Chapter six describes the process used in Spot imagery analysis. It presents the damage maps derived from Spot imagery. Evaluation of the results according to ground truth data is also provided in this chapter.

Chapter seven presents aerial video imagery analysis. The methodology applied for the damage assessment analysis and the result of the analysis are described.

Chapter eight provides the conclusion from the analysis done in chapter five, six and seven in relation to research objectives and questions.

2. Post-earthquake damage assessment

2.1. Introduction

Urban damage assessment can be analysed in three categories: social (loss of lives or injures), economic (loss of property, production) and physical loss (number of damaged buildings or infrastructure). Remote sensing provides information about the physical aspect of the damage. Social and economic damage can be derived by integration of remote sensing and GIS.

Remote sensing technology in earthquake damage assessment has been applied to the Hyogoken-Nanbu, (Kobe) earthquake, 1995 (Matsuoka & Yamazaki, 1998), the Chi-Chi (Taiwan) earthquake, 1999 (Suga *et al.*, 2001) and the Kocaeli (Turkey) earthquake, 1999 (EDM, 2000; Estrada *et al.*, 2000; Olgun, 2000; Turker & San, 2003). After the launch of Ikonos, higher resolution data were tested after the Gujarat earthquake India, 2001 (Chiroiu & Andre, 2001; Yusuf *et al.*, 2003). Further explanation on the previous studies is given in Section 2.7 of this chapter.

Although many studies on post-earthquake damage assessment have been carried out, there is still not straightforward methodology. The main challenge is the 3D characteristic of the damage to the buildings. This situation creates limitations to some extend in the application of remote sensing technology for damage assessment, as most of the remote sensing data (optical satellite imagery, standard airborne photos and multi spectral scanners) give a vertical view of the ground surface. Height (laser, radar and stereo images) and facade information (oblique aerial photos and aerial videos) are important contribution for the damage assessment. On the other hand, characteristics of earthquakes and urban morphology are also important determinants for the appropriate data and methodology selection for post-earthquake damage assessment applications, as each settlement (in terms of building size, density etc.) and earthquake (in terms of magnitude, extend of affected area etc.) has its own specific characteristic.

Moreover, the challenge for the post-earthquake damage assessment is not only related to the nature of the disaster itself and the urban areas, but also related to the data requirement, data availability and use of optimum methodology. In this chapter, there will be a review of the available data sources, methodologies and previous applications for post-earthquake damage assessment. Limitations, advantages and disadvantages of the each element will be emphasized.

Advantages of use of remote sensing technology for post-earthquake damage assessment (modified from Kerle and Oppenheimer (2002) and Paulsson (1992)).

- Not affected by the disaster
- Overcomes access problems
- Minimal fieldwork (increased safety)
- Continuous coverage area
- Digital processing and quantitative results
- Easy integration of GIS, elevation and map data, to generate imagery – derived map products.
- Unlimited number of sample points (area -rather than location- specific sampling)
- Images can be archived and reused, to check repeatability of a method or to test a new theory.

Disadvantages

- Temporal limitations, still none of the sensor has real time response capability after disaster
- Slow data dissemination
- Potentially limited by weather condition
- 3D characteristic of the building damage after earthquake
- High cost of data, which is good quality and has high spatial resolution

2.2. Urban areas and remote sensing

The historical development of urban remote sensing started with the aerial photography as a tool for urban analysis. As urban remote sensing applications are more dependent on the resolution of imagery, the use of satellite imagery started just after technological improvement in the resolution of the satellite imagery. Compared with conventional aerial photography, digital multi-spectral satellite images have the advantage of more widespread availability, higher frequency of update, fast processing time and lower cost (Donnay *et al.*, 2001).

Donnay *et al.* (2001) examines the development of the use of satellite imagery for urban studies in three stages. The first stage starts with the invention of the first-generation satellite sensor Landsat MSS (Multispectral Scanner System) with a resolution of 60 m. It allows analysing regional urban systems and explatory investigations of large cities in North America. The second generation satellites are Landsat TM (Thematic Mapper) and Spot HVR (High Resolution Visible), which have the resolution of 30 /20 m and scale at 1/10.000-1/25.000, and can give notable contributions on rural-to-urban land conversion and estimation of housing and population density (Donnay *et al.*, 2001; Puissant & Weber, 2002). The third generation satellites are very high spatial resolution (< 5m.) satellites, such as Ikonos, Quickbird, Spin-2, which correspond to the scale of 1/10.000 and 1/25.000. This improvement in resolution helps to analyse discrimination of the dense and heterogeneous milieu of the old urban cores of the European countries and to examine the morphology of the rapidly expanding cities in developing countries (Donnay *et al.*, 2001; Mesev, 2003). The scale of the third generation satellites corresponds to the scale of urban planning projects at tactical level (Puissant & Weber, 2002). On the other hand, slow processing, high storage capacity, and cost of the data are the major problems of working with this new generation imagery (Kuffer, 2001). Other possibilities for urban remote sensing application are laser scanning and radar, which allow deriving three-dimensional characteristics of the urban features, such as buildings. As they are active sensor systems, they have capability of taking images at night times. Laser scanning can be used to derive Digital Surface Models (DSM) of urban areas with a high degree of accuracy (Baltsavias & Gruen, 2003).

To study urban areas with using remotely sensed data differs from studying the natural environment. To assess the building damage is challenging task because of the different characteristics of the settlements all over the world. First of all, as urban land use classes include detailed information about the buildings, transport networks, business, parks and variety of mixed uses, to study urban areas requires higher spatial resolution. Moreover, the size, densities and the contrasts of urban areas around the world are not the same (Welch, 1982). So it is difficult to decide on the appropriate spatial resolution for all urban areas. Characteristics of the urban areas decide the appropriate spatial resolution for this specific urban area. Welch (1982) compares the Asian urban areas with Western countries. The former case is characterized by the smaller parcel, compact structures and narrower street patterns in comparison with urban areas in western countries. Therefore urban studies in Asian countries require higher spatial resolution. In addition, contrast between land cover classes is also another determinant for the spatial resolution. According to Welch (1982), as the contrast between land cover classes for urban areas in less developed countries is lower, higher spatial resolution is required for urban studies in developing countries compared with developed countries. On the other hand, higher resolution does not always mean that improvement in classification accuracy (Kuffer, 2001). Furthermore, the selection of the resolution is much more dependent on the objective of the project.

The building sizes, densities, the contrast of the urban environments and the objective of the project are the main determinants of the spatial resolution. The adequate studies for developed countries cannot be assumed that they are applicable for other countries of the world (Welch, 1982). Therefore, to select appropriate data for post-earthquake damage assessment requires prior knowledge about the settlement characteristics.

2.3. Data requirements for post-earthquake urban damage assessment

The nature of the disaster is one of the important determinants of the data selection for post-earthquake damage assessment. The first criterion is the extent of the disaster. Data requirement for small-scale disasters, such as tornados, is different from the data requirement for more extensive disasters, such as floods, hurricanes, forest fires, earthquakes and nuclear accidents. Therefore while for the former case there is a need for local information, which can be derived from aerial photography or even ground based efforts, later case requires larger coverage area of the image, which can be used to direct workers on the ground (Zimmerman, 1991).

The second important point for data selection is the characteristic of the disaster. For example in the case of ***flooding***, optical sensors are limited by cloud coverage, which often present during a flood event. Moreover, radar data, which gives information about the moisture, precipitation intensity, amount and coverage to estimate surface soil wetness, can be important data source for flood event (Van Westen, 2002). In the case of ***volcanic activity***, thermal infrared bands can distinguish heat sources (Alexander, 1991). Moreover, visible and infrared radiation can be useful to discriminate between fresh rock and vegetated surface. SAR can be used to derive information about the topography (Van Westen, 2002). On the other hand, ***landslide*** disasters require more detailed optical imagery, such as aerial photo and Ikonos data. Weather satellites can be used to locate the ***tropical cyclone*** centres and their movements (Van Westen, 2002). Therefore, data requirement for specific disaster is much more depend on the characteristics of the disaster itself and its impact on the earth surface.

In the case of earthquakes, ***high spatial resolution*** of the image, ***high temporal frequency*** of the sensor and capability of the ***quick response time*** are the main requirements for the urban damage assessment. Moreover, the 3D characteristic of the damage is another consideration for data selection. To assess the damage, there is a need for prior knowledge about the damage characteristic of specific area. Damages to buildings are usually described based on damage classes, which may differ from country to country (Steinle *et al.*, 2001). Markus *et al.* (2003) proposes an internationally usable damage catalogue (see Figure 2.1.).

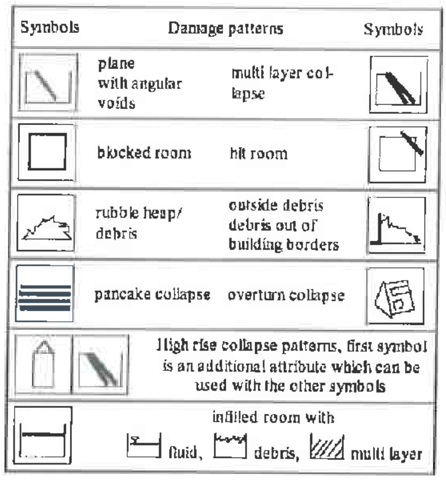


Figure 2.1. Building damage patterns (Markus *et al.*, 2003)

To choose the optimum data for urban damage assessment, it is important to know the data types with their different characteristics, as all of them have different spatial, spectral and temporal resolution. Parameters for data selection are consideration of area coverage, urgency, weather and spatial resolution of images (Yamazaki, 2001). Main differentiation comes from the type of platform and the type of the sensor. Here, sensor types will be examined in two different platforms: airborne and space-borne.

2.3.1. Airborne remote sensing technology

Airborne remote sensing is one of the major data source for gathering information about the disaster area due to the higher spatial resolution. To obtain detailed inventory and to collect damage data of built environment is possible by using airborne remote sensing. They are very useful to observe buildings and infrastructure in urban areas (Yamazaki, 2001). Airborne remote sensing is the best alternative for local disasters. Conventional aerial photos, small format aerial photos, multi-spectral scanners, laser, airborne SAR and aerial video imagery are the main types of the data sources. On the other hand, because of the higher spatial resolution, the coverage area of the airborne sensors is limited. The main advantage of the air borne imagery is that aircraft can react in a short time period after earthquake, if the weather permits and aircraft is available. A summary of advantages and disadvantages of different types of airborne remote sensing data sources is provided in Figure 2.2.

i) Aerial photographs are important for detailed information. The spatial resolution of aerial imagery is so high that it creates an advantage compared with space-borne imagery. However, data acquisition process can be long, as it requires long logistic preparation process, such as mission planning. In addition, to get such detailed information, there is a high price to be paid (Warner *et al.*, 1996). As the cost of the aerial photography is high, the temporal resolution of the aerial photographs is quite low (5-10 years). So, it is almost impossible to get aerial photo just before and just after disaster. Moreover, analogue characteristics of the typical aerial photos create limitation for computer-aided image processing, which can speed up the process time. Therefore, there is a need for format transformation from the analogue format to digital format. Turker and Cetinkaya (2002) uses 2 set of stereo aerial photography for the earthquake damage assessment in the case of the Kocaeli earthquake, 1999, Turkey to detect damaged buildings.

ii) Small format aerial photo (SFAP) can be obtained by the use of lightweight cameras, which can be lifted by manned or unmanned platforms. They can overcome the high cost of the conventional aerial photos. They are useful for small area mapping (Warner *et al.*, 1996). The preparation for data acquisition process is shorter compared with conventional aerial photography. These characteristics of SFAP offer more flexibility. For small scale and local earthquakes, small format aerial photos can be a better alternative. The SFAP taken with oblique view presents façade information of the structures. Oblique viewing can improve and contribute valuable information about damage on structures, as it overcomes the limitation of vertical viewing. In addition, the scale of the SFAP is larger compared with the conventional aerial photography as it is a way to obtain low-height aerial images. This characteristic can result in increase in the detailed information about the damage. On the other hand, one disadvantage of SFAP is perspective view, which can create difficulties in locating the image in 2D map reference. Integration with GPS can be helpful in locating the images in map coordinate. Applications of the SFAP includes detecting recent changes in the land due to natural disasters, analysing urban changes and land use or monitor and document movement of wildlife (Acosta, 2004).

After the 1999 Kocaeli earthquake Turkey, MCEER team (2000) used SFAP for qualitative information in the time of ground survey.

iii) Digital cameras record image data with CCD and CMOS sensors rather than with film. They provide digital imagery. The advantage of the digital cameras compared with conventional photography is size, weight, dynamic range, optical sensitivity, linearity and durability (Warner *et al.*, 1996). Compared with aerial photography, digital cameras have higher turnaround time, as images are available for viewing during the flight and immediately afterward. Although in the case of aerial photographs need to be scanned to produce computer-computable data, digital images derived from digital cameras are ready to process in computers after data acquisition. Most digital cameras have the capability of recording positional data obtained from a GPS receiver (Lillesand & Kiefer, 2000). However, they are quite expensive (Warner *et al.*, 1996).

iv) Aerial video imagery is a way of taking continuous overlapping frames of an area to record image data in analogue form on magnetic videotape. It has become popular tool for mapping of linear features, such as roads, pipelines, power lines and even coastlines. Moreover, the advent of video analysis and Global Positioning System (GPS), which permit multiple flight lines to be referenced, resulted in broader application areas (Ham, 1998). The most widely used analogue formats for aerial videography are the Super-VHS and Hi-8 formats with a resolution of about 400 television lines (TVL). The number of pixels in one frame of a Hi-8 recording has 535x485 or about 260.000 pixels, which are only 1/25 of the number of pixels of one frame taken by a digital frame camera. On the other hand, high definition television (HDTV) has 1920x1080 pixels and 2.0 million pixels per frame (Lillesand & Kiefer, 2000). Analogue video imagery can be converted to digital frames using video digitising. But the result of the video digitising is not always useful for digital image purposes. There are some technical limitations, which create problems in digital image processing of video imagery. First of all, there are dramatic changes in the radiometric sensitivity and repeatability of various video cameras. Moreover, vignetting (light fall off) away from the centre of the digitised image, which can affect the spectral signatures extracted from scene is one of the serious problem (Jensen, 1996).

Aerial video imagery taken from helicopters and light planes are a practical and powerful tool to survey urban areas. Since the response time can be very short, they are useful in the early post-disaster damage detection (Yamazaki, 2001). The main advantage of the video imagery is their digital characteristics, which allows data analysis immediately after flight. In addition the cost of the video imagery is cheaper compared with other aerial data acquisition means (Ham, 1998). Oblique viewing characteristic is another advantage, which can give information about not only collapsed building information (as other vertical viewing data types do), but also the nature and the degree of the damage. However, main disadvantage of aerial video imagery is its poor spatial resolution in comparison with film or digital cameras. This feature results in difficulties in digital image processing. Moreover, analogue characteristic of the tape can create limitations for indexing when subsequent viewing of discrete image segments is desired (Lillesand & Kiefer, 1994). In addition, accurate measurement or digitising requires special equipment, such as GPS or expertise (Ham, 1998). On the other hand, if the time requirement for the data is the most important issue, one can prefer to work with lower spatial resolution for quick response.

Aerial video imagery was applied to the 1999 Chi-Chi, Taiwan, the 1999 Kocaeli, Turkey earthquakes (Mitomi *et al.*, 2000), the 1995 Hyogoken-Nanbu, Kobe earthquake (Hasegawa *et al.*, 1999), and the 2001 Gujurat, India earthquake (Yamazaki, 2001) for post-earthquake damage assessment.

v) Laser scanning (Light Amplification by Stimulated Emission of Radiation) measures three dimensional points, which are distributed over the terrain surface and on objects rising from the ground (Haala & Brenner, 1999). Information derived from the laser scanner is important as it allows creating Digital Surface Model (DSM) of the build-up or vegetated areas.

Using the height information obtained from pre and post-disaster laser imagery, it is possible to detect change in the building height. This comparison of pre and post-earthquake laser scanning images gives the information on collapsed or slumped building (Markus *et al.*, 2003). Derivation of DSM is useful not only for damage assessment, but also volume of the rubble calculation, which can be useful information for rescue teams to track their movements (Rodarmel *et al.*, 2002). Another important characteristic is the high accuracy of the laser data. Using Airborne laser scanning technology, it is possible to generate DSM data with vertical accuracy, up to approximately 10 cm, and high spatial resolution as small as less than 1 m (Murakami *et al.*, 1999). It has capability of data acquisition in any time even night times. Time requirement for data collection and processing is very short, if laser scanner is available (Markus *et al.*, 2003).

Murakami *et al.* (1999) used the laser scanning technology to detect the change in the buildings in the city of Minokamo, Japan. At the end of the study, he concluded that buildings changes could be detected without omission errors by using airborne laser scanner. It can provide accurate information about the building height changes. This study shows that laser data can contribute important information for the earthquake damage assessment. However, it is important to keep in mind that not all the damage type is resulted in change in the building height.

On the other hand, the main disadvantage of using laser data is to have blind characteristic, since it gives only the height information. So the use of laser data can be effective only by integrating other data sources, which shows the current situation of the disaster area, such as, aerial photography or imagery. Nowadays-new technology allows integration of airborne laser scanner (ALS) with a CCD array sensor. Acquisition of DSM data and optical imagery at the same time is important tool for automated generation of ortho-images (Murakami *et al.*, 1999). Another disadvantage of using laser scanner is the high cost and complex image processing. In addition it is not widely used throughout the world.

vi) Airborne radar is not widely used either. One of the reason for this is the high cost of technologies used in data acquisition. Airborne SAR image has a resolution of 0.5 to 10 m. Repeat pass interferometry is quite difficult to achieve with airborne interferometry (Yuan *et al.*, 1999). Moreover, radar applications for urban areas are limited by side looking characteristic of the system, which is resulted with shadow and layover in the image (Stilla *et al.*, 2003).

Airborne multi-spectral scanners can overcome the limitations of the aerial photography, in terms of spectral resolution and digital format. Cost is one of the limitations for both applications. Mitomi *et al.* (2003) used airborne multi spectral scanner to assess the damaged areas after the 1995 Hyogoken – Nanbu, Kobe earthquake.

DATA TYPE	ADVANTAGES	DISADVANTAGES
Conventional aerial photo	▪ High spatial resolution ▪ Stereo photographs allows deriving height information	▪ Long response time, in terms of data acquisition, aircraft availability, mission planning ▪ Lack of multi-spectral information, only visible part of the spectrum ▪ Difficulties in data processing because of analogue characteristic, slow ▪ High cost and delays ▪ Security restrictions ▪ Long logistics preparation ▪ Need for ground control
Small format aerial photo	▪ High spatial resolution ▪ Shorter response time relative to conventional aerial photo ▪ Low cost ▪ Practical ▪ Low complexity	▪ Analogue format ▪ Limited to small surveys
Aerial video imagery	▪ Easy data acquisition, ▪ Short response time ▪ Low cost ▪ Practical	▪ Lower quality ▪ Digital format allow computer based processing
Laser scanning	▪ Accurate information about building height ▪ DSM generation ▪ Night-time data acquisition ▪ Useful for volume calculation	▪ Blind image, only height information can be derived, need for data integration ▪ High cost ▪ Data availability, it is not widespread ▪ Complexity in image processing
Multi-spectral scanner	▪ High spatial resolution ▪ Multi-spectral information	▪ High cost ▪ Data availability, not widespread use
Airborne radar	▪ Night-time data acquisition ▪ May not affected from weather conditions at some extend	▪ Complex image processing ▪ Data availability, not widespread ▪ High cost

Figure 2.2. Advantages and disadvantages of different type of airborne remote sensing data
(Modified from Paulson, 1992)

2.3.2. Space-borne remote sensing technology

The main superiority of space-borne remote sensing technology is the large coverage area, which is difficult to achieve by using airborne remote sensing technology. In contrast to aerial imagery, satellite imagery offers information at regional scale. Therefore, space-borne remote sensing technology can be useful for damage detection in large-scale natural disasters (Yamazaki, 2001). Main advantages and disadvantages of the use of space-borne remote sensing technology in damage assessment can be seen in Figure 2.3.

ADVANTAGES	DISADVANTAGES
▪ Synoptic, continuous coverage ▪ Availability of pre event, reference imagery ▪ Variety of complementary sensors ▪ Availability of increasingly sophisticated and easy to use software and algorithms ▪ Pointable sensors allow acquisition or stereo images or elevation data ▪ Rapidly increasing sophistication of satellites ▪ No security restrictions ▪ No ground control ▪ Possibility of time series ▪ Fast production	▪ Delayed initial image acquisition, especially for non-pointable sensors ▪ Low number of operational radar (i.e. all weather) satellites ▪ Lack of central inventory of available satellites and their current location ▪ Frequent data incompatibility problems ▪ Large image file size, which makes electronic use/dissemination in the field is difficult ▪ Lack of global coverage by ground receiving stations for some satellites, resulting in incomplete coverage ▪ Limited use of optical sensors in cloudy situations ▪ Variable equatorial crossing times (And, consequently variable illumination) of some polar orbiters

Figure 2.3. Advantages and disadvantages of satellite remote sensing for damage assessment
(Kerle & Oppenheimer, 2002)

Space-borne remote sensing used in damage assessment can be examined in two categories: optical and microwave systems.

i) In optical systems, the wavelengths extend from approximately 0.3 to 1.4 μm. They give information about the reflected energy of objects. In urban damage assessment, the main assumption is that the value of the damaged structures in post-earthquake image can be higher because of the collapse of the buildings than pre-earthquake image (Yusuf *et al.*, 2003). Changes in the reflectance values of damaged structures is used to assess the damaged areas, although there are several external factors, which can create change in reflectance values of objects, such as seasonal, atmospheric changes. On the other hand, it is not possible to detect all damage levels just by looking at the reflectance values of the damage buildings, as some of the damage types, such as pancake collapse, do not create change in the reflectance value of the buildings. Generally, medium (Landsat TM (30 m), Landsat ETM+ (15 m), Spot HRV MSS (20 m) and PAN (10 m)) and high resolution of satellite images (IRS 1C&1D (5.8 m), Spin (2 m), Ikonos (1 m), Quickbird PAN (0.67 m)) are used in urban damage assessment. The disadvantage of optical satellite images is that they can be affected easily by the seasonal or atmospheric conditions like snow, clouds, smoke. To compare images under different atmospheric conditions is difficult. While some of the satellites have steerable characteristic, which allows data acquisition almost every day, most of the orbital satellite sensors fail to fulfil the rapid response requirement for damage assessment application. This subject will be examined in the next part of the paper.

Night-time imagery is another data source, which can be used in post-earthquake damage assessment. The basic assumption of the use of night-time imagery is that to detect the reduction of the night-lights in urban areas due to the failure in electric power after earthquake is possible. Defence Meteorological Satellite Program's Operational Linescan System (DMSP/OLS) images from NOAA/NGDC have the capability to detect lights of the cities and it can monitor the same area twice a day. The main advantage of the use of night-time imagery is the high temporal resolution, which is the basic requirement (short revisit time) for damage assessment. On the other hand, the poor spatial resolution (2.7 km) is not enough to assess the damage in urban environment accurately. Moreover, the basic assumption behind the use of night-time imagery does not consider the fires, which can be triggered by earthquake and increase the light reflection. DSMP/OLS night-time imagery was used to detect early identification of the damaged areas in the 1999 Kocaeli, Turkey earthquake (EDM, 2000).

ii) In microwave systems, the wavelength is approximately in the range of 1 mm to 1 m. They give information about surface roughness and surface moisture. The typical spatial resolution of space-borne Sar image is 5 to 100 m (Yuan *et al.*, 1999). Microwave sensor systems can overcome the weather limitations of optical images, since they can penetrate haze, clouds and smoke. Being active sensor, they do not depend on the sunlight. Therefore they can work even at night. This characteristic of the radar data is highly effective in damage surveys when optical remote sensing is difficult due to existence of clouds, smoke (EDM, 2000; Yamazaki, 2001). Synthetic Aperture Radar (SAR) records the backscattering intensity of the earth surface. Basic assumption of use of radar imagery in post-earthquake damage assessment is that change in the roughness due to collapse of buildings can be resulted with change in the backscattering intensity. The backscattering intensity value of the collapsed structures in post-earthquake image may become lower than the value in pre-earthquake image because of the rough surface of the rubbles (EDM, 2000). Radarsat SAR images in the case of the 2001, Gujarat India earthquake (Yusuf *et al.*, 2003), ERS-2 SAR data in the case of the 1999 Chi-Chi Taiwan earthquake (Suga *et al.*, 2001) were used for identification of damaged areas. However, as it is mentioned in the previous part, difficulties in analysing radar data in urban areas create limitations for the applications.

On the other hand, coherence between images, which is required for differential interferometry, can be lost due to weather conditions (rainfall, snowfall, freezing). Seasonal change is also another limitation due to vegetation growth. Atmospheric heterogeneities, like small pocket of humidity, will lead to different propagation times of the waves (Yuan *et al.*, 1999).

2.3.3. Revisit time of the sensors and real time disaster monitoring

Revisit time of the sensors is one of the limitations for the quick response after disaster. Especially in the case of sudden disaster, frequency of observation is a critical factor (Walter, 1990). Long time gap between disaster and data acquisition can diminish the value of the acquired data. On the other hand, after data acquisition, the time for downlink data, processing it into information and dissemination of the final products to the response teams in the field are the other parameters for the time requirement (Ayanz *et al.*, 1997; Birk *et al.*, 1995).

Time requirement for each disaster type differs, as the impact of the disaster changes. For example, in the case of drought, it could be slow, although in the case of earthquake, it could be very rapid (Van Westen, 2002). Approximately 72 hour is the time limitation for life safety of people in the rubble after earthquake. In the case of fire, the value of the information is very high within 15 minutes after fire initiation and it become useless after one hour (Ayanz *et al.*, 1997).

Predictability of the events and their consequences is also another important criteria for real time disaster monitoring application. Drought, volcanic eruption, hurricane and floods are often moderate to highly predictable, although in the case of earthquakes, predictability is very low or zero (Alexander, 1991). This situation creates another limitation for the real time post-earthquake damage assessment.

Limitations on the temporal resolution of the remote sensing technology can restrict the operationalization of the real time disaster monitoring applications. On the other hand, currently meteorological satellites, such as DMSP, are used operationally in real time monitoring of weather related disasters (Alexander, 1991; Ayanz *et al.*, 1997). However, their spatial resolution is very low for assessing damage in urban areas. The solution of this problem is the pointable imagery, such as Spot, which can select scenes from broad field of view and increase the temporal resolution of the sensor (Walter, 1990).

Moreover, successive data acquisition at the revisit time of the satellite is also depending on the weather and atmospheric conditions at that time. Cloud coverage in the revisit time of the satellite reduces the temporal resolution of the sensors for useful data acquisition. According to Walter (1990), approximately half of the opportunities for observing the earth are lost because of cloud cover.

According to EDM report (2000), to acquire relevant DMSP/OLS images from NOAA/NGDC took one week, and to disseminate the final results required an additional two weeks after the disaster (EDM, 2000). On the other hand for effective emergency response, the whole process should be reduced to less than 72 hours. In Appendix 2, there will be an evaluation of the revisit time of current satellites.

On the other hand, satellite constellations dedicated to hazard assessment and disaster management can be the solution of the limitations of revisit time of each and every satellite. Major objective of the constellations is to reduce revisit time and provide rapid response after a disaster. Although there are some constellations, which are only theoretical concepts, 3-satellite constellation systems are being constructed: Disaster Management Constellation, COSMO/SkyMed and FUEGO (Kerle & Oppenheimer, 2002).

2.4. Data access through internet

Here there will be some Internet web pages where the archives of different sensor systems, and current information useful for disaster management can be searched.

- The US Federal Agency (http://www.fema.gov)
- The Office of Foreign Disaster Assistance of the United States Agency for International Development (http://www.info.usaid.gov/ofda)
- Relief Web (http://www.reliefweb.int/w/rwb.nsf)
- The Disaster Preparedness and Emergency Response Association (http://www.disasters.org/deralink.html)
- The European Space Agency (http://odisseu.esrin.esa.it/eoli/eolinojava.html)
- The Spot image online catalogue, Sirius (http://sirius.spotimage.fr)
- The Space Imaging online catalogue, Carterra (http://carterraonline.spaceimaging.com)
- The Indian Remote Sensing Satellite (http://www.nrsa.gov.in/engnrsa/imagesearch/imagesearch.html)

2.5. Data integration

Data integration is important issue as none of the remote sensing system can fulfil the all requirements. Due to limited spatial, spectral and temporal resolution, which is also restricted by cloud cover, of each sensor, there is a need for use of multiple sensor (Van Westen, 2002). Data integration can be described as merging of remote sensing data coverage with other remotely sensed data and spatial ancillary data types (Lunetta, 1999). Without using data coming from other sources, such as maps or measurement stations, the use of remote sensing data may not be effective (Van Westen, 2002).

Data integration can be an alternative to enhance not only data quality, but also quantity of data, which cannot be derived by using only one sensor. Integrated data is much more powerful than only one imagery. For the data integration process, there is a need for careful analysis of the optimum data set required various response situations (Rodarmel *et al.*, 2002).

In the case of September 11, 2001 attack on the world trade centre; a LIDAR[6] sensor, a high-resolution digital camera, and a thermal camera were used to assess damaged areas. Digital images were used to get information about rubble pile, while LIDAR data were used to calculate rubble volumes. In addition, thermal image provided helpful information for identification of hotspots (Rodarmel *et al.*, 2002).

2.6. Methodology

Methodology for assessing damage can be examined in two categories: Qualitative and quantitative.

2.6.1. Qualitative damage assessment

Qualitative damage assessment is the easiest way to assess damage. It can be done by visual interpretation of the image. For visual interpretation, either mono temporal or multi temporal images from the disaster area can be used. This method is costly, tiresome and time consuming. It is always subjected to errors (Murakami *et al.*, 1999). Another disadvantage of visual interpretation can be the requirement of high spatial resolution as visual interpretation using lower spatial resolution, such as Spot and Landsat images, could be difficult. Chiriou and Andre (2001) used visual interpretation for detecting damaged building in the case of the 2001 Bhuj, India earthquake as other computer based methodologies failed to detect damaged areas.

2.6.2. Quantitative damage assessment

Quantitative damage assessment can be done by computer processing of digital imagery. Dependent on the methodology applied for damage assessment, data requirement can differ in terms of temporal resolution (Mono or multi temporal). There are three different methodologies, which are applied to previous studies: Change detection, image classification and texture analysis. Comparison with visual interpretation, time requirement is shorter. In this part, each methodology will be evaluated, in terms of advantages, disadvantages and limitations.

a. Change detection

Singh (1989) defines change detection as the process of identifying differences in the state of an object or phenomenon by observing it at different points in time. The use of change detection techniques can be applied to a very broad arena, which includes environmental studies, urban studies and disaster studies. Basic idea is that change in land cover result in the change in radiance values. Moreover, this change should be higher than radiance changes, which are caused by temporal characteristics (like atmospheric conditions, sun angle) of two images (Ingram *et al.* 1981 in Singh, 1989). In change detection analysis, the main problematic point is to make a differentiation between radiance changes due to external factors and radiance change due to land cover change.

There are several digital algorithms which can be used in change detection analysis: image differencing, image rationing, image regression, principal components analysis, change vector analy-

[6] LIDAR is the American term of laser scanning and stands for Light Detection And Ranging

sis, multi-date classification, vegetation index differencing and post-classification comparison (Singh, 1989). However, there is no standard technique, which can be appropriate for all change detection analysis (Eastman 1995 in Olgun, 2000). Different methods of change detection produce different maps of cover change (Singh, 1989). Moreover, selection of the algorithms and spectral band for change detection depends on the environmental conditions and application objectives.

In post-earthquake damage assessment, there is quite a lot use of pixelwise change detection algorithms, which work on the pixelwise operation and makes the process simple (Singh, 1989). Pixel values of two images taken at different times are used to produce land cover change maps. Accuracy of this method is dependent on the selection of the threshold value, which identifies the limit of the change and no change values (Yuan *et al.*, 1999). Image differencing and image rationing are the mostly applied algorithms to post-earthquake damage assessment studies (EDM, 2000; Estrada *et al.*, 2000; Olgun, 2000; Turker & San, 2003; Yusuf *et al.*, 2003).

i) Image differencing is a very simple and straightforward algorithm (Olgun, 2000). In this technique, co-registered digital images are subtracted. The subtraction process is done pixel by pixel. The new image produced after subtraction shows the numerical differences between the pixels of each image (Yuan *et al.*, 1999). Riordian (1980 in Yuan *et al.*, 1999) criticized this method, in terms of the sensitiveness to image mis-registration, existence of mixed pixel, and radiometric differences between the input images.

ii) Image rationing the main assumption of this technique is that without significant spectral change the ratio between two images will be similar. Therefore, to get this ratio, two co-registered images are rationed band by band. Change can be observed with higher or lower ratio value. The main consideration is the selection of spectral bands, which have to have quite different spectral reflectance (EDM, 2000). Just like image differencing method, this technique is also sensitive to mis-registration and mixed pixels (Yuan *et al.*, 1999).

Yuan *et al.* (1999) tested different change detection methods using Landsat Multispectral Scanner (MSS) images. According to result of the study, image differencing gives better result compared with image rationing. Singh (1989) worked on finding out an optimal algorithm for forest change detection. He concluded that simple techniques, such as image differencing, performed better than much more sophisticated change detection algorithms. The most important conclusion is that different change detection techniques can produce different results even in the same environment.

Pixel based change detection algorithms have been used in several post-earthquake damage assessment studies. Olgun (2000) used three different change detection algorithms (image differencing, image rationing and NDVI) for damage assessment in the case of the 1999 Kocaeli earthquake, Turkey. For the same area, Turker and San (2003) applied image differencing. Yusuf *et al.* (2003) used image differencing and NDVI to detect damage in the case of the 2001 Gujarat earthquake, India.

b. Digital image classification

Conventional digital image classification concept is based on the different characteristics of different materials on the earth surface. Different reflectance values of objects allow automated classification of earth features. On the other hand using spectral reflectance in urban areas is usually poorer than the classification of non-urban features, in terms of the number of classes or the accuracy of the classification (Donnay *et al.*, 2001). Conventional multi-spectral classification can be improved by adding spatial information of the urban objects. Automated image classification is divided into supervised and unsupervised classification. The main supervised classification algorithms are the minimum distance, the parallelpiped and gaussian maximum likelihood classifier (Lillesand & Kiefer, 1994). Mitomi *et al.* (2003) used maximum likelihood classification for post-earthquake damage assessment.

c. Texture analysis

For urban areas, using spectral information is not enough to make land use/cover classification due to the lower variance of the reflectance values of the urban features. Therefore, to improve the classification, there is a need to use spatial characteristics of the features, such as size, shape, texture etc. Texture analysis can be overcome the limitations of the conventional spectral classification methodologies (Zhang, 1999).

Although there is no universal definition of texture, it can be defined as a function of the spatial variation in pixel intensities (Tuceryan & Jain, 1998). The parameters used for texture measures can be categorized mainly into first and second order grey level statistics, and Fourier power spectrum, and measures based on fractals. First order statistics of local areas are means, variance, standard deviation and entropy (Lillesand & Kiefer, 2000). The measurement of a texture pattern of a pixel is carried out by a moving window. The window size can change according to the size of the texture primitives in an image. Second order statistics are based on brightness value spatial dependency grey level co-occurrence matrices (GLCM). Based on GLCM, there are three more widely used parameters: Angular second moment, contrast and correlation (Lillesand & Kiefer, 2000). Textures features derived from an image can be used in classification, as texture is the most important cue in identifying homogenous areas. This is called texture classification (Tuceryan & Jain, 1998).

The studies on damage assessment using texture analysis (Hasegawa *et al.*, 1999; Mitomi *et al.*, 2000; Yamazaki, 2001) have shown that it is possible to determine building damages using digital frames derived from post-earthquake aerial video imagery.

2.7. Previous studies

In this part, previous post-earthquake damage assessment studies will be examined according to use of different data sources: Night-time imagery, optical imagery, radar imagery, aerial photography, airborne MSS imagery and aerial video imagery.

Nighttime imagery: EDM team (2000) used DMSP/OLS imagery for early identification of the damaged areas in the case of the 1999 Kocaeli earthquake, Turkey. Using the thermal infrared and stable light images, cloud influence was checked. Damage detection was derived from the differences of DNs of pre and post-earthquake images. Examining the histogram of difference map, threshold value for identification of damaged areas (reduction in night-time lights) was decided. The areas, having a reduction in lights, are determined as damaged. EDM team concluded that the study of post-earthquake damage assessment using night-time imagery is considerably accurate. However, low spatial resolution is the major constraint for post-earthquake urban damage assessment.

Optical imagery: Turker and San (2003) used two Spot images acquired on 17 July 1999 and 20 August 1999 to detect damage in the case of the 1999 Kocaeli earthquake, Turkey. After pre and post-earthquake images were corrected geometrically and radiometrically, multispectral and panchromatic bands were merged. Damage was detected by subtracting the near infrared band of the merged images. For the accuracy assessment, aerial photos, taken on 8 September, were used for ground truth data. The overall accuracy of the change map was found to be 83%. He concluded that post-earthquake damage location is successfully defined by using Spot merged image differencing.

Ozdogan (2002) used Landsat TM and IRS-D satellite imagery to assess the damaged areas in the case of the 1999 the Kocaeli earthquake, Turkey. Image differencing, rationing, PCA and texture characteristics of the images were used in the research. The results of the research show that PCA is less intuitive than the image arithmetic operations. In addition, an increase in the value of texture of damaged areas was observed.

In the case of the 2001 Gujarat, India earthquake, Yusuf *et al.* (2003) used Landsat-7 data to detect post-earthquake damage. Image differencing methodology was used in the research. Good correspondence of the result was declared.

Matsuoka *et al.* (1998) used Landsat and Spot imagery to detect the damage after the 1995 Hyogoken-Nanbu earthquake. Using image-differencing methodology, the damage information relatively agreed with actual damage survey was derived.

In the case of the 1997 Jabalpur earthquake, India, IRS Pan pre and post-earthquake imagery was used to assess damage (Saraf, 1998). Saraf (1998) used pseudo colour transformation methodology, which combines various bands in different colour schemes.

Rathje and Crawford (2003) used Quickbird imagery in the case of the 2003 northern Algeria earthquake. Three different methodologies were applied in the research: change detection, spectral classification and texture classification. Although in the first methodology, pre and post-earthquake imagery were used in the analysis, for other methodologies, only post-earthquake imagery was used. Limitations of the change detection methodology were emphasized in the results. Using texture information in the classification, a decrease in the omission and commission error was observed.

Although all researches show that optical imagery is useful for post-earthquake damage assessment, none of them can give information about the degree and type of the damage. Vertical characteristic of the optical satellite imagery creates limitation to assess the damage, since not all the damage type create change in the vertical view, such as soft story collapse, pancake etc.

Radar imagery: In Suga *et al.*'s (2001) study, ERS-2 SAR data were used to detect damage in the case of the 1999 Chi-Chi earthquake, Taiwan. Two SAR image taken pre-earthquake and one SAR image taken post-earthquake were used. Urban damage was detected by using coherence information obtained from InSAR technology. They conclude that a good interferometric condition was essential to detect urban damages caused by building collapse.

Huyck *et al.* (2003) used ERS-SAR imagery in the case of the 1999 Kocaeli earthquake, Turkey. SAR intensity, image correlation, coherence and cross-power information were used to detect post-earthquake damage. The research concluded that use of SAR imagery for damage assessment was more successful in areas with very large buildings due to of corner reflector.

Although radar imagery can overcome the weather conditions at some extend, use of radar imagery in urban areas is limited due to side looking characteristic of it.

Aerial MSS imagery: Mitomi *et al.* (2003) used post-earthquake airborne multi-spectral scanner images for damage assessment in the case of the 1995 Kobe earthquake. Selecting training areas using GIS data, based on field damage survey, maximum likelihood classification algorithm was applied to detect damaged and non-damaged buildings. He concluded that damage assessment was in relatively good agreement with the field survey data. However, the cost of the airborne multi spectral scanner imagery is so high that it is still limited in most of the applications.

Aerial photos: Turker and Cetinkaya (2002) used pre (1994) and post-earthquake (1999) aerial photographs at 5m spatial resolution to detect the damage in the case of the 1999 Kocaeli earthquake, Turkey. After derivation of DEMs from aerial photographs, a difference DEM was created. The difference DEM was analysed at the building level to detect the damaged buildings whose height difference exceed a specific threshold. The producer accuracy was found to be 84%. He concluded that collapsed buildings can be successfully derived by using aerial photographs. Nevertheless, height differences can only give information about totally collapsed buildings. There is also other type of damages, which does not necessarily produce height differences of the buildings.

San and Turker (2002) used panchromatic orthophoto in the case of the 1999 Kocaeli earthquake to detect the collapsed buildings through utilizing shadow of the buildings. Building without shadow was considered as damaged. Overall accuracy of the study was 96%. The main strength of this study compared with the previous one is that only post-earthquake orthophoto is used to detect damaged buildings.

Van Westen and Hofstee (2001) used aerial photos at scales ranging from 1:6.000 to 1:8.000 in the case of the 1999 Quindio earthquake, Colombia. Visual interpretation of the aerial photos was carried out. Damage is categorized into four classes: total collapse, roof collapse, roof partly damaged and no visible damage. A reasonable correlation was found in comparison of visual interpretation with field survey results.

***Aerial video imagery*:** Mitomi *et al.* (2000) used images of damaged areas, taken a few weeks after the 1999 Kocaeli earthquake, Turkey using a digital video camera from a helicopter and images taken four days after the Taiwan earthquake using a high-definition television (HDTV) camera from a helicopter. After damaged pixels were indicated on the basis of colour indices and edge elements, texture analysis was applied to detect damaged areas. Comparison of damage assessment results with visual inspection of the damaged buildings shows that collapsed buildings were identified properly. Main advantages of using video imagery are low cost, oblique viewing and rapid response capability. However, low quality of the imagery can create limitation for digital processing.

Further research on damage assessment from video imagery was carried out by Mitomi *et al.* (2001). They used maximum likelihood classification for detection of damaged areas in the case of the 1999 Kocaeli earthquake, Turkey, the 1999 Chi-Chi earthquake, Taiwan, and the 1995 Kobe earthquake, Japan. The result shows an improvement in the extraction ratios of training data especially in the case of Kobe and Japan. On the other hand, there is no investigation on other frames of the same video using the same training data. Therefore it is difficult to say that this training data will work on the whole video imagery. Otherwise there will be a need for collecting different training data for every scene, which is very difficult and time consuming, as there are 25 frames per second in a video imagery.

***Laser*:** Murakami *et al.* (1999) used airborne laser scanner to detect changes of buildings by acquiring a digital surface model (DSM) data of urban areas. Comparing DSM information, building height changes were detected without omission error.

To detect damaged buildings based on change in the height information, Steinle *et al.* (2001) used laser scanning data to extract and reconstruct man made objects. They also emphasized on detection of blocked roads as well as the search for the alternative passages for rescue vehicles.

The most important contribution of the laser data is that it can give information about volumnia change in built-up areas. This characteristic is important for the search and rescue teams as they need to know about the stability and probability of finding people locked in the damaged buildings (Steinle *et al.*, 2001). In addition, laser data can provide highly accurate information. However, to have a blind characteristic and giving only height information are the major disadvantages of laser. Data integration with other data sources, such as aerial photo, MSS imagery etc., can increase value of information.

2.8. Conclusion and discussion

In this chapter, post-earthquake damage assessment was examined, in terms of data requirements and methodology. Post-earthquake damage assessment is a challenging task, as there are significant limitations for data and methodology. These limitations can be summarized as:

- Working in urban areas – different morphology of the urban areas;
- Higher temporal resolution requirement for damage assessment;
- Different characteristics of sensors, in terms of spatial, spectral and temporal resolution;
- Cost of the high spatial resolution data;
- Restrictions of change detection methodology – requirement for pre-disaster image;
- Limited revisit time of satellites
- Lack of straight forward damage assessment methodology
- 3D characteristic of the building damage

In conclusion, there is a need for further research, which can overcome these limitations and create more practical and flexible solutions for post-earthquake damage assessment. Data integration can be promising solution, as using only one sensor will not give all information about the earthquake damages. Especially integration of space-born and airborne imagery may be important when the disaster is widespread. Satellite imagery can give information about the region, but its vertical viewing characteristic fails to detect all type of damages. Here airborne imagery can be complementary data source for complete damage assessment. Using oblique characteristic of the video imagery, it is possible to see the facades of the buildings. Façade view of the buildings can improve the damage assessment, as it make possible to make a differentiation in the damage type and damage level.

3. The 1999 Kocaeli earthquake and study area: Golcuk and its environs

3.1. Location and main characteristics of the region

The study area is situated in the Marmara region, which is in the north-western part of Turkey and straddles both Asia and Europe (see Figure 3.1). The Marmara region takes its name from the Marmara Sea. The study area includes Golcuk, Izmit and Korfez districts of Kocaeli province. The Gulf of Izmit is surrounded by hilly areas and most of the urban areas are situated near to the coastline.

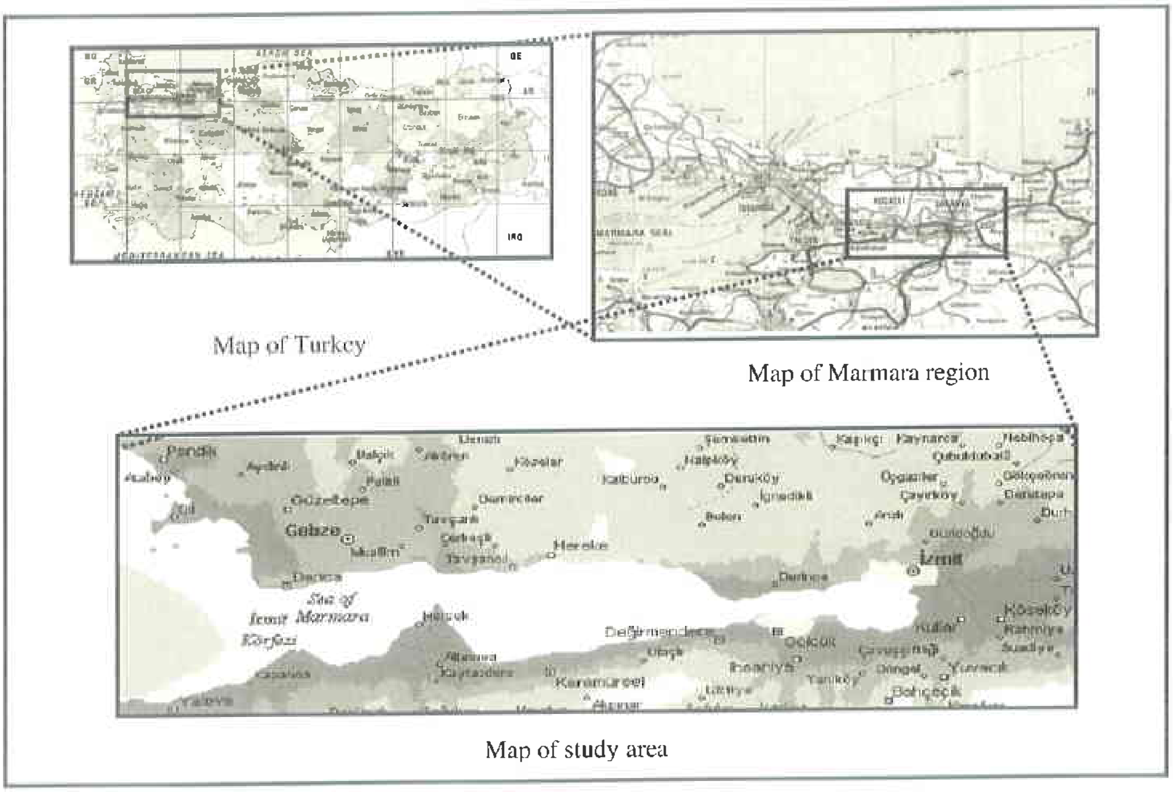


Figure 3.1. Location of the study area

The region is significant not only because of high population density, but also its dynamic economic characteristics (AIJ, 2000). After the 1970, this area became an attractive place for industrial development, as it is near to Istanbul and accessible by different means of transportation facilities, such as highway, railroad and ship. This industrialization period coincided with an increased urbanization rate. Because of the concentration of the industries, this region is also called "industrial heart of Turkey". The major industries are autos, petrochemicals, manufacturing and repair of motor (and railway) vehicles, basic metals, production and weaving of synthetic fibres and yarns, paint and lacquer production, and tourism. A number of international companies are also situated in this region (Bibbee *et al.*, 2000).

Place	Urban population	Percentage (%)	Rural population	Percentage (%)	Area (Km^2)	Density	Population increase rate
Izmit	195.699	52.46	177.335	47.53	974	383	19.26
Derince	93.997	96.62	3.286	3.37	223	436	33.64
Golcuk	55.790	51.84	51.825	39.92	199	541	-3.46
Korfez	81.938	77.81	19.155	39.48	314	335	23.00

Figure 3.2. Regional population distribution

(http://www.kocaeli.gov.tr visited on 10 November 2003)

The region is assigned to the first-degree earthquake zone on the seismic map of Turkey prepared by the Earthquake Research Department, General Directorate of Disaster Affairs (see Appendix 3). Izmit and its surroundings lie on the North Anatolian Fault. The following section of this chapter provides details about the geological characteristic of the region, the 1999 Marmara earthquake and its effects on the region.

3.2. Geologic characteristics of the area

Turkey is situated within the Mediterranean sector of the Alpine-Himalayan orogenic system, which is identified with high mountain ranges and one of the seismically active continental regions of the world with a long and well-documented history of earthquakes. The Anatolian block is a small continental plate sandwiched between the Arabian, African and the Eurasian Plates (see Figure 3.3; Olgun, 2000). Northward movement of the African plate causes lateral movement of the Anatolian block to the west and southwest (AIJ, 2000).

There are two major strike-slip fault zones on the Anatolian Block: the North Anatolian Fault (NAF) and the East Anatolian Fault (EAF), which were created by the collision of the African and European Plates. The North Anatolian Fault, which is one of the world's longest and best recorded faults, extends approximately 1.200 km from Karliova triple junction to the Aegean Sea (Bibbee *et al.*, 2000). It is a right lateral, intra-continental strike-slip fault, which accommodates the westward motion, and counter clockwise rotation (AIJ, 2000). The total displacement along the fault is about 40 km in the east and 20-30 km in the west (Olgun, 2000). The last sequence of earthquakes along the NAF started with the 1939 Erzincan earthquake, and was followed by earthquakes in 1942, 1943, 1944, 1951, 1957, 1967, and finally by the 1999 earthquake (see Figure 3.4). Westward migration of previous earthquakes prepared potential danger for the 1999 earthquake (Erdik, 2003).

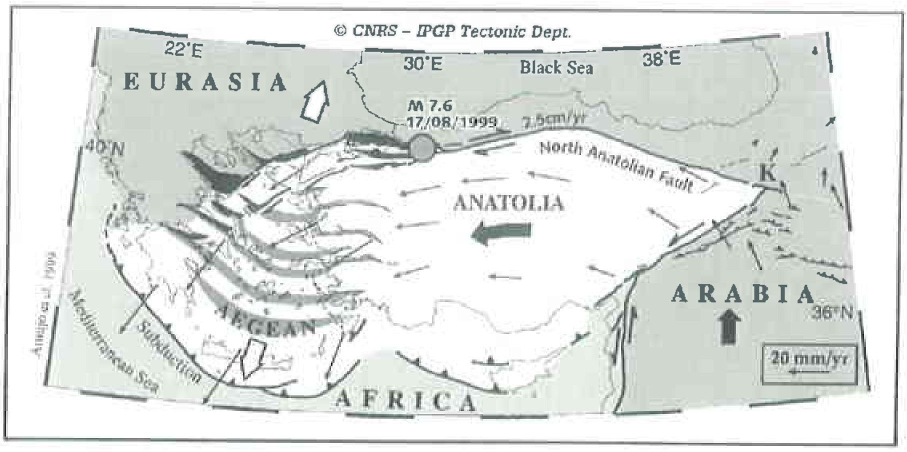


Figure 3.3. Simplified tectonic map of Eastern Mediterranean

(http://www.ipgp.jussieu.fr visited on 10 November 2003)

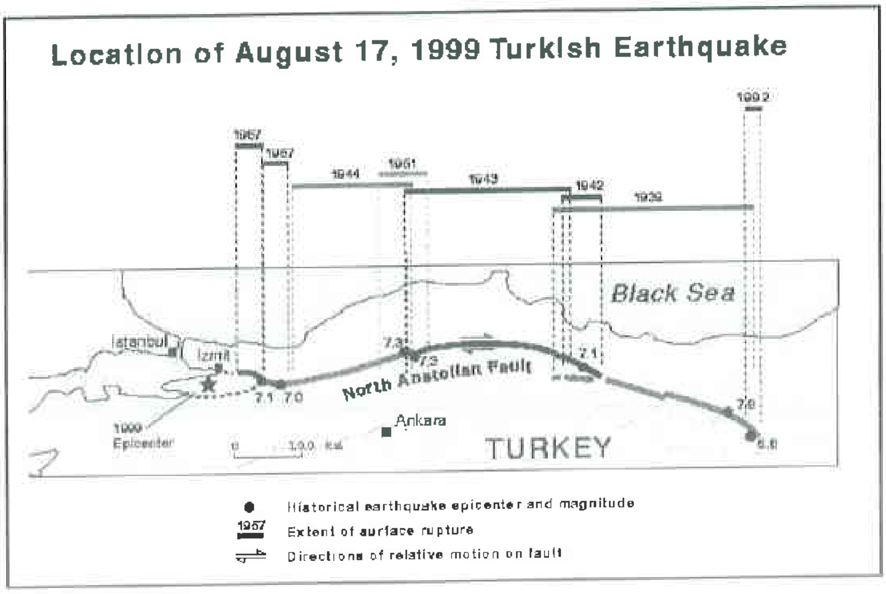


Figure 3.4. North Anatolian Fault Zone

(http://geohazards.cr.usgs.gov/html_files/turkey/turkey.html visited on 14 November 2003)

3.3. The 1999 Kocaeli earthquake

A large earthquake with the moment magnitude 7.4 (Mw; Ms: 7.8) occurred in the Marmara region at 3.02 a.m. local time (00.02 GMT) on Tuesday 17 August 1999. It was the largest earthquake in the region during this century (Olgun, 2000). The epicentre of the earthquake was situated between Izmit and Golcuk, defined as 40.70 N, 29.91 E by the Earthquake Research Department (ERD) of the General Directorate of Disaster Affairs; 40.76 N, 29.97 E by the Kandilli Observatory and Research Institute (KOERI); and 40.70N, 29.98E by the United State Geological Survey, (USGS; AIJ, 2000). Other earthquake parameters are summarized in Figure 3.5.

Research group	Magnitude (Mw)	Depth (km)	Epicentre		Time (GMT)
			Lat.	Lon.	
ERD	7.4	15.9	40.70	29.91	00.01.39.07
KOERI	7.4	18.0	40.76	29.97	00.01.37.60
USGS	7.4	17.0	40.70	29.99	00.01.39.80

Figure 3.5. Earthquake parameters according to ERD, KOERI, and USGS

(AIJ, 2000)

The duration of the main shock was 30 seconds. The number of the after shocks was approximately 300, with magnitudes ranging from 4.0 to 6.0 (Olgun, 2000). The released seismic energy was 8.4+1.2*10**18Nm (USGS). The ruptured fault starts from Golyaka in the Duzce basin, passes through Akyazi, Arifiye, Sapanca, Basiskele, Golcuk, Hersek Delta, and terminates nearby Yalova. The observed fault length was 120 km and the width was 15 km. The average displacement was measured to be 2.5 m (Erdik, 2003). The facts of 5 meters of horizontal fault slip and 2 metres of vertical slips underline the severity of the earthquake (Bibbee *et al.*, 2000). Large sea waves with 2.5 m height were observed in the Izmit Bay along the shores of the middle basin of the Gulf of Izmit between Hereke and Degirmendere (Erdik, 2003). There were two major geotechnical effects of the earthquake. The first one was large-scale ground subsidence, occurred along the southwestern shore of the Izmit

Gulf. The second major failure was liquefaction[7], which resulted in buildings sinking or tilting in Adapazari (Erdik, 2003).

The earthquake affected mainly four provinces: Kocaeli, Sakarya, Bolu and Yalova. These four provinces contribute over 7 percent of the country's GDP and 14 percent of industrial value added. Though containing only 4 percent of the nation's population, the region contributes over 16 per cent of budget revenues (see Appendix 4; Bibbee *et al.*, 2000). The earthquake also affected the neighbouring cities. The damage was reported in Istanbul, Bursa and Eskisehir (Olgun, 2000). After the earthquake, due to the large extend of affected area, there was a huge need of effort for removal of tons of debris, constructing shelters, supplying food and water, and surveying damage buildings. Besides the widespread physical damage, disruptions on economic and social activities increased the loss account. The total damage cost, including direct and indirect cost, was estimated at US$ 5-9 billions by the World Bank. The building cost was reported around US$ 1 billion. The damage cost to the enterprises was US$ 1.1-2.6 billions. Damage to infrastructure was estimated to be US$ 0.9 billions (see Appendix 5; Bibbee *et al.*, 2000).

3.3.1. Social damage

According to the Government Crisis Center, around 15.000 people are estimated to have died, and around 24.000 were injured (see Figure 3.6). Up to 600.000 people were forced to leave their homes. Moreover, many of the survivors, especially children, were left deeply traumatised. In the critical first hours, rescue efforts were provided by survivors (Bibbee *et al.*, 2000). In some areas, rescue operation could only start on the second day, due to damage to transportation system

Province	Dead	Injured
Bursa	263	348
Eskisehir	86	83
Istanbul	976	3.547
Bolu	264	1.163
Izmit	8.648	9.211
Sakarya	2.627	5.084
Tekirdag	-	35
Yalova	2.501	4.472
Zonguldak	3	26
Total	15.370	23.954

Figure 3.6.Casualties

(Government Crisis Center, last update 09 September 1999)

3.3.2. Structural damage

The Kocaeli earthquake caused considerable damage to the residential and commercial buildings, and to public facilities. The major structural damage was in the towns situated along the southern shoreline of the Marmara Sea and in Adapazari. Around 41.000 building were heavily damaged or totally collapsed during the earthquake. The number buildings suffered from pancake collapse was estimated to be in the range of 3.000-3.500 (Erdik, 2003).

Provinces	Heavy to collapse	Medium	Slight
Istanbul	3.614	12.370	10.630
Sakarya	11.373	5.815	8.763
Izmit	3.614	12.944	13.335
Bursa	32	109	431
Yalova	9.637	8,988	12.677
Bolu	2.664	3.360	1.968
Eskisehir	70	32	204
Total	41.266	43.618	48.008

Figure 3.7. Damage assessment

(Government Crisis Center, last update 09 September1999)

[7] Liquefaction is a process by which water saturated sediment temporarily looses its strength and acts as a fluid. Earthquake shaking can cause liquefaction (USGS, 2003).

3.3.2.1. Types of damages

The main reasons for the damage were buildings situated on liquefiable soils and close to fault lines, construction engineering problems, poor construction materials (Bibbee *et al.*, 2000) and low quality control in the building construction site (Yoshimura *et al.*, 2003).

Reinforced concrete frames with unreinforced masonry infills are the predominant structural system used for the buildings in urbanized area in Turkey. The typical reinforced concrete frame building has a regular, symmetric floor plan, with square or rectangular columns (Bruneau, 2002; Erdik, 2003). The main types of damage to reinforced concrete building structures:

1. *Foundation failure* was resulted with the severe settlement of the buildings or overturned structures mostly seen in Adapazari. Soil liquefaction or bearing pressure failures were the ain reason for the foundation failure (Bruneau, 2002).

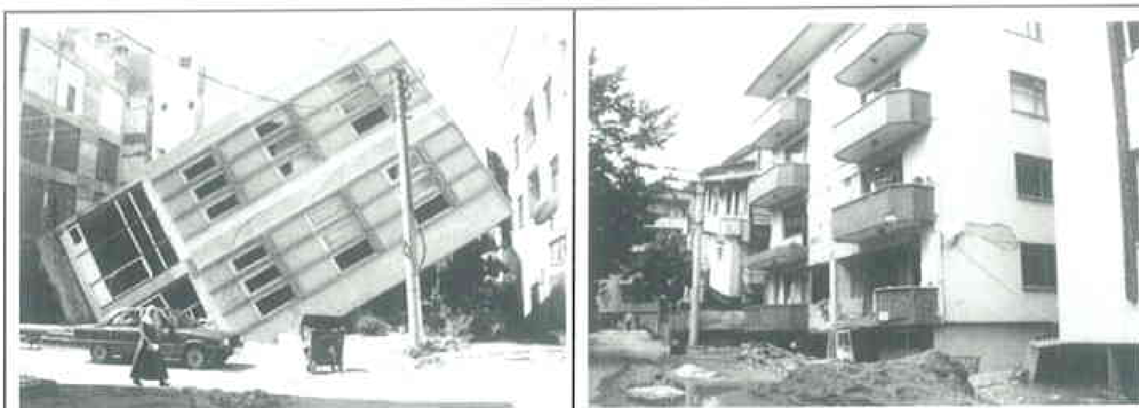


Figure 3.8. Damage due to foundation failure
(AIJ, 2000)

2. *Existence of soft story*, which is a floor that is structurally significantly more flexible and weaker than the others, increases the demand for deformation and puts the entire burden of energy on the soft stories. Commercial use of the first or lower floors, which were entirely or partially, enclosed by glass was major reason for soft story collapses (Bibbee *et al.*, 2000; Bruneau, 2002).

Figure 3.9. Damage due to soft first storey
(http://mceer.buffalo.edu visited on 14 November 2003)

a. Damage to buildings with soft first story (Yoshimura *et al.*, 2003). It was the most common collapse.
b. Damage to buildings with soft lower stories (Yoshimura, *et al.*, 2003).
c. Damage to buildings with soft intermediate stories (Yoshimura *et al.*, 2003).

Figure 3.10. Total collapse of intermediate storey
(Yoshimura, *et al.*, 2003)

3. *Strong beams and weak columns* resulted in failure in the form of compression crushing, plastic hinging, or shear failure (Bruneau, 2002).

Figure 3.11. Strong beams weak columns
(Bruneau, 2002)

4. *Lack of column confinement and poor detailing practice* resulted in damage on the column ends (Bruneau, 2002)

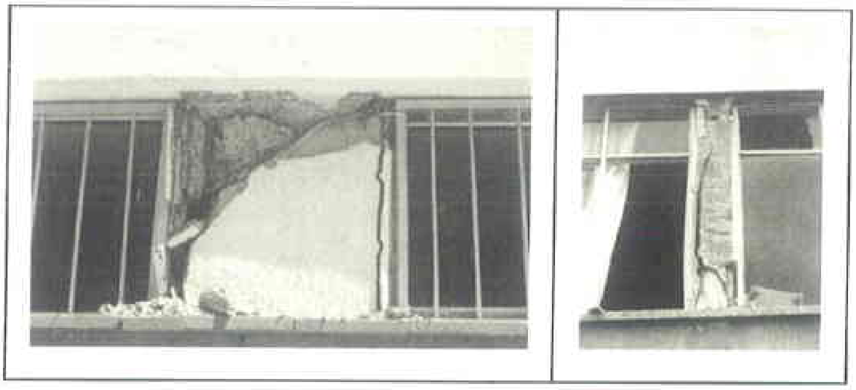


Figure 3.12. Shear failure in short captive columns 'trapped' between partial height infill, and flexural failure in non-ductile reinforced concrete plastic hinges
(Bruneau, 2002)

5. _Totally collapsed buildings_ (Pancake collapse) occurred where reinforced concrete columns reached their flexural moment capacities and resulted with the upper floor or floors, ceiling or roof to pancake down into the lower floors. It was the most serious damage as there was less opportunity for people to escape. In some cases of pancake damage, there was almost no clearance between adjacent floor slabs (Yoshimura *et al.*, 2003).

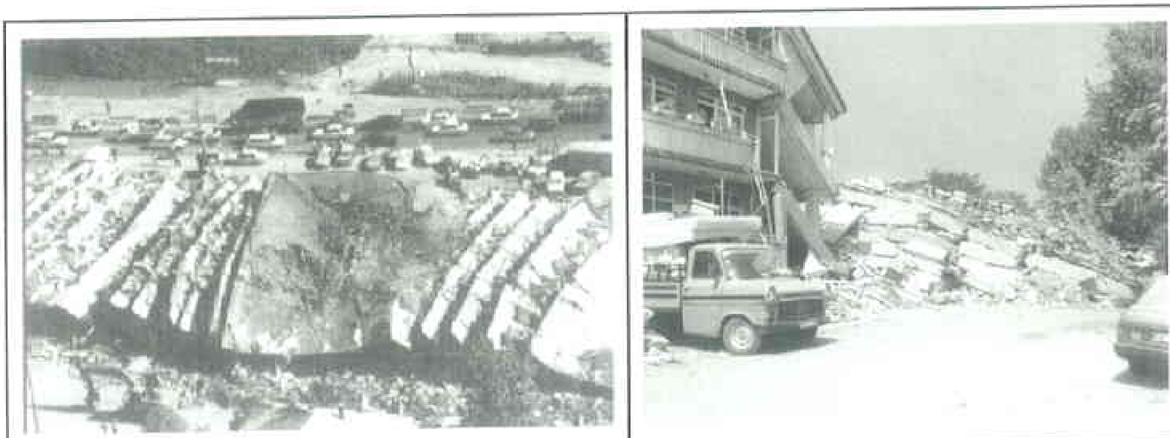


Figure 3.13. Pancake crash of multi-story building

(Erdik, 2003; http://www.eqe.com visited on 18 February 2004)

3.3.3. Damage to lifelines

Communications over public phone lines stopped immediately after the earthquake, and cellular phones also were also out of order due to the damage on the main fibre optic cable and batteries in the central telecommunication facilities (Erdik, 2003). The Telecom Company repaired and restored the communication facilities after two days with some limitations (ERD, 1999).

Regarding electricity, 3.400 distribution towers and 490 km of overhead lines were estimated to be damaged or destroyed. The damage on the two main substations on the electric power grid caused widespread power blackout across Turkey (Bibbee *et al.*, 2000).

In Arifiye, collapse of a bridge over the Trans European Motorway (TEM) due to the fault movement, caused interruption in the transportation system (AIJ, 2000). Main railroad tracks between Ankara and Istanbul were distorted to an 'S' shape by the fault offset (Erdik, 2003). Because of the damage on the transportation system, it was impossible to reach the region before the afternoon (ERD, 1999). Besides the actual damage caused by the earthquake, transportation and communication systems were overwhelmed by the outsiders trying to phone or to drive to the region (Bibbee *et al.*, 2000).

Figure 3.14. Collapse of Arifiye overpass on TEM highway

(Erdik, 2003)

3.3.4. Damage to industrial facilities

Tupras is one of the largest refineries of Turkey, processing about one third of Turkey's oil. It is the 7 the largest refinery in Europe (AIJ, 2000) with a production capacity of 12 million tons per year. Tupras is situated 5 km away from the fault line. Besides significant structural damage to the refinery itself due to earthquake, the consequent fire in the refinery caused extensive additional damage. Six tanks out of 120 tanks in the farm tank were damaged due to ground shaking and fire. The fire continued for three days and created danger for whole region. The economic loss was estimated to be US$350 million (Erdik, 2003).

Figure 3.15. Fire in Tupras petrochemical complex
(Erdik, 2003)

3.4. Study settlement Golcuk

Golcuk is 4th largest district of the Kocaeli province. The urban population of Golcuk city in 2000 was about 56.000 people. The distance to Izmit, the capital of the Kocaeli province, is 16 km. It is surrounded by Yalova in the west, the Samanli Mountains in the south, Izmit in the north east, and Izmit Bay in the North. The total area of the settlement is about 199 km^2. The most populated area of the settlement is the coastal zone, which is about 3.5 km in the east west direction, and 700 m in the north-south direction (AIJ, 2000).

After establishment of the dockyard (1950), the population of Golcuk started to increase. During 1970, the rate of increase raise up because of the industrial developments in the region. The population density is the highest compared with the other districts of Kocaeli (AIJ, 2000).

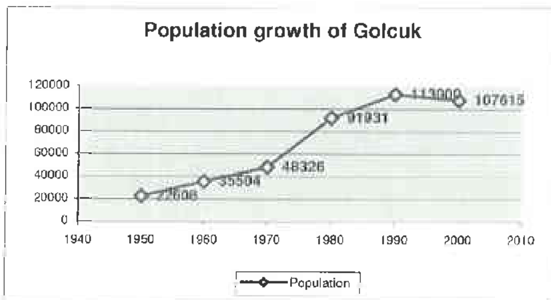


Figure 3.16. Population growth of Golcuk
(AIJ, 2000)

The major industrial facility is the dockyard, which is managed by the Navy. Small-scale agricultural activities take place because of the lack of suitable land for agriculture.

The epicentre of the earthquake was estimated to be 10 km east of Golcuk (Erdik, 2003). The western edge of surface fault was found in Golcuk. The fault line crossed the city of Golcuk from the southeast to the north-west direction. The vertical offset was about 1.0 and 1.5 m and the right lateral surface offset was about 2 m (AIJ, 2000).

Subsidence and submerge were the major geotechnical affects of the earthquake in the city of Golcuk. Flat coastal land in the northeast of the town subsided approximately 2 m. An area of approximately 1 km by 1 km submerged into the sea. The swimming pool, amusement and sport facilities, which were situated in this area, were submerged accompanied with the ground subsidence (AIJ, 2000). The buildings located along the coastline also severely affected from the earthquake (see Figure 3.17 and Figure 3.18).

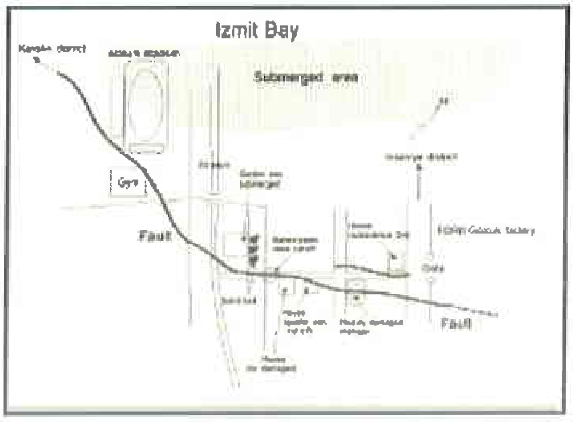


Figure 3.17. Fault line and submerged area in Golcuk
(AIJ, 2000)

Figure 3.18. Submerged area in Golcuk
(Show TV, 1999)

The naval base and port situated in the west part of the city severely damaged by the fault rupture. According to the Golcuk municipality, 90 per cent of the roads were damaged. While water system in the south part of the city was damaged partially, in the northern part of the city, it was totally damaged.

2.350 building were collapsed or heavily damaged. The number of collapsed housing unit was to be estimated around 12.500. 1.816 buildings were moderately, and 2.772 building slightly damaged (Kocaeli Provice, 2003). According to the Golcuk municipality, the number of the building in pre-earthquake situation was 6.000. This figure shows that more than 30 percent of the total buildings were collapsed or heavily damaged. The number of total building damages of the Kocaeli province is presented in Appendix 6.

Figure 3.19. A general view of building damage in Golcuk
(Erdik, 2003)

According to the Kocaeli provincial authority, the total death toll in Golcuk is estimated to be 5,384, and the number of injured people is 5,252 (http://www.kocaeli.gov.tr last updated 23 May 2000). These numbers show the significance and severity of human loss caused by the earthquake (35% of total death toll; 56% of death toll of the Kocaeli province and 21% of total injured people; 53 % of injured people of the Kocaeli province). The number of total death toll and injured people in the Kocaeli province is shown in Appendix 7.

3.5. Conclusion

In conclusion, being on the seismological active area, earthquakes are always a danger to human life and structures in Turkey. The 1999 Kocaeli earthquake, which killed thousands of people and caused extensive damage to buildings and infrastructure, was one of the major earthquakes in Turkey in recent history. Statistical figures of damage and death toll show that city of Golcuk was highly affected from the Kocaeli earthquake.

4. Data description and methodology

4.1. Introduction

This chapter describes the data used and methodology applied to data analysis in this research. Data used in the research can be categorized in three main parts: Remote sensing data, ancillary data and user information requirement of the emergency agencies in Turkey. The methodology will be examined into four parts: data preparation, analysis of user information requirements, analysis of Spot imagery and analysis of video imagery.

4.2. Data

4.2.1. Remote sensing data

- ***Satellite imagery:*** Images taken by Spot 4 HRVIR (High-Resolution Visible and Infrared) were used in the research. The spectral and spatial characteristics of the Spot 4 are shown in the Figure 4.1. Spot 4 HRVIR has 1 panchromatic, 3 multi-spectral and 1 short wave infrared band. One Spot scene is about 60 km long and can range from 60 to 80 km in width, depending on the viewing angle of the satellite. It has a sun-synchronous orbit with equator crossing time at 10.30 a.m. Revisit time of the satellite is 26 days. However, the oblique viewing characteristic of Spot (+/- 27 degree relative to the vertical) can decrease the revisit time to 1-4 days (average 2.4 days; http://www.spotimage.fr, visited on 11 November 2003). General technical characteristics of Spot 4 HRVIR are provided in Appendix 8.

In the research, 4 Spot scenes, acquired on 15 July and 20 August 1999 (pre and post-earthquake, respectively), were used for the analysis. Each date has panchromatic and multispectral scenes. Although the post-earthquake imagery was taken just 3 days after earthquake, the pre-earthquake image was acquired about 1 month before earthquake. Characteristic of the image used is shown in Figure 4.2.

Band	Wavelength	Resolution
Panch.	0.61-0.68 µm	10 m
Band 1	0.50 –0.59 µm	20 m
Band 2	061-0,68 µm	20 m
Band 3	0,79-0,89 µm	20 m
Band 4	1.58-1.75 µm	20 m

Figure 4.1. Spectral and spatial characteristics of Spot 4 HRVIR
(http://www.spotimage.fr, visited on 11 November 2003)

Date dd.mm.yyyy	Time hh.mmm.ss	Central Longitude	Central Latitude	Platform	Spectral mode	HVR/HRG Instrument number	Path track	Row	Incidence angle
15.7.1999	08.41.58	29.54°E	40.46°N	SPOT 4	10m Panchromatic	1	102	268	-26.9
15.7.1999	08.41.58	29.54°E	40.46°N	SPOT 4	20 m Multi spectral	1	102	268	-26.9
20.8.1999	08.49.28	29.53°E	40.46°N	SPOT 4	10 m Panchromatic	2	102	268	-15.4
20.8.1999	08.49.28	29.53°E	40.46°N	SPOT 4	20 m Multi spectral	2	102	268	-15.4

Figure 4.2. Image characteristics

(http://sirius.spotimage.fr, visited on 11 November 2003)

- ***Aerial video imagery:*** Video imagery, taken from a helicopter, was provided by a media channel, Show TV. Video imagery was collected on the same day of earthquake (17 August 1999). A Betacam camera was used for image acquisition. Resolution of the image is 720x576 lines. Total footage was around five minutes. As it is typical television footage (not planned for scientific applications), the movement of the helicopter and zoom in and out actions of the camera itself affects the quality of the imagery.

4.2.2. Auxiliary data

- ***Damage information:*** Two kinds of damage information were used to assess the result of the damage assessment research. The first one was provided by the Provincial Directorate of Disaster Affairs. The last update of the damage information was 25 August 1999. Damage information was aggregated at village, municipality, and district level. Damage information was categorized in three-damage stages: collapsed or highly damaged, moderately damaged, and slightly damaged commercial and residential units. This information was used to verify the result of the damage assessment analysis at the regional level.

The second source of damage information was a report prepared by the Architecture Institute of Japan (AIJ). The field survey was carried out Golcuk and Degirmendere on 5-13 September 1999 (18 days after the earthquake). The damage level of each building was assessed according to the European Macroseismic Scale, (1998 version; see Appendix 9), which categorizes the damage in five stage. The damage information was aggregated into 38 zones for the Golcuk survey (see Figure 4.3). In these zones, 2.746 buildings were investigated.

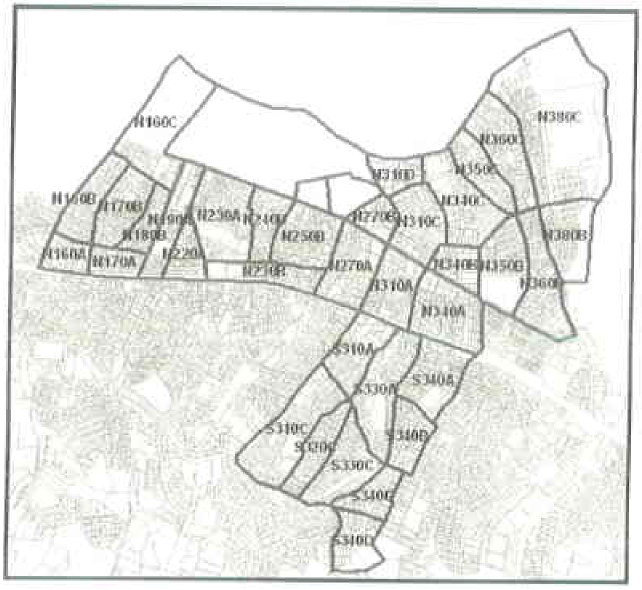


Figure 4.3. Investigation zones for damage survey carried out by AIJ

(AIJ, 2000)

- ***Reference map:*** Six topographic paper sheets at the scale of 1/25.000 were used in the geo-referencing process. The maps were produced by the General Directorate of Mapping in 1976.

- ***Digital data sets:*** Regional settlement, road network, building footprints, cadastral boundary, and a digital topographic map of Golcuk were used as additional auxiliary data. Regional settlement and road network maps were provided by the Marmara Research Institute. The dataset was dated 1 November 1999. It was prepared by digitising on IRS imagery during the site selection project for new settlement areas. The digital topographic map of Golcuk was prepared by the General Directorate of Bank of Provinces and approved on 9 March 2000. These digital topographic maps were provided by Golcuk Municipality in the DXF format. It is used to create building footprint and parcel boundary maps.

4.3. Methodology

To achieve the main objectives, as detailed in chapter 1, the research methodology was carried out using four major steps: data preparation, assessment of user information requirement, analysis of Spot imagery, analysis of video imagery and evaluation.

4.3.1. Data preparation

Data preparation included geo-referencing scanned topographic maps and preparation of damage maps at regional and local levels. Statistics of the damage information at regional level were entered into the database. For local level damage information, after digitising the boundaries of zones, damage information was connected to the polygon map. Cadastral boundaries, which were available 36 digital map sheets in DXF format at 1/1.000 scale, were converted to the vector map. After format conversion, a polygon map of parcels was created. The general process is shown in Figure 4.4.

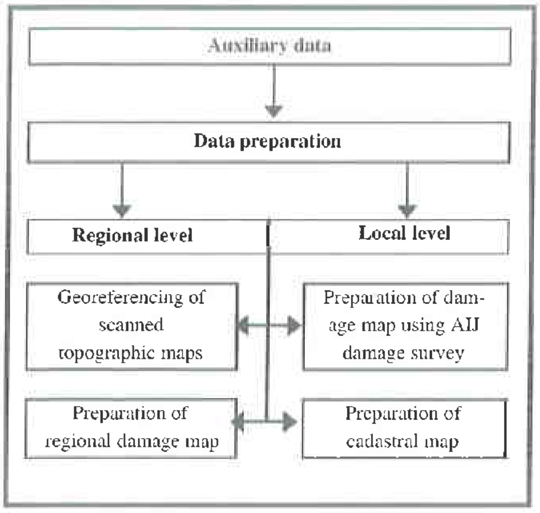


Figure 4.4. Data preparation process

4.3.2. Assessment of user information requirements

An assessment of user information requirements was carried out by interviewing with key informants of different stakeholders participating in the emergency response activities in Turkey. The main steps for assessment include selection of end user, preparation of questionnaires, interviewing the key informants and defining the information requirements of end users.

Stakeholders were classified into three categories: government, non-government, and other. Government agencies were stratified in three levels: national, regional and local. The structure of the selected interviewee is provided in Appendix 10.

Interviews were carried out with key representatives of different stakeholders. An open-ended and semi-structured interview type was selected to give flexibility to the interviewee. The questionnaire was divided into 3 main sections: Institutional background, data requirement and previous experiences. In the first part, the main workload and technical capacity of the institution were investigated to determine the potential use of remote sensing technology. In the second part, data requirements were defined according to data type, format, time, scale, and accuracy. In the last part of questionnaire, to define the actual problems of practical life, previous experiences with earthquake emergency situation were investigated. A sample of the interview question sheet is provided in Appendix II.

4.3.3. Analysis of Spot imagery

In analysing the Spot imagery, change detection methodology was used to assess the damaged areas. The main idea behind the change detection is that any change in the objects on the earth surface will result in change of the pixel value. The main steps in digital change detection are geometric correction, radiometric correction and selection of change detection algorithm.

After geometric registration of the scanned topographic maps to the map projection system used in Turkey, the pre-disaster panchromatic image was registered to the map. By using pre-disaster panchromatic image as a reference, the pre-disaster multispectral, post-disaster panchromatic and multispectral images were geometrically corrected. As pixel by pixel comparison of reflectance values is carried out by digital change detection algorithm, the root mean square error (RMSE) should be less than 0.5 pixels to avoid spurious change detection results (Jensen, 1996).

Nearest neighbourhood resampling method was used to align the original pixel grid to the new grid. This method was selected, as it does not change the original pixel values of image. The pixel values without averaging them (as the other methods do) is assigned to the pixel that is closest to the retransformed coordinates (x, y) (Erdas, 2002).

The use of temporal datasets requires normalization of the pixel values to make them comparable. This process requires the elimination of external effects on the reflectance values of the pixels. On the other hand, use of historical data set causes difficulties in locating atmospheric attenuation information, such as sun angle, atmospheric and soil moisture conditions. In such cases, relative radiometric correction is a way to correct radiometric differences of the historical images. In relative radiometric correction, pseudovariant ground targets (meaning they do not change spectrally from image to image) are used to normalize multitemporal data sets to a single reference scene (Jensen, 1996).

After relative radiometric correction, to eliminate the change in reflectance value of vegetation and water bodies, vegetated areas and water surfaces were excluded from the images.

Band substitution was applied to merge panchromatic and multi spectral bands of Spot image. The advantage of band substitution method is that it does not change the radiometric qualities of any of the data (Jensen, 1996). As the spectral region of Spot panchromatic band is the same with Spot Band 2, it was substituted directly for Band 2 (red). Figure 6.7 is a display of the merged dataset with SPOT XS3 (near infrared), SPOT PAN and SPOT XS1 (green) in the colour composite plane.

After merging the images, IHS transformation was applied to obtain intensity values of each date. Intensity images for pre and post-earthquake were used for the change detection analysis. An image-differencing algorithm was selected for change detection analysis. Although it is the simple technique for change detection analysis, it performs better than sophisticated change detection algorithms (Sign, 1989).

Standard deviation of the pixel values of the difference image was used to define threshold value for the change and unchanged areas. After deriving the changed areas, aggregation was carried out at the parcel level. At the end of the analysis, the result of the change detection analysis was compared with the ground survey result at the regional and local levels. The overall process diagram of analysing Spot imagery for assessing damaged areas using change detection methodology is presented in Figure 4.5.

4.3.4. Analysis of video imagery

The analysis of video imagery was carried out in two steps: visual interpretation and digital image processing. By visual interpretation, damaged parcels were defined and mapped. For digital image processing of video imagery, multi level threshold classification, based on colour, edge and texture features, was carried out. The main steps in digital analysis of video imagery were pre-processing, damage detection based on feature layers and comparison of results with actual damage information.

The pre-processing phase includes frame grabbing, image stacking and image enhancement. Frame grabbing is a process of converting analogue video imagery to digital ones. Representative areas for different type of damage and settlement characteristic were selected for frame grabbing process. For digital processing there is a need for enhancement of digital frames as the quality of the video images is poor. The enhancement process was carried out by Astrostack software, which uses the sequence of scenes for stacking process. The main purpose of the image stacking process is to improve the image quality of a scene. Image sharpening was applied to enhance the image.

For damage detection, colour indices and edge elements were used. Local variance, which is one of the texture parameters, was applied to the colour indices and edge layers. Contrary to conventional image classification algorithms, which are based on the use of spectral information, texture analysis uses the variations of grey levels in predefined local area. Therefore, each new pixel of the texture image has a brightness value representing the texture at that location (Jensen, 1996).

Training data to determine the threshold values for damaged areas were selected. The threshold values were used for multi level thresholding of feature layers.

At the end of the analysis, the result was compared with the actual damage information observed from video imagery for accuracy assessment. The whole process flow for video imagery analysis is provided in Figure 4.6.

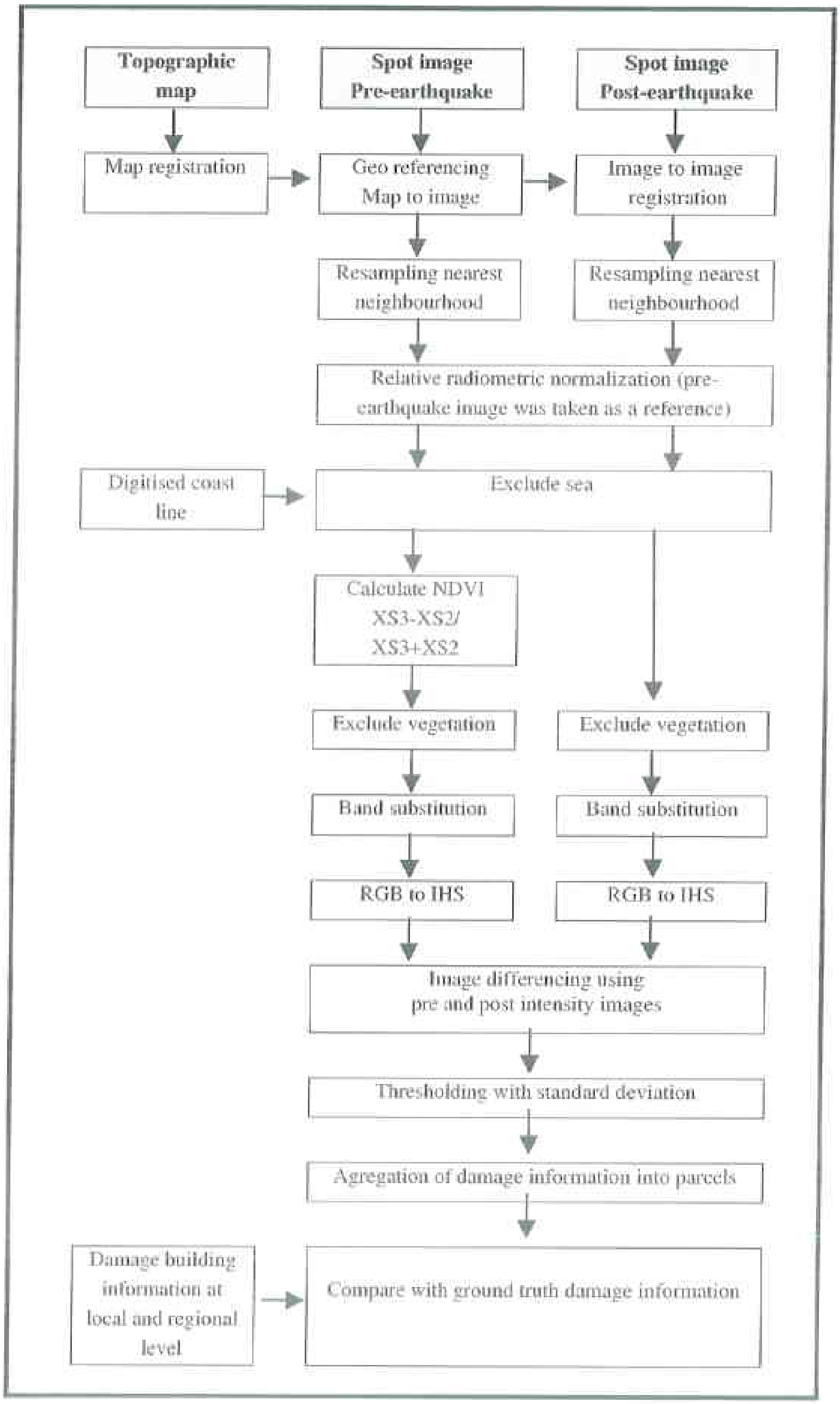


Figure 4.5. Damage assessment using Spot imagery

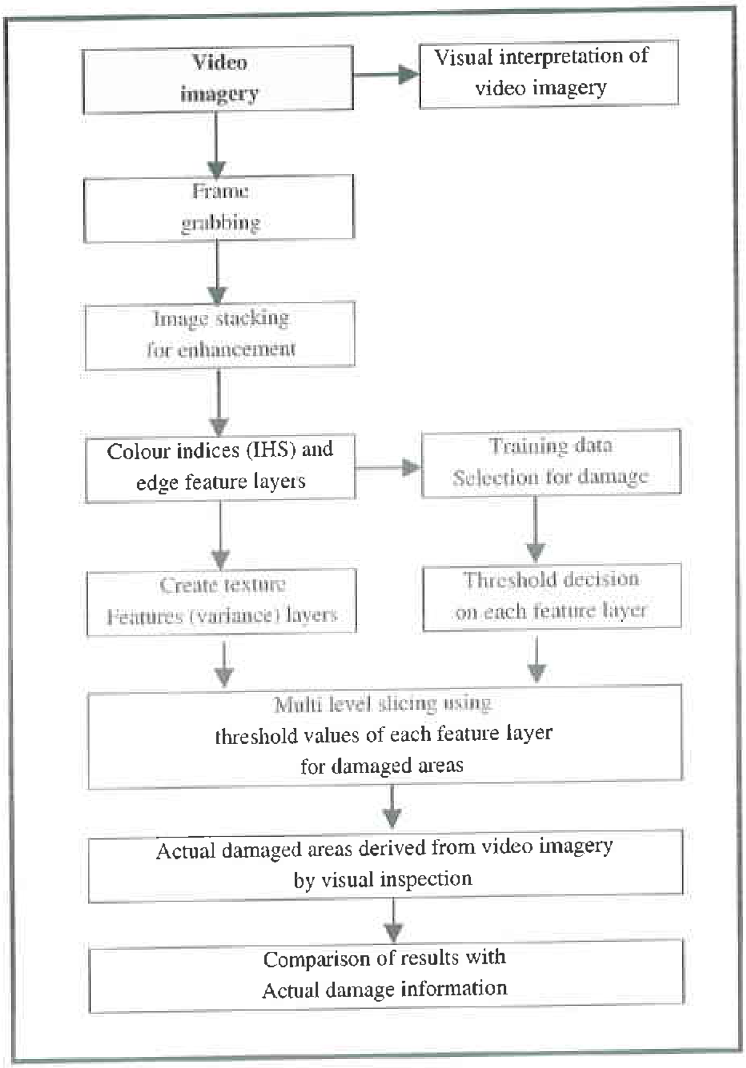


Figure 4.6. Damage assessment using video imagery

5. User information requirements in the case of Turkey

5.1. Introduction

Although remote sensing is an important information source that can assist emergency managers to take appropriate decisions for response activities, in the practical life, the use of remote sensing technology in emergency management is not widespread. There are mainly two reasons, which create a gap between user and technology. The first one is the continued limited awareness of emergency managers about remote sensing technology and its potential for disaster management. The second one is the lack of full understanding of technologists about the emergency activities (Bruzewicz & McKim, 1995).

The main objective of this chapter is to get an overall idea about the information requirements of emergency agencies in the case of Turkey. To fill the gap between emergency management and remote sensing technology, there is a need for understanding information required. Information is useful when it is understandable and manageable by the user. Ayanz *et al.* (1997) emphasizes the importance of provision of user-oriented information, which is handled by managers of a disaster situation. He states that "*technology must fit to the user not to the provider*".

On the other hand, providing user-oriented information is not enough by itself, if the right information is not disseminated to the appropriate user easily and in a timely manner (Ayanz *et al.*, 1997). Considering the severe time constraint after a disaster, rapid information dissemination is an important aspect for effective emergency management. To manage such an objective, there is a need for an emergency information system, which can improve the capacity of decision makers to take right decisions (Klenk, 1997). Because of the wide variety of activities carried out by different stakeholders in the time of emergency and the need for processing substantial amounts of data to accommodate immediate relief effort needs, there is a strong requirement such an information system (Birk *et al.*, 1995). Official channels, which provide the typical way of information flow, tend to be too slow to handle emergency information (Ayanz *et al.*, 1997). Especially when emergency managers are subject to stress, it is difficult to handle the information rapidly and objectively (Alexander, 1991).

Klenk (1997) divided the required emergency information system into four major categories: identifying needs, collection and analysis of data, and dissemination of information (see Figure 5.1).

Identifying needs can be the most important step in the cycle, as it will define the content and direction of the other steps. For effective information management, there is a need to complete the cycle by subsequent steps: gathering data, analyzing and processing information, and dissemination of information. Although this chapter basically emphasizes the user information requirement, it is also important to have overall idea about emergency information management to evaluate the applicability of remote sensing technology and effective use of remotely sensed information in the specific case of Turkey.

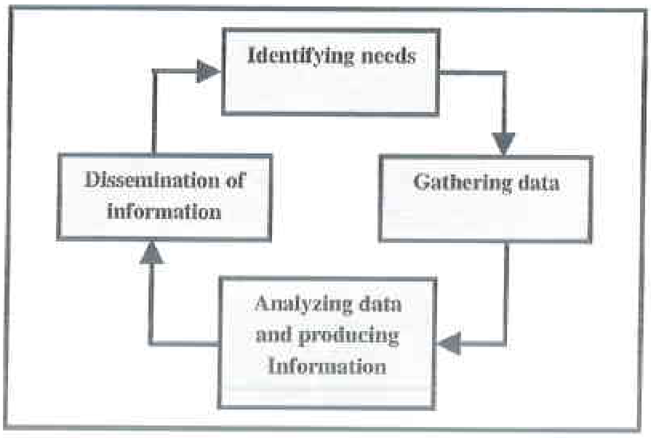


Figure 5.1. Emergency information management cycle
(Klenk, 1997)

5.1.1. Identifying needs

In times of emergency, there are wide varieties of users, who have specific information requirements for their specific activities at a specific time. Although some of the information requirements may be identical regardless of type of disaster, information requirements can vary depending upon the time requirement for data in relation to disaster type and disaster magnitude (Bruzewicz & McKim, 1995). These parameters are the main determinants for the information requirement and its characteristics, such as amount of detail, accuracy etc.

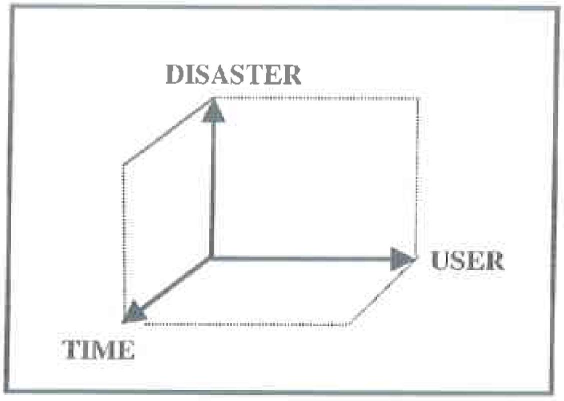


Figure 5.2. Information requirement parameters

The user and their activities determine the detail of the required information. Klenk (1997) describes the users as:

- Government response organizations (national, regional and local authorities)
- Military forces and civil defense units
- Non-governmental organizations (global, national, regional, local)
- UN organizations
- Private donors
- Public donors
- Religious institutions
- Affected population
- The media (international and local)

The United States Federal Emergency management Agency (FEMA) has identified the following as essential information for emergency support functions (Birk *et al.*, 1995).

FEMA response and recovery requirements		
1. Casualties /injured people	8 Petroleum distribution centers	15. Interstate highways, roads and bridges
2. Homes affected	9. Petro-chemical or industrial complexes	16. Sewage treatment plants
3. Location of hospitals	10. Television stations	17. Water distribution systems
4. Location of nursing homes	11. Telephone systems	18. Water distribution systems
5. Location of schools	12. Location of airports	19. Food distribution warehouses
6. Energy distribution systems	13. Railway lines / systems	20. Ports and harbors and impact on navigation
7. Collapsed structures	14. Mass transit, including bus/ rail systems	21. Structural, forest or other types of fires

Figure 5.3. User information requirement for emergency support functions
(Modified from Birk *et al.*, 1995)

The information requirement table shows the needed data, which are all spatial in nature. Although most of the information can be derived using remote sensing technology, it is not enough by itself to fulfill the all information requirements. There is also a need for baseline information, which shows the pre-disaster situation, such as demographic information, economic social, environmental statistics, geologic and topographic surveys, land registration data, transportation routes, water sources and networks (Klenk, 1997). This information can be used to create a base map for change detection, damage assessment and the presentation of impacts (Birk *et al.*, 1995).

User needs identified by U.S. organizations show that tactical teams require information from address files containing geo-coordinate locations to identify the location and extend of damage to utilities, roads, communication facilities, civil and governmental buildings, and dwellings (Birk *et al.*, 1995). After the hurricane Andrew disaster in 1992, Digital Matrix Services prepared a report to FEMA about the activities carried out during the hurricane response and recovery phases. The report highlights "GIS technologies were critically important in locating and tracking the diverse mission-critical facility location and image data, when incorporated into the GIS environment, is proved to be invaluable" (Birk *et al.*, 1995).

5.1.2. Data gathering

Emergency managers typically obtain data from findings submitted by assessment or monitoring teams, situation reports from field staff, counterpart organizations and media reports (Klenk, 1997). However, using data from a wide range of sources can create confusion and decrease the reliability of the information. Accuracy of the information is always critical for decision makers. At the time of the emergency, the media also play an important role, since it is the quickest means of getting information about the disaster (Klenk, 1997). On the other hand, there is always a possibility that the media will concentrate on only well-known and highly damaged areas. This situation can mislead the decision maker, if there are also emergency cases in remote areas.

Remote sensing is one way of data collection after a disaster. Although it has many advantages, the use of remote sensing by emergency agencies is primarily dependent on availability of financial resources, expertise and time (Klenk, 1997). Availability of financial resources is the principal constraint for the use of remote sensing technology. The use of remote sensing technology requires some basic technological infrastructure. Although some larger organizations, such as FEMA, already use the geo-information technology (remote sensing, geographic information system, digital mapping), for smaller emergency organizations the expense to establish such a system is typically too high enough. The actual cost of remotely sensed data will then be quite small compared with the initial investment in technological infrastructure. In addition to improvement in technological infrastructure, there is a need for efficient data network among remote sensing data acquisition and processing facilities on a national and inter national level (Birk *et al.*, 1995). To access the available data, the main requirement is establishment of data downlink facilities in the organizations at national level, which can provide information to the emergency organizations at regional or local level through setting up a network among them.

Ancillary spatial data, which cannot be obtained from remotely sensed data, can be provided from the other government organizations, such as mapping, planning agencies. Establishment of national spatial data infrastructure can speed up the data gathering process.

5.1.3. Data analyzing

Generally, provision of raw data to the user is not enough by itself without any analysis. Decision makers require analysis results to organize the activities. The main challenge in data analyzing is the handling of the large volumes of data, which come from different sources and in different formats. Integration of data requires modifications in formats (Birk *et al.*, 1995). This can create difficulties for the analysis of data at the time of emergency, and lead to significant delays. Standardization of data formats at the national level can solve the problem of data integration.

The use of computers can speed up the data analysis process, which, naturally, requires data processing and analyzing laboratories (Birk *et al.*, 1995). Available hardware and software can be a determinant for application and use of remote sensing technology in emergency activities.

On the other hand, according to Birk *et al.* (1995), as it can not be assumed that each disaster response stakeholder has the technological capacity (hardware, software and expertise) to analyze or to gather data, hard copy photographs or charts are still the main format for distributing remotely sensed information at times of emergency.

5.1.4. Data dissemination

Data dissemination is arguably the most important part of the emergency information management, since information is only valuable if it reaches to the right organization at the right time. Research on user needs assessment for the Philippines, Indonesia, Thailand and People's Republic of China has shown that development of a data transmission network to distribute the information about disasters is one of the major user requirements (Birk *et al.*, 1995). The data sharing capacity between agencies is the main determinant for data dissemination. Without any willingness of data sharing, information produced for emergency activities may not reach the decision maker. To share the data, there is a need for establishment of data sharing environment, which allows to the user to obtain timely information. Computer networking allows faster and easier access to, and transfer of data between different users and providers. Moreover, the World Wide Web (www) provides an important platform for information network and data exchange (Montoya & Masser, 2000).

5.2. Anaylsis of information requirement of users in the case of Turkey

5.2.1. Research methodology

One of the objectives of this research is to analyze the information requirement of emergency agencies in Turkey for post-earthquake response activities. Research was carried out by interviewing 14 key informants from different emergency organizations. Besides defining the information requirement, the current situation, in terms of technological capacity, information exchange, organizational structure was also investigated to analyze the applicability and usefulness of remote sensing technology for emergency activities in the case of Turkey. The structure of the research was:

- Identification of potential user and data providers
- Identification of information requirements
- Identification of current situation

There were two main limitations in the research. The first one was subjectivity of interviews. As the research was carried out by interviewing key representatives from emergency agencies, it was subject to personal opinions of the interviewee. The second one was limited unawareness of decision makers about remote sensing technology. Therefore, it was not always possible to get detailed information. The result of the research was designed to shape the overall profile of emergency activities and information requirements of the major stakeholders in disaster management in Turkey.

5.2.2. User definition

Users were selected at the three government levels: national (7), regional (2) and local (2). Besides government agencies, one NGO, one research center, and one data provider were visited. Although major organizations that take a role at the time of emergency were selected, Turkish military which had a great effort in emergency activities after the Kocaeli earthquake was missing in the research because of the security rules.

At the national level

- General Directorate of Civil Defense
  - Search and Rescue Operation Division
- General Directorate of Disaster Affairs
  - Earthquake Research Center
  - Disaster Survey and Damage Assessment Division
- Turkish Red Crescent
  - AFOM (Disaster Organization Center)
  - BILMER (Information Center)
- General Directorate of Turkish Emergency Management

At regional level

- Kocaeli Province Government
- Kocaeli Civil Defense Directorate

At local level

- Golcuk Municipality
- Golcuk Civil Defense Directorate

Others

- Search and Rescue Association (AKUT)
- Marmara Research Center
- Inta Space Imaging Euroasia

5.2.3. Information requirement of user

Evaluation of the interviews has shown that different organizations require different types of data. Information requirements differ depending on mainly two parameters. The first one is the governmental hierarchy. Generally, at the national level, the overall information about the affected area is the principal information requirement, while at the local level detailed and accurate information gains importance. The second one is the activities that organization carried out. For search and rescue operations, information on collapsed building is required. Moreover, population information at the building level is also important, as the number of the people buried under the rubble is one of the criteria for rescue operators. The use of the building, such as hospitals, business or residential, plays an important role in organizing the rescue operation. For emergency aid activities, rather than information about collapsed buildings and the probable number of people at danger, the number of people, who survived from the disaster is much more important, as they need to know the requirements for food, and shelter. Information requirement of the emergency agencies in Turkey is summarized in Figure 5.4.

Time requirement: Usually, in the first 1 hour, information about the disaster and its magnitude is known. In the first 24 hours, there is a need for getting information about the current situation in the disaster area. In the first day and first hours, decision makers need to organize the response activities. Therefore, there is an immediate need for information. For search and rescue operations, the first 48 hours are critical. After 72 hour, the chance for exposed and/or injured people to survive approaches zero. Other activities, such as damage assessment and excavation work, start after search and rescue operation. At least the day after, teams are sent to the disaster area. On the other hand, urgency and need for information about the disaster is also dependent on the magnitude and extend of the disaster. In the case of the Marmara earthquake, to get information and reach to Golcuk took 3 days, because of the extensive damage to roads and communication systems. During the first two days, there were accessibility problems. However, in the case of the Bingol earthquake, after only 20 minutes information about the disaster reached the national government agencies. After 2 hours, the Red Crescent team was in the disaster area.

Organizations	Damage information	Disaster information	Baseline information
National level	▪ Extent of the damage at regional level ▪ Affected towns ▪ Overall number of collapsed buildings at regional level	▪ Magnitude of the earthquake ▪ Damage on transportation system to assess the accessibility to disaster area ▪ Death and injured toll ▪ Estimated affected population at regional, local, neighborhood, village level	▪ Road network ▪ Land use ▪ Population ▪ Elevation ▪ Geological characteristic of the area ▪ Ownership information
Regional level	▪ Extent of the damage at regional level ▪ Affected districts ▪ The number of damaged buildings at regional level		
Local level	▪ Extent of the damage at local level ▪ Affected neighborhoods and villages ▪ Detailed information on damage type and the number of damaged buildings at neighborhood level		
Search and rescue	▪ Collapsed building information at local level ▪ Information about the building security to enter for rescue operations ▪ Use of the building ▪ Number of people living in buildings ▪ Type of the collapse		
Red crescent	▪ Affected population, who need an accommodation and food at provincial and neighborhood level		
Research	▪ Microzonation ▪ Construction type of the buildings		

Figure 5.4. Information requirement of emergency agencies in Turkey

Data characteristics: In terms of accuracy, timeliness and detail, information requirements show variation according to the different levels of the response activities. These characteristics of required information were analyzed in two levels: National and regional/local level (see Figure 5.5).

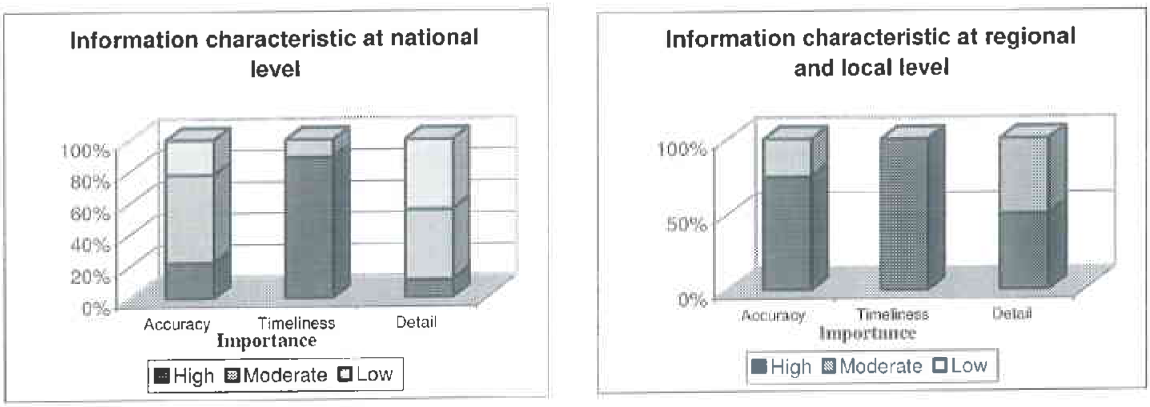


Figure 5.5. Required information characteristics at national and regional/local level

For all levels of government (national, regional and local), timeliness of the information is the most important characteristic. Therefore, it can be said that each and every emergency organization requires information as soon as possible after an earthquake. On the other hand, accuracy and the detail of the information become more valuable at the regional and local level, as at the national level overall information about the damage is enough to take an action.

5.2.4. Current situation and previous experiences

Current emergency activities are carried out by the establishment of crisis centers at the different levels of the government (national, provincial, district, neighborhood and village) following a disaster. At the national levels, crisis centers were established and work under the direction of Prime Minister. The crisis center at the national level includes participants from the Prime Ministry and related ministries depending on the disaster type. The magnitude of the disaster and the extend of the affected area are the main determinants of establishment of crisis centers at the required levels. The General Directorate of Turkish Emergency Management provides coordination between different emergency agencies. Due to centralized government characteristic, governors and sub-governors are the main responsible bodies at the regional and local level. They report the damage information and take direction from the national government authorities. At the regional level, crisis center managed by governor of the city includes Mayor, directors of Security, Health, Education and Construction and Settlement. The crisis center manages the service groups, which are responsible for rescue and recovery activities. These service groups include Rescue and Debris mover, First aid and Medical, Damage survey& temporary shelter, Transportation, Communication, Security, Utility, Buy & Rent & Distribute and Agricultural affairs.

In the first step, search and rescue operations take place. Damage assessment work starts after search and rescue activities. Damage assessment is organized by the General Directorate of Disaster Affairs. This work is carried out by investigating the damage for each residential and commercial unit in the buildings based on the address. Visual investigation inside and outside of the building is done to assess the damage level of each unit. A damage assessment team includes technical staff, such as civil engineers and architects. According to the results of the damage assessment, the need for new housing as well as ownership rights are determined. Therefore, damage assessment is a sensitive, legal and difficult issue. After the Kocaeli earthquake (1999), some court cases are still pending in relation to damage assessment results. According to the Damage Assessment Department of General Directorate of Disaster Affairs, survey of building facades alone is not sufficient for their work, as buildings can be collapsed inside without a change to the façade. Therefore, the use of remote sensing information can be useful to organize the activities at the strategic level, such as guiding the damage assessment teams according to the first damage indications.

Generally, remote sensing is not used for damage assessment activities. But it is used for defining tectonic plates and active faultlines by the Earthquake Research Center. After the Kocaeli earthquake, the Kocaeli Province Crisis Center used IRS images as a base map to visualize the disaster area. The Science of Earth and Sea Research Center (YDAM) of the Marmara Research Center (MAM) used IRS images for a project called "Site Selection of New Residential Areas Using Remote Sensing and Geographic Information System".

Data gathering: There are two main information sources for getting damage information following a disaster. The first one is damage and loss estimation provided by the Department of Earthquake Research of the Disaster Affairs. This estimation is based on the magnitude of an earthquake, building type, population and risk maps. The second and more common source is field reports. The information flow at the time of emergency follows the government hierarchy. The lowest government authority in disaster area informs the higher level about the damage. On the other hand, past experiences show that damage to communication systems has affected data flow during past disasters. Today satellite communication systems are used for emergency activities. The media and military forces are the other source of information. Besides information coming from the field, each organization sends its own advance survey team to get specific information for their specific response activities.

Data analyzing: Most of the official work is computerized in the organizations. However, even though there is a strong need for spatial information for all type of emergency activities, computers are used for office work rather than for analyzing and processing spatial data.

The main challenge for the organizations is to get spatial information of the disaster area. Depending on the technological infrastructure and data processing capacity, the required format of the information changes. Although the Earthquake Research Department –Disaster Affairs and the BIL-MER –Turkish Red Crescent, who had already established data analyzing laboratories, emphasized the requirement for the digital data; for other interviewees hardcopy is the prefered format of information for operational activities.

Analysis of the required information has shown that there is a strong need for baseline information. However, except for the Earthquake Research Department, none of the agencies at local, regional and national level has a database for spatial information. Spatial information gains importance at the national rather than local level, since after a disaster the useful information stored at the local agencies may be difficult to access due to emergency situation.

For most organizations involved in disaster management, the accuracy of spatial information is difficult to be analyzed. The important thing is to get information about the disaster area as soon as possible. One interviewee from the Turkish Red Crescent explained the situation as: " Any kind of information in the time of emergency is important for response activities. In the first hours after a disaster, to have an overall idea about the current situation is enough for decision maker. But at later stages, accurate and detailed information becomes important."

Data dissemination: Current data sharing is based on the satellite communication systems, mobile phones and radio. In the crisis centers at every level of government, there are communication centers, which work 24 hour a day for any kind of emergency situation.

Although Internet access in all organizations is available, a FTP server, which allows large amounts of information to flow through the Internet, is only available in the Earthquake Research Department. The Earthquake Research Department used this technology in the case of the 2003 Bingol Earthquake to download imagery, which was provided by the International Charter on Space and Major Disasters. The Earthquake Research Center obtained IRS and Spot images through International Charter six days after the Bingol earthquake. The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through authorized users without any payment. It was declared formally operational on November 1, 2000. An authorized user can now call a single number to request the mobilization of the space and associated ground resources (RADARSAT, ERS, SPOT) of the three agencies to obtain data and information on a disaster occurrence. According to Earthquake Research Centre, Turkey was expecting to have an authorization in September 2003. However, till now Turkey still is not an authorized user, as authorized users are all associated with Charter members (http://www.disastercharter.org). Space agencies currently member of the International Charter is shown in the Figure 5.6.

Member	Space resources
European Space Agency (ESA)	ERS, ENVISAT
Centre national d'études spatiales (CNES)	SPOT
Canadian Space Agency (CSA)	RADARSAT
Indian Space Research Organisation (ISRO)	IRS
National Oceanic and Atmospheric Administration (NOAA)	POES, GOES
Argentina's Comisión Nacional de Actividades Espaciales (CONAE)	SAC -C

Figure 5.6. Member space agencies of International Charter
(http://www.disasterscharter.org visited on 1 December 2003)

To get a better idea about data gathering possibilities, Space Imaging Euroasia, which has a data acquisition and processing station in Ankara, was visited. The company provides Ikonos and Spot images. According to the interview, data acquisition is arranged according to client request. But in the case of a disaster, the company does not wait for the request. 12 hours is enough to arrange an image acquisition. After data acquisition, processing of the raw data is achieved within half an hour. The process of producing coordinate sensitive image requires 24 hours. There is also a possibility to prepare projects like damage assessment, but with doubling of the cost. Data dissemination is provided in two ways: hardcopy or softcopy. For softcopy dissemination, there is a need for an FTP server. Until now, there was no request for image acquisition for emergency situation from organizations. The cost of the images starts at 28 US$/km^2. There is also a possibility to use archived images, which cost about 20-22 US$/km^2. Each scene covers 121 km^2, resulting in a cost of approximately 2.500 US$. These figures show that the cost of imagery with a high resolution is quite high, which can create a limitation for the emergency agencies to use remote sensing technology.

On the other hand, new developments in space technology in Turkey are promising for the possibility of further improvements in the use of remote sensing technology for disaster management. The first Turkish Earth observation satellite, BILSAT, with 12m panchromatic and 26m multi-spectral resolution was launched in October 2003. It will be a part of "Disaster Monitoring Constellation" (DMC), which has been organized by Surrey Space Technologies LTD (SSTL). England, Algeria and Nigeria have already agreed to join in this constellation. Moreover, Vietnam, Thailand and China are also expected to join. The constellation, with a one-day temporal resolution allows image acquisition from any satellite in this constellation in case of a disaster. The nominal temporal resolution of BILSAT is 4 days and the passing time over Turkey will be around 10 a.m. A pointable capability sensor increases the temporal resolution (Tunali *et al.*, 2002). The first images were acquired from Cape Town/S. Africa (taken on 18 Oct. 2003), İskenderun Bay/Turkey (taken on 30 Oct 2003) and Kuwait City/Kuwait (taken on 6 Nov 2003). Although it is promising for future developments, most of the interviewees were not aware of these developments, except The Turkish Red Crescent, which was carrying out a project on establishment of database and use remote sensing for emergency activities.

For an effective emergency management, the interviewees noted the following additional requirements:

- Need for expertise;
- Need for awareness of local communities - education and planning about the disasters;
- Need for coordination between agencies;
- Legal arrangements for defining responsibilities of emergency agencies;
  - In the current situation, each disasters type is dealt with by different organizations;
- Standard information format to share, integrate and use the available information;
- Technical improvements, in terms of hardware and software are required for data processing;
- Need for increased data dissemination capacity;
- Need for baseline information;

5.3. Conclusion

Although remote sensing technology can provide valuable information for emergency activities, the requirements for use of this technology still create some limitations.

First of all, the information requirement list shows that remotely sensed data alone is not enough without integration of other base data, such as population, roads, and infrastructure. Therefore, there is a need for integration of remote sensing and geographic information system technologies. Baseline information is an important part of the user information requirement. The establishment of a spatial database infrastructure at every level of emergency activities can create a baseline for future developments.

According to the user information requirement analysis in the case of Turkey, as remotely sensed data cannot provide information for all levels of damage caused by an earthquake, it cannot fulfill the requirement of complete damage assessment. At the local level, there is a need for more detailed and accurate information. Therefore, remote sensing technology can be important at the early stage of the disaster to get an overall idea for strategic level in decision-making.

The 24-hour time requirement for information gathering also creates a limitation for applicability of remote sensing technology to aid emergency activities. If we think about the time requirement for data acquisition, processing and dissemination of the information, 24 hour may not be enough. But future developments in data gathering through the International Charter and BILSAT will create a possibility for more rapid data gathering.

Organizational aspects of information flow are the main challenge for the application. To fulfill the requirements for data gathering, analyzing and dissemination of information, there is a need for improvement of technological and technical infrastructure of the involved organizations. Expenses for this kind of improvements is a major constraint for effective use of information derived from remotely sensed data.

6. Analysis of Spot imagery

After analysis of the user information requirements in the case of Turkey, analysis of remote sensing data for damage detection will be carried out in the following parts. In this chapter, there will be an emphasis on the Spot imagery analysis to detect the damage at the regional level. Analysis includes pre-processing, change detection, integration with vector data and evaluation of results at the regional and local level.

6.1. Pre-processing of Spot imagery

Pre-processing includes three major steps for preparation of images for further analysis: geo-referencing, radiometric correction and exclusion of vegetated areas and water bodies.

6.1.1. Geometric correction

Geometric correction is an important step of the change detection analysis, as misregistration between two images may result in the failure of identification of change areas. Especially pixel based change detection methodologies, such as image differencing, rationing etc., compares the reflectance values of each pixel for each date. Therefore, the registration error should be less than 0.5 pixels (Jensen, 1996).

The Turkish coordinate system includes two different projection systems at the local and national level. The topographic maps at a scale of 1 / 25.000 are projected to the UTM projection system with a zone width of 6°. The ellipsoid reference is International 1909. The study area is situated on UTM zone 35. The local projection system also uses UTM but with the zone width of 3°, and a scale factor at origin of 1.0. In the first step of the geo-referencing process, all scanned maps were projected to the national coordinate system; and then re-projected to the local coordinate system. Because of the distortions in the map sheets, besides the 1st order polynomial transformation, the 2nd order transformation and rubber sheeting were also used in geo-referencing process of the scanned topographic map sheet.

Two different registration procedures were applied in the geo-referencing process: image to map rectification and image-to-image rectification. Image to map geometric correction was applied to geo-reference the pre-disaster panchromatic image, which was chosen as a reference image. A 2nd order polynomial transformation was used in the geo-referencing process. Due to the lack of a DEM for the whole region, orthorectification of the image was not possible. Therefore, even getting better RMSE result using a 2nd order polynomial transformation, mountainous areas were still problematic. 55 evenly distributed ground control points were used for geo-referencing process (Total RMSE: 0.30 X residuals: 0.20, Y residuals: 0.22).

In the last step, using pre-disaster panchromatic image as a reference, other images (pre-disaster multispectral image, post-disaster panchromatic and multispectral image) were rectified image to image. In the rectification process a 2nd order polynomial transformation was applied. The result of the geo-referencing process is summarized in Figure 6.1.

Image	Number of ground control points	X residuals	Y residuals	Total RMSE
Spot 4 – PAN 15th July	55	0.20	0.22	0.30
Spot 4 – MSS 15th July	93	0.16	0.16	0.22
Spot 4 - PAN 20th August	107	0.25	0.16	0.30
Spot 4 – MSS 20th August	107	0.23	0.17	0.29

Figure 6.1. Geo-referencing process

A nearest neighbour resampling method was applied in the rectification process, as it has the advantage of using the value of the closest pixel to assign to the output pixel value. Unlike other resampling methodologies, the nearest neighbour resampling method does not change the value of the pixels (Erdas, 2002). After geo-referencing, the study area was defined as Izmit Gulf and its environs. In the subset area, 1 provincial district, 1 district, 15 municipalities, and 29 villages were situated. The general overview of the area is shown in Figure 6.2.

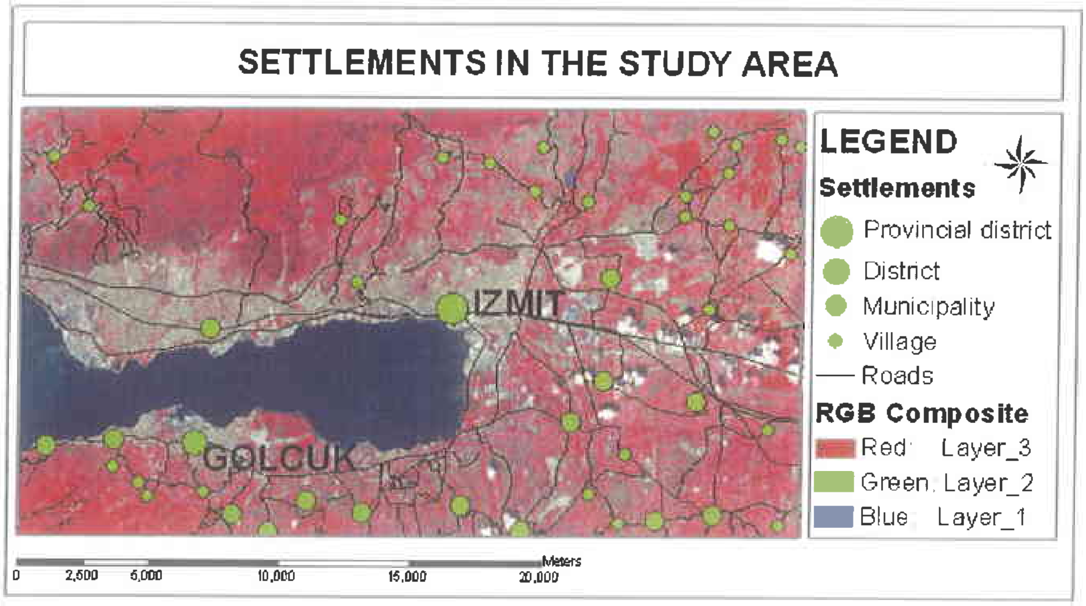


Figure 6.2. Subset image and settlements

6.1.2. Radiometric correction

Image normalization is used to reduce pixel brightness value variation caused by non-surface factors, such as sun angle, earth-sun distance, atmospheric conditions and sun-target sensor geometry. Reducing these affects allows detecting the actual changes in surface conditions (Jensen, 1996).

Relative radiometric correction was used to normalize the reflectance value of post-earthquake Spot images to the pre-earthquake imagery. To achieve the relative radiometric correction, pre-earthquake imagery was taken as reference. Radiometric normalization targets were selected according to acceptance criteria presented by Eckhardt *et al.* (1990). For radiometric correction 9 target pixel values were selected. Five dark target values were selected from deep-sea water and a lake situated north of the area. Four bright target values were selected from the Outlet, Ford, Seka roofs and an air-port road.

The brightness values of post-earthquake image targets were regressed against the brightness values of reference images (pre-earthquake image) targets. The coefficients and the intercepts of the equations were used to compute normalized post-earthquake Spot dataset. The normalization equations for each individual band are summarized in Figure 6.3.

Image	Intercept	Slope	R2
Panchromatic	-2.3968	1.3317	0.985
Mss- Band 1	-31.547	1.1018	0.985
Mss-Band 2	-6.2426	1.4190	0.985
Mss-Band 3	-5.7062	1.3692	0.997
Mss-Band 4	-1.7099	1.4349	0.999

Figure 6.3. Equations used to normalize the radiometric characteristics of post-earthquake Spot images.

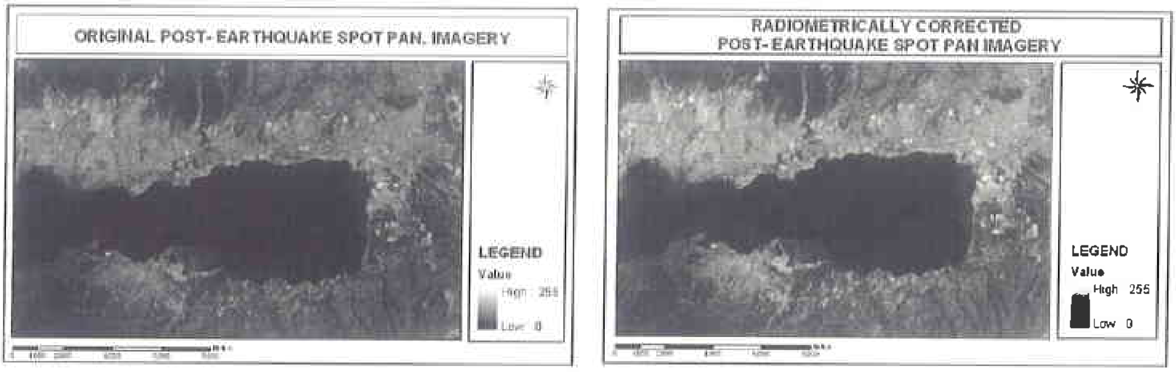


Figure 6.4. Comparison of original and normalized post-earthquake panchromatic image

6.1.3. Exclusion areas

Sea and vegetated areas were excluded from the scenes to derive the change in pixel values of built-up areas due to earthquake damage. Firstly, the boundary of the sea was digitised. Digitised sea map was used for masking process to exclude sea from all other images. In the second step, NDVI was calculated by using multi-spectral bands of pre-earthquake imagery. The threshold value for the NDVI was defined at 150 by visual investigation. Figure 6.6 shows the determination of threshold values for exclusion of vegetated areas.

$$NDVI = \frac{XS3 - XS2}{XS3 + XS2}$$

For standardization of NDVI values, the following formula was applied:

$$NDVI = \frac{XS3 - XS2}{XS3 + XS2} * 128 + 127.5$$

6.2. Change detection

The change detection process includes 3 steps: band substitution, colour space transformation and image differencing. In the first step of the process, the multispectral bands were resampled to 10 m. As the spectral region of Spot panchromatic band is the same with Spot band 2, it was substituted directly for band 2 (red). Figure 6.7 is a display of the merged dataset with SPOT XS3 (near infrared), SPOT PAN and SPOT XS1 (green) in the colour composite plane. Band substitution was carried out by layer stacking in Erdas. The resulting image has the spatial detail of the SPOT panchromatic data (10x10 m) and spectral detail of SPOT multispectral data (20x20 m). The advantage of band substitution is that it does not change the radiometric qualities of any of the SPOT data (Jensen, 1996).

In the second step, intensity of the merged data set was calculated using the formula below (Pellemans *et al.*, 1993 in Jensen, 1996). Intensity describes whether the colour is light or dark and it varies from black (0) to white (255) (Jensen, 1996). As it can be seen in the formula, it gives the average value of three bands in RGB composition. Therefore any change in one the band results in a change in intensity values. Figure 6.8 shows the intensity values of the pre and post-earthquake merged data set. The intensity values shows increase in the damaged areas in central part of the Golcuk.

$$\text{Intensity} = \frac{Band_1 + Panch + Band_3}{3}$$

In the third step, an image-differencing algorithm was used for the change detection analysis. To obtain the change in brightness value of pre and post-earthquake intensity images, pre-earthquake intensity image was subtracted from the post-earthquake intensity image. In the application the result of the change detection analysis were used without constant value.

$$D_{ijk} = BV_{ijk(1)} - BV_{ijk(2)} + C \quad \text{(Jensen, 1996)}$$

Where
D_{ijk} = Change pixel value
$BV_{ijk(1)}$ = Brightness value at time 1
$BV_{ijk(2)}$ = Brightness value at time 2
C = A constant
i = Line number
j = Column number
K = A single band

The resulting difference image shows the areas of change. Image statistics are summarized in Figure 6.5. Threshold of the change and non-changed pixel value was determined according to the standard deviation of the pixel values. -/+ standard deviation from the mean value was used for the classification of positive change, unchanged and minus changed areas shown in Figure 6.9.

Statistics	Values
Mean	-1.42
Standard deviation	16.82
Minimum	-206
Maximum	137

Figure 6.5. Statistics of pixels values of change map

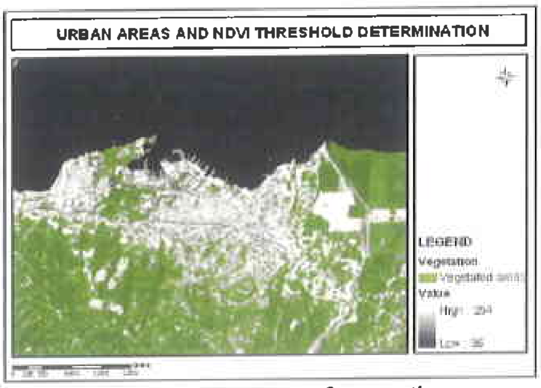


Figure 6.6. Exclusion areas of vegetation

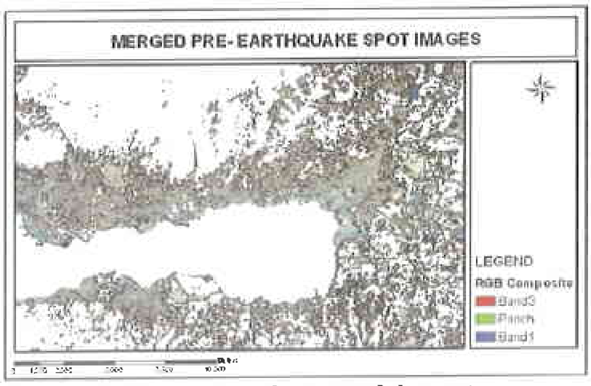


Figure 6.7. Pre-earthquake merged data set

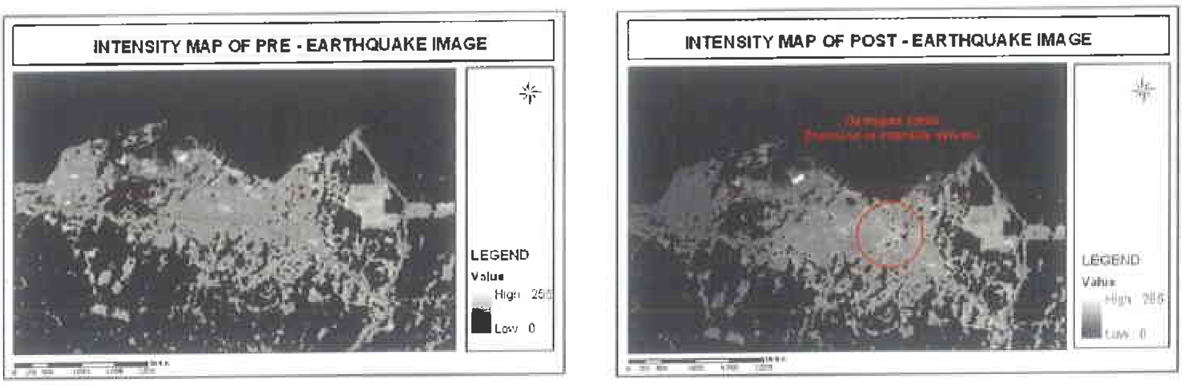


Figure 6.8. Intensity values of pre and post-earthquake merged data set

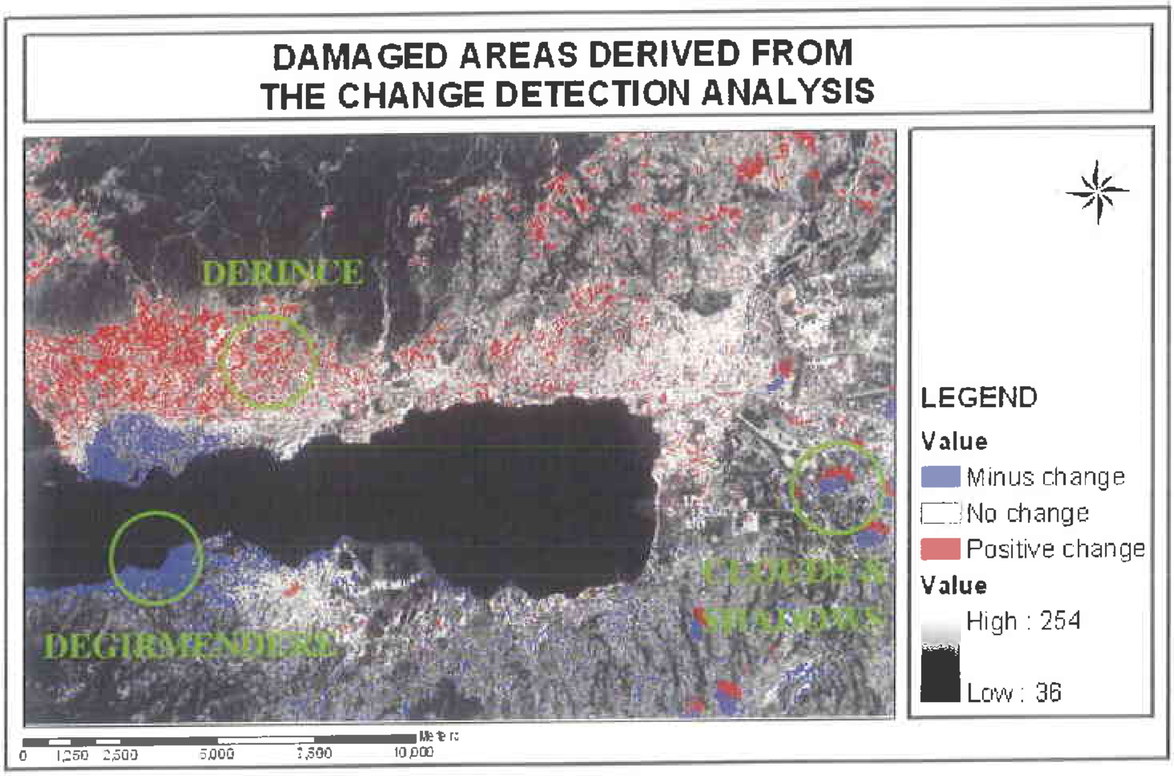


Figure 6.9. Result of change detection analysis

Although the result of the change detection has shown mainly underestimation of damaged areas in the western part of the image, overestimation of damaged areas in the northern part of the image was observed. Due to the smoke from the fire in Tupras, some settlements have shown negative change in pixel values. Degirmendere and some part of Derince were under the affect of smoke (see Figure 6.9). Overestimation has been observed in Derince and some part of Izmit. Besides the effect of the smoke, difference in the incidence angle between pre and post-earthquake disaster can be a reason for over and underestimation for damaged areas. Moreover, orthorectification requirement for the hilly areas can be another reason. Because in flat areas the change values are more significant compared with the hilly areas. Due to pixel-by-pixel comparison of intensity values in image differencing methodology, any error in image-to-image referencing results in a change in pixel values. So there is a need for orthorectification of hilly areas. Moreover, clouds and shadows also create limitation for change detection results. In conclusion, it is quite difficult to make a differentiation between actual damaged areas and change values due to external factors. Therefore, Spot imagery has limited potential in detecting damaged areas.

6.3. Integration of change detection result with vector data

Integration with vector data of the damage assessment result can increase the value of the information, as it can provide more meaningful display to the user. Therefore, damage information derived from the Spot imagery was integrated with the vector data of Golcuk, which was provided by Golcuk Municipality (see Figure 6.11.).

The result of the change detection was aggregated into parcel level. The area of damage per each parcel was calculated. According to the percentage of the damaged area per parcel and actual damaged area per parcel, parcels are classified into 5 damage stages. The average building size was calculated as 141 m^2 according to current buildings in Golcuk city. Classification of damaged parcels was carried out according to the values presented in Figure 6.10.

Class	Damaged area	Percentage of damaged area
Highly damaged	> 70 m^2	> 50 %
Moderately damaged	70 - 35 m^2	25 – 50 %
Slightly damaged	35 – 14 m^2	10 – 25 %
Affected	1.4 – 14 m^2	1 – 10 %
Excluded	< 1 m^2	< 1 %

Figure 6.10. Classification of damaged parcel

Integration of change detection results with vector data (parcel boundaries in this research) increases the visualization and interpretability of the results. As it can be seen in Figure 6.12, without vector data integration (A), to evaluate the result and locate the damaged areas in the settlement is quite difficult, especially for the user, who is not keen on remote sensing data.

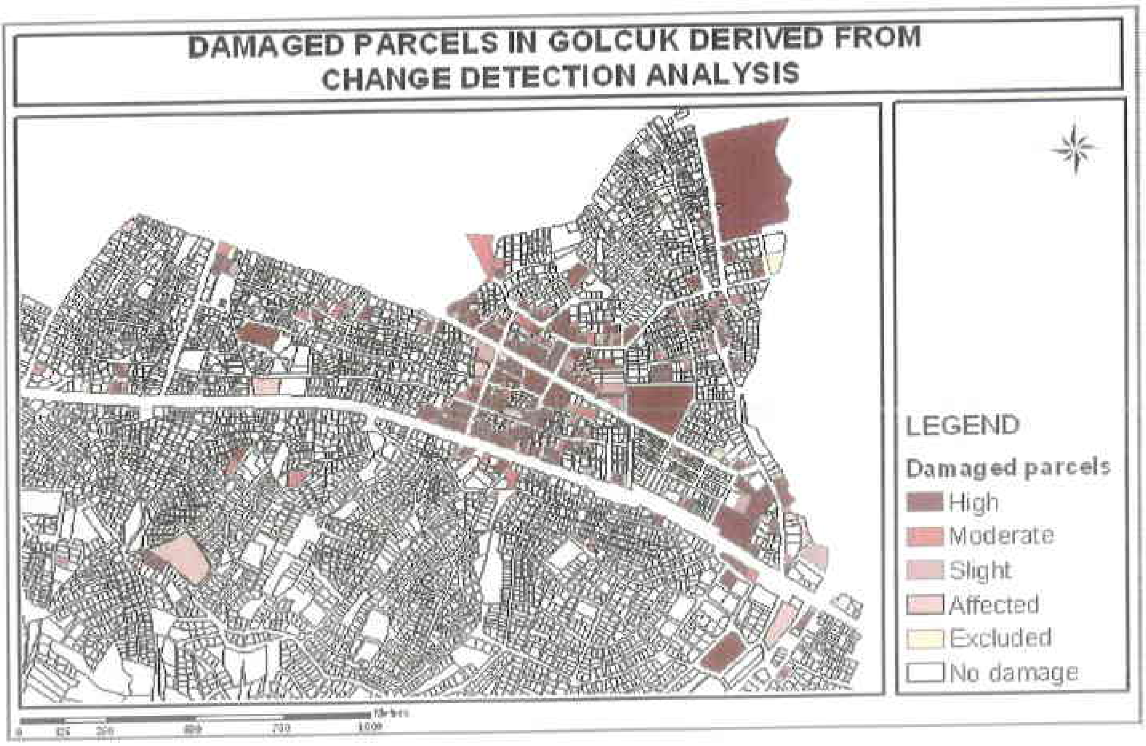
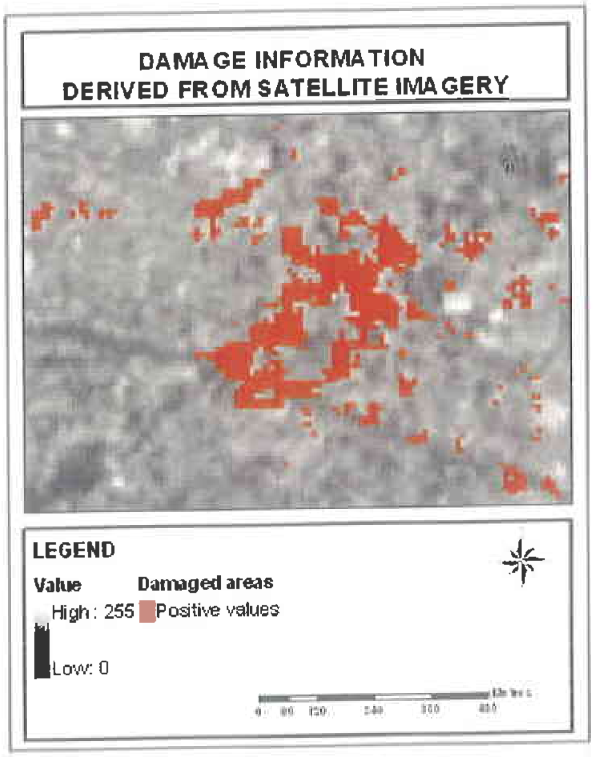
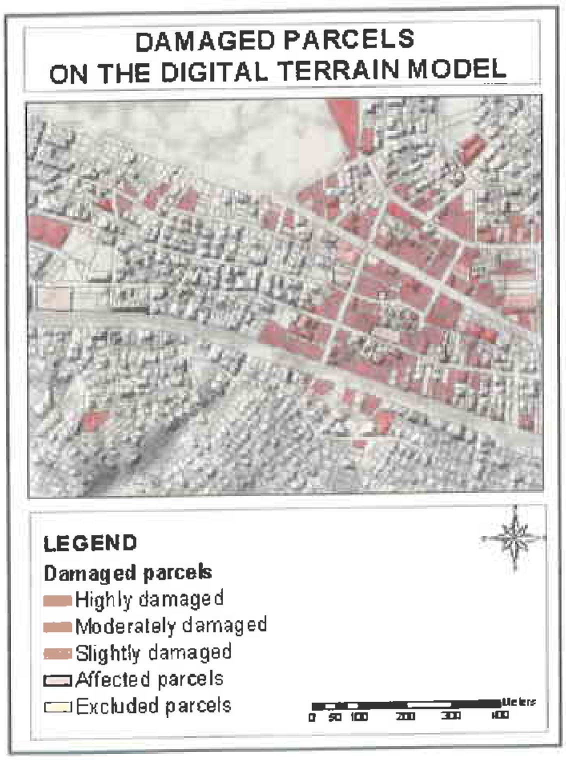


Figure 6.11. Integration of vector data



(A)



(B)

Figure 6.12. Comparison of original result of change detection (A) with vector data integration (B)

6.4. Evaluation of results at regional and local level

The result of the change detection analysis was compared with the ground survey at the regional and local level. The General Directorate of Disaster Affairs provided damage information at the regional level, which was aggreagated into settlement level. At the local level, damage information carried out by Architecture Institute of Japan (AIJ) in Golcuk, was used for the evaluation.

6.4.1. Regional level:

At the regional level, the damage information obtained by the General Directorate of Disaster Affairs was used. Damage is categorized into three levels (collapsed or heavily damaged, moderately damaged and slightly damaged buildings) for different settlement levels, such as village, neighbourhood, municipality, district. On the other hand, damage data gives only the number of buildings for each settlement. Therefore, it was not possible to locate exact place of the damage in the settlement areas. Due to lack of spatial information, comparison was carried out by visual interpretation. Regional damage evaluated at three categories: villages, municipalities and districts.

Villages: There were 29 villages in the study area. Average population of the villages is 416. The damage information of villages is shown in Figure 6.16. The classification of damage levels of the villages was carried on according to natural breaks. Figure 6.13 presents the comparison of the actual damage information with change detection results. Total number shows the total number of villages in indicated category. Other categories in the X-axis show the result of Spot imagery analysis. The Y-axis indicates the classified damage levels of villages. According to comparison results, damage assessment derived from Spot imagery at village level was not successful. Four of them were not recognizable from the Spot imagery. Two of them were under cloud coverage. The damage in seventeen villages could not be assessed and 5 of them were overestimated. None of the villages, which were highly damaged, were recognized by Spot imagery analysis. Only two of them have shown some positive change values in built-up area.

		Result of Spot imagery analysis					
		No damage	Cloud coverage	Smoke	Over estimation	+Change in pixel values of built-up areas	Total number
Actual damage information	Slight (1-10)	11 (79%)	1 (5%)	-	2 (11%)	1 (5%)	14 (100%)
	Moderate (10-50)	3 (38%)	1 (12%)	-	3 (38%)	1 (12%)	8 (100%)
	High (50-103)	3 (100%)	-	-	-	-	3 (100%)

Figure 6.13. Comparison of damage information at village level

Municipalities: There were 15 municipalities in study area with populations between 2.039 and 96.501. The actual damage information of the municipalities was shown in the Figure 6.17 (Source: Kocaeli Governorship). The result of visual comparison of change detection analysis and actual damage values is shown in Figure 6.14. The damage levels of settlements were classified using natural break points. Although 33 % of municipalities having slight damage have shown positive change in built-up areas, damage in the rest of the municipalities (66%) could not be detected. 80% of moderately damaged municipalities have shown positive change in built-up areas. One municipality with having high damage was overestimated due to external factor. One reason for this failure can be that the settlement was situated on rough terrain, which requires orthorectification for avoiding misregistration.

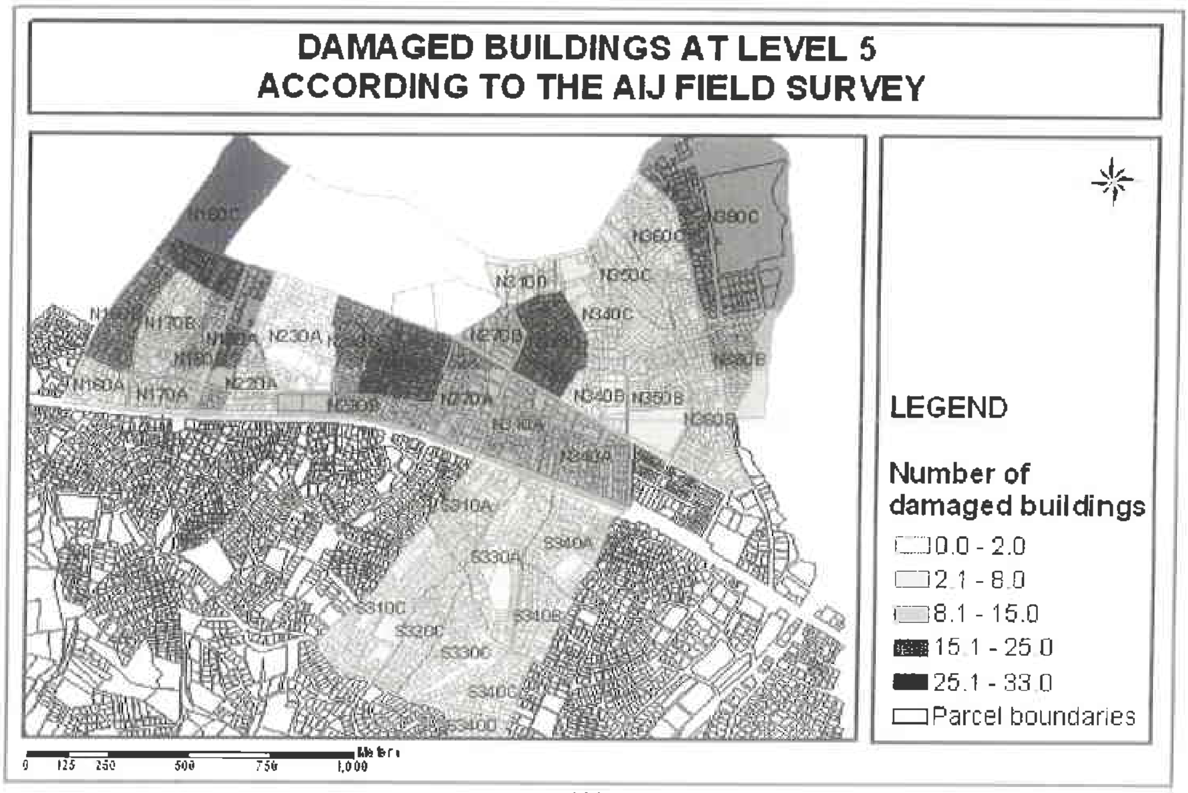
		Result of Spot imagery analysis					
		No damage	Cloud coverage	Smoke	Over estimation	+ Change in pixel values of built-up area	Total number
Actual damage information	Slight (26-843)	3 (33%)	2 (22%)	1 (11%)	-	3 (33%)	9 (100%)
	Moderate (844- 2310)	-	-	1 (20%)	-	4 (80%)	5 (100%)
	High (2311-8615)	-	-	-	1 (100%)	-	1 (100%)

Figure 6.14. Comparison of actual damage information with change detection analysis

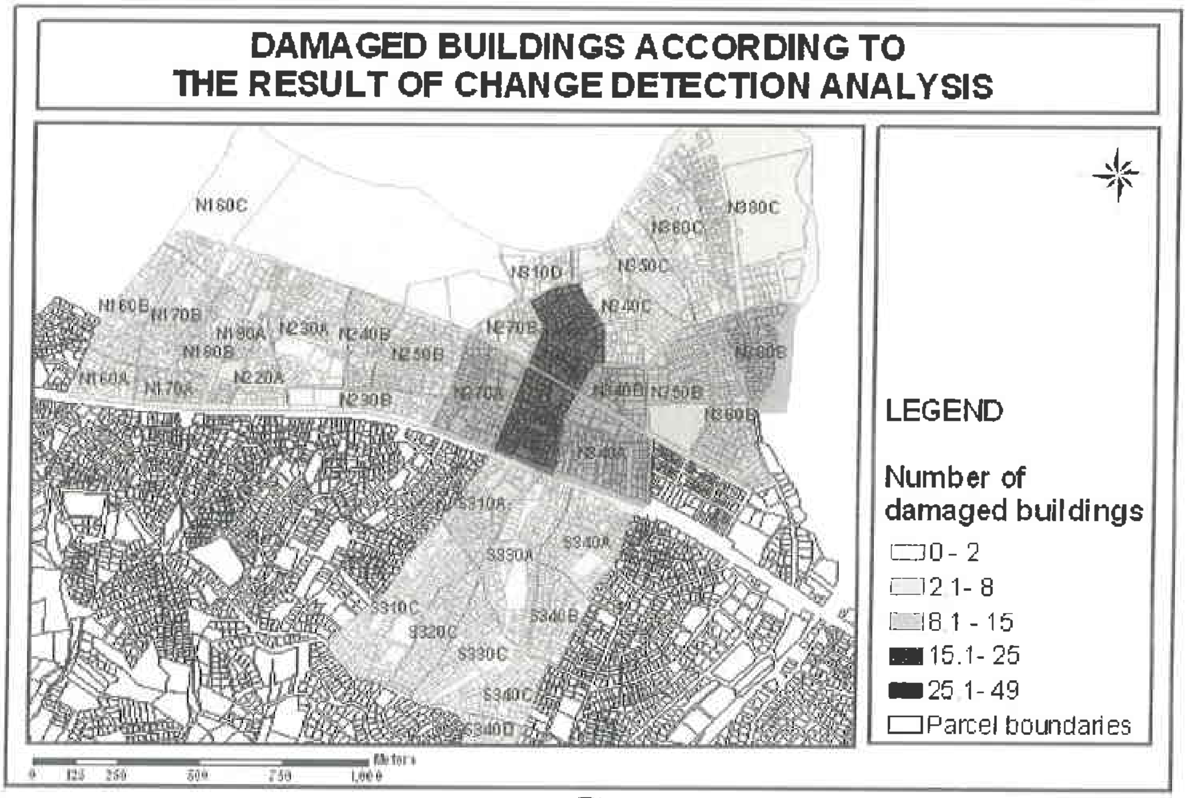
Districts: There were two districts in the study area: Golcuk and Izmit provincial district. The actual damage information is presented in Figure 6.17. The damage information in Golcuk will be evaluated in the next part. Although damage information derived from the Spot imagery was acceptable range in flat areas, there was significant overestimation in hilly part of the city.

6.4.2. Local level

At the local level, damage information obtained by the AIJ field survey was used. For the comparison, the average number of buildings per parcel (0.67) was found according to current building information. Damaged building numbers derived from the change detection analysis were aggregated into the zones defined by the AIJ survey. Before comparison, the correlation between the number of damaged buildings obtained from change detection analysis and the number of buildings at different levels was investigated. The highest correlation (0.205) was obtained between damage level 5 and total damaged building numbers. Damage level 5 presents destruction of buildings (Very heavy structural damage) or collapse of ground floor or parts (i.e. wings) of buildings. This result shows that Spot imagery can detect damage at the level five, although the correlation is still very low (0.2). Figures 6.15 and Figure 6.18 demonstrate the comparison of damage distribution in the zones. According to the comparison, the damage on the western part of the city was not recognizable from change detection analysis (zone numbers N160B, N160C, N230B). On the other hand, damage in the central part of the survey area was overestimated (Zone numbers N310A, N340B). The comparison of AIJ ground survey and the result of Spot imagery analysis is provided Appendix 11.



(A)



(B)

Figure 6.15. Comparison of damage information in the zones: (A) AIJ field survey result, (B) Change detection analysis result based on Spot data

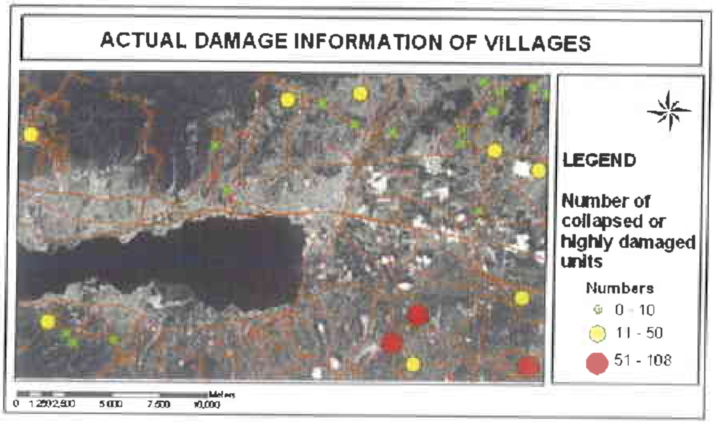


Figure 6.16. Actual damage distribution of villages
(Source: Kocaeli Governorship)

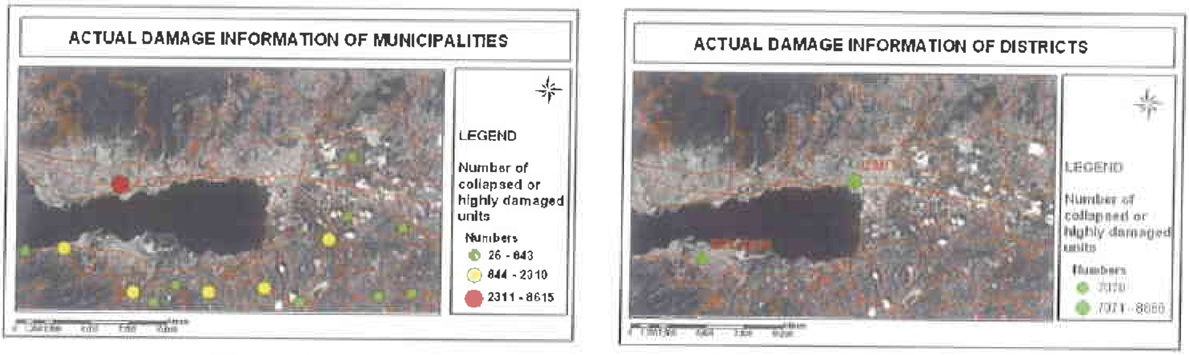


Figure 6.17. Actual damage distribution of municipalities and districts
(Source: Kocaeli Governorship)

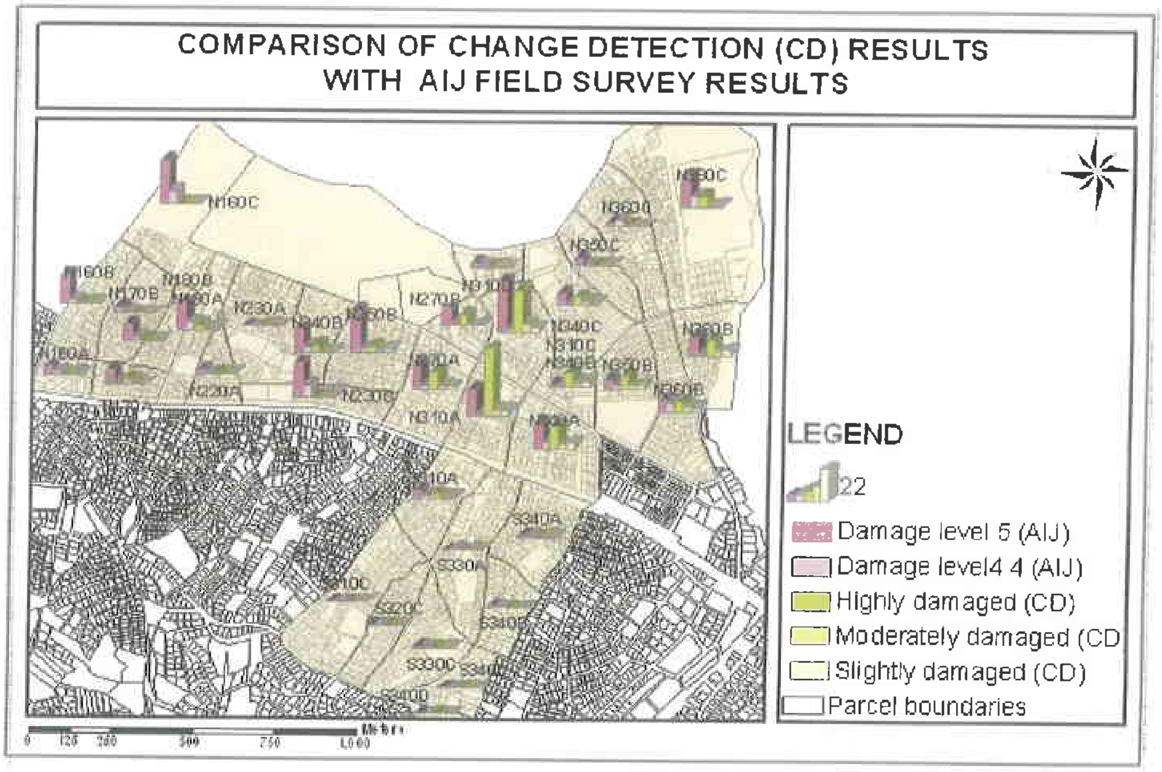


Figure 6.18. Comparison of change detection results with AIJ field survey results

6.5. Conclusion

In this chapter, Spot imagery was analysed to detect damaged areas at the regional level. Change detection methodology was used in the analysis. Evaluation of results was carried out at the regional and local level. At the regional level, ground truth damage information carried out by the General Directorate of Disaster Affairs, was provided by the Kocaeli Provincial Authority. At the local level, a ground survey carried out by AIJ in Golcuk was used.

The main limitation of the research was lack of damage information at building base. At the regional level, available ground truth data, damaged building numbers, were at the settlement base. At the local level, AIJ team used zones for aggregation of results. The same aggregation levels were used in the evaluation of analysis results. Due to the lack of building footprint of pre-earthquake situation, first aggregation was carried out parcel base. Moreover, the lack of DEM for the whole region and difference in the incidence angle of pre and post-images were also other limitations for change detection methodology. Moreover, in the methodology, only one threshold value for exclusion of vegetation areas was used. But in reality, it was not suitable for regional analysis, since there is variation in threshold values for rural and urban areas. Therefore, using a hierarchical thresholding for the exclusion of vegetated areas can give better results at the regional level. In the radiometric correction process, smoke was another constraint for regional analysis, since it reduces the brightness values of western part of imagery.

The evaluation of Spot imagery analysis results at the regional level shows substantial overestimation and underestimation of damaged areas. Due to fire in Tupras Oil Refinery, there was failure in detecting damage in western part of the study area. Clouds and shadows were also another factor for failure. Overestimation of damaged areas was observed in hilly areas. It was mainly because of orthorectification requirement in hilly areas. Although damage assessment using Spot imagery failed in detecting damage in villages, positive changes in intensity values in built-up areas (indicating damaged areas) at the municipal and district level were observed. There were also difficulties in making differentiation between actual damage and change due to external factors. Integration with vector data increased the interpretability of results.

For evaluation of results at the local level, damage information aggregated into parcel level in the case of Golcuk. Integration of Spot imagery analysis results with vector data increased the visualization and interpretability of the results. This valuable contribution of vector data is important for the users, who generally do not have experience with remote sensing imagery. The evaluation of results at the local level shows that Spot imagery can detect concentrated damage at level 5. It can be useful for overall information about highly damaged areas. Although the correlation value is still very low (near to random), the highest correlation (0,2) between damage derived from Spot imagery analysis and damage level 5 derived from AIJ field survey was observed. Moreover, damage in the north-western part of the city could not be detected.

Although this research found substantial limitations in use of Spot imagery in post-earthquake damage assessment, Turker & San (2003) conclude their research with high accuracy (83%) using Spot HVR in the case of the 1999 Kocaeli earthquake. However, the main shortcoming of the study was that evaluation of the result was carried out for only central part of Golcuk (85 building block in the central part). This may result some misleading conclusions, as there were some variations in damage types and affect of external factors for different part of the city, such as affect of smoke in north-western part of the city. Moreover, in spite of its high accuracy, one totally collapsed building block was identified as non-damaged and 2 non-damaged, 2 light-damaged blocks were identified highly damaged in the analysis. On the other hand, author thinks that current study provides better understanding of limitations and capabilities of use of moderate resolution optical imagery in post- earthquake damage assessment, as the evaluation of results was carried out at the regional and at the local level for the whole city.

In conclusion, damage assessment using Spot imagery has significant limitation due to external factors. Integration with vector data improves the visualization, interpretability and evaluation of results especially for differentiation between actual damage and change values due to external factors. It can be helpful to get overall information about concentrated and highly damaged areas. Moreover, may be the most important point is that change detection methodology gives information about the change in pixel intensity values not about the nature of the damage, which is important for the user.

7. Analysis of video imagery

After analysing Spot imagery at the regional and local level, in this chapter, there will be analysis of video imagery to improve damage assessment at the local level. Besides its technical limitations (such as revisit time, cloud coverage, low spatial resolution), vertical viewing characteristic of satellite imagery is the major limitation for post-earthquake damage assessment. The 3D characteristic of building damage requires seeing the façade of the buildings to assess the damage, a point, where video imagery can contribute valuable information about the damage to buildings. Analysis of video imagery will be carried out in three steps: visual interpretation, digital image processing and further experimental researches. At the end of the chapter, there will be evaluation of the results of these three different methodologies.

7.1. Visual interpretation of video imagery

In the first part of the video analysis, visual interpretation was carried out. This part includes visual interpretation results, discussion about the limitations of the study and comparison of video imagery visual interpretation result in Spot imagery analysis result.

Due to lack of coordinate information of video imagery, visual interpretation was achieved by taking some reference points at the time of the field survey. Before visual interpretation, a part of flight path of the helicopter was estimated (see Figure 7.1). In the visual interpretation process, parcels were categorized in three classes: Non-damaged parcels, heavily damaged parcels and totally collapsed parcels. The result of the visual interpretation is shown in Figure 7.3.

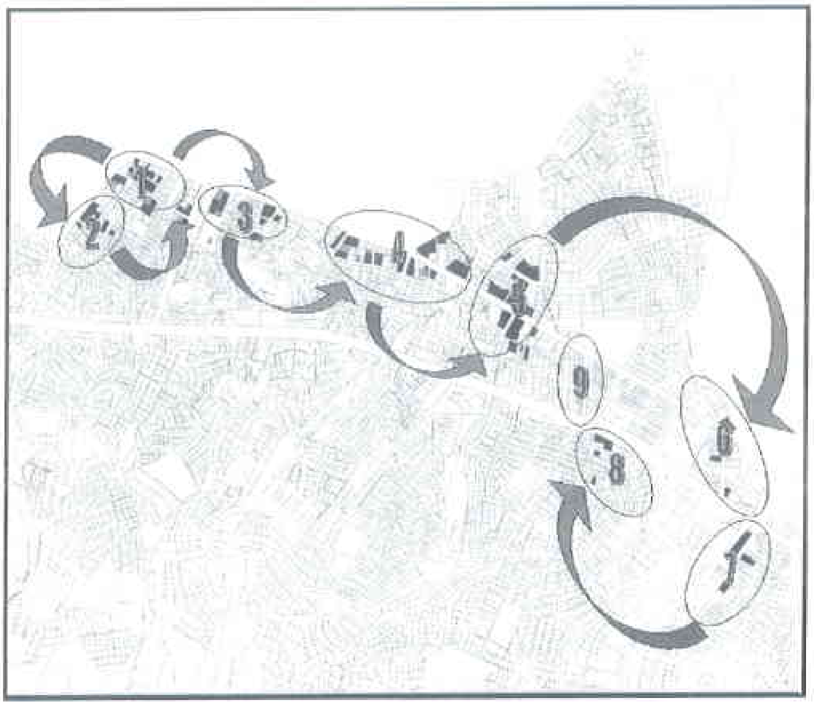


Figure 7.1. Estimated flight path of the helicopter

Seeing the facades of the buildings gives the advantage of differentiation of building damage types, such as pancake, soft story and intermediate story collapse (see Figure 7.5). The main requirement for visual interpretation of video imagery is prior knowledge about the settlement, since video data typically do not contain coordinate information. Moreover, since the imagery was acquired by a media agency, there was no planned flight path. Therefore, it was not possible to assess damage for the whole city. Therefore, contrary to Spot imagery, damage assessment using video imagery was limited for some part of the city. Since a media agency collects information for news, there is always a chance that video imagery could concentrate on the highly damaged areas of the city, making a comprehensive damage assessment impossible. The density of high-rise buildings created a limitation to see all building facades. Moreover, vegetation was another problem for the low-rise buildings, since some of the low-rise building facades were hidden by the trees. These limitations and data acquisition requirements will be further discussed in Chapter 8.

For further investigation, the results of the visual interpretation of video imagery were compared with the result of the change detection analysis based on Spot imagery. In visual interpretation of video imagery, 470 parcels were classified, of which 130 parcels were identified as collapsed. Out of 130 parcels, 50 parcels (38 %) were identified as highly damaged according to change detection analysis. If we include the moderate and slightly damaged parcels, the percentage of parcels defined as damaged reaches 44%. However, 53 % of collapsed parcels were identified as non-damaged in change detection analysis. Therefore, even though Spot imagery provided damage information for the whole settlement, it failed to detect much of the severe damage. Using video imagery can improve the damage information at the local level.

The comparison results were presented in Figure 7.2 and Figure 7.4. The substantial damage in the western part of the city was not detected in the Spot imagery analysis. One reason for this result can be different damage type, pancake collapse, first floor collapse that cannot be detected with Spot imagery due to the vertical view. Although in the western part most of the buildings were tilted or had soft story collapse, in the middle part of the city buildings had totally collapsed. On the other hand, another reason for this failure can be the affect of the smoke.

In conclusion, visual interpretation of video imagery can improve the damage assessment derived from Spot imagery.

Satellite / Video	Highly damaged	Moderately damaged	Slightly damaged	Affected	Excluded	No damage	Total
Collapsed	50 (38%)	4 (2%)	4 (2%)	1 (0.6%)	1 (0.6%)	70 (53%)	130 (100%)
Highly damaged	4 (26%)	0 (0%)	0 (0%)	0 (0%)	1 (0%)	10 (66%)	15 (100%)
No damage	27 (8%)	10 (3%)	12 (3%)	10 (3%)	1 (0.3%)	265 (81%)	325 (100%)

Figure 7.2. Percentage of damaged parcels (according to visual interpretation of video imagery)

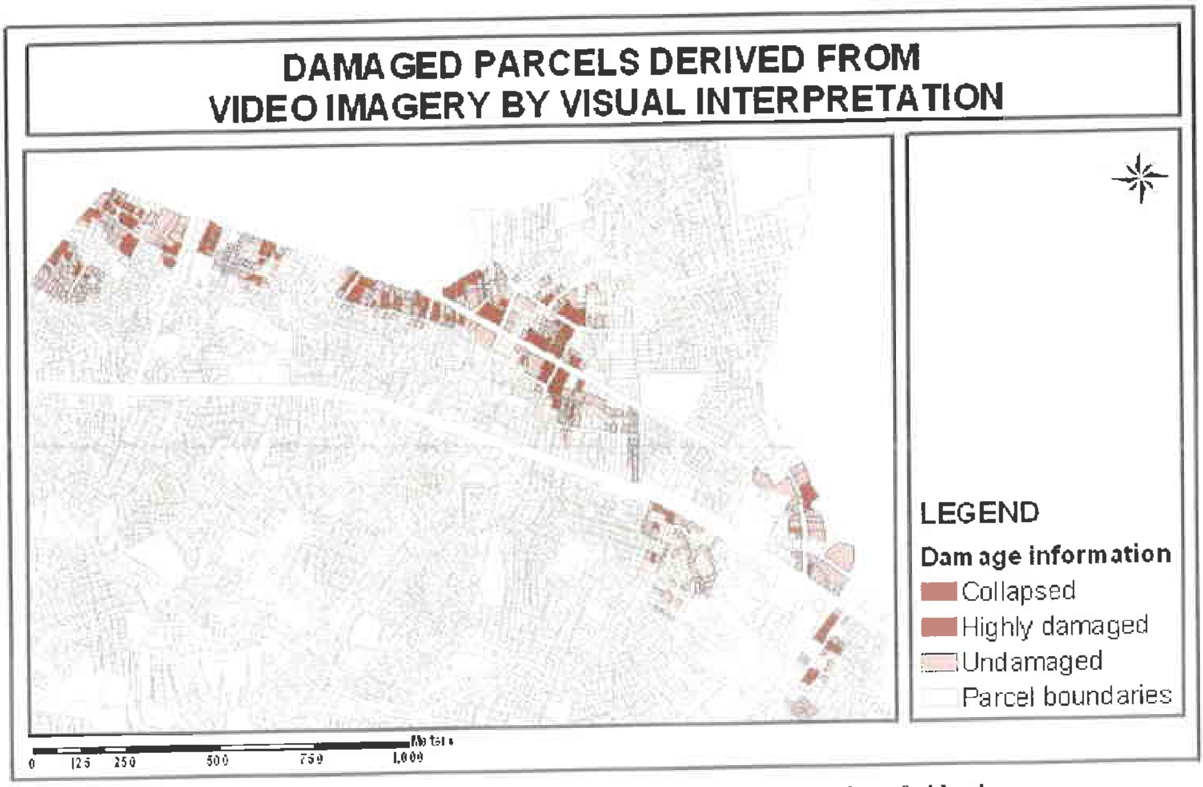


Figure 7.3. Damage information derived from visual interpretation of video imagery

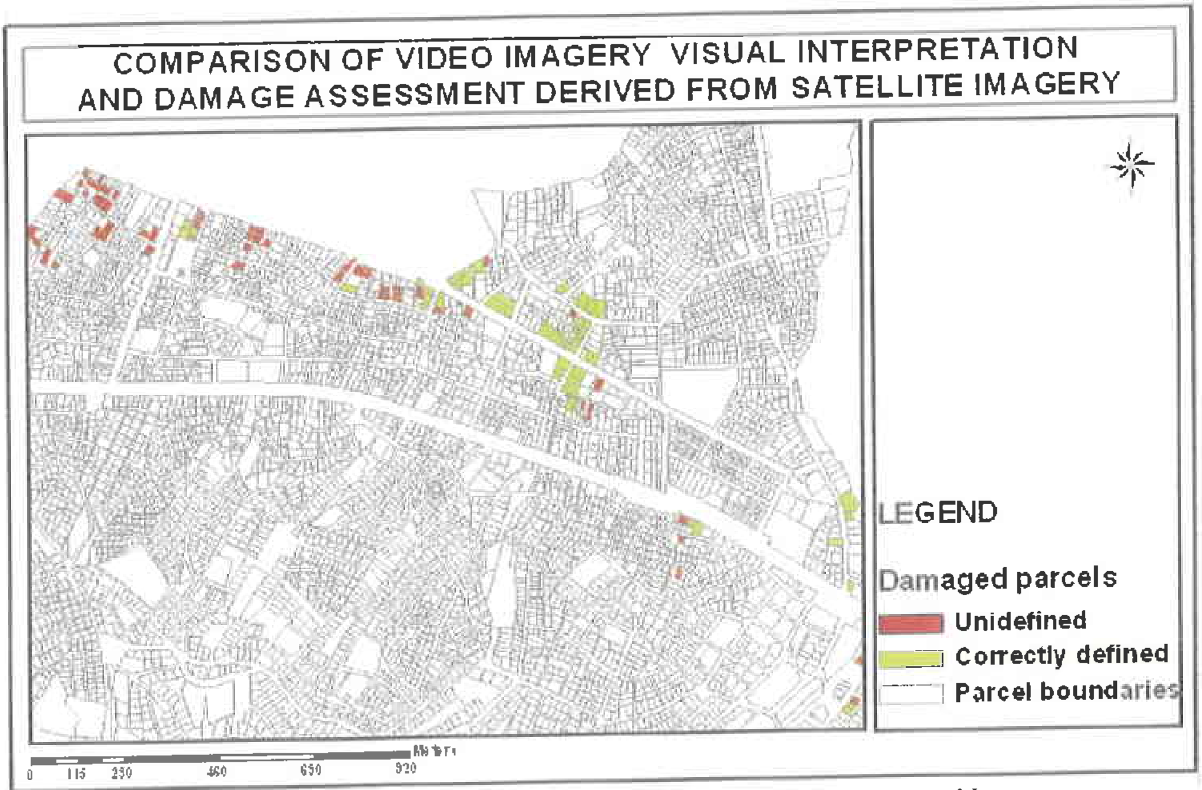


Figure 7.4. Comparison of visual interpretation of video imagery with the result of change detection analysis

Figure 7.5. Characteristic of damage in different part of the city

7.2. Digital image processing of video imagery

In the first part, visual interpretation of video imagery was carried out. Although visual interpretation is a powerful tool to detect damaged areas, it is a time consuming and subjective process. Therefore, in the second part of the video imagery analysis, digital image processing will be applied to detect damaged areas.

Mitomi *et al.* (2000) used colour indices, edge intensity and variance of edge intensity to identify the damaged buildings in the case of the 1999 Kocaeli earthquake, Turkey and 1999 Chi-Chi earthquake, Taiwan. Using training dataset for damaged and undamaged areas, threshold values were determined. Although damage extraction ratio for training data set ranges 55% and 70% in the case of Turkey, in the case of Taiwan the ratio reduces to 12% and 60%. On the other hand, the methodology was tested on only one frame from the whole video imagery. So, it is difficult to say that this threshold values are also valid for other frames or not. Moreover, in the research, threshold values were empirically determined.

Maximum likelihood classification was applied for further improvement of damage extraction from video imagery (Mitomi *et al.*, 2001). The damage extraction ratio in the case of Turkey ranges between 59% and 66%.

The methodology used in this study was based on first approach-defined above.The comparison of results with previous studies will be discussed in section 7.2.3. Damage detection through digital image processing includes mainly three steps: data preparation, data analysis, and evaluation of the results.

7.2.1. Data preparation

The data preparation part includes frame grabbing and image enhancement of the frames, which were derived from analogue video imagery.

Frame grabbing: Frame grapping is a process of extracting digital frames from analogue video imagery, which contains 25 frames per second. Selection of the frames was carried out by visual inspection of quality, as some of the frames had very poor quality due to camera movement and zooming. In the frame grabbing process, Matrox RT2500, which captures analogue frames and converts them to digital format, was used. Six representative frames with different type of damage in different parts of the city were selected to examine the applicability and effectiveness of the methodology for different damage types (see Figure 7.3). In the next step, the two images adjacent to each of the 6 representative frames were also extracted. This resulted in a total of 18 digital frames with 720 x 576 lines.

Image enhancement: For improvement of image quality, Astrostack software was used. Astrostack is a program, which takes a series of images or a piece of video and combines them into one picture. The expected result of stacking of frames is a noisefree and more detailed image (for more information see http://www.innostack.com). In the case of video imagery, changes in rotation and scale of each frame create limitations for layer stacking. Best results were obtained by using a small number of frames (3 or 4). In the stacking process, there are several steps, which are defined by the program itself: loading frames, assessing frame quality, stacking frames, combining frames to picture, and image enhancement. Astrostack uses the universal image quality index, which is designed by modelling any image distortion as a combination of three factors: loss of correlation, luminance distortion, and contrast distortion (Wang & Bovik, 2002). Defining the acceptance threshold for quality assessment, the programme selects the proper frames. In the video frame selection, the quality index was defined at 900, where 1.000 is the highest and given to the reference frame. For the combining of frames to a picture, the mean of the pixel values in different layers was used to calculate the new pixel value. To enhance the result, an image-sharpening mask was used. Figure 7.6 illustrates the image stacking process and its results. For the stacking process, 3 sequences of frames were used. In the resulting image, colour was less washed out and the overall detail and appearance was better. According to quality index, average 3.66% improvement in the image quality was achieved. The highest improvement in quality with 4.5% was in frame 3. On the other hand, as stacking process changes the spectral characteristic of the original data set, it was not possible to use the same threshold values, derived from the stacked ones, to detect damaged areas from the original frames.

Figure 7.6. Image stacking process to enhance the video frames for further image processing

7.2.2. Data analysis

The data analysis part involved selection of feature layer, determination of threshold values, multilevel thresholding and aggregation of results.

The first step in data analysis was the creation of feature layers. Colour indices, edge characteristics and their local variance as a texture feature were produced. At the end of this process, 8 different layers for each representative frame were obtained: Hue, saturation, intensity, edge, hue variance, saturation variance, intensity variance, edge variance. The result of the feature layers was allocated a 1-byte value. The feature layers are provided in Figure 7.8 (for frame 02.06.02). The intensities of edge elements were calculated by a unidirectional Prewitt–gradient filter with 3x3 window size. The texture measure of local areas was carried out by local variance, which is one of the first order statistical parameters for texture measure. Local variance computes the variation in the pixels intensities in the pre-determined window size. Local variance of feature layers including colour indices and edge intensity was analysed for the area of 5x5 pixels. The algorithm for the calculation of local variance is defined as (Erdas, 2002):

$$\text{Variance} = \frac{\sum (X_{ij} - M)^2}{N-1}$$

Where Xij= DN value of pixel (ij)
N = Number of pixels in a window
M = Mean of the moving window
Where

$$Mean = \frac{\sum X_{ij}}{N}$$

For defining threshold values of damaged areas, frame 02.06.02 was taken as a reference frame and some training data sets were selected. According to their mean and standard deviation values, thresholds for each layer were defined. Threshold values were shown in Figure 7.7.

Feature layer	Mean	Standard deviation	Threshold
Hue	82	44	38-126
Intensity	207	50	157-255
Saturation	88	90	0-178
Edge	40	34	6-74
Hue variance	67	36	31-103
Intensity variance	63	37	26-100
Saturation variance	137	61	76-198
Edge variance	12	13	0-25

Figure 7.7. Threshold values of training data set for each feature layer

Hue, saturation variance, edge and edge variance layers were used in multi-thresholding process. The same thresholds were applied to other five frames to assess the effectiveness of the methodology. A 61x61 mean texture window was used to aggregate and to remove spurious pixels derived from the multi-thresholding process. The size of the window (61x61) was decided based on the average building size in the video frame. The result of the analysis of video imagery is provided in Figure 7.9.

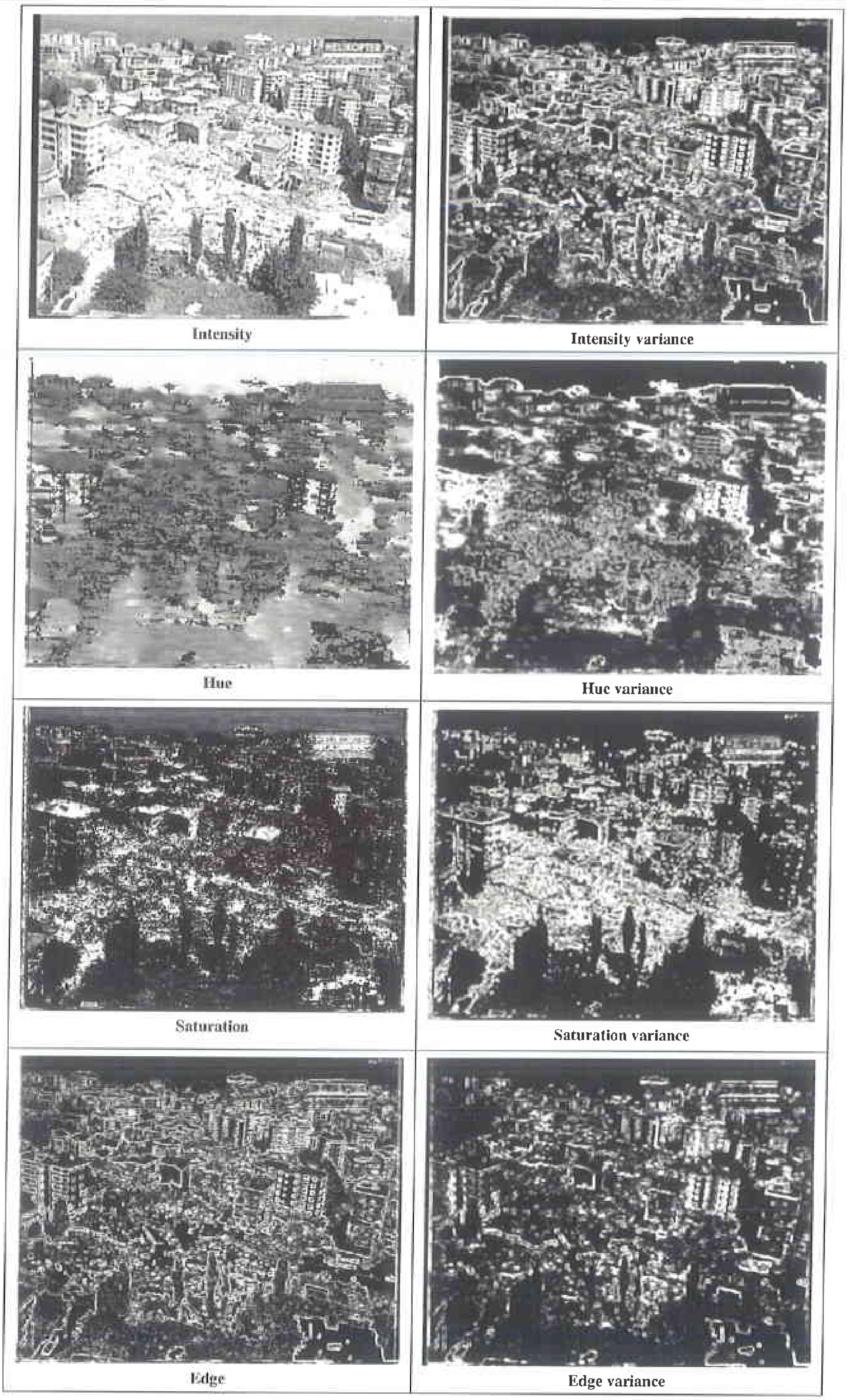


Figure 7.8. Feature layers

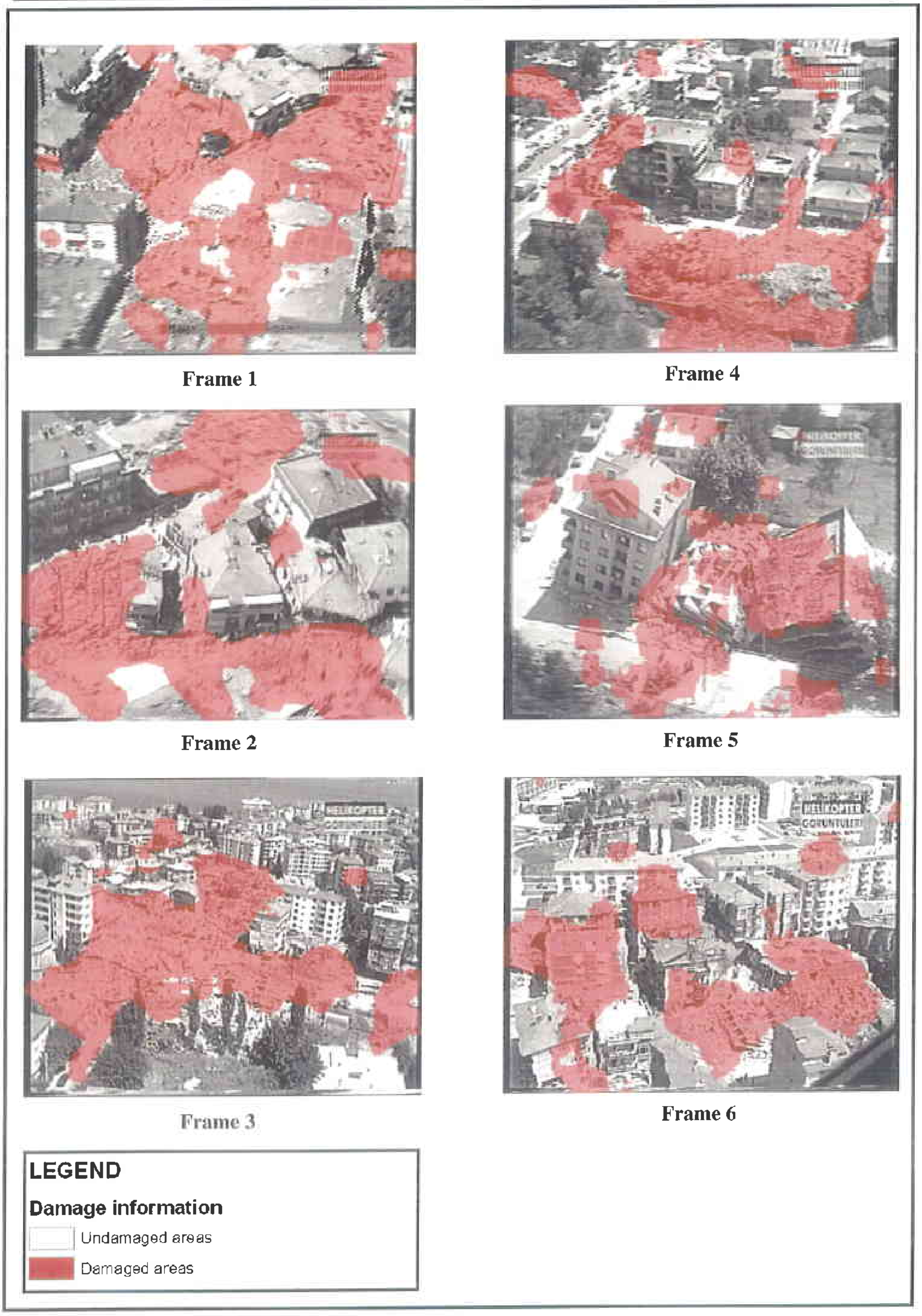


Figure 7.9. Damaged areas derived from the video imagery

7.2.3. Evaluation of video imagery analysis result

To assess the accuracy of the results, actual damage visually identified from the video imagery was digitised. Digitised damaged areas were cross-tabulated with the result of the analyses. The accuracy of each frame is shown in Figure 7.10. The highest overall accuracy was obtained in frame 3 (02.06.02), which was taken as a reference for training data. The lowest overall accuracy was obtained in frame 5 (68%).

These statistical figures show that the damage assessment is much more powerful in the frames, which were taken from a higher elevation, such as frame 3 and 4. The reason for this situation could be an increase in unnecessary details in the frames with close up view, such as chimneys on the roofs, people and cars on the roads. On the other had, another reason for this situation can be the variation in filter window size between frames.

Frame no:	User accuracy (%)	Producer accuracy (%)	Overall accuracy (%)
Frame 1	73	55	69
Frame 2	69	59	70
Frame 3	62	83	86
Frame 4	66	80	85
Frame 5	55	46	68
Frame 6	47	63	78

Figure 7.10.Accuracy of damage assessment derived from video imagery

Besides accuracy assessment, it is also important to distinguish the identified and unidentified damage types. Figure 7.12 shows the correctly identified, unidentified and incorrectly identified damaged areas in each frame. According to the results, analysis of video imagery failed to detect intermediate (Frame 3) and first floor collapse (Frame 1 and frame 5). It is effective in detecting rubble. On the other hand, scale variations between proximal and distal parts of the frame create some failure in damage detection, as some areas in the backside have the same features with rubble. In addition some building facades, which are under construction, were also identified as damaged (Frame 3).

To assess the sensitivity of each layer, the methodology was tested by changing the threshold values of one layer each time. The analysis was carried out on frame 3. The result of the analysis is shown in Figure 7.13. According to the results, saturation variance was the most sensitive feature layer. A change in threshold values in edge and edge variance changed the accuracy only 2%. Changes in the results due to changes in threshold values of feature layers are presented in Figure 7.11.

Layer	User accuracy (%)	Producer accuracy (%)	Overall accuracy (%)
Reference frame 3	62	83	86
Hue	58	83	83
Saturation variance	54	79	81
Edge	60	82	84
Edge variance	58	84	84

Figure 7.11. Change in accuracy due to change in threshold values

For further analyses, the damaged areas derived from sensitivity analyses were compared with the reference frame (Frame 3). According to the comparison, edge and edge variance did not make a significant difference. A change in threshold value in the hue layer resulted in an increase in damaged areas including one building and roof. In the case of saturation variance, even some green areas were detected as damaged. There was no improvement in the damage assessment in all the cases (hue, saturation variance, edge and edge variance) compared with reference frame (see Figure 7.14).

The last evaluation of the results was carried out to assess the improvement in the damage assessment by using image enhancement. The same methodology was applied by using original data set (frame 3). Threshold values were defined according to the training data set derived from the original frame. The result of the analysis shows that the image enhancement applied in the methodology was no contribution in improvement of digital analysis of video imagery. Although the visualization of the stacked image was better than the original ones, the overall, user and producer accuracy was the same, which was obtained in the stacked images. The reason for this situation could be the poor quality of frames used in the process, so they could not improve the quality of original frames as expected. Secondly, the low level of improvement in image quality (the highest improvement: 4.5%) was not enough to improve the result of damage assessment. On the other hand, increase in the visualization through enhancement process can increase the interpretability of the damaged areas, which is important for visual interpretation.

Although the methodology is still data specific, in terms of threshold determination, there are significant improvements compared with previous studies, in terms of accuracy, threshold determination and testing of methodology on different damage types and frames derived from the same video imagery. First of all, in this study, the overall accuracy was between 68% and 86%. Although the total extraction value in Mitomi *et al.* (2000) ranged between 55% and 70%, in this study the ratio (user accuracy) was between 46% and 83%. Secondly, Mitomi *et al.* (2000) defined threshold values in an empirical way. On the other hand, this study used mean and standard deviation of the training data set for threshold determination. Thirdly, in previous studies, methodology and threshold values were tested neither on other frames derived from the same video imagery, nor on different types of damages, such as first story collapse, pancake etc. However, the methodology applied in this study is still depend on the threshold values, which are determined according to training data set derived from specific video imagery. So this threshold values are not valid for all types of video imagery.

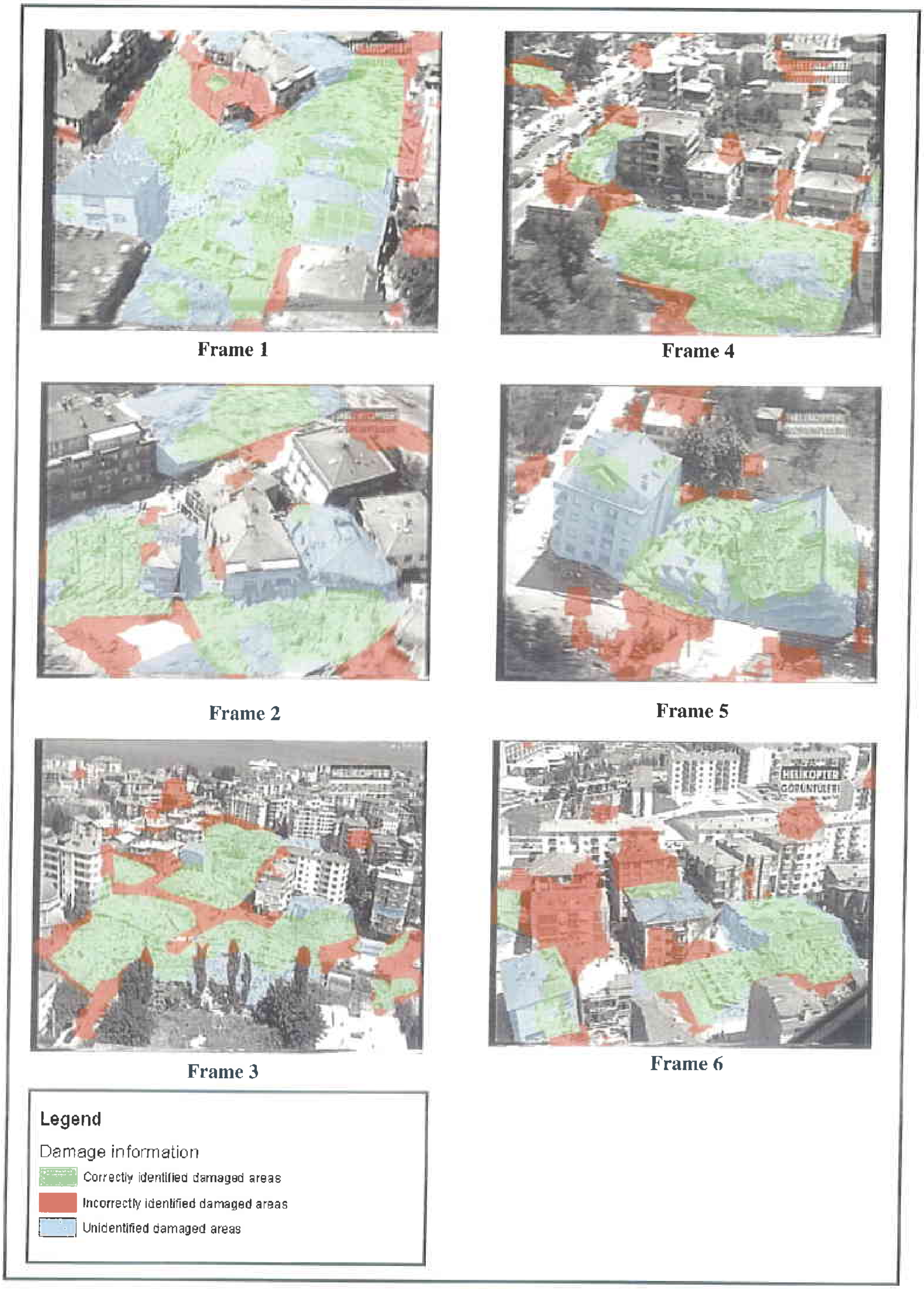


Figure 7.12. Accuracy of video imagery analysis

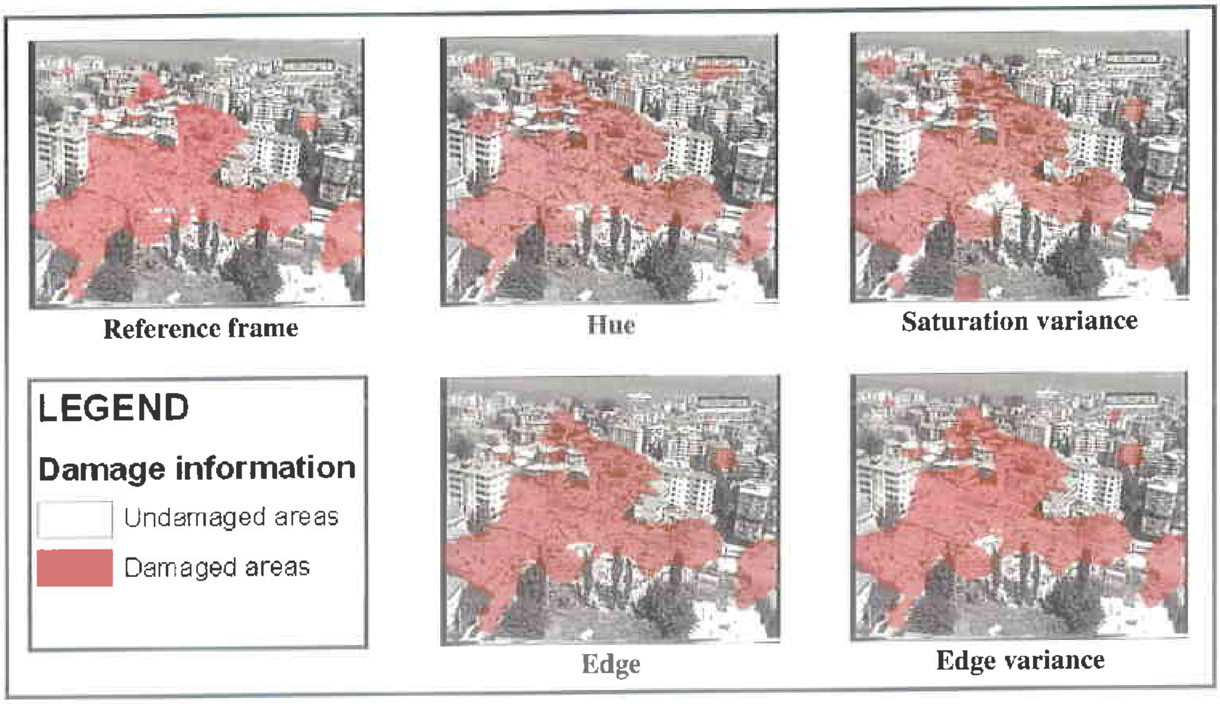


Figure 7.13. Damaged areas derived by changing threshold in one feature layer

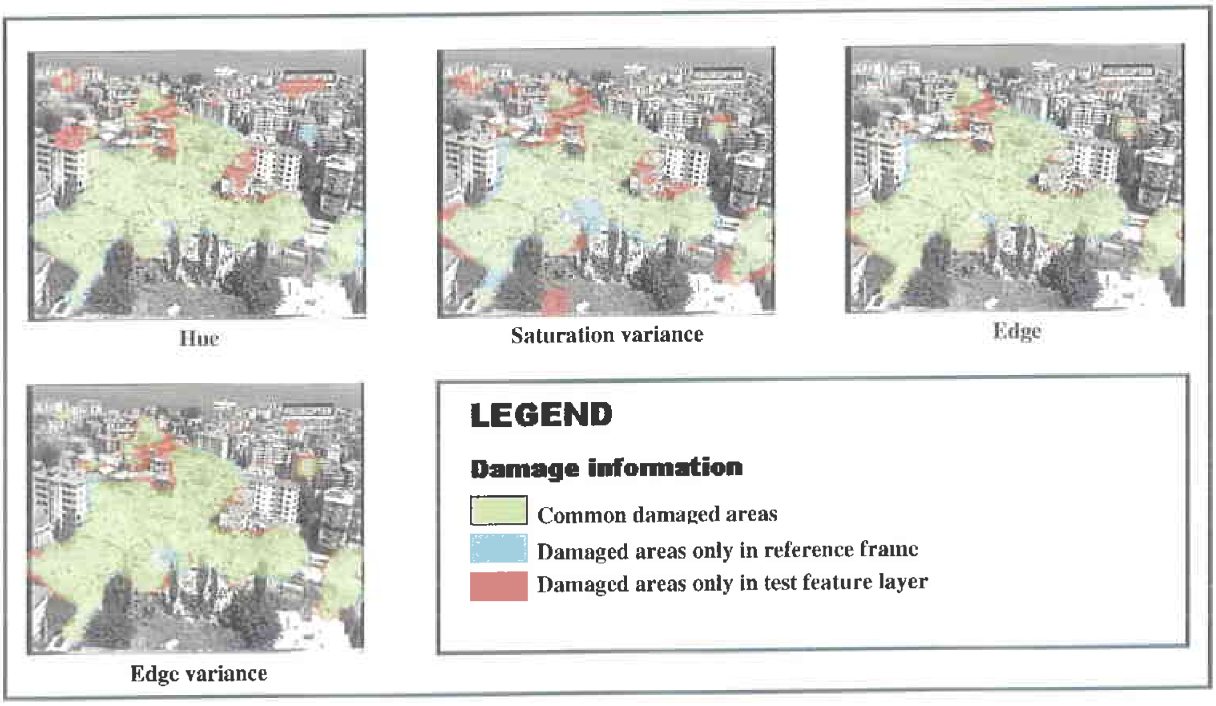


Figure 7.14. Comparison of result of sensitivity analysis with reference frame

7.3. Further experiments

In the previous part of the analysis, damage information was derived by using colour indices, edge intensities and their local variances. The threshold values were determined according to training data set. On the other hand, it is obvious that these threshold values are not ideal for every video imagery, due to differences in the illumination, video camera used and scale of imagery. Therefore in this part of the research, there will be some explanation on the experiments on finding a generic methodology, which does not depend on the specific characteristic of the imagery.

7.3.1. Conditional unidirectional local variance

The first experiment was done by using the conditional unidirectional local variance, which calculates the average absolute value differences of neighbouring pixels on each side. Unidirectional local variance was successfully applied to detect textural features of trees from aerial images (Zhang, 1999). In that study, the classification accuracy increased from 67%, by a multispectral classification, to 96%, by the texture integrated classification method. The main idea behind conditional unidirectional local variance is to eliminate the areas, which are located either in a homogenous area or on a line on the side of the structures. The same logic is also applicable for damaged areas, where the homogeneity of areas and lines of the structures have disappeared. In the unidirectional variance detection the pixel variance on each side of the central pixel is first calculated. When the variance value on one of the four sides is less then a threshold, this pixel is eliminated from variance calculation.

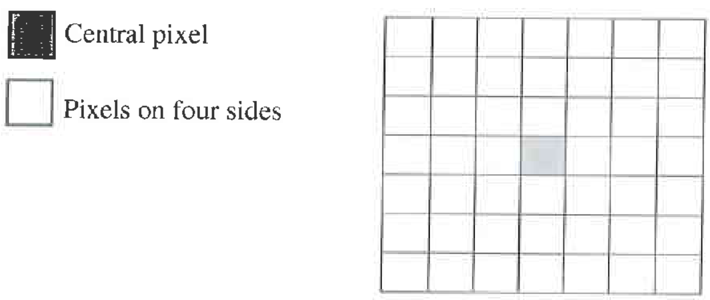


Figure 7.15. Operation window for calculating the unidirectional variance on each of four sides (Zhang, 1999)

The algorithm for calculation of unidirectional local variance;

$$UdVar = \frac{1}{n}\sum_{i=-n}^{n-1}\left|f_{(i,j)} - f_{(i+1,j)}\right|$$

$i<0, j=0$, for the left side; $i>=0, j=0$ for the right side

$$UdVar = \frac{1}{n}\sum_{j=-n}^{n-1}\left|f_{(i,j)} - f_{(i,j+1)}\right|$$

$i=0, j<0$, for the upper side; $i=0, j>=0$ for the down side

The result of the unidirectional local variance was not successful to detect damaged areas. Figure 7.17 illustrates the result of conditional unidirectional local variance. The expected output was the elimination of lines belonging to the buildings. Although most of the lines were eliminated (compare with Figure 7.16), the rest was not able to give any identification of damaged areas. One of the reasons for this failure is the scale variation in the frames. In the backside of the frame the lines belonging to structures and the homogeneity of the areas also decrease like in damaged areas. Scale differentiation requires further experiments with a using different size of moving window over the frame. Another reason was that the methodology takes into account mainly horizontal and vertical directions. But in the case of video imagery, lines are not necessarily in the horizontal or vertical direction due to the oblique characteristic of the frame and lack of camera stability leading to frame rotation.

Figure 7.16. Intensity variance

Figure 7.17. The result of conditional unidirectional local variance

7.3.2. Line detection

The second experiment was carried out by using line detection. The main consideration was to exclude the lines belonging to undamaged buildings to derive the damaged areas. A simple line detection kernel was applied (see Figure 7.18).

$$\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}$$

Northwest diagonal

$$\begin{bmatrix} -1 & -1 & 2 \\ -1 & 2 & -1 \\ 2 & -1 & -1 \end{bmatrix}$$

Northeast diagonal

$$\begin{bmatrix} -1 & 2 & -1 \\ -1 & 2 & -1 \\ -1 & 2 & -1 \end{bmatrix}$$

Vertical

$$\begin{bmatrix} -1 & -1 & -1 \\ 2 & 2 & 2 \\ -1 & -1 & -1 \end{bmatrix}$$

Horizontal

Figure 7.18. Line detection kernels used in the analysis

Line detection layers in four directions were thresholded to eliminate the lines. But the result was also unsuccessful (see Figure 7.19). Although the lines of the buildings were eliminated successfully, the rest was homogeneously distributed noise and was not useful for detecting damaged areas. One of the reasons for this failure was the poor resolution of the video imagery. Moreover, most of the lines were wider than one pixel. The same limitations mentioned in the previous experiment were also valid for line detection, such as scale differentiation and oblique characteristic of video scene.

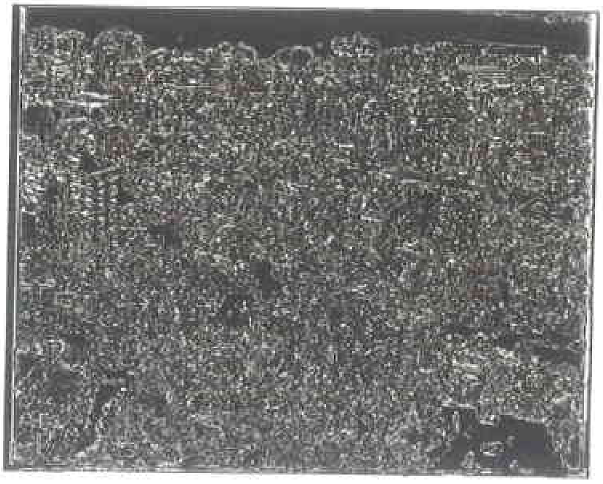


Figure 7.19. Elimination of detected lines

7.3.3. Local binary patterns and contrast

The final experiment focused on contrast (C) and local binary patterns (LBP), which provide knowledge about the spatial structure of the local image texture. These simple spatial operators were used in image texture segmentation (Pietikainen & Ojala, 2003). The methodology was also applied in segmentation of natural scenes. Pietikainen & Ojala (2003) concluded that the distributions of local spatial patterns and contrast play very important complementary roles in texture discrimination. The main consideration of this experiment was to discriminate damaged and undamaged areas using textural features. The calculation of LBP is shown in Figure 7.20. The pixels in the neighborhood are thresholded by the value of the center pixel. If the neighboring pixel value is higher than the center pixel value, its value is assigned to 1. If the neighboring pixel value is lower than the center pixel value, it is assigned to 0. After multiplication with the corresponding weights, all values are summed to obtain a number for the center pixel.

Example

6	5	2
7	6	1
9	3	7

Thresholded

1	0	0
1		0
1	0	1

Weights

1	0	0
8		0
32	0	128

LBP = 1+8+32+128 =169
C = (6+7+9+7) / 4-(5+2+1+3) / 4 = 4.5

Figure 7.20. Computation of Local Binary Patterns (LBP) and Contrast measure(C)
(Pietikainen & Ojala, 2003)

The result of the application of the LBP and C to video imagery was not successful (see Figure 7.21). There are several reasons for this failure. First of all, in the urban scenes there are substantially different types of texture patterns. In urban areas, patterns do not have homogenous texture characteristics, which is the case in the nature scene. Moreover, the size of the texture pattern, such as building itself or part of the buildings, is quite large. On the other hand, boundaries between different textures in the video scene were almost unrecognizable.

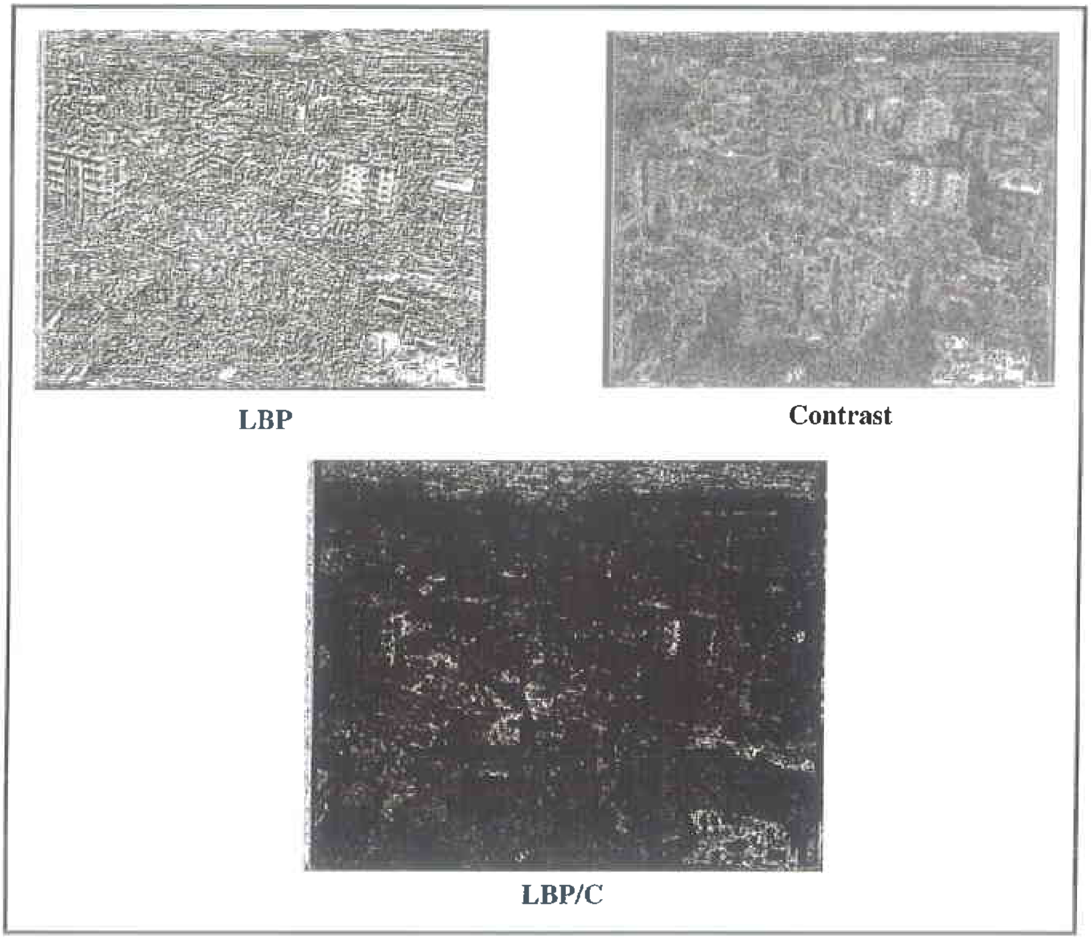


Figure 7.21. Local binary pattern and contrast layers

In conclusion, all the methodologies applied in this part (unidirectional local variance, change detection, local binary patterns and contrast) failed to detect damaged areas. Data characteristics, such as high obliquity, poor resolution, heterogonous texture characteristics, were the main obstacles. In the next part, there will be a summary of all methodologies applied in video imagery analysis and evaluation of the results.

7.4. Conclusion

In this chapter, aerial video imagery, taken by a media agency on the same day as the earthquake, was analyzed by visual interpretation and digital image processing to assess the damaged areas at the local level. In the third step further experimental research was carried out.

The main limitation of using video imagery taken by a media was lack of geographic coordinate information. It was therefore important to have prior knowledge about the area to locate the frames on the map. The lack of camera parameters, the unorganized flight path, unstable camera, and zoom in-out action of the camera were other obstacles for data analysis. Moreover, as the media agency collects information for the news not for the damage assessment, there was more concentration on highly damaged or collapsed buildings in the video imagery. Therefore, damage assessment did not cover the whole city in contrast to the Spot imagery. Damage assessment was therefore only possible for some part of the city.

The result of visual interpretation of video imagery shows that it can improve damage assessment derived from Spot imagery. It is powerful, in terms of detecting different type of damages, which is visible from building facades, such as pancake, intermediate and soft story collapse etc. Use of an expert on damage assessment can improve visual damage assessment. On the other hand, high-rise buildings in neighbourhood with high density and vegetation were the main obstacles for visual interpretation, as it was not possible to see the buildings behind high-rise structures or vegetation. Therefore, it was much easier to detect damaged buildings in neighbourhoods with low density. Due to lack of technical parameters, such as camera parameter and flight path information, prior knowledge, were used to locate video frames on the map. Although visual interpretation is powerful in detecting damaged areas, it is subjective and time-consuming process especially in the time of emergency.

Digital analysis of video imagery can overcome the limitations of visual interpretation, in terms of time requirement and subjectivity. The result of digital analysis of video imagery shows that it is useful for detecting totally collapsed buildings with rubble. Even though other damage types, such as first story or intermediate story collapse, could not be reliably detected, compared with Spot imagery analysis there were significant improvement in damage assessment. The accuracy of the damage assessment ranges between 68% and 86%. Moreover, the accuracy of damage assessment of frames taken from higher altitude was significantly higher than the ones taken from lower altitude. Besides poor quality of the video frames, movement of helicopter, unstable camera and zoom in and out function of the camera were the main obstacles for digital image processing. Stacking process for enhancement of the video imagery slightly improved image quality, but could not improve the result of digital image processing for damage detection. However, visual enhancement of the frames, derived from stacking process, can contribute valuable information for visual interpretation process. Moreover, highly oblique characteristic of the imagery and scale variations in and between frames created difficulties in data analyzing. Although the methodology still depends on the data specific threshold values, there are significant improvements compared with previous studies, in terms of accuracy, threshold determination and testing on different type of damages and frames derived from the same video imagery.

In the third part of the study, further experimental research was carried on to improve the result of damage assessment derived in the previous part. The main concern was to find a generic methodology using geometry of the damaged and undamaged structures. Conditional unidirectional local variance, line detection, local binary patterns (LBP) and contrast (C) were used to detect damaged areas. However, all the methods failed to detect damaged areas. Oblique characteristic resulting in scale variation in frames, lines in all direction, poor resolution, heterogeneous and large size pattern characteristics of urban scene, and lack of clear boundary between different patterns were main obstacles in the analysis.

In conclusion, three different approaches starting from very simple (visual interpretation) to more complicated ones (unidirectional local variance, line detection, LBP and C) were applied to detect damaged areas from video imagery. The result of the analysis shows that increase in complexity of analysis did not improve damage information. Simple methods such as visual interpretation and threshold-based classification provide better results than more complex ones. Although visual interpretation is subjective and time consuming, using expertise and prior knowledge about damage types in visual interpretation provide valuable information. The second methodology is better, in terms of computerized process due to data characteristics, objectivity and time requirement. Although there are several difficulties in digital image processing, still it is promising and encouraging for further research, as it improved damage assessment compared with Spot imagery.

In the final chapter, there will be an assessment and discussion of user information requirement, Spot and aerial video imagery analysis results. For further improvement of damage assessment, methodology used in this research will be discussed.

8. Conclusions and discussions

8.1. Introduction

The motivation of the study comes from the need for rapid, accurate and reliable information about the affected areas in the critical hours after a strong earthquake. On the other hand, in reality it is not always possible to get proper information due to the damage on communication and transportation systems. Moreover, the information coming from different sources creates confusions and reduces the reliability of the information. In this point, remote sensing is a useful tool to get information, as it does not depend on the infrastructure within the disaster area. However, every sensor has its own limitation, in terms of spectral, spatial and temporal resolution. So, it is difficult to fulfil the information requirements by using only one data source.

Under these conditions, the main objective of the study was to integrate space-borne and airborne imagery to improve damage assessment at the regional and local level. Moreover, it also aimed to define the user information requirements, since information is only valuable whenever the user uses it effectively. Other secondary objective of the study was to define the damage levels, which can be derived from space-borne, and airborne imagery.

The research was carried out in the case of the 1999 Kocaeli earthquake, Turkey, which resulted in approximately 15.000 fatalities and 40.000 collapsed buildings. The devastating earthquake with a magnitude of 7.4 affected mainly 4 provinces situated in the north-western part of Turkey, which is characterized by high industrialization and urbanization rates. At the local level, Golcuk and its environs, which was one of the most damaged towns with 5.000 fatalities and 2.300 collapsed buildings, was selected as a case study area for the local level analysis.

Pre and post-earthquake Spot imagery and aerial video imagery taken by a media agency on the same day after the earthquake were used to detect damaged areas. The data selection was mainly based on two criteria: regional effects of the earthquake, and 3D characteristics of building damage. Due to the synoptic coverage of Spot imagery, it was used to assess damage at a regional level. Moreover, the cost of high spatial resolution data was considered as a limitation to use in practical life for a developing country. Secondly, to improve the damage assessment at the local level, aerial video imagery, which can overcome the vertical viewing limitations of satellite imagery, was selected. In addition, the low cost of data acquisition and rapid response capability were other consideration in the selection of aerial video imagery. For an evaluation of the results, damage information and vector data at regional and local levels were used.

The study includes mainly four parts: (i) analysis of user information requirement, (ii) analysis of Spot imagery, (iii) analysis of aerial video imagery and (iv) evaluation of results of last three parts.

In the first part of the study, the analysis of user information requirements was carried out by interviewing key informants from emergency agencies at different level of the government hierarchy in Turkey. Data requirements, in terms of time, scale, and format were investigated. Moreover, for an effective use of information, the current situation of the organization, in terms of technical capacity and expertise was examined.

In the second part, pre and post-earthquake Spot imagery were analysed using change detection methodology. The results were evaluated at the regional and local level. At the regional level, recognizable damage in settlement hierarchy (village, municipality and district level) was investigated. At the local level, detectable damage using Spot imagery was examined.

In the third part of study, to improve damage assessment at the local level, aerial video imagery was analysed by visual interpretation and digital image processing. Further experimental research was carried on to enhance the digital image processing result.

In the fourth part, which follows later in this chapter, the findings of the first three parts are summarized and evaluated according to the user information requirements. Moreover, the results are discussed, in terms of limitations of the research and requirements for improvement of damage assessment.

8.2. Main findings

Main findings of the research are summarized in three parts; analysis of user information requirements, Spot imagery and aerial video imagery.

8.2.1. Analysis of user information requirements

- Analysis of user information requirement shows that there are significant variations of information requirements according to type of the activity and different level of governmental hierarchy.

- Moreover, information derived from remote sensing is not enough by itself to fulfil the information need of the end user. There is a need for integration with base line data, such as population, density, land use etc.

- The required accuracy of the information increases for lower levels of government hierarchy. Although at the national level the overall information about affected population was enough to organize the activities, at the local level there is a need for more accurate and detailed information based on neighbourhood or address. Search and rescue teams need to know the location of collapsed buildings, type of collapse, potential number of people in the rubble, and use of building. Contrary to search and rescue teams, the Red Crescent Society needs to know the number of people survived from disaster to serve accommodation, medication and food.

- The time limitation for getting information about damage is approximately 24 hour. Decision makers need to get information for organization of appropriate activities. Timeliness is the most important characteristic of required information compared with detail and accuracy.

- To provide information is not enough by itself without organizational change of the current situation. For effective use of information in data gathering, sharing, analysing and dissemination, there is a need for improvement, in terms of information management, technical infrastructure and expertise. Expenses for these improvements are the main constraint.

8.2.2. Analysis of Spot imagery

- Analysis of Spot imagery using change detection methodology shows both significant overestimation and underestimation of damaged areas. The main reasons for this situation were the difference in incidence angle between pre and post-imagery, smoke, clouds and orthorectification requirement for hilly areas. These external factors reduce the interpretability of results, as it is difficult to differentiate actual change values and spurious change values.

- Smoke due to fire in the Tupras Oil Refinery affected the western part of the image. It caused failure in detecting damage in settlements covered by the smoke.
- Clouds and shadows were other external factors for failure. Although clouds were detected as positive change areas, shadows were detected as negative change.
- There was also overestimation of damaged areas in rough terrain, especially in the northern part of the imagery. Compared with rough terrain, flat terrain gave better results.

- Regional level analysis:
  - Spot imagery failed to detect damage in villages. Some villages are not recognizable at all in Spot imagery without vector data integration.
  - Positive change of pre and post-intensity values (indicating damage) were observed in built-up areas at the municipal and district level.
- Local level analysis:
  - The highest correlation (0.2; even though it is still very low) between damage level 5 (destruction, see Appendix 9) and change detection results was observed.
  - The damage in the central part of Golcuk was overestimated. There was also failure in detecting damage in the north-western part of the city. The reason for this situation is most likely smoke, or a different type of damage, such as pancake and first floor collapse.
  - The comparison of the result of Spot imagery analysis with the result of video imagery visual interpretation shows that more than 50% of collapsed buildings were not detected by the Spot imagery analysis.
- Another important result is that the contribution of vector data is valuable for the further interpretation and visualization of results. Without any vector data integration, it is very difficult to locate the damaged areas.
- Change detection analysis gives information about the change values of the pixels, not about the nature of damage or type of the damage.

8.2.3. Analysis of video imagery

- Visual interpretation:
  - Using video imagery, visual interpretation can improve the damage assessment. Although it is a time consuming process, it can give information about the type and degree of damage, which cannot be derived from Spot imagery.
  - One disadvantage of using video imagery is that it is typically not possible to survey a whole city, as is possible with Spot imagery. Moreover, unplanned nature of the video data captured by media agency resulted in narrower coverage area compared with Spot imagery. Therefore, damage assessment was carried out only for some part of the city by using video imagery captured by media. There is always a possibility of concentrating on highly damaged or well-known areas.

- Vegetation, high-rise buildings and the high density of structures and create limitation to see the building facades. Especially, to detect first floor collapse of buildings in the back-side was difficult. Moreover, high-rise buildings were an obstacle for the damaged buildings situated behind. Trees situated in front of the buildings were another limitation for detecting damage from façade. Therefore, it is not always possible to assess building damage due to occlusion.
- The method is more useful for low-density areas, such as the north-eastern part of the city.
- Due to lack of coordinate information, prior knowledge of the areas was necessary to locate damaged areas onto map.

➢ Digital image processing

- It is useful for detecting totally collapsed buildings, especially for detecting rubble.
- There was a failure in detecting first and intermediate story collapse, as the structure of the buildings hardly changes.
- The overall accuracy ranges between 68% and 86%. User accuracy ranges between 47% and 73%. Producer accuracy ranges between 46% and 83%.
- The low quality of the image and low altitude of the image acquisition, movements of the helicopter, rotation of the camera, zooming in or out and scale variation in and between frames create difficulties in digital image processing.
- Lack of camera calibration parameter, flight path details, in terms of height, looking angle, and high oblique viewing characteristic create limitation for georeferencing the highly oblique video images.

8.3. Discussions

In this part, the results will be discussed under four sub-sections: (i) user information requirements, (ii) organizational requirements, (iii) data requirements, and (iv) methodology perspective.

8.3.1. User information requirements perspective

In this part, the results of the Spot imagery analysis and aerial video imagery will be evaluated according to user information requirements, to assess the usefulness of information derived from remotely sensed data.

Spot imagery can be useful for national agencies to get an overall idea about the damaged areas. On the other hand, to differentiate the actual damage and spurious change values, and evaluate the results, there is a need for vector data integration. Moreover, GIS data integration increases the value of information to estimate the potentially affected population. This estimation may not be accurate, but it can provide information for first insight.

Spot imagery will not be enough for regional and local emergency activities, as they need more detailed and accurate information compared with the one at the national level. Video imagery can provide more useful and detailed information for emergency agencies at the regional and local level.

For search and rescue operations, it is more important to know about collapse type, use of the building, potential number of people in the rubble. In this aspect, Spot imagery analysis will not give appropriate information, as to differentiate collapse types is not possible due to vertical viewing characteristic. Video imagery combined with prior knowledge or expertise on damage can provide valuable and more detailed information to search and rescue teams. Viewing façade of the buildings from video imagery is helpful to differentiate damage types. In addition, integration of video imagery with GPS can improve the value of information, as search and rescue teams need to know the exact location of collapsed buildings. Moreover, laser as an alternative data source can provide valuable information to search and rescue teams. Laser data give information about volumnia change in the damage, which is useful to decide the operation type or possibility of finding alive people in the rubble. On the other hand, each additional data will increase the cost of the information, which is a constraint for application in limited budget of developing countries.

For the Red Crescent activities, there is a need for information at a neighbourhood level on the population that survived the event. To estimate survived population, it is important to identify collapsed or highly damaged buildings. In this point, Spot imagery may not be helpful to Red Crescent Society, as it cannot provide accurate and detailed information at the neighbourhood level. However, video imagery can provide valuable information. But only damage information is not enough by itself, it should be integrated with baseline data, such as population. Besides damage information, video imagery can also provide information for site selection of temporary accommodation, public kitchen and medication centres.

Neither Spot imagery nor aerial video imagery can fulfil the information requirement of formal damage assessment activities, which aim to define the right of ownership. They need to know all types of structural damage of each unit, which requires ground surveys of each and every unit in the buildings. On the other hand, video imagery can guide the effective distribution of field survey teams depending on the damage level in different parts of the city.

As it can be seen in the previous part, remote sensing data is not enough by itself to fulfil the information requirement of end user. The integration of damage information with base line data, which shows the pre-disaster situation (such as demographic information, transportation routes, land use, geology map, land registration map) is useful to assess the damaged areas after disaster. Moreover, the severe time constraint has a critical importance for data gathering and dissemination at the time of emergency.

In conclusion, moderate-resolution optical satellite imagery has still limitation for use in emergency activities. Aerial video imagery is a much more powerful tool to detect damaged areas, in terms of time requirement for data acquisition and amount of damage information. Although using video imagery may not enough for complete damage assessment, it can be useful to organize the activities at strategic level, such as guiding damage assessment and search and rescue teams according to the first damage indications derived from aerial video imagery.

8.3.2. Organizational requirements perspective

In the first part, results of the analysis were compared with the end-user information requirements. The main discussion was established on how remotely sensed data can be useful for the users, who take a role in emergency activities. On the other hand, for effective use information derived from the remotely sensed data, it should be disseminated to the appropriate user, in the proper format and at the proper time. In this part, main organizational requirements will be discussed.

Rapid information dissemination requirements for emergency activities are a basic issue for effective emergency management. For effective sharing and access of information (both remote sensing and base line data) between different types of user, there is a need for the establishment of emergency information systems at the national, regional and local level. Standardization of data formats can make it easier to share and effectively use information between users. As time is the most important criteria for data gathering in the emergency situation, data networks between users can speed up data gathering process. Moreover, the World Wide Web (www) provides an important platform for information network and data exchange (Montoya & Masser, 2000). In the current situation, it is also possible to use established, largely Internet-based, information networks, such as Reuter's Alertnet (http://www.alertnet.org) and ReliefWeb (http://www.reliefweb.int; (Kerle & Oppenheimer, 2002).

Besides these technical requirements, limited awareness of emergency managers about remote sensing technology and its potential use is another constraint for use of remote sensing in emergency management activities. Improvement of remote sensing knowledge of emergency managers can lead to more efficient use of information.

Coordination between emergency agencies and legal arrangements for defining responsibilities of each emergency agency are other organizational requirements for efficient disaster management. Unorganised activities of emergency agencies result in loss of time, effort and money due to repetition of works carried out by different agencies.

Wakana *et al.* (2002) presents a disaster monitoring, management and mitigation system (DM3), which includes airborne video and still photo data acquisition, relay from the aircraft via Ka-band satellite communications, and a model disaster management centre, which houses a computer data base accessible from the internet. In the system, disaster information collected in the disaster management centre is delivered though Internet to the professional organizations and to the users in the real time. Although it is a promising system from a disaster management point of view, the technical requirements for such a system are quite high for a developing country. The concept of DM3 is provided in Figure 8.1.

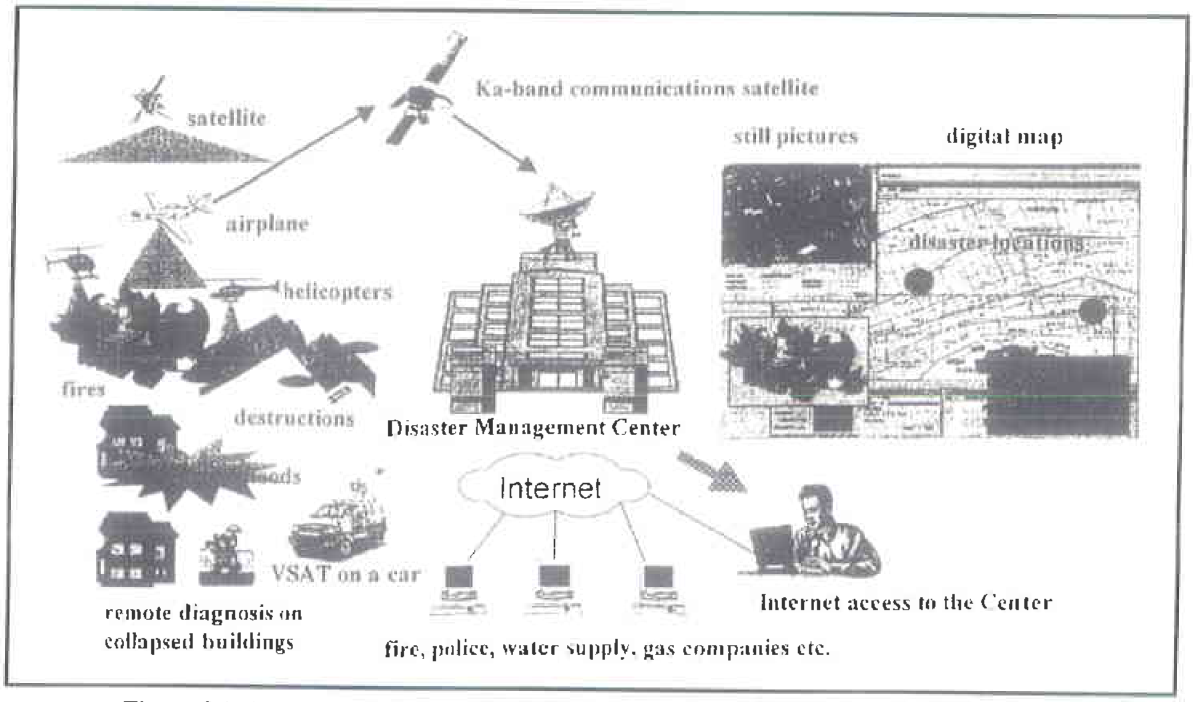


Figure 8.1. A concept of the disaster monitoring, management and mitigation system
(Wakana *et al.*, 2002)

In conclusion, there is a need for improvement in the organizational structures of emergency agencies for an efficient use of remote sensing technology in emergency activities. The author thinks that one proposal for this improvement can be the establishment of disaster management centre at the national level. In the case of Turkey, the General Directorate of Turkish Emergency Management is already in charge of the coordination of emergency activities. Improvement can be achieved under this agency through:

- Establishment of download and processing facilities for remote sensing data;
- Setting up of a spatial database for different base line data that users need at the national level;
- Establishment of information network between all emergency agencies at the international, national, regional and local level;
- Preparation of an imagery archive;
- Providing education for emergency manager about disaster management, emergency information system, remote sensing;
- Setting up of procedures to be used after a disaster.

It can play an important role not only for easy access and sharing of information for all end user from one centre, but also for effective emergency management.

8.3.3. Data requirements perspective

One of the major characteristics of data requirements for post-earthquake damage assessment is the rapid response capability after disaster. The limited revisit time of satellites is an obstacle for real time applications. The cost of high spatial resolution data (such as Ikonos and Quickbird), which is preferable for urban applications, is another limitation for most developing countries. Moreover, even use of high spatial resolution data is limited in detecting damaged buildings due to vertical viewing characteristics. Especially in the case of pancake, first and intermediate floor collapsed buildings with intact roofs, vertical view is not enough to assess the damage.

On the other hand, the International Charter on Space and Major Disaster, which aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through authorized users without payment, is promising for faster data gathering after a disaster (http://www.disasterscharter.org). Moreover, current developments, such as the Disaster Monitoring Constellation (DMC), which allows one-day temporal resolution has a substantial potential for use of remote sensing technology in emergency activities. Turkey has joined the DMC with the first Turkish Earth observation satellite, BILSAT, which was launched in October 2003 (http://www.bilten.metu.edu.tr).

Although there is significant progress in satellite imagery, in terms of spatial resolution, and revisit time, the study on post-earthquake damage assessment in the case of the 1999 Kocaeli earthquake has shown that the use of satellite imagery is still limited due to external factors. Moreover, the 3D characteristics of building damage are one of the major constraints for satellite imagery application.

As an alternative to satellite imagery, airborne systems can overcome some of the limitations with flexible revisit times. Moreover, façade-viewing characteristics of aerial video imagery improve damage assessment at the local level. The low cost of data acquisition is another advantage compared with satellite imagery.

However, data used in the study were acquired by a media agency. Therefore, the major aim was collecting information for news, not for damage assessment. Lack of coordinate information, an unstable camera and an unplanned flight path were major constraints for the application. For future operational use of video imagery in damage assessment, there is a need for detailed inventory videography. Ham (1998) summarizes the requirements for detailed inventory videography;

- Requires precise scaling and georeferencing;
- Needs differentially corrected GPS (with the accuracy of 3-10 m) and laser altimeter;
- Higher accuracy mapping requires aircraft motion to be measured and compensated for; gyroscope for pitch and roll, compass for azimuth, high quality GPS.

Moreover, a constant flight height (maximum flight height is normally 500 metres with corresponding ground coverage of 250-300 metres; (Ham, 1998) is recommended to keep the scale constant over the study area. Moreover, stabilization of the camera will increase the image quality (less blurred and higher contrast). In addition, for complete damage assessment of the whole settlement, there is a need for flight path planning. A first inventory can be done along the streets for the whole settlement. Later on, more emphasize can be given to damaged areas. Data acquisition can be carried out by military or civil defence agencies. After data acquisition, it can directly be connected to the disaster management centre to share the data with other users.

Another alternative for local data acquisition can be laser integration with aerial digital camera. Although the cost of this alternative is very high, it can improve damage assessment. Height information derived from laser data can give information about volume change, which is important for search and rescue teams (Steinle *et al.*, 2001).

Moreover, a cheaper (and may be the most practical one) alternative to the previous one can be small format aerial photography. Besides its low cost, it does not require a complex preparation phase for data acquisition. It can be useful for initial damage assessment.

In conclusion, there are significant limitations for use of moderate-resolution optical satellite imagery in post-earthquake damage assessment, in terms of external factors, revisit time, cost, and vertical viewing characteristic. Current developments in space- borne imaging are promising for use of satellite imagery in emergency activities. Aerial video imagery can improve damage assessment compared with Spot imagery, since it can provide information about damage, which can be observed from the building facade. However, there is a need for improvement and standardisation of data acquisition process for better results.

8.3.4. Methodology perspective

In the fourth part of the discussion, emphasis will be given on the methodology used in the study. The main limitations of the methodology and other alternatives for improvement of the research will be discussed. The structure of this part was established according to methodologies used in Spot and aerial video imagery analysis.

Spot imagery analysis

Change detection methodology was used in the Spot imagery analysis to detect damaged areas. Besides technical limitations of the data (differences in incidence angle), there were also other limitations, such as lack of DEM data for the whole region, smoke due to fire in western part of study area, and threshold differentiation between rural and urban areas.

First of all, pre and post-earthquake Spot imagery taken from different incidence angle (pre-earthquake: -26.9, post-earthquake: -15.4) was used in the analysis. Data acquisition of an object from different angle result in different illumination values of the same object, even though there is no actual change in the structure of the object. Comparison of the data taken from different incidence angle will give spurious change values of the objects. Therefore, the data set used in change detection should be acquired approximately the same look angle to avoid spurious result (Jensen, 1996). In the analysis, there were also significant spurious change values, due to the difference in the incidence angle.

Moreover, as change detection methodology requires pixel-by-pixel registration, any misregistration results with change in pixel values (although there is no actual change in illumination of objects). Therefore, in hilly areas there was orthorectification requirement to register images pixel by pixel. On the other hand, due to lack of DEM data for the whole region, it was not possible to orthorectify the images in the research.

Another constraint was radiometric correction. As there is a fire in Tupras Oil Refinery, the smoke was disturbing the western part of the scene. Although the emphasis was given to take evenly distributed target object around the scene, to correct the whole scene with one regression formula is difficult.

In the research, one threshold value was used to exclude vegetation areas. But the reflectance value differentiation between built-up and vegetation is much clearer in urban areas than in rural areas. Therefore, to exclude vegetation areas at the regional level requires hierarchical NDVI threshold determination for rural and urban areas.

At the regional level, available damage information was aggregated into settlement levels; village, municipality and district. Due to lack of spatial damage information, it was not possible to make an accuracy assessment. So the comparison was carried out by visual interpretation. There is a need to use spatial damage information to evaluate the results. To compare the results with spatial damage information at the regional level can improve the understanding of accuracy of change detection results.

At the local level, the aggregation of damage information derived from Spot imagery analysis was carried out at the parcel level, due to lack of building footprint data for pre-disaster situation. Moreover, dispersion of the rubbles from other parcels also can create wrong classification. Having pre-disaster building footprint data and damage information at the building level can give more reliable comparison results.

In conclusion, Spot imagery has limitations for post-earthquake damage assessment application. T video frames he methodology can be improved by overcoming technical issues and data limitations mentioned above.

Aerial video imagery

Aerial video imagery was analysed by three different approaches: Visual interpretation, digital image processing using colour indices and edge feature layers, and experimental researches based on conditional unidirectional local variance, line detection, local binary patterns, contrast.

Main limitations of visual interpretation methodology were high density of structures, high rise buildings and vegetation, which was mentioned in Section 8.2.3. The highly oblique characteristic of the image does not allow damage assessment for the whole scene, as it was not possible to see the building facades situated in the backside of the frame. The study showed that visual interpretation can be more useful in low-density settlements where to see the single building frames is easier. Moreover, use of expertise knowledge on building damage can improve the damage information derived from video imagery by visual interpretation.

In digital image processing of video imagery, data acquisition characteristics (see Section 8.2.3), which resulted in blurred colours and lack of details in the imagery, create difficulties in digital image processing. Stacking process to improve the image quality resulted better visualization. Although slight improvement in quality (3.6%) couldn't not contribute any improvement in the result of digital image processing, it may be useful for visual interpretation. Therefore, standardization of data acquisition process (see Section 8.3.3 above) can improve resulting imagery to analyse digitally. Moreover, highly oblique characteristic of image was another limitation for the application. Due to high oblique characteristic, there was scale variation in and between frames. In the methodology used in this study, a standard window size was applied for all frames. Use of adaptive window size for different scales can overcome the scale variation problem and improve the damage detection results. Although there are improvements in damage detection compared with previous studies, the methodology has still data specific characteristic, due to the use of threshold values derived from the training data set. Moreover, in generally it was not possible to differentiate the type of damage, such as total collapse, first floor collapse etc. Despite these limitations, significant improvement in damage assessment by digital analysis of video imagery was observed as compared with Spot imagery.

Lack of clear boundary of objects due to poor resolution, heterogonous large size pattern characteristic of urban scenes and variation in line characteristics in different section of frame, in terms of direction, width, length due to high oblique viewing caused failure in detecting damaged areas using conditional unidirectional local variance, line detection, local binary patterns and variance.

Although in visual interpretation, prior knowledge was used to map damaged areas, it was not possible to map the result of the digital analysis of video imagery, since there was no coordinate information. To map the damaged areas, there is a need for rectification and mosaicing of images. Here, there will be an emphasis on requirements for rectification and mosaicing process and discussion on the limitations of the research.

Rectification of video imagery: Generally, the main obstacles for rectification of video imagery come not only from video imagery itself, but also vibration of helicopter, which affect the geometry of resulting imagery. For rectification of a video imagery, there is a need for defining exterior and interior orientation parameters. External orientation defines the position and angular orientation associated with an image, which describe the relationship between the ground space coordinate and the image space coordinate. Exterior orientation can be solved by using well-distributed and accurate ground control points (GCP). Moreover, as the main aim is to analyse oblique imagery, there is a need for using stereo pair of frames, which overlap at least 60%. After all these requirements are fulfilled, using collinearity equations, space resection[8] can be applied. Collinearity equation based orthorectification produces the most reliable for raw image data by incorporating the sensor or camera orientation, relief displacement and earth's curvature (Erdas, 1999). In the result of this process, real world coordinates (X, Y, Z) are calculated according to GCP in stereo pair frames (X_1, Y_1 and X_2, Y_2), and rotation parameters (Phi, Omega and Kappa). On the other hand, for interior orientation, which defines the internal geometry of a camera at the time of data capture, there is a need for camera calibration parame-

[8] Space resection is a technique that is commonly used to determine the exterior orientation parameters based on known ground control points (Erdas, 1999).

ters. As video cameras are considered to be non-metric cameras[9], usually these calibration parameters are unknown (ERDAS IMAGINE On-Line Help). For this process, there is a need for additional parameters for collinearity equations or bundle orientation to calculate the interior orientation parameters.

On the other hand, the obliquity of the images also plays an important role in the rectification process of video imagery. If the scene is relatively near to vertical, a standard space resection will yield the image exterior orientation and get reasonable XY coordinates, insensitive to focal length selection. On the other hand, if the scene is highly oblique and there is no information about interior orientation of camera, there is a need for plausible focal length selection to apply resection approach for orthorectification of the image.

Erdas OrthoBASE software is a promising tool for ortorectification of oblique video imagery, as it allows estimating the video camera parameters by Self Calibrating Bundle Adjustment. Fries (1999) explains the use of Erdas OrthoBASE in the orthorectification process. It is PC based software and significant, in terms of ability of integrating imagery acquired using any camera and sensor, through the adoption and integration of self-calibration methods. The self-calibrating bundle adjustment (SCBA) feature of the software is capable of deriving a series of parameters to model the inner geometry of the sensor, which was an obstacle in rectification of video imagery as is mentioned in the previous paragraph. On the other hand, there are some dangers in use of SCBA, since the accuracy of derived parameters is highly dependent upon the geometry defined by the measurements available, both image and control. Therefore, inaccurate parameters derived from SCBA can yield inaccurate ortho-photos. Moreover, it is difficult to assess the accuracy of the parameters for the user due to lack of camera calibration parameters.

Stojic (2004) used OrthoBASE for orthorectification of an oblique imagery, which overlap 80% to 100%. Twenty ground control points (GCPs) surveyed using a total station and SCBA (to derive necessary information for creating accurate orthorectified images: focal length, principal point offsets, camera station positions and orientation at the time of image capture) were used in orthorectification process. At the end, five images were orthorectified and mosaicked.

On the other hand, in the case of aerial video imagery of Golcuk, besides lack of camera parameters and flight information, the main challenge was the lack of accurate ground control points. Because most of the buildings, which were observed as standing in the video imagery, were reconstructed after the earthquake. The available building footprint data were produced after the earthquake (almost after 1 year, 3 October 2000). Therefore it was not possible to calculate accurate ground control points. Moreover, the highly oblique characteristic of the imagery was another obstacle for orthorectication.

Mosaicing is a process of merging frames, which allows capturing a much wider field-of-view than, is possible with single-frames of video or regular still images. Raven View is a software, which provides tools to turn video data into other useful products, such as still image mosaics, dynamic mosaics, georeferenced video and updated image-maps (http://www.observera.com/ravenview.html). Observera Inc. provided some samples of mosaic of video imagery used in the research (see Figure 8.2) In the first mosaic, 345 (4693-5038) and in the second one 193 (0-193) video frames were used for the mosaicing process. The main advantage of the mosaic image is that it gives better overview of the settlement. Although the first attempt for mosaicing process is promising for further research, there are some problems to overcome. First of all, there are some geometric distortions of objects in the mosaic

[9] A non-metric has not been calibrated in a laboratory to define its internal geometry. The primary camera parameters, which have not been calibrated, include focal length, principal point, lens distortion and fiducial marks.

compared with the original frames. These geometric distortions can create problems in digital analysis of video imagery, as it affects texture and geometry based algorithms. Secondly, some artificial buildings appeared in the imagery. Decrease in the visualization can also affect the results of visual interpretation. One solution for these problems can be to select frames with a higher quality and to enhance the image quality (stacking) of frames used in mosaicing process.

In conclusion, analysis of video imagery shows that, the quality of the image, which affects the results, is an important subject for further analysis of the imagery. Visual interpretation was the most powerful method in damage assessment, although it is time-consuming and subjective methodology. Digital image processing can overcome these limitations of visual interpretation. Compared with Spot imagery analysis, there was significant improvement in damage assessment by using digital analysis of video imagery. Moreover, further research on finding a generic methodology, georeferencing, and mosaicing to map the damaged areas can improve the results.

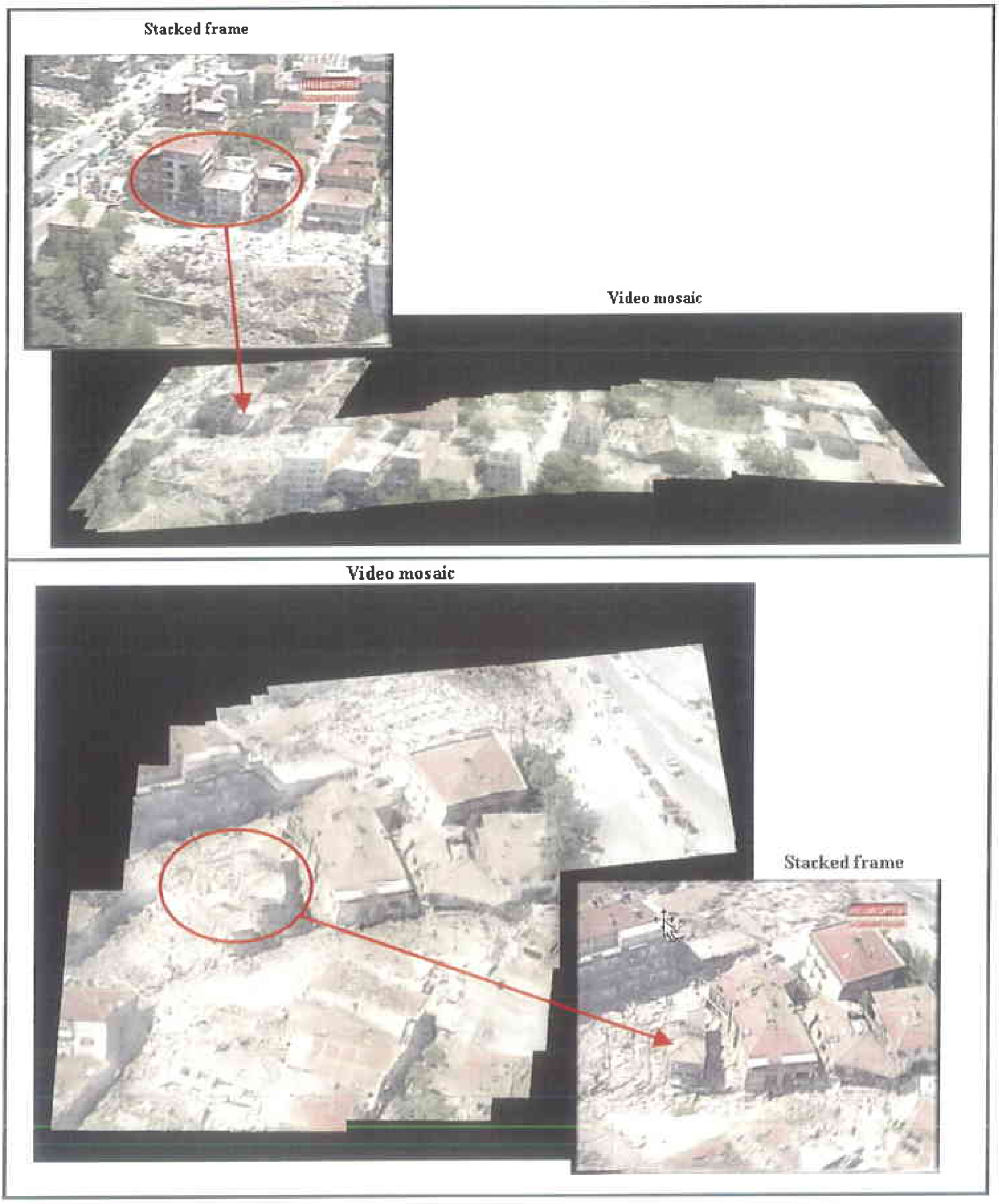


Figure 8.2. Two examples of video mosaicing

8.4. Conclusions

Research on post-earthquake damage assessment in the case of the 1999 Kocaeli earthquake has shown that Spot imagery has limited use for post-earthquake damage assessment, due to external factors and technical limitations (vertical viewing characteristic, spatial and temporal resolution). Moreover, change detection methodology is also limited, as it can provide information about change values of the pixels, not about the nature or type of damage. Although the detection of damage in villages was not possible using Spot imagery, positive change values in built-up areas, indicating damaged areas, were observed at the municipal and district level. Spot imagery can provide overall information about concentrated and highly damaged areas. Vertical viewing characteristic restrict to detect al type of damages. Furthermore, without any vector data integration, it is difficult to differentiate between change values due to actual damage and external factors. Integration with vector data increases the interpretability and visualization of the information. This is important for the users, who do not have experience with the remote sensing technology.

Although video data pose substantial processing, registration and integration challenges, façade-viewing characteristic of oblique aerial video imagery contributes valuable information to damage assessment. Some of these technical problems due to unplanned data acquisition by media agency can be overcome by systematic data acquisition for detailed inventory videography (see Section 8.3.3), such as mission planning, integration with GPS etc. Visual interpretation of aerial video imagery improves the damage assessment at the local level, as it gives information about damage type, which can be recognized from the building facade. Prior knowledge of the area is important for locating damaged areas on a map, in the case of lack of coordinate information. Subjectivity and time requirement problems of the visual interpretation can be overcome by digital image processing. The results of digital analysis of aerial video imagery based on multi level thresholding have shown that it improves the damage assessment at the local level compared with Spot imagery analysis and previous studies. The accuracy (ranging 68% and 86%) of the damage assessment results using digital image processing is promising and encouraging for further improvements of the methodology. For registration process, there is a need for accurate ground control points, interior and exterior orientation parameters of the data acquisition. Erdas OrthoBASE is promising software to use in registration process due to SCBA. Further research on differentiation of damage types, detecting soft and intermediate story collapse, rectification of highly oblique imagery and video imagery mosaicing will improve the damage assessment by using digital analysis of video imagery. Further experiments on damage detection based on texture and geometry of object using line detection, unidirectional local variance and local binary patterns show that simple techniques, such as visual interpretation and threshold based classification, performed better than more sophisticated methods used in the last part of the analysis.

Analysis on user information requirements in the case of Turkey has shown that damage information requirement varies depend on the governmental hierarchy and activities of the agencies. Moreover, there is a strong need to integrate baseline data with remotely sensed data. Although, even using video imagery cannot fulfill the information requirements of the users by itself, it is still one of the important information sources due to rapid response, which is the major characteristic of information required by the emergency agencies. For effective use of information, in terms of data gathering, sharing, analyzing and dissemination, there is a need for improvement in organization structure of emergency agencies. Damage information derived from Spot imagery can be useful at the national level in strategic decision-making. It can guide airborne video image acquisition for more detailed images to be used in response activities. Video imagery can be helpful in decision-making at the local level to co-ordinate emergency activities, and direct the Red Crescent, ground survey, and search and rescue teams on the ground.

8.5. Recommendations for further research

Due to lack of data and time constraints, this research has been carried out with some limitations, as discussed in Section 8.3. In this section, there will be a summary of recommendations for further research.

In this research, damage information was aggregated into settlement level and zones defined by AIJ field survey, due to the lack of damage information at building level. Using damage information at the building level, accuracy assessment can be carried out for further research.

In this research, the methodology used for digital analysis of aerial video imagery for damage detection is still data specific due to use of threshold values derived from training data set. It is obvious that threshold values are not identical for every video imagery, as each of them differs in terms of illumination factors, camera used in data acquisition, scale of the imagery etc. Therefore, there is a need for research on a more generic methodology.

The main concept of damage data extraction was based on characteristics of damaged areas (threshold definition) in this study. However, it could also be the other way around: eliminating undamaged areas to extract damaged areas. To do this, there is a need for defining the characteristic of undamaged areas, such as vegetation, water bodies, sky, roads, undamaged building facades and roofs etc.

Moreover, the methodology applied in this study for video imagery analysis was capable of extracting damaged areas in some extend. But there is also a need for defining the type of the damage, which is more important for the user. In further research, more emphasis should be give to differentiate different types of damage.

In addition, the filter size used in the methodology was identical for all frames. But there is variation in scale in and between frames dependent on the viewing angle. Therefore, use of adaptive filter size sensitive to scale variation may produce better results.

In Section7.3, experimental research was carried out to find a methodology to extract damage information based on the geometry and texture pattern of objects. Further research on the geometry of structures for damage extraction can yield a generic methodology, which can be applicable for all kinds of video data. Geometric primitives of damaged and undamaged structures that are either horizontal or vertical can be used for identification of damaged areas.

On the other hand, the use of artificial neural network can be a promising methodology due to the powerful learning algorithms, which may be utilized to achieve better classification results. The main advantage of the artificial neural networks is that it can identify subtle and non-linear patterns, which is not always the case with traditional statistical methods. Moreover, it can be used to integrate data from different sources and with different, poorly defined or unknown distributions, such as spectral information, per pixel data of altitude or soil type, and texture information. However, difficulties in the training process due to lack of rules for the configuration of the network is the major disadvantage of neural network (Ardo *et al.*, 1997).

Besides these methodological aspects, georefencing and mosaicing of oblique imagery to map damaged areas can be another research question for further study.

9. References

Acosta, S., (2004). *Application of Small Format Aerial Photography with Focus on Squaw Creek National Wildlife Refuge*. Retrieved 22 January 2004, from the World Wide Web: http://www.emporia.edu/earthsci/student/acosta4/

AIJ, (2000). *Report on the Damage Investigation of the 1999 Kocaeli Earthquake in Turkey*: Architecture Institute of Japan, Japan Society of Civil Engineers, The Japanese Geotechnical Society.

Alexander, D., (1991). *Information Technology in Real Time for Monitoring and Managing Natural Disasters*. Progress in Physical Geography, 15*(3)*, 238-260.

Alexander, D., (1993). *Natural Disasters*. United Kingdom: USL Press.

Ardo, J., Pilesjo, P., & Skidmore, A., (1997). *Neural Networks, Multitemporal Landsat Thematic Mapper Data and Topographic Data to Classify Forest Damages in the Czech Republic*. Canadian Journal of Remote Sensing, 23*(3)*, 217-229.

Ayanz, J., Verstratete M., Pinty, B., Meyer-Roux, J., & Schmuck, G., (1997). *The Use of Existing and Future Remote Sensing Systems in Natural Hazard Management Specifications and Requirements*. Retrieved 19 August 2003, from the World Wide Web: http://natural-hazards.jrc.it/documents/fires/1997-presentation/venarmers.pdf

Baltsavias, E., & Gruen, A., (2003). *Resolution Convergence*. In Mesev, V. (Ed.), Remotely Sensed Cities. New York: Taylor & Francis.

Bibbee, A., Gonenc, R., Jacobs, S., Konvitz, J., & Price, R., (2000). *Economic Effects of the 1999 Turkish Earthquakes: An Interim Report* (247). Paris: Organization for Economic Co-operation and Development.

Birk, R., McCandless, S., & Svejkovsky, J., (1995). *An Approach to Applying Remote Sensing to Disaster Management*. Retrieved 17 June 2003, from the World Wide Web: http://ltpwww.gsfc.nasa.gov/ISSSR-95/disaster.htm

Bruneau, M., (2002). *Building Damage from the Marmara, Turkey Earthquake of August 17, 1999*. Journal of Seismology, 6, 357-377.

Bruzewicz, A., & McKim, H., (1995). *Remote Sensing and Geographic Information Systems for Emergency Management: Effective Implementation*. Retrieved 11 August 2003, from the World Wide Web: http://ltpwww.gsfc.nasa.gov/ISSSR-95/remotese.htm

Chiroiu, L., & Andre, G., (2001). *Damage Assessment Using High Resolution Satellite Imagery, Application to 2001 Bhuj, India Earthquake*. Retrieved 12 March 2003, from the World Wide Web: http://www.riskworld.com/Nreports/2001/Bhuj,India,earthquake2001.PDF

Cutter, L., (2003). *GI Science, Disasters and Emergency Management*. Transactions in GIS, 7*(4)*, 439-445.

Donnay, J., Barnsley, M., & Longley, P., (2001). *Remote Sensing and Urban Analysis*. In Donnay, J.,Barsnley, M. & Longley, P. (Eds.), Remote Sensing and Urban Analysis (Vol. 9). New York: Taylor & Francis.

Eckhardt, D., & Verdin, J., (1990). *Automated Update of an Irrigated Lands GIS Using SPOT HVR Imagery*. Photogrammetric Engineering & Remote Sensing, 56*(11)*, 1515-1522.

Economic & Political Weekly, (2001). *Gujurat earthquake & after*. Retrieved 19 August 2003, from the World Wide Web: http://www.epw.org.in

EDM, (2000). *Report on the Kocaeli, Turkey Earthquake of August 17, 1999* (6). Japan: The Institute of Physical and Chemical Research.

ERD, (1999). *The August 17 Kocaeli Earthquake*. Retrieved 13 July 2003, from the World Wide Web: http://www.deprem.gov.tr/Kocaeli/info-i/mit-1.htm

Erdas, (1999). *Imagine OrthoBase Tour Guide*.Manuscript, Georgia.

Erdas, (2002). *Erdas Field Guide*.Manuscript, Georgia.

Erdik, M., (2003). *Report on 1999 Kocaeli and Duzce (Turkey) Earthquakes*. Retrieved 10 November 2003, from the World Wide Web: http://www.koeri.boun.edu.tr/depremmuh/Kocaelireport.pdf

Estrada, M., Yamazaki, F., & Matsuoka, M., (2000). *Use of Landsat Images for the Identification of Damage due to the 1999 Kocaeli Earthquake*. Retrieved 28 February 2003, from the World Wide Web: http://www.gisdevelopment.net/aars/acrs/2000/ps3/ps3014.shtml

FEMA, (1996). *Guide for All-Hazard Emergency Operations Planning*. Retrieved 20 June 2003, from the World Wide Web: http://www.fema.gov/rrr/allhzpln.shtm

FEMA, (2003). *Earthquake*. Retrieved 20 June 2003, from the World Wide Web: http://www.fema.gov/hazards/earthquakes/

Fries, J., (1999). *Bridging the Gap Between Digital Photogrammetry and GIS?* Retrieved 07 January 2004, from the World Wide Web: http://www.geoinformatics.com/Issues/Dec99/Softrev.htm

Haala, N., & Brenner, C., (1999). *Extraction of Buildings and Trees in Urban Environment*. ISPRS Journal of Photogrammetry and Remote Sensing, 54, 130-137.

Ham, D., (1998). *Aerial Photography and Videography Standards: Applications for Stream Inventory and Assessment*. Retrieved 13 December 2003, from the World Wide Web: http://srmwww.gov.bc.ca/risc/pubs/aquatic/aerialvideo/aerialvid-04.htm

Hasegawa, H., Aoki, H., & Yamazaki, F., (1999). *Attempt for Automated Detection of Buildings Using Aerial HDTV Images*. Retrieved 30 July 2003, from the World Wide Web: http://www.gisdevelopment.net/aars/acrs/1999/ts3/ts3097.shtml

Huyck, C., Mansori, B., Eguchi, R., Houshmand, B., Castner, L., & Shinozuka, M., (2003). *Earthquake Damage Detection Algorithms Using Optical and ERS-Sar Satellite Data - Application to the August 17, 1999 Marmara, Turkey Earthquake*. Retrieved 11 June 2003, from the World Wide Web: http://imagecatinc.com/reports/pubs/00105.pdf

Jensen, J., (1996). *Introductory Digital Image Processing: A Remote Sensing Perspective*. Second ed. London: Prentice-Hall.

Kabeyasawa, T., Shiohara, H., Kudo, K., Fujita, K., Kusu, K., Suzuki, N., Kitayama, K., Takahashi, I., Kanata, K., Kimura, H., Kanno, T., Okada, H., Masuda, Y., Tanaka, H., Kono, S., Kobayashi, K., Kikuchi, K., Kobayashi, J., Arai, H., Kuroki, M., Yoshimura, K., Nagao, T., Watanabe, H., Altay, G., Kilic, S., Erdik, M., Yuzugullu, O., Ozel, O., Karadogan, F., Boduroglu, H., & Gulkan, P., (2000). *Progress Report on Damage Investigation After Kocaeli Earthquake by Architectural Institute of Japan*. Housing Science, 24*(1)*, 97-126.

Kerle, N., & Oppenheimer, C., (2002). *Satellite Remote Sensing as a Tool in Lahar Disaster Management*. Disasters, 26*(2)*, 140-160.

Klenk, J., (1997). *Emergency Information Management and Telecommunications*. Retrieved 01 September 2003, from the World Wide Web: http://www.undmtp.org/english/telecom/telecoms.pdf

Kuffer, M., (2001). *Monitoring Density Changes in Informal Settlements in Dar Es Salaam by Remote Sensing: Exploring the Use of Spot, ERS and Small Format Aerial Photography*. MSc. Thesis, International Institute for Geo-Information Sciences and Earth Observation, Enschede.

Lillesand, T., & Kiefer, R., (1994). *Remote Sensing and Image Interpretation*. Third ed. Canada: John Wiley & Sons Inc.

Lillesand, T., & Kiefer, R., (2000). *Remote Sensing and Image Interpretation*. Fourth ed. New York: John Wiley & Sons Inc.

Lunetta, R., (1999). *Applications, Project Formulation and Analytical Approach*. In Lunetta, R. (Ed.), Remote Sensing Change Detection. London: Sleeping Bear Press.

Markus, M., Fiedrich, F., Gehbauer, F., & Hirschberger, S., (2003). *Strong Earthquakes, Rapid Damage Assessment and Rescue Planning*. Retrieved 27 February 2003, from the World Wide Web: www.rz.uni-karlsruhe.de/~gm32/pdf/TIEMS_2000.pdf

Masser, I., (2001). *Managing Our Urban Future: The Role of Remote Sensing and Geographic Information Systems*. Habitat International, 25, 503-512.

Matsuoka, M., & Yamazaki, F., (1998). *Identification of Damaged Areas due to the Hygoken-Nanbu Earthquake Using Satellite Optical Images*. Retrieved 28 February 2003, from the World Wide Web: http://www.gisdevelopment.net/aars/acrs/1998/ps2/ps2009.shtml

MCEER, (2000). *The Marmara, Turkey Earthquake of August 17, 1999: Reconnaissance Report* (00-0001). New York: Multidiciplinary Center For Earthquake Engineering Research.

Mesev, V., (2003). *Remotely Sensed Cities: An Introduction*. In Mesev, V. (Ed.), Remotely Sensed Cities. New York: Taylor & Francis.

Mitomi, H., Yamazaki, F., & Matsuoka, M., (2000). *Automated Detection of Building Damage due to Recent Earthquakes Using Aerial Television Images*. Retrieved 16 April 2003, from the World Wide Web: http://www.gisdevelopment.net/aars/acrs/2000/ts8/hami0010.shtml

Mitomi, H., Yamazaki, F., & Matsuoka, M., (2001). *Development of Automated Extraction Method for Building Damage Area Based on Maximum Likelihood Classifier*. Paper presented at the 8th International Conference on Structural Safety and Reliability.

Mitomi, H., Yamazaki, F., Matsuoka, M., Taniguchi, H., & Ogawa, Y., (2003). *Determination of Areas with Building Damage due to the Kobe Earthquake Using Airborne MSS Images*. Retrieved 31 July 2003, from the World Wide Web: http://www.edm.bosai.go.jp/team2/matsu/others/igarss02_hm.pdf

Montoya, L., (2002a). *GIS and Remote Sensing in Urban Disaster Management*. Paper presented at the 5th AGILE Conference on Geographic Information Science, Palma.

Montoya, L., (2002b). *Urban Disaster Management A Case Study of Earthquake Risk Assessment in Cartago, Costa Rica*. Phd Thesis, Utrecht University, Enschede.

Montoya, L., & Masser, I., (2000). *GIS in Urban Disaster Management.* City Development Strategies*(3)*, 49-52.

Murakami, H., Nagakawa, K., Hasegawa, H., Shibata, T., & Iwanami, E., (1999). *Change Detection of Buildings Using an Airborne Laser Scanner.* ISPRS Journal of Photogrammetry & Remote Sensing, 54, 148-152.

Olgun, E., (2000). *Izmit (Turkey) Earthquake, August 17,1999 and the Application of Change Detection Techniques for Damage Assessment Using Spot4 Satellite Images* (Individual Final Assignment). Enschede: International Institute of Aerospace Survey and Earth Observation.

Ozdogan, M., (2002). *Multi-source Satellite Data for 1999 Kocaeli Earthquake.* Paper presented at the 3rd International Symposium Remote Sensing of Urban Environment, Istanbul.

Paulsson, B., (1992). *Urban Applications of Satellite Remote Sensing and GIS Analysis.* Washington D.C.: The World Bank.

Pietikainen, M., & Ojala, T., (2003). *Nonparametric Texture Analysis with Simple Spatial Operators.* Retrieved 19 January 2003, from the World Wide Web: http://www.mediateam.oulu.fi/publications/pdf/50.pdf

Puissant, A., & Weber, C., (2002). *The Utility of Very High Spatial Resolution Images to Identify Urban Objects.* Geocarto International, 17*(1)*, 33-43.

Rao, D., (2000). *Disaster Management.* Retrieved 27 February 2003, from the World Wide Web: http://www.gisdevelopment.net/application/natural_hazards/overview/nho0004.htm

Rathje, E., & Crawford, M., (2003). *Earthquake Damage Identification Using High-Resolution Satellite Images From the 2003 Northern Algeria Earthquake.* Retrieved 26 January 2004, from the World Wide Web: http://shino8.eng.uci.edu/Remote_Sensing-2003/Ellen%20M%20Rathje.pdf

Rejaie, A., & Shinozoka, M., (2003). *Urban Damage Assessment from Remotely Sensed Images.* Retrieved 10 March 2003, from the World Wide Web: http://www.mceer.buffalo.edu/publications/sp_pubs/01-SP02/sra_ind/08.pdf

Rodarmel, C., Scott, L., Simerlink, D., & Walker, J., (2002). *Multisensor Fusion Over the World Trade Center.* Optical Engineering, 41*(9)*, 2120-2128.

San, B., & Turker, M., (2002). *Earthquake Damage Assessment of Buildings from Aerial Photographs.* Paper presented at the 3rd International Symposium Remote Sensing of Urban Areas, Istanbul.

Saraf, A., (1998). *Japalpur Earthquake: Assessing the Causes and Damages Using Remote Sensing and GIS.* Retrieved 02 September 2003, from the World Wide Web: http://www.gisdevelopment.net

Singh, A., (1989). *Digital Change Detection Techniques Using Remotely Sensed Data.* Journal of Remote Sensing, 10*(6)*, 989-1003.

Steinle, E., Kiema, J., Leebmann, J., & Bahr, H., (2001). *Laserscanning for Analysis of Damages Caused by Earthquake Hazards.* Paper presented at the OEEPE Workshop on Airborne Laserscaning and Interferometric SAR for Detailed Digital Elevation Models, Stockholm.

Stilla, U., Soergel, U., & Thoennessen, U., (2003). *Potential and Limits of INSAR Data for Building Reconstruction in Built up Areas.* Journal of Photogrammetry and Remote Sensing, 58, 113-123.

Stojic, M., (2004). *River Channel Modelling Using Oblique Imagery: An IMAGINE OrthoBASE Case Study.* Retrieved 13 February 2004, from the World Wide Web: http://support.erdas.com/apps_gallery/river_channel/River%20Channel%20Modeling.htm

Suga, Y., Takeuchi, S., Oguro, Y., Chen, A., Ogawa, M., Konishi, T., & Yonezawa, C., (2001). *Application of Ers-2/SAR Data for the 1999 Taiwan Earthquake.* Advances in Space Research, 28*(1)*, 155-163.

Tuceryan, M., & Jain, A., (1998). *Texture Analysis.* In Chen, A.,Pau, L. & Wang, P. (Eds.), The Handbook of Pattern Recognition and Computer Vision (Second ed.): World Scientific Publishing Co.

Tunali, E., Zontul, H., Yuksel, G., & Leloglu, U., (2002). *Yer gozlemde kucuk uydular, savunma amacli kullanimlari ve bilsat uydusu.* Retrieved 28 October 2003, from the World Wide Web: http://www.bilten.metu.edu.tr

Turker, M., & Cetinkaya, B., (2002). *Automatic Detection of Earthquake Damaged Buildings Using DEMs Created from Pre and Post Earthquake Stereo Aerial Photographs.* Paper presented at the The 3rd International Symposium Remote Sensing of Urban Areas, Istanbul.

Turker, M., & San, B. T., (2003). *Spot HVR Data Analysis for Detecting Earthquake Induced Changes in Izmit, Turkey.* International Journal of Remote Sensing, 24*(12)*, 2439-2450.

UN, (2004). *Reducing Disaster Risk A Challenge for Development.* New York: United Nations Development Programme, Bureau for Crisis Prevention and Recovery.

Van Westen, C., (2002). *Remote Sensing and Geographic Information Systems for Natural Disaster Management.* In Skidmore, A. (Ed.), Environmental Modelling with GIS and Remote Sensing (pp. 200-226). London: Taylor & Francis.

Van Westen, C., & Hofstee, P., (2001). *The Role of Remote Sensing and GIS in Risk Mapping and Damage Assessment for Disasters in Urban Areas.* Retrieved 15 November 2003, from the World Wide Web: http://www.dkkv.org/forum2001/Datei61.pdf

Wakana, H., Li, H., Miura, A., Nirei, Y., & Arakida, M., (2002). *Airborne Imaging and Ka-band Satellite Communications in an Experimental Disaster Management System.* Space Communications, 18, 157-166.

Walter, L., (1990). *The Use of Satellite Technology in Disaster Management.* Disasters, 14*(1)*, 20-35.

Wang, Z., & Bovik, A., (2002). *A Universal Image Quality.* IEEE Signal Processing Letters, 20, 1-4.

Warner, W., Graham, R., & Read, R., (1996). *Small Format Aerial Photography.* Scotland: Whittles Publishing.

Welch, R., (1982). *Spatial Resolution Requirements for Urban Studies.* International Journal of Remote Sensing, 3*(2)*, 139-146.

Yamazaki, F., (2001). *Applications of Remote Sensing and GIS for Damage Assessment.* Bangkok: International Center for Urban Safety.

Yoshimura, K., Kikuchi, K., & Kuroki, M., (2003). *Damage to Reinforced Concrete Moment Resisting Residential Building Frames Caused by the 1999 Kocaeli (Izmit) Earthquake in Turkey.* Retrieved 10 November 2003, from the World Wide Web: http://www.arch.oita-u.ac.jp

Yuan, D., Elvidge, C., & Lunetta R., (1999). *Survey of Multispectral Methods for Land Cover Change Analysis.* In Lunetta, R. (Ed.), Remote Sensing Change Detection: Environmental Monitoring Methods and Application. London: Sleeping Bear Press.

Yusuf, Y., Matsuoka, M., & Yamazaki, F., (2003). *Detection of Building Damages due to the 2001 Gujarat, India Earthquake Using Satellite Remote Sensing.* Retrieved 10 March 2003, from the World Wide Web: http://www.edmbosai.go.jp/Landsat/paper_landsat.pdf

Zhang, Y., (1999). *Optimisation of Building Detection in Satellite Images by Combining Multispectral Image Classification and Texture Filtering.* ISPRS Journal of Photogrammetry and Remote Sensing, 54, 50-60.

Zimmerman, P., (1991). *The Role of Satellite Remote Sensing in Disaster Relief.* Space Communications, 8, 141-152.

9.1. Online references

- http://www.alertnet.org visited on 10 February 2004
- http://www.bilten.metu.edu.tr visited on 10 November 2003
- http://www.disasterscharter.org visited on 1 December 2003
- http://www.fema.gov visited on 10 June 2003
- http://www.imostack.com visited on 15 December 2003
- http://www.observera.com/ravenview.html visited on 10 February 2004
- http://www.reliefweb.int visited on 10 February 2004
- http://www.spotimage.fr visited on 11 November 2003
- http://sirius.spotimage.fr visited on 11 November 2003
- http://www.unisdr.org visited on 3 November 2003
- http://www.usgs.gov visited on 20 November 2003

10. Appendix

Appendix 1. Review of previous studies for post-earthquake urban damage assessment by using remote sensing data

Location	Reference	Image type	Techniques	Acc. Ass.	Ground truth	User need ass.
Kocaeli (Turkey) 1999	(Olgun, 2000)	Spot HVR (Pan,XS)15 August 99 Spot HVR (Pan,XS)20 August 99	Image differencing Image ratio differencing NDVI	-	-	-
Kocaeli (Turkey), 1999	(Turker & San, 2003)	Spot HVR (Pan,XS)17 July 99 Spot HVR (Pan,XS)20 August 99 Orthophoto (1994-1999)	Image Differencing	83%	Orthophoto 112 sample 55 damaged	-
Kocaeli (Turkey) 1999	(Estrada *et al.*, 2000)	Landsat TM 27 March 1999 Landsat TM 27 March 1999	Image ratio differencing	-	-	-
Kocaeli (Turkey) 1999	(Turker & Cetinkaya, 2002)	Stereo aerial photo 1994 Stereo aerial photo 1994	DEM Height differencing	84%	Orthophoto 673 sample 50 collapsed	-
Kocaeli (Turkey) 1999	(EDM, 2000)	DMSP/OLS night time VNIR images, 16 August 99 night time VNIR images, 17 August 99	Image differencing	-	-	-
Chi-chi (Taiwan) 1999	(Suga *et al.*, 2001)	ERS 2 23 Sep 1999 ERS 26 May 1999 ERS 2 21 Jan.1999 Spot pan 9 Feb.1999 Spot pan 27 Sep.1999	Multi look intensity images, coherence images, Spot images	-	-	-
Gujarat (India) 2001	(Yusuf *et al.*, 2003)	Landsat 7 3 Jan. 2001 Landsat 7 9 Feb. 2001	Image differencing Ndvi	-	-	-
Bhuj (India) 2001	(Chiroiu & Andre, 2001)	Ikonos, 26 Jan. 2001 KVR 1000 1998	Visual interpretation Multi temporal change detection			
Chi Chi (1999) Kocaeli (1999)	(Mitomi *et al.*, 2000)	Aerial video imagery	Texture Analysis	-	-	-
Jabalpur (India) 1997	(Saraf, 1998)	IRS Pan	Pseudo Colour Transformation	-	-	-
Hyogoken-Nanbu (Japan) 1995	(Matsuoka & Yamazaki, 1998)	Spot 22 March 1990 Landsat 17 August 1994 Spot 20 January 1995 Landsat 24 January 1995	Image differencing	-	Detailed survey results by AIJ	-
Quindio (Colombia) 1999	(Van Westen & Hofstee, 2001)	Vertical and oblique air photos	Visual interpretation		Ground survey	

Location	Reference	Image type	Techniques	Acc. Ass.	Ground truth	User need ass.
Kocaeli (Turkey) 1999	(Huyck *et al.*, 2003)	Spot 4 ERS SAR	Image differencing After before correlation Sar intensity SAR image correlation SAR coherence SAR cross power	-	AIJ survey	-
Kocaeli (Turkey) 1999	(San & Turker, 2002)	Post earthquake panchromatic orthophoto	Detection of shadow of the buildings	96%	Visual interpretation	
Kocaeli (Turkey) 1999	(Ozdogan, 2002)	Landsat – 27 March.1999 Landsat – 18 August 1999 IRS – 8 August 1999 IRS – 30 August 1999	Image Differencing Image rationing PCA Texture		AIJ field survey	
Boumerdes (Algeria) 2003	(Rathje & Crawford, 2003)	Quickbird 22 April 2002 Quickbird 23 May 2003 Quickbird 18 June 2003	Change detection Spectral classification Texture classification			
Kocaeli (Turkey) 1999 **Kobe (Japan) 1995** **Chi-Chi (Taiwan) 1999**	(Mitomi *et al.*, 2001)	Aerial video imagery	Maximum likelihood classification		Visual inter-preation	

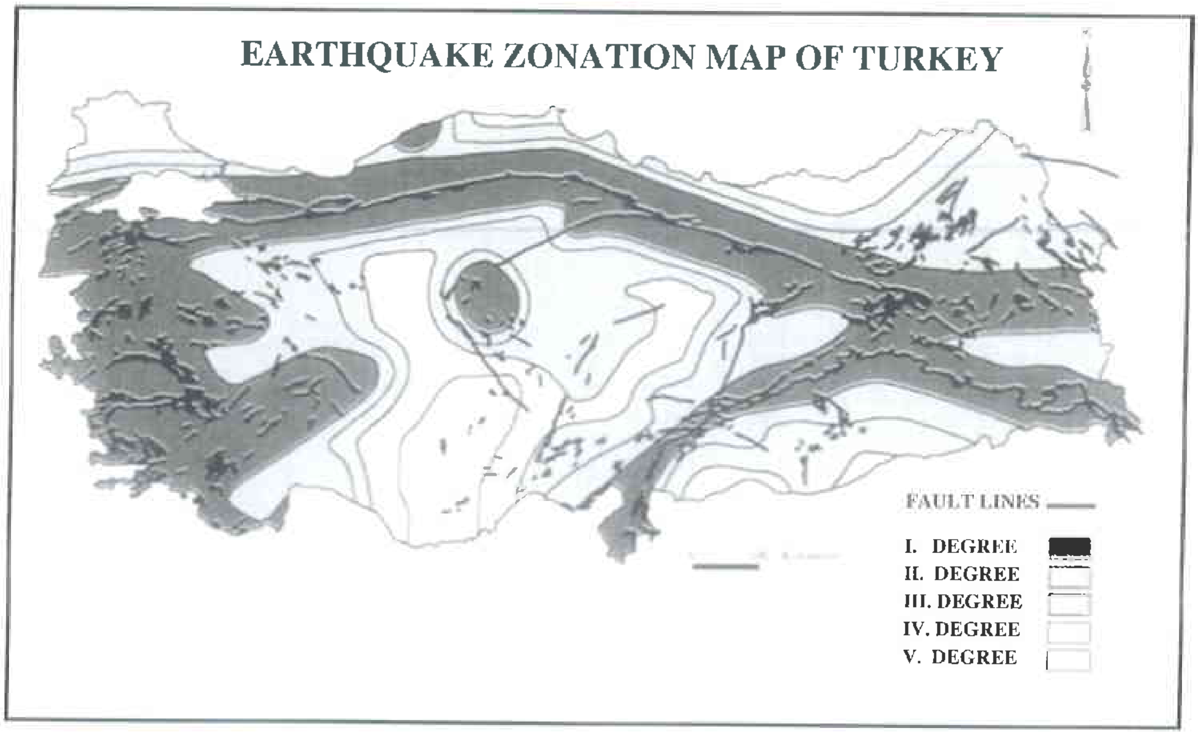
Appendix 2. Satellite response time

(Modified from Birk *et al.*, 1995 and http://www.itc.nl/research/products/sensordb/AllSatellites.aspx visited on 20 February 2004)

SENSOR	REVISIT TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	29	21	22	23	24	25	26	27	28	29	30
NOAA	24 HOURS	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
LANDSAT 4 & 5 &7	16 DAYS	□																□													
IRS 1C & 1D–L ISS3	24 DAYS	□																								□					
SPOT 2 & 34& 5	4–6 DAYS	□				□	□	□				□	□	□				□	□	□				□	□	□				□	□
IRS 1C& 1D – PAN	5 DAYS	□					□					□					□					□					□				
IKONOS	1-3 DAYS	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
QUICKBIRD	1-3 DAYS	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
ERS –2	35 DAYS	□																													
RADARSAT	24 DAYS	□																								□					
ENVISAT	35 DAYS	□																													
DMSP	12 HOURS	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □	□ □
ASTER	16 DAYS	□																□													
MODIS	2 DAYS	□		□		□		□		□		□		□		□		□		□		□		□		□		□		□	
BILSAT	4 DAYS	□				□				□				□				□				□				□				□	

AERIAL PHOTOGRAPHS: 5 Years
TERRESTIC SURVEY: 50 Years

Appendix 3. Earthquake zonation map of Turkey
(http://www.deprem.gov.tr visited on 10 November 2003)



Appendix 4. Economic indicators of affected area
(Bibbee *et al.*, 2000)

Provinces	Population	Share in GDP	Share in industrial value added	Per capita income	Share in budget tax revenues
	Thousands	Per cent		$	Per cent
Kocaeli	1.177	4.8	11.3	7.845	15.8
Sakarya	732	1.1	1.1	2.734	0.4
Yalova	164	0.4	0.7	4.966	0.1
Bolu	553	0.9	0.7	3.104	0.3
Bursa	1.959	3.5	5.0	3.434	3.0
Eskisehir	661	1.2	1.1	3.335	0.8
Istanbul	9.199	22.8	26.8	4.728	37.5
Kocaeli + Sakarya+ Yalova + Bolu	2.626	7.2	13.8	5.243	16.6
Total of 7 Cities	14.444	34.7	46.7	4.581	58.0
Turkey	62.866	100.0	100.0	3.031	100.0

Appendix 5. Macroeconomic costs of the earthquake (US$ billion)
(Bibbee *et al.*, 2000)

Cost	TÜSIAD [10]	World Bank
Direct costs	**10**	**3.1 to 6.5**
Housing	4	1.1 to 3
Enterprises	4.5	1.1 to 2.6
Infrastructure	1.5	0.9
Indirect costs	**2.8**	**1.8 to 2.6**
Value-added loss	2	1.2 to 2
Emergency relief expenditures	0.8	0.6
Total damage costs (rounded)	**13**	**5 to 9**

Appendix 6. Damage assessment results for Kocaeli province
(Kocaeli provincial authority, 2003)

Place	Collapsed/ Highly damaged	Moderately damaged	Slightly damaged
Izmit	4.642	3.816	6.630
Derince	729	1.195	1.930
Gebze	403	1.211	2.998
Golcuk	2.350	1.816	2.772
Kandira	108	278	541
Karamursel	344	561	1.154
Korfez	671	1.094	1.654
Toplam	9.247	9.971	17.679

Appendix 7. The number of casualties in the Kocaeli province
(Kocaeli provincial authority, 2003)

Place	Death	Injured
Izmit	3349	3054
Gebze	48	695
Golcuk	5384	5252
Kandira	-	9
Karamursel	163	314
Korfez	533	557
Toplam	9477	9881

[10] TUSIAD (Turkish Industrialisation and Businessmen's Association)

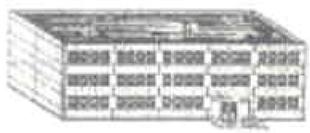
Appendix 8. General characteristics of Spot 4 HRVIR
(http://www.spotimage.fr visited on 11 November 2003)

Launch date	24.03.1998		
Launch vehicle	Ariane 4	**Imaging swath**	60 km x 60 km to 80 km
Nominal lifetime	5 years	**Image dynamics**	8 bits
Orbit	Sun-synchronous	**Absolute location accuracy (no ground control points, flat terrain)**	< 350 m (rms)
Local Equator crossing time (descending)	10:30 a.m.	**Angle of incidence**	±31.06°
Altitude at equator	822 km	**Revisit interval (depending on latitude)**	1 to 4 days
Inclination	98.7°	**Orbital period**	101.4 minutes
Sensor	2 HRVIR (High-Resolution Visible and Infrared), pushbroom linear CCD array	**Spectral bands and resolution**	. 1 panchromatic (10 m) . 3 multi-spectral (20 m) . 1 short-wave infrared (20 m)
Attitude control	Earth-pointing	**Orbital cycle**	26 days
Recording capacity	Two 120-Gbit recorders plus 9-Gbit solid-state memory (~ 560 images on each recorder + 40 images, with an average decompressed file size of 36 Mb)		

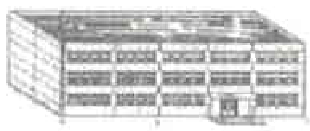
Appendix 9. Classification of damage to reinforced concrete buildings according to European Macro- seismic Scale

(Montoya, 2002b)

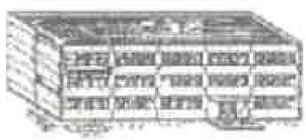
Reinforced concrete buildings



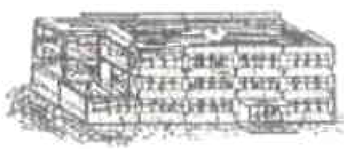
Grade 1: Negligible to slight damage (No structural damage, slight non-structural damage)
Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.



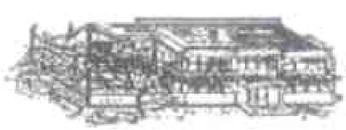
Grade 2: Moderate damage (Slight structural damage, moderate non-structural damage)
Cracks in columns and beams of frames and structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from joints of wall panels.



Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)
Cracks in columns and beam column joints or frames at the base and at joints of coupled walls. Spalling of concrete cover, bucking of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.



Grade 4: Very heavy damage (Heavy structural damage, very heavy nonstructural damage)
Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.



Grade 5: Destruction (Very heavy structural damage)
Collapse of ground floor or parts (i.e. wings) of buildings.

Appendix 10. Time schedule of data used in research

1976	Paper topographic maps at scale : 1/25.000
15 July 1999	Spot XS / PAN
17 August 1999	Marmara Earthquake
18 August 1999	Video Imagery
20 August 1999	Spot XS / PAN
25 August 1999	Damage investigation by Disaster Affairs
13 September 1999	AIJ reconnaissance report
01 November 1999	Regional road and settlement vector data
03 October 2000	Digital topographic map (DXF format)
September 2003	Interviews with emergency agencies