The Marmara, Turkey Earthquake: Using Advanced Technology to Conduct Earthquake Reconnaissance

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Research Objectives

1. To conduct high level reconnaissance using satellite imagery, Differential Global Positioning Systems (GPS), and in-field GPS-GIS interfaces
2. To validate damage information contained in early U.S. State Department Damage Maps
3. To serve as a model case study for exploring the use of remotely sensed data for post-earthquake damage assessment.
4. To reinforce the collaborative activities between MCEER and EDM

The Marmara earthquake occurred during a time of unprecedented technological development. Post-disaster information and data that once took months to generate were developed within a matter of days in this event. Furthermore, the ability to comprehensively understand the meaning of these data was significantly enhanced because of the use of sophisticated database management programs and geographical relational algorithms, e.g., geographic information systems, (GIS). In the most general sense, we were able to literally map the effects of the earthquake in “real time.”

One area that has benefited immensely from this technology explosion is earth observation and mapping (see Figure 1). From over a dozen different platforms, we are able to view and quantify with surprising precision the different properties of the earth’s surface. Topographic features are clearly seen from low earth-orbiting optical satellites. Urban areas are also visible in these images. In addition, using an analysis technique called “interferometry,” it is possible to detect minute changes in the earth’s surface by comparing a series of radar images taken at different times. It is from the perspective of testing the use of advanced technologies for post-earthquake reconnaissance that we provide our analysis of the Marmara earthquake.

The following discussion offers a preliminary report on a joint reconnaissance effort between MCEER and the Earthquake Disaster Mitigation (EDM) Research Center in Miki, Japan. This reconnaissance took place
approximately one and a half months - between September 28th through October 4th - after the disastrous main shock of the Marmara earthquake. The team leaders were Ronald T. Eguchi of ImageCat, Inc. (formerly of EQE International), who led the MCEER team and Professor Fumio Yamazaki of Tokyo University, who led the EDM team. The collaboration with EDM has been ongoing since the 1994 Northridge earthquake in the U.S. and the Kobe earthquake in Japan (1995). Both Centers have committed substantial resources to explore the use of advanced technologies for natural disaster management. The investigation of the Marmara earthquake represents the latest collaboration between these two organizations.

The following sections discuss the purpose of the trip and the meetings that were held, the new technologies that were used during this reconnaissance trip, a “thumbnail” sketch of specific in-field studies

The data collected during this reconnaissance will benefit various user groups. First, this information will help researchers validate new damage detection models based on remote sensing technologies. Second, the lessons learned during this trip will help to improve earthquake reconnaissance techniques and procedures by encouraging the use of new and advanced technologies. Of particular significance is the contribution that advanced GIS-GPS interface systems have in recording damage information in real-time. Finally, the results of this research will ultimately help future emergency responders by providing more reliable methods of assessing post-earthquake damage. Assessing damage sooner will allow responders to act more quickly and more effectively in deploying limited resources.
that were conducted, and finally, the usefulness of these advanced technologies in assessing damage from this devastating event.

Itinerary

The itinerary for the trip was established several weeks before departing for Turkey. The trip consisted of meetings with Turkish researchers and investigators, and brief field visits to several of the hardest hit areas. The details of the field visits are discussed in more detail later in this section. Provided below are brief summaries of the meetings that were held during the first two days of this trip. Table 1 summarizes the itinerary for this trip.

During our visit with Professor Mustafa Erdik at the Kandilli Observatory and Earthquake Research Center of Bogaziçi University, the research team was able to ask general questions about the extent of damage to western Turkey. We found that although the earthquake was initially named after one of the cities closest to the main shock (i.e., İzmit), damage in this area was not as severe as other areas further away from the epicenter. We were told that Gölcük (located on the southern side of İzmit Bay and roughly 80 kilometers east of İstanbul) and Adapazari (located roughly 125 kilometers east of İstanbul) had experienced far more damage than the town of İzmit.

We were also shown preliminary ground motion records from this event, learning that the peak ground acceleration in Adapazari reached about 40 percent g. At the time of our visit, a number of portable instruments were being installed in order to record ground motions from large aftershocks. Before leaving this facility, the MCEER/EDM team was given a tour of the Kandilli Observatory Laboratory where we viewed other ground motion data that was being collected.

At TÜBİTAK (Turkish Scientific and Technical Research Institute) Marmara Research Center, several different meetings were held. The first meeting was with the Earth Sciences Research Institute where the team met with Dr. M. Namık Yalçın, the Director of the Earth Sciences Institute at TÜBİTAK Marmara Research Center, and Dr. Semih Ergintav, a member of the Earth Sciences Research Institute. The purpose of this meeting was to determine the availability of GPS information for the earthquake. The team was particularly interested in collecting data on post-earthquake displacements for towns that were hardest hit by this earthquake. This information would be used to compare permanent ground displacements calculated using Synthetic Aperture Radar (SAR) with those derived from the continuous GPS network. We understood that a continuous GPS system was in

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place at the time of the earthquake and that displacements at several sites were being monitored. We also understood that the primary interest in these data was to map the co-seismic slip of the fault, and not the relative tectonic movement of the region. The results of this work were presented at the Annual American Geophysical Union meeting that was held in San Francisco in December 1999.

The second meeting was held with the Space Technologies Group at TÜBİTAK. The investigation team met with Dr. Hülya Yıldırım, the Director of Remote Sensing and Geographic Information Systems at the Marmara Research Center. Before the earthquake, this group was involved with numerous environmental and agricultural studies. One study involved the preparation of watershed maps for the five provinces surrounding İzmit, which is in the province of Kocaeli. After the August 1999 earthquake, this group was assigned the responsibility of
producing GIS maps that documented damage in the İzmit area. While lacking any prior earthquake experience, this group immediately began integrating available GIS maps with satellite imagery to identify those urban regions that were most affected by this event.

One analysis, which was based on a comparison of pre- and post-earthquake SPOT images, showed large areas in Gölcük that were clearly affected by the earthquake. Several of these images are shown in Figures 2 and 3. In addition, other satellite-derived images showed extensive areas along the shore near Gölcük that were inundated as a result of ground subsidence caused by liquefaction. Figure 4 shows an aerial view of the inundation area.

Field Investigations

During this trip, the MCEER/EDM team was able to survey earthquake damage in four areas: Avcılar, Seymen, Gölcük and Adapazarı. Where possible, we applied GPS technology linked with GIS systems to record damage information. In addition, satellite imagery and aerial photographs were available for some areas. The following sections discuss the data that were collected, the technologies that were used in recording this information, and the analyses that have been performed – since our return – to interpret the effects of this earthquake. Before discussing these field investigations, we discuss very briefly the technologies that were used on this trip.

New Technologies

Radar Images. The MCEER/EDM team was fortunate to obtain numerous satellite images of the İzmit area prior to its departure. Through a cooperative research agreement with the European Space Agency (ESA), EQE International received a series of radar images, both before and after the earthquake, via the ERS-1 and ERS-2 satellites. A tabulation of these data is listed in Table 2. As will be discussed later, several of these scenes (i.e., images) are being used to create interferograms that will hopefully identify areas of significant damage.

The project team also received post-earthquake Radarsat images of western Turkey. These, however, were received after the team returned from Turkey. We have yet to process this information.

Optical Satellite Images. In addition to the radar data, ESA also provided Landsat 5 images taken several days after the earthquake. Figure 1 shows a Landsat 5 image of the İzmit Bay region. Visible in this image is the fire that occurred at the Tüpraş Oil Refinery, approximately 70 kilometers southeast of Istanbul.
Table 2. ESA Synthetic Aperture Radar (SAR) Data and Images

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Note: RAW refers to unprocessed data; SLC is single look complex; and PRI is precision averaging. Asterisks refer to scenes that were used to create interferograms for this event.

Figure 5. Vehicle used to collect damage/GPS data in Avcilar and Adapazari. Note the antennae being held by front passenger.
**Aerial Photographs.** Some aerial photos were taken of the affected areas; these, however, have yet to be widely distributed. One photo was published in a local İstanbul newspaper. The photo was scanned by one of our collaborators in Turkey (IMAGINS) and was used during our field survey of the Avcılar area. This is discussed further in the next section.

**Global Positioning Systems.** Two separate GPS systems were used in the field during this investigation. The first was a high-precision single-frequency 12-channel NovAtel GPS receiver. This system was generally used while driving through the different study areas, see Figure 5. A second system – a handheld Magellan unit – was used when field studies were conducted on foot.

**Real-time GPS-GIS Interface.** One of the major improvements in documenting the effects of this earthquake was the use of a real-time GPS-GIS system. Using the GPS systems mentioned above, the MCEER/EDM team was able to associate damage information, including photographs, with accurate geographical coordinates. Where there was real-time Differential GPS broadcast data (FM-RDS), which was the case in Avcılar, the positional accuracy was one meter or less. When using the handheld Magellan unit, the accuracy level dropped to plus or minus 30 meters. Figure 6 shows the equipment setup for this GPS-GIS interface. One of the advantages to using this system was that the investigation team was able to create reasonably accurate road maps when none were available. These maps were created by plotting GPS coordinates (while in transit) directly onto Landsat 5 imagery. The interface between the NovAtel GPS receiver and the MapInfo GIS software was provided by GeoTracker from Blue Marble Geographics.

**Avcılar**

Avcılar is located in the southwestern part of İstanbul bordering the Marmara Sea. Although located roughly 80 kilometers from the epicenter of the August 17, 1999 earthquake, there was substantial – but isolated – damage to multi-story residential buildings. At the time of our visit, most of the severely damaged structures had already been demolished. Since there was very little to record, other than the location of these demolished buildings, the team opted to use this time as an opportunity to refine and calibrate our GPS-GIS data collection system.

Figure 7 shows an aerial photo of the part of Avcılar that we focused on. Visible on this photograph – scanned from a newspaper article – is the shoreline facing the Marmara Sea, at the bottom of the figure.
In this part of Avcılar, there were about a dozen buildings that experienced significant damage, resulting in complete collapse of the structure, or substantial damage requiring demolition of the building. While traveling to each of these sites, the investigation team utilized the real-time Differential GPS-GIS system. With accuracy levels within one meter, we were able to record the precise location of each of the demolished buildings. This information will be used to assess whether these particular sites can be recognized from either satellite imagery or aerial photos. Most other structures in this area experienced little, if any, damage.

Seymen

Seymen is located on the southern side of İzmit Bay, just east of Gölcük (40° 42’ N latitude and 29° 54’ E longitude). This particular area was of interest to the MCEER/EDM team because 1) damage to buildings (the area is composed of entirely residential apartment buildings) varied widely ranging from slight to complete collapse; 2) the area was unoccupied at the time of our visits, and 3) the buildings were situated in large, open areas. From the standpoint of detecting damage from spaceborne systems, this area would be ideal. Figures 8 through 10 show some of the buildings where detailed data were collected by the investigation team.

As part of an ongoing research project, researchers at the University of Southern California (Mansouri and Shinozuka) are exploring ways in which SAR data can be used to characterize earthquake damage to buildings. Simulation algorithms are being developed that will model such failures as tilting, first floor collapse and complete building failure (i.e., massive pancaking). During this reconnaissance trip, Mansouri collected detailed measurements on several of the buildings that had collapsed during the earthquake. All of the

Figure 7. Aerial photograph of the city of Avcılar. Shown on this figure are sites (identified by small circles) visited by the MCEER/EDM team in September 1999.

Figure 8. Isolated building in Seymen. This building experienced first floor collapse and well as damage to the top floor. This building should be visible from aerial photos; it may be detectable using radar pre- and post-event images.
buildings were constructed of reinforced concrete with rectangular footprints and had tiled roofs. Because of the orientation of these buildings (two rows of six buildings each) and because of the large spaces between buildings, this site was considered an ideal one from the standpoint of testing or validating their analytical models.

As indicated earlier, SAR images of this area – both before and after the earthquake – have been obtained from ESA and RADARSAT. Pre- and post-event SAR data is preferred for detecting damage after catastrophic events. Using SAR data, it is possible to create images at night or through cloud cover. Also, because of its ability to facilitate change detection analysis, SAR technology is considered the most effective technology in attempting to “quantify” the effects of large disasters.

Over the next year, Mansouri and Shinozuka will be calibrating their simulation algorithms by testing them against the Seymen data. Some of the questions that they will attempt to answer are: (1) what damage conditions or failure modes are detectable using coarse resolution SAR data, (2) can damage be accurately simulated using these new simulation algorithms, and (3) how can these findings be extended to assess damage to larger areas.

Adapazarı

The town of Adapazarı is located about 125 kilometers east of Istanbul. The town sits on a recent lakebed, and suffered extensive liquefaction during this earthquake. This was one of the most heavily damaged areas in this event; damage to multi-story apartment buildings was severe, many commercial structures were also seriously damaged.

The MCEER/EDM team spent an entire day in Adapazarı attempting to collect damage information from local authorities. Despite the fact that the requests were made almost two months after the earthquake, there was still very little data available on number of damaged buildings, whether structures were safe or unsafe, and how many people had perished in this earthquake. Because of this, the investigation team...
decided to conduct its own survey of Adapazari.

One of the primary objectives of this trip was to collect enough information to validate a series of earthquake damage maps that were produced by the U.S. State Department shortly after the earthquake. These maps appeared on the Internet on the Kandilli Observatory website. In total, the U.S. State Department produced five maps: Yalova, Seymen, Derence, Adapazari and West Gölcük.

One example of the type of map distributed by the State Department is seen in Figure 11 for the Adapazari area. The map identifies areas of catastrophic and extensive damage. This map was put on the Internet on August 20, 1999, three days after the earthquake. According to officials at the State Department, high-resolution satellite images were used to classify the town into these two damage categories. Our purpose in validating these maps was to create a “ground truth” database that could eventually be used to calibrate a series of interferograms developed from this earthquake.

Unfortunately, the scale and projection of these maps was a little misleading. When compared directly with Landsat images – which were in a valid geographical projection – many of the obvious features (roads, rivers, and city boundaries) – did not match. The State Department maps appeared to present a distorted image of the affected areas.

Since returning from Turkey, EQE spent considerable time trying to “warp” the images so that the State Department maps actually coincided with the major land features and roadways of the region. As it turns out, it is possible to approximately fit these maps to the correct projections by overlaying the maps onto available Landsat images and “warping” the map to match obvious landmarks (e.g., roads, rivers, major intersections, etc.) The next section discusses how the MCEER/EDM team attempted to validate the damage maps.

Figure 12 shows a Landsat 5 image of the Adapazari area. Shown on this same figure is the route taken by the investigation team on October 2nd. It is interesting to note that at the time of our visit, there appeared to be no publicly available maps of the city. Therefore, our only means of tracking our route was to plot the latitude/longitude of the van – as determined from the portable GPS system – directly onto a Landsat image of Adapazari. Although it took some time to set up, this system was invaluable in assigning geographical coordinates to specific damage sites.

The route, shown in Figure 12 as a black line, began near the Mosque
Using Advanced Technology to Conduct Earthquake Reconnaissance

“As part of an ongoing research project, researchers at the University of Southern California are exploring ways in which SAR data can be used to characterize earthquake damage to buildings.”

Figure 12. Landsat 5 image showing Adapazarı (light area in center of figure) and the route taken by the MCEER/EDM team on October 2, 1999 (route shown as a continuous black line). Also seen are individual damage assignments that were made along the route. Note: A damage index of 1 is associated with an observation of slight to no damage; an index of 5 reflects catastrophic damage.

(center of the figure) and proceeded in a counterclockwise direction. Also noted on Figure 12 are color-coded circles that represent various levels of site damage (on a city block level), ranging from none or slight to catastrophic damage. Unlike the Avcılar survey, we did not have access to Differential GPS. Therefore, some wavering of the route trace is noted. In theory, the coordinates that are registered are within a block of the actual location.

To help select the best route to take, we enlisted the services of a government worker who was familiar with many of the city’s reconstruction projects. With her help, we were able to map out a route that took us through the most heavily damaged areas, as well as other areas (generally outside of town) which did not suffer much damage. Most importantly, this route took us in and out of those areas that were classified as catastrophic and extensive damage by the U.S. State Department.

In addition to assigning damage levels to each block, we attempted to record this information via (1) digital still cameras, and (2) digital video camera. Also recorded via laptop computer were written comments regarding our damage observations at specific sites. Some of these comments appear on Figure 12. Note on the figure, the area designated as “Circle Area.” This was one of the most devastated areas in the city.

Figure 13 shows two ERS radar images of the Adapazarı area, taken before and after the earthquake. As in Figure 12, the team’s route is seen
in these figures as a string of small circles. Unlike the previous image, which was optical, the images in Figure 13 were derived from processed SAR data and show up as pixels of varying intensity. Each pixel in the raw data set represents a rectangular area of approximately 4 meters by 21 meters, depending on the terrain. Since each of these images was taken from the same satellite track, the view or position of the image is similar.

To process these data, EQE imported the single-look complex images into the ENVI (the Environment for Visualizing Images) software, a special imaging processing program designed specifically for remotely sensed data. The single-look complex images provide the highest resolution possible using a SAR imaging system. The resolution or pixel size is dependent on a number of factors including radar hardware parameters. For our data set, the pixel size is about 4 meters in the azimuthal direction (i.e., the direction of the radar platform) and 21 meters in the cross direction. In order to reduce the inherent noise in the radar image (e.g., speckle noise), we applied an averaging filter in the azimuthal direction. This process is normally referred to as multi-look averaging. This reduction in noise, however, comes at the expense of reduced spatial resolution. The end product, after this processing, is a 21 meter by 21 meter pixel.

We anticipate that with this resolution, it will be difficult to recognize from these images physical structures having dimensions of less that 20 meters. Therefore, unless a structure takes up several pixels, it may be difficult to assess any change between before- and after-earthquake images. We are also investigating a "correlation" approach to detect pixel level changes; however, these analyses are not complete at this time.

The two images that are shown in Figure 13 were taken almost five months apart. The first image was taken in late spring (4/24/99); the second image was taken less than...
one month after the August 17th earthquake (9/10/99). Generally, there would be image differences caused by seasonal change. However, for this area, temperature differences within that time span are expected to be mild (55 °F in late spring to 70+ °F in summer); average monthly rainfall between these two periods is also expected to vary only slightly.

In general, pixel intensity will depend upon vegetation level, the density of buildings and their shapes, moisture levels, season, etc. Brighter areas are those that reflect more of the radar energy sent down from the sensor. In Figures 13a and 13b, the brighter areas are associated with the built-up area of Adapazarı. Both images were exported to MapInfo where they were geo-referenced to the Landsat 5 data. Since the resolution of these images is fairly coarse, we generally see only the major features of the region, e.g., major roadways and streets and some very large buildings. A cursory examination of both images does show some differences between the two figures. In order to view these changes in detail, we must concentrate on smaller portions of these images.

In order to identify any significant changes between the two images, we had to isolate part of the previous figures and concentrate on those areas that the team spent some time investigating while in the field. Once such area is the "Circle Area" which shows up at the tail end of the route (see Figure 12 for approximate location). To examine the changes between the two images, we drew a circle of 0.25-mile radius around this area. Comparison of the two images reveals that the after-earthquake image (Figure 14b) contains fewer bright spots. As was explained before, many of the buildings in this area had either completely failed (total collapse) or were severely damaged (many tilted buildings). It is expected that this type of damage would result in more scattering and thus, duller images.

Figure 15 shows two photographs of damage in the "Circle Area." The first photograph (Figure 15a) is taken looking west along the main road. The second photograph is taken from the same location,
looking northeast. Note that many of the damaged buildings have been torn down and the debris hauled away (Figure 15a). Since the second image was taken about one month after the earthquake, it is possible that the bare ground was being imaged at that time. At any rate, the second image was able to pick up this change.

In the next several months, we will be examining these data in more detail. In addition to the “Circle Area,” we hope to examine other sites where we have collected field data on the earthquake. One useful source is a digital video that was taken on the second trip to Adapazarı in November. By examining these images in more detail, and perhaps, by creating a series of correlation or coherence maps, we can begin to explain the meaning of these image changes. In addition, we hope to return to Turkey to collect other data that may help to quantify the extent of damage to this town.

Summary

Although largely untested in earthquakes, all of the new technologies employed during our reconnaissance proved to be invaluable in documenting the effects from this earthquake. Listed below are some of the lessons learned while performing this investigation.

1. The Landsat images proved to be invaluable in calibrating on-ground data, such as the locations of major roads, the boundaries of urban regions, and in some cases, the location of large buildings, i.e., buildings with large footprints. Because the resolution was fairly coarse (30 meters), it was difficult to use these data to detect or quantify earthquake damage. These images, however, were easily processed and were available soon after earthquake.

2. The ERS-1 and ERS-2 data proved to be useful once the MCEER/
EDM team left the field and returned home. Although these data were available before the trip, it was difficult to process this information because of map registration problems, and because the data contained more than just image data. We are now beginning to work with these data to explore how useful they are in detecting damage through interferometric techniques. We speculate that correlation or coherence maps developed from an analysis of pre- and post-earthquake images will result in the best use of these data and could possibly detect areas where significant damage (e.g., collapsed buildings) has occurred.

3. The use of GPS equipment was essential in documenting the activities of the team. Precise coordinates were established for important damage sites. This information was crucial in relating satellite imagery data to on-ground observations. Also, when connected to the portable laptop computer, many critical analyses were possible in real-time. There was also a significant difference in results when Differential GPS was available. In Avcılar, geographical coordinates were accurate to within one meter. In Adapazari, where Differential GPS measurements were not possible, coordinates were accurate to within 30 meters. This difference could be critical when attempting to document damage to individual buildings.

4. Having access to in-field GIS software made the documentation process extremely efficient. Many of the records – such as the Adapazari survey – would not have been possible had it not been for the GPS-GIS setup. The actual survey that was discussed in the previous section took less than 4 hours. If paper maps or other manual methods of documenting damage had been employed, it would have taken at least several days to accomplish what was done in half a day using these new mapping technologies.

5. One important piece of equipment – which was used by investigation team members for the first time – was a digital camera. The advantages to using such a camera is that the images that are taken are immediately viewable, they can be downloaded immediately for transmission to some other site, and when connected to a GPS unit (which was not done on this trip), could produce more reliable documentation of an event.

Endnotes

1 SPOT is a French company that provides satellite imagery data throughout the world. SPOT stands for Satellite Pour l’Observation de la Terra.

2 As it turns out, one of the guides that we used during this half-day trek had a tourist map of the city, which she kindly turned over to us as we departed.

3 A digital video camera was used on a second trip to Adapazari on November 20, 1999.
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