POST-EARTHQUAKE DAMAGE ASSESSMENT USING SATELLITE AND AIRBORNE DATA IN THE CASE OF THE 1999 KOCAELI EARTHQUAKE, TURKEY

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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, there is a need for rapid, accurate and reliable damage information in the critical post-event hours. Remote sensing technology can provide valuable information for response activities due to potentially high spatial-temporal resolution and synoptic coverage. This work aims at integrating (not in a sense of image fusion, but of synergy) vertical satellite and oblique airborne imagery to improve damage assessment in the case of the 1999 Kocaeli earthquake, Turkey. Pre and post-earthquake Spot4 HRVIR were analyzed using change detection methodology to detect damaged areas at the regional level. Since vertical satellite imagery has limitations in detecting structural damage, airborne oblique video imagery was used to improve the damage information at the local level. Aerial video imagery of Golcuk was analyzed by visual interpretation and multi level thresholding of texture and color indices feature layers. Additionally, to determine the effectiveness of the use of remote sensing technology in emergency activities, user information requirements were investigated by interviewing emergency organizations in Turkey. The results indicate significant limitations of moderate-resolution optical satellite imagery for post-earthquake damage assessment. Despite substantial processing, registration and integration challenges of aerial video imagery, it can improve damage assessment at the local level. On the other hand, even using video imagery cannot fulfil all user information requirements, as most of the information requires integration of GIS and RS data.

1. INTRODUCTION

1.1 Motivation

Natural disasters are described as rapid and extreme events within the geophysical system that result in mortality and property damage, which exceeds the response and recovery capabilities of the affected area (Kerle and Oppenheimer, 2002). Prevention of disasters is only rarely achieved with today's technology and knowledge. However, it is possible to avoid or to diminish the impact of disasters with effective disaster management strategies. The main objective of disaster management is to increase preparedness, provide early warning, monitor the disaster in real time, assess the damage and organize relief activities (Ayanz *et al.*, 1997). For effective disaster management there is a need for a variety of geo-spatial information at different scales. Geo-information science, including geographic information systems (GIS), remote sensing (RS), and the Global Positioning System (GPS), can provide concrete support for disaster management activities in terms of efficiency, and speed up the data management, manipulation, analysis, output and lead to more informed decisions (Montoya, 2002). Within the disaster management cycle, arguably the most challenging phase is the response stage, since the situation after the event is usually not clear, little is known about what exactly happened, where it happened and how many people were affected (Steinle *et al.*, 2001). Following a disaster, potential high-speed acquisition and dissemination of air and space-borne data with synoptic coverage allow the event to be detected and monitored. The use of remote sensing technology provides a quantitative base for information about damage and aftermath monitoring to assist response operations (Van Westen, 2002). Earthquakes are a type of disaster with a high mortality rate and widespread destruction. Unpredictability and rapid affects are the major characteristics of earthquakes. Urban areas are most vulnerable with their concentration of buildings, infrastructure and population. In the time of emergency, due to interruptions of communication systems and confusing information coming from different sources, getting timely, accurate and detailed information about the disaster situation is usually a challenging task. For quick mobilization of response and relief communities, data need to be captured and analysis result made available rapidly in the first 72 hours after the earthquake, as people, injured or exposed by the disaster, will not normally survive more than 72 hours. Remotely sensed data for post-earthquake damage assessment can provide valuable information for emergency activities.

1.2 Research Objectives

Substantial research on post-earthquake damage assessment using remotely sensed data has already been carried out (Turker and San, 2003; Yusuf *et al.*, 2003; EDM, 2000). Although a multi-temporal approach using change detection is the most commonly used methodology, it has substantial limitations, such as a short time gap between pre and post-event imagery, changes in brightness values due to external factors. Visual interpretation and texture analysis (Chiroiu and Andre, 2001) using only post-disaster imagery provide more flexible solutions compared with the previous one. Remotely sensed data are useful for damage assessment in urban areas, but each sensor has its own characteristics in terms of viewing direction, and spatial and temporal resolution. Oblique viewing characteristics, and high temporal and spatial resolution are the main requirements for data used in damage detection. Although satellite imagery provides synoptic coverage, cloud coverage, high cost of high spatial resolution data and vertical viewing are the main disadvantages of satellite imagery. The characteristics of urban areas, 3D nature of building damage and rapid onset of the disaster itself create the main obstacles for data selection. Even using high spatial resolution data may not help to detect pancake collapse with intact roofs. The use of night time imagery to detect damaged areas can speed up data gathering due to high revisit time, e.g. captured by DMSP/OLS. But it suffers from low spatial resolution (2.7 km; EDM, 2000). Laser scanners have significant advantages as they can give information about building heights and allow the creation of DSMs. On the other hand, the high cost, complexity in processing the data and occlusion are the main disadvantages of the technique. Standard aerial photography can provide high spatial resolution for urban areas, but the cost of data acquisition and time requirement for processing are the main obstacle.

Aerial video imagery is useful for rapid data acquisition at lower cost. Moreover, the oblique viewing characteristic allows imaging of building façades, which can improve damage assessment. However, the low quality of the video imagery is a major problem in digital analysis. Mitomi *et al.* (2000) used aerial video imagery to detect damaged areas following the 1995 Chi-Chi (Taiwan) and 1999 Kocaeli (Turkey) earthquakes. In conclusion, even though none of the sensors alone can fulfil all requirements, limitations can be overcome by integration of different data sources. In the case of 11 September 2001 attack on the World Trade Center, a LIDAR sensor, high resolution digital camera, and thermal camera were used to assess damaged areas. Digital images were used to get information about rubble piles, while LIDAR data were used to calculate rubble volumes and thermal image provided helpful information for identification of fires (Rodarmel *et al.*, 2002).

This research aims to integrate, in terms of synergy, space-borne and airborne imagery to improve damage assessment. The synoptic coverage of satellite imagery can provide information at the regional level. Oblique airborne video imagery can complement the satellite imagery analysis at the local level. On the other hand, despite of usefulness of remote sensing technology, the use of this technology is still not widespread in emergency management activities. Limited awareness among emergency managers of remote sensing technology and its potential for disaster management, and frequent lack of full understanding of emergency activities among remote sensing technologist are the main reason for this situation (Bruzewicz and McKim, 1995). Information is only useful when it is accessible, understandable and manageable by the user (Ayanz *et al.*, 1997). Therefore, this research also aims to define the end user information requirements at different levels in emergency activities to assess the effectiveness of the research results.

1.3 Case Study: 1999 Kocaeli Earthquake, Turkey

Kocaeli is situated in the north-western part of Turkey, lying within the North Anatolian Fault Zone, which is one of the world's longest and best known faults (Figure 1). Industrialization and high population density are the major characteristics of the region. A devastating earthquake (M: 7.4) occurred on 17 August 1999 and resulted in widespread and extensive damage, affecting 4 provinces in the region: Adapazari, Kocaeli, Bolu, Yalova. Over 15.000 people are estimated to have died and 40.000 building collapsed or were heavily damaged after the earthquake. Golcuk was one of the most damaged towns in the region with a death toll of 5.384 and 2.300 collapsed building. Because of the effect on the large area, assessing the damage for the relief works was a challenging task in the time of emergency after the disaster. Pancake collapse was the most serious damage, as there was the least opportunity for people to escape.

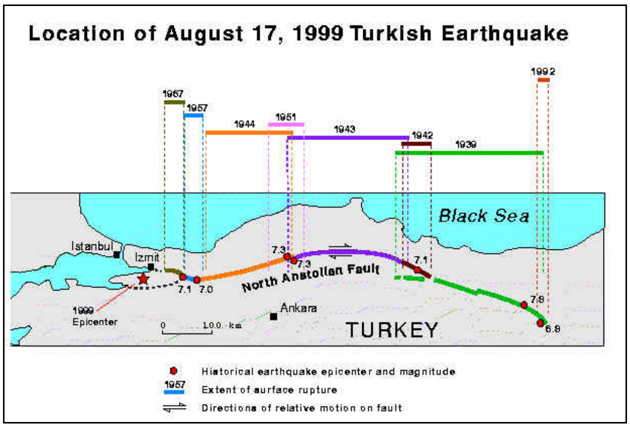

Figure 1. North Anatolian Fault Zone and case study area (http://geohazards.cr.usgs.gov accessed on 14 November 2003)

2. DATA AND METHODOLOGY

In this research two different types of remote sensing data were used to detect damaged areas: moderate resolution satellite imagery and aerial video imagery. For regional assessment of damage, pre- and post-earthquake (15 July and 20 August 1999, respectively) SPOT 4 HRVIR panchromatic and multispectral images were used. For local level damage assessment, aerial video imagery taken by a media agency on the day of the earthquake (17 August 1999) was used in the research. Total footage was around five minutes with a resolution of 720x576 lines. Damage assessment surveys results at the regional level were provided by the General Directorate of Disaster Affairs, Turkey. At the local level, a damage assessment survey, carried out by the Architecture Institute of Japan (2000) for Golcuk city, was used to verify the results of the analysis. Cadastral boundaries provided by Golcuk Municipality were used to aggregate damage information at the local level. The research was carried out in four steps: (i) analysis of user information requirements of emergency agencies in Turkey, (ii) analysis of Spot imagery, (iii) analysis of aerial video imagery and (iv) evaluation of results by comparison with the ground survey.

An assessment of user information requirements was carried out by interviewing 14 key informants from different emergency organizations in Turkey, such as national, regional and local government agencies, NGOs and a research centre participating in the emergency activities in Turkey. Institutional background, data requirement and previous experiences were investigated in the interviews.

Spot imagery was analysed using change detection methods shown in Figure 2. After geometric correction, a critical step in

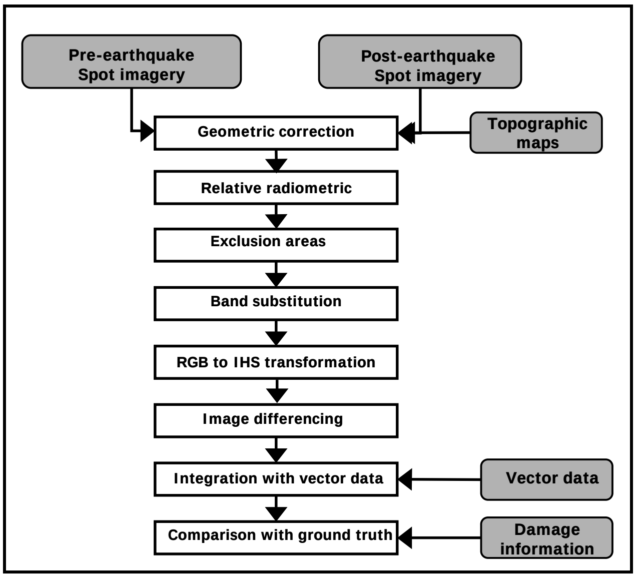

Figure 2. Damage assessment using Spot imagery

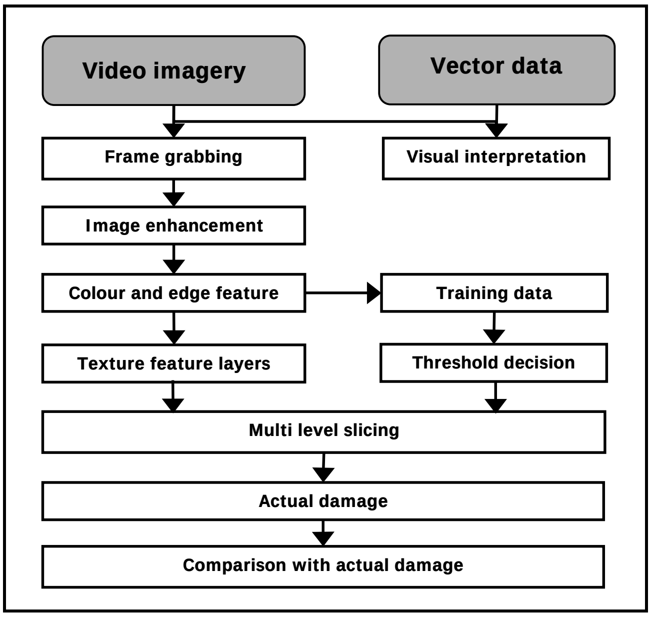

Figure 3. Damage assessment using video imagery

change detection to avoid spurious results (Jensen, 1996), relative radiometric correction was applied to normalize pixel values of the multitemporal data sets. Vegetation areas and water bodies were excluded from the analysis. Band substitution, which does not change radiometric qualities of any of the data (Jensen, 1996), was applied to merge Spot data set. The panchromatic band was substituted directly for Band 2. Intensity values of the merged data set were used for the change detection. Image differencing (Singh, 1989), which is one of the simple change detection algorithms, was applied in the methodology. To assess the damaged areas at the regional and local level, the result was thresholded and aggregated into parcel level.

The analysis of video imagery was carried out in two steps: (i) visual interpretation and (ii) digital image processing. Visual interpretation was carried out at the parcel level. In digital image processing, frame grabbing was the first step to convert analogue video frames to digital ones. Astrostack software was used to improve the quality of the frames (http://www.innostack.com). Colour indices (hue), edge feature layers (edge) and local variance (saturation variance and edge variance), which is one of the texture parameters, were used to detect damaged areas. Threshold values derived from training data set of damaged areas 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 in the video imagery. The overall process of aerial video imagery analysis for damage assessment was shown in Figure 3.

3. DATA ANALYSIS

3.1 Analysis of User Information Requirements

According to the results of the analysis, information requirements differ depending on government hierarchy and activities of the agencies. Although at the national level, there is a need for overall information about the damage, at the local level detailed information becomes most important for the user. Moreover, each organization requires different types of information in terms of scale, detail and characteristic based on their activities. For search and rescue operations, only information on collapsed buildings, as well as their inhabitants and use are required. On the other hand, for emergency aid activities, the number of people who survived the disaster is important, as they need to know food, accommodation and medication requirements. Rapid data gathering following the disaster is required, as after 72 hour, the chance for exposed and/or injured people to survive approaches zero.

The analysis has shown that remotely sensed data without integration with baseline data are not enough by themselves to fulfil the information requirements of the user. Baseline data showing the pre-disaster situation, such as population, road network, land use, ownership information, are critical for an optimal use of the potential of remotely sensed data. Moreover, for an effective use and flow of information derived from remote sensing technology, there is a need for organizational improvements. In the time of emergency, the main challenge is dissemination of different types of information, which requires an information network between emergency agencies, as information is only valuable if it reaches to the right organization at the right time.

3.2 Analysis of Spot Imagery

The results of the Spot imagery analysis were evaluated at regional and local levels (Figure 4). At the regional level, damage assessment using Spot imagery showed both significant overestimation and underestimation of damaged areas. Due to smoke coming from fire at the Tupras Oil Refinery, there was underestimation in the western part of the area. Overestimation in the northern part of the image shows the need for orthorectification for hilly areas. Moreover, differences in the incidence angle, the pixel-by-pixel registration requirement, which can cause spurious changes in the change detection analysis (Jensen, 1996), clouds and shadows were other obstacles for change detection. Differentiating between damaged areas and change values due to external factors is a challenging task without vector data integration. The results of the change detection analysis were compared with damage assessment information derived from ground survey (General Directorate of Disaster Affairs). The comparison showed that damage in the villages was not recognizable from Spot imagery. However, positive change values of pixels indicating damaged areas at the municipal and district levels were observed.

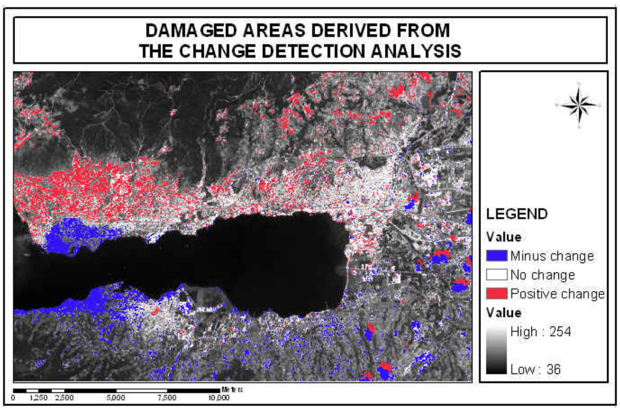

Figure 4. Result of change detection analysis

At the local level, the analysis results were compared with data from a ground survey carried out by the Architecture Institute of Japan (AIJ). Damage information derived from the change detection analysis was aggregated into parcel level to be comparable. Integration with vector data improved visualization and interpretability of the results, a critical requirement for the user (Figure 5).

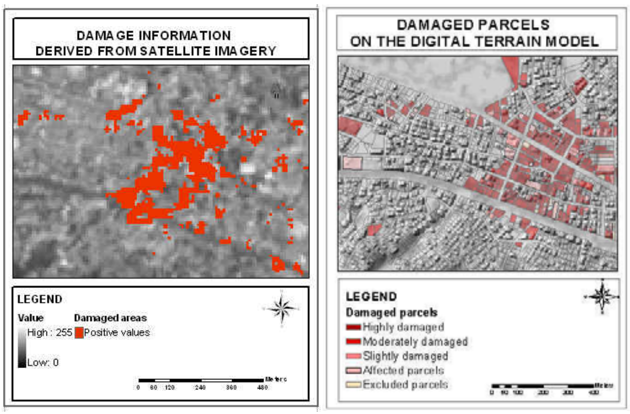

Figure 5. Comparison of original result of change detection with vector data integration

According to the comparison, the highest correlation (0.205, even thought it is still low) was found between damage level 5 (total destruction, AIJ ground survey) and totally damaged buildings derived from Spot Imagery analysis. According to Figure 6, Spot imagery failed to detect damaged areas in the northwestern part of Golcuk city. Moreover, there was overestimation of damaged areas in the central part of the city. In conclusion, Spot imagery has significant limitations due to external factors. Furthermore, change detection gives information about the change in pixel intensity values, but not about the nature of the damage, which is important for the user. Despite its limitations, Spot imagery can be helpful to get overall information about concentrated and highly damaged areas.

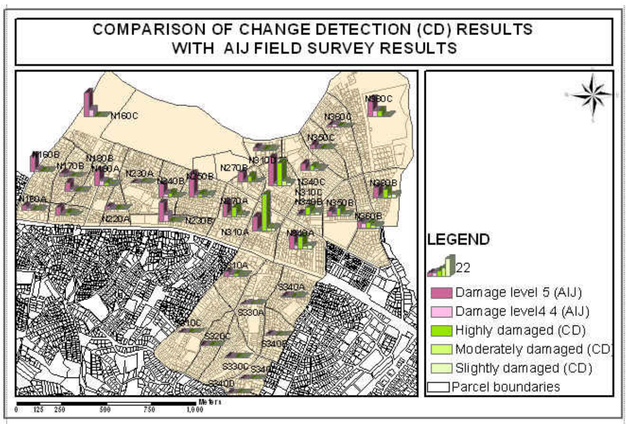

Figure 6. Comparison of change detection results with AIJ field survey results

3.3 Analysis of Video Imagery

To improve damage assessment at the local level, oblique aerial video imagery, which allows imaging of building façades, was used in damage assessment. The first step in the analysis of video imagery was visual interpretation for part of the area, as explained below. Based on the oblique imagery, affected buildings were classified as heavily damaged and totally collapsed (Figure 7). Structural damages, indeterminable from the building façade, could not be classified using video imagery. The results of the visual interpretation were compared with the Spot analysis results. The comparison shows that there was significant improvement in the damage assessment at the local level. Damaged areas in the northwestern part of the city, which were not recognized in Spot imagery, were clearly observed in video imagery. Moreover, more than 50% of totally collapsed building, observed from video imagery, were detected as non-damaged areas in Spot. This result also underlines the limitations of Spot imagery in damage assessment studies.

However, use of video imagery taken by a media agency created some limitations for the applications. First of all, as a media agency collects information for the news, there was a focus on highly damaged areas, making comprehensive damage assessment impossible. Moreover, lack of coordinate information and camera parameters created limitations for locating video frames on the map. Therefore, in visual interpretation, prior knowledge was used to locate damaged areas.

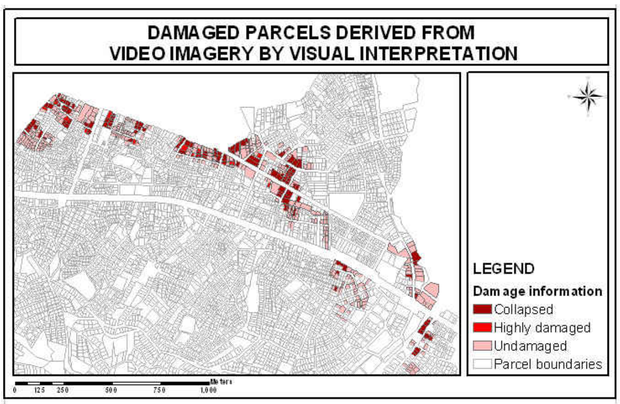

Figure 7. Damage information derived from visual interpretation of video imagery

Although visual interpretation is a powerful tool, it is a subjective and time-consuming process, which is of critical importance in the time of emergency. To overcome these problems, digital analysis of video imagery was carried out. The methodology was tested on six representative frames, which were selected according to different damage types in different parts of Golcuk city. Hue, edge, saturation variance and edge variance were used as feature layers, and the pixels values of each layer were allocated a 1-byte value. The intensities of edge elements were calculated by a unidirectional Prewitt-gradient filter with a 3x3 window size. Local variance of feature layers was analysed for the area of 5x5 pixels. Threshold values of damaged areas were determined according to mean and standard deviation of pixel values of training data sets selected from the reference frames. +/- standard deviation from the mean value was used for multilevel thresholding for each frame (Hue: 38-126, Edge: 6-74, Saturation Variance: 76-198, Edge variance: 0-25). After the multilevel thresholding process, a 61x61 mean texture window, chosen based on the average building size in the video frame, was used to aggregate and remove spurious pixels. The results of digital analysis of video imagery are shown in Figure 8. The results were compared with actual damage information observed from video imagery (Figure 9). Overall accuracy ranged between 68% and 86% (Producer accuracy: 46%-83%, user accuracy: 47%-73%).

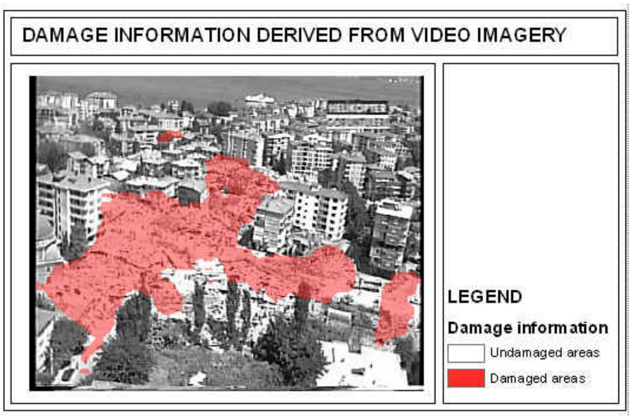

Figure 8. Damage information derived from video imagery

Further investigation was carried out to determine the recognizable and unrecognisable damage types using digital analysis of video imagery (Figure 9). The result shows that digital analysis of video imagery failed to detect intermediate and first floor collapse, but was effective in detecting rubble. On the other hand, scale variations between proximal and distal parts of the frame created failure in damage detection, as some distal areas have the same textural features as rubble. In addition, some building façades, which are under construction, were also identified as damaged.
In conclusion, the use of highly oblique aerial video imagery improved damage assessment compared with Spot imagery, as it allowed seeing the façade of the buildings. Although there are significant difficulties in digital image processing, the accuracy assessment results are promising and encouraging for further research. Movement of the helicopter, an unstable camera and frequent scale chances due to zooming resulted in poor quality, blurred imagery, which creates difficulties in digital image processing. Moreover, the highly oblique characteristic, scale variation in and between frames, heterogeneous and large size pattern characteristic of urban scene are other obstacles for digital image analysis of video imagery. In addition, there are also difficulties in mapping damaged areas derived from the analysis, due to lack of external and internal camera parameters, and accurate ground control points required for the orthorectification process. Moreover, methodology used in the research is still data specific, as threshold values are determined from training data sets.

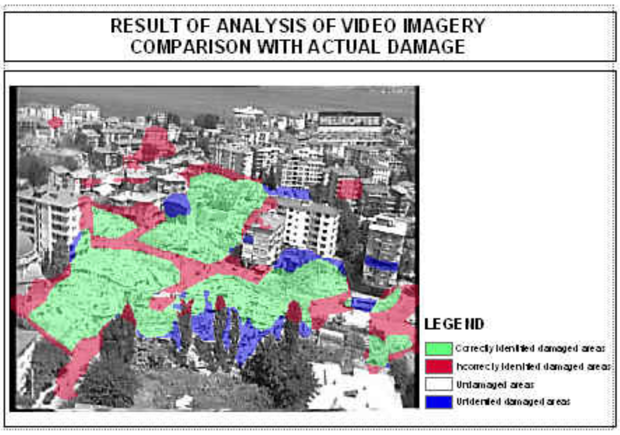

Figure 9. Comparison of analysis of video imagery with actual damage

4. CONCLUSIONS AND DISCUSSIONS

In conclusion, post-earthquake damage assessment in the case of the 1999 Kocaeli earthquake has shown that Spot imagery is of limited use for post-earthquake damage assessment due to external factors and technical limitations (vertical viewing characteristic, spatial and temporal resolution). In addition, change detection gives information about change values of the pixels, but not about the nature of the damage. Spot imagery can provide overall information about concentrated and highly damaged areas. With the integration of vector data, visualization and interpretability of the results improved.

Although video data pose substantial processing, registration and integration challenges, façade viewing characteristics contribute valuable information. The results of visual interpretation and digital analysis of video imagery have shown that it improves the damage assessment at the local level compared with Spot imagery analysis.
Analysis of user information requirements in the case of Turkey showed that damage information varies depending on the governmental hierarchy and activities of the agencies. There is a strong need for base data integration with remote sensing data. Spot imagery can be useful in strategic decision-making at the national level and can guide airborne data acquisition at the local level. Aerial video imagery can be helpful in coordinating emergency activities and directing ground teams. For an effective flow of information between different emergency agencies, there is a need for improvements not only in technical infrastructure, but also in organizational structure. As a proposal of the research, the establishment of a Disaster Management Centre at the national level, which is in charge of setting up a spatial database, downloading and processing facilities for remote sensing data, and information network, can coordinate information flow between different users.

The International Charter on Space and Major Disasters, a unified system of space data acquisition and delivery, and Bilsat, the first Turkish Earth observation satellite launched October 2003, part of the Disaster Monitoring Constellation, are promising improvements for rapid data gathering and future application of remote sensing data in disaster management activities. Some of the limitations of video data can be overcome by systematic data acquisition for detailed inventory videography (Ham, 1998), such as mission planning, integration with GPS etc. As threshold values used in this research are not identical for all video data, there is a need for further research on a more generic methodology based on geometry and texture pattern of damaged areas. For registration of video imagery, there is a need for accurate ground control points, internal and external parameters of camera.

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