

# Application of High-Resolution Optical Satellite Imagery for Post-Earthquake Damage Assessment: The 2003 Boumerdes (Algeria) and Bam (Iran) Earthquakes

by Beverley J. Adams, Charles K. Huyck, Babak Mansouri, Ronald T. Eguchi and Masanobu Shinozuka

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## Research Objectives

The objectives of this research are to develop techniques for post-earthquake urban damage detection, based on the comparative analysis of remote sensing images acquired before and after the event, and to develop the technological infrastructure for integrating these techniques into field-based reconnaissance activities.

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Remote sensing technology is increasingly recognized as a valuable post-earthquake damage assessment tool. Recent studies performed by research teams in the U.S., Japan and Europe have demonstrated that building damage sustained in urban environments can be readily identified through the analysis of optical (Matsuoka and Yamazaki, 1998; Chiroiu et al., 2002; Huyck et al., 2002; Mitomi et al., 2002; Yusuf et al., 2002; Shinozuka et al., 2000; Saito and Spence, 2004) and synthetic aperture radar (SAR) (Aoki et al., 1998, Huyck et al., 2002; Yusuf et al., 2002) imagery.

Under the broad aim of identifying ways in which post-earthquake response and recovery activities can be improved through the integration of remote sensing technologies, a Multidisciplinary Center for Earthquake Engineering Research (MCEER) team has been investigating their use for urban damage detection and emergency response (Eguchi et al., 1999; Eguchi et al., 2000a, 2000b; Eguchi et al., 2003; Huyck and Adams, 2002; Huyck et al., 2002). Research to date has focused on various aspects of damage detection, including the development of post-earthquake damage detection algorithms that use optical and SAR data to locate building collapse, and a mapping system to display and disseminate earthquake-related multimodal geospatial data.

This paper describes an extension of the methodology previously developed for the 1999 Marmara (Turkey) earthquake (see Eguchi et al., 2003), to detect building damage caused by the 2003 Boumerdes (Algeria) and Bam (Algeria) earthquakes (see also Adams et al., 2003a, 2003b, 2004). For the Marmara event, change detection algorithms were based on moderate resolution SPOT4 optical and ERS SAR coverage. Following the recent launch of Quickbird and IKONOS commercial satellite systems, a new generation of very high-resolution imagery has become available. The Boumerdes

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## Research Team

**Beverley J. Adams**, Remote Sensing Group Leader,  
**Charles K. Huyck**, Senior Vice President, **Michael Mio**, Programmer Analyst, and **Ronald T. Eguchi**, President, ImageCat, Inc.

**Babak Mansouri**, Project Scientist, ImageCat, Inc., University of California, Irvine and M-K-Beton

**Bijan Houshmand**, Adjunct Associate Professor, Electrical Engineering Department, University of California, Los Angeles

**Masanobu Shinozuka**, Distinguished Professor and Chair, Department of Civil and Environmental Engineering, University of California, Irvine

## Previous Summaries

**2001-2003:**

*Eguchi et al.,*  
[http://mceer.buffalo.edu/  
publications/resacom/0103/  
09eguchi.pdf](http://mceer.buffalo.edu/publications/resacom/0103/09eguchi.pdf)

**2000- 2001:**

*O'Rourke et al.,*  
[http://mceer.buffalo.edu/  
publications/resacom/0001/  
rpa\\_pdfs/14orourkegis-4.pdf](http://mceer.buffalo.edu/publications/resacom/0001/rpa_pdfs/14orourkegis-4.pdf)

**1999-2000:**

*Eguchi et al.,*  
[http://mceer.buffalo.edu/  
publications/resacom/9900/  
Chapter7.pdf](http://mceer.buffalo.edu/publications/resacom/9900/Chapter7.pdf)

**1997-1999:**

*Eguchi et al.,*  
[http://mceer.buffalo.edu/  
publications/resacom/9799/  
Ch1eguchb.pdf](http://mceer.buffalo.edu/publications/resacom/9799/Ch1eguchb.pdf)

and Bam earthquakes mark the first two occasions for which this imagery was collected before and soon after the event. However, the increase in spatial resolution from 10 meter to sub-meter accuracy calls for a number of methodological refinements. Initially, a 'Tiered Reconnaissance System' (TRS) is conceptualized, which extends the scope of information collected to include damage visualization for individual structures. Following details of a methodological refinement at the pre-processing stage, implementation of the revised methodology is described for the Boumerdes and Bam events. The paper goes on to provide details of its subsequent deployment as a post-earthquake reconnaissance tool within the VIEWS (Visualizing Impacts of Earthquake With Satellites) system, before concluding with a brief discussion of future research directions.

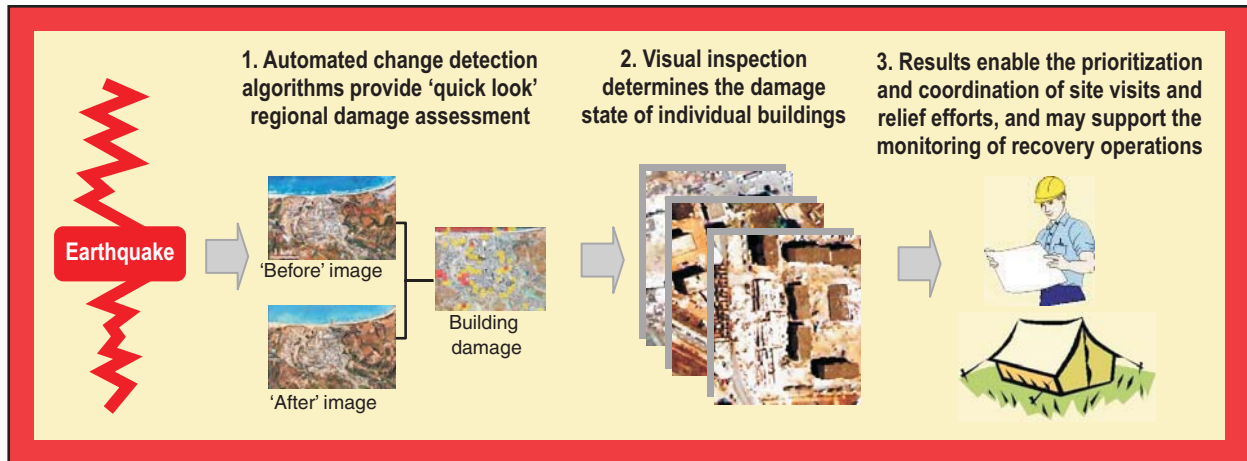
## Technical Summary

In the aftermath of extreme earthquakes such as the 2003 Boumerdes and Bam events, remote sensing imagery provides a detailed overview of damage sustained. The location and severity of building collapse can be rapidly determined, facilitating the scaling

and prioritization of relief efforts, and potentially the extended monitoring of the recovery operations.

As shown in Figure 1, this reconnaissance process may be conceptualized as a 'Tiered Reconnaissance System' (TRS). First, automated change detection algorithms offer a 'quick-look' city-wide damage assessment. These algorithms compare images acquired before and after the earthquake occurred, according to the methodological approach in Figure 2. Initial pre-processing involves registering the input images and georeferencing them within a common coordinate system. For very high-resolution imagery, an additional image processing step involves edge detection and texture analysis (further details are given in the following section). The theory is that building collapse produces a distinct textural signature compared with non-damaged structures, characterized by dense and irregular edges. This approach was not viable for SPOT4 coverage of the 1999 Marmara earthquake, since the textural characteristics of individual structures are indiscernible at 10m resolution. Damage is then computed in terms of 'changes' between the pre-processed scenes, measured using a simple arithmetic operator, such

Results from this research will bring significant benefits to emergency response personnel in the aftermath of extreme earthquake events. Damage detection techniques will furnish first responders, government officials, international aid agencies and reconnaissance teams with a quick look regional damage assessment and detailed visualization of damage sustained on a per building basis. These tools will enable the prioritization and coordination of relief efforts and site visits.

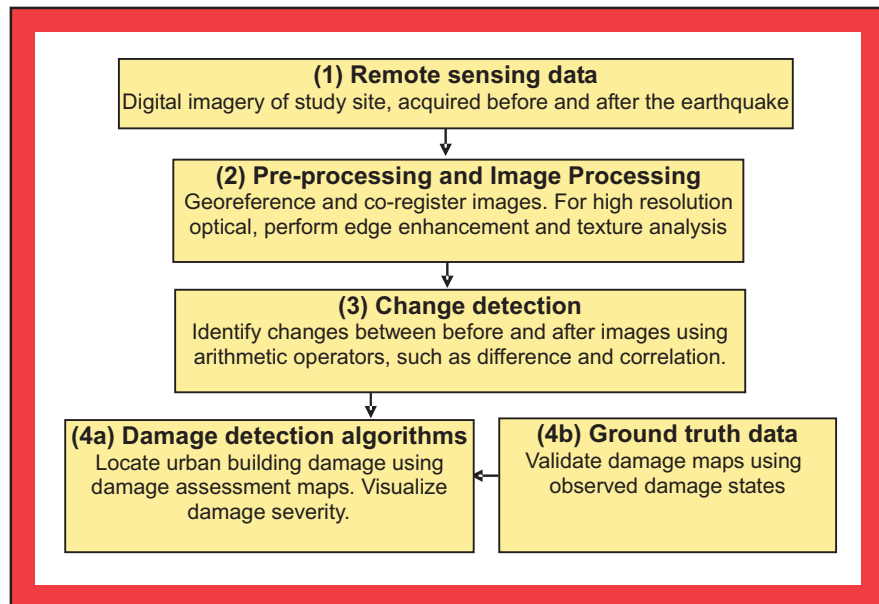


■ **Figure 1.** Schematic representation of the post-earthquake Tiered Reconnaissance System (TRS), which uses satellite imagery to determine the location, extent and severity of building damage. Output from the TRS guides the scale and prioritization of site visits and relief efforts.

as difference or correlation. Similar change detection algorithms have successfully been used to evaluate damage in cities affected by the 1999 Turkey (Eguchi et al., 2000a, 2000b, 2002, 2003), 1993 Hokkaido, 1995 Kobe (Matsuoka and Yamazaki, 2002), and 2001 Gujarat earthquakes (Matsuoka and Yamazaki, 2002, 2003). Lastly, detected building damage is displayed using a damage assessment map.

This quick-look assessment provides the focus for more detailed inspection of building damage, using visualization techniques. Given the fine detail depicted on very high-resolution imagery, it is possible to interpret the condition of individual structures by comparing enlarged representations from the 'before' and 'after' datasets. This comparative visual analysis is straightforward when the co-registered 'before' and 'after' images can be displayed side by side.

Finally, having performed the initial reconnaissance of damage location and severity, remote sensing imagery may have a longer-term role to play in monitoring clean-up operations. When possible, the acquisition of extended temporal coverage enables progress with debris clearance and reconstruction to be tracked.



■ **Figure 2.** Building damage detection methodology.

## Urban Damage Detection Following the 2003 Boumerdes and Bam Earthquakes

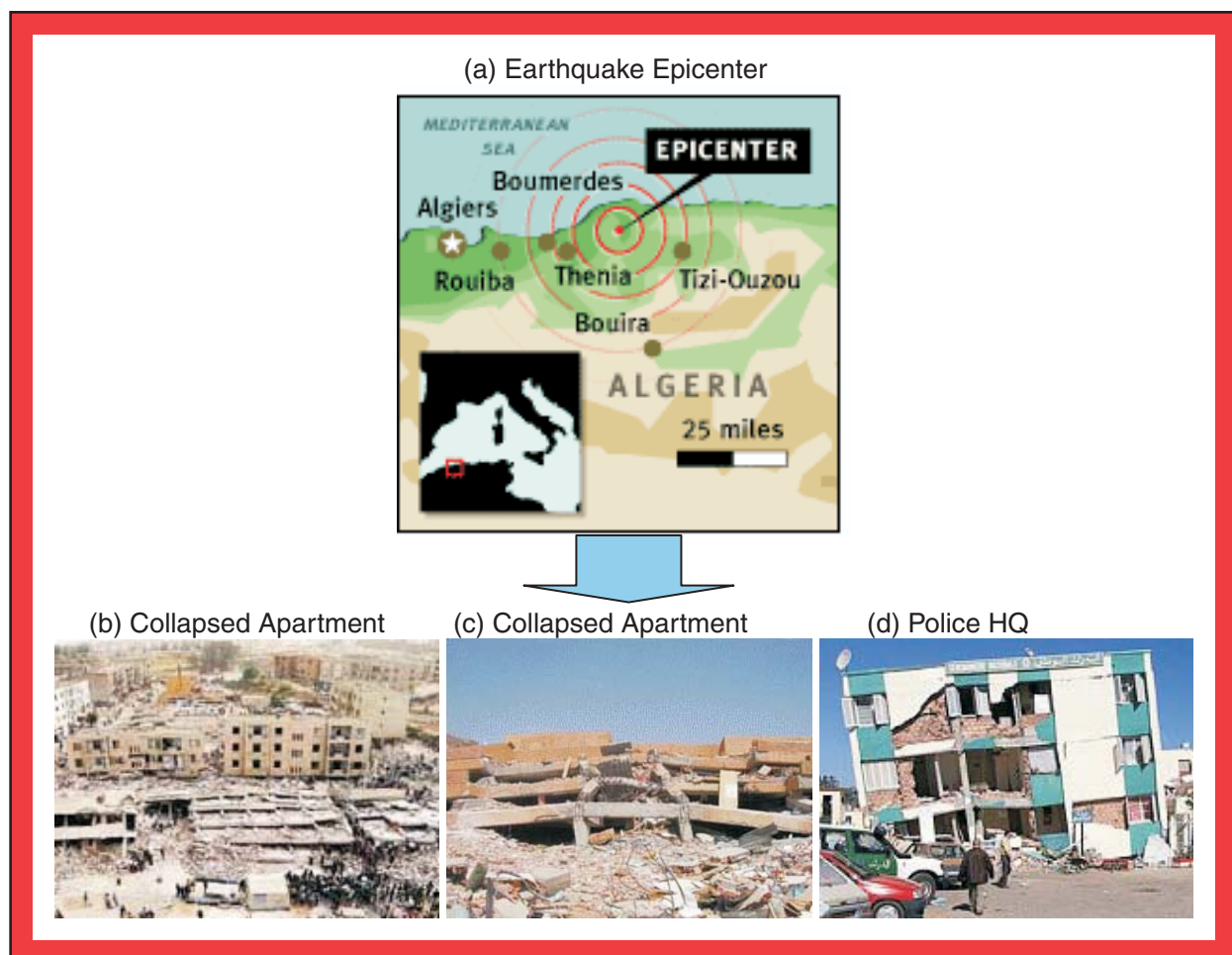
The TRS approach to urban damage detection was implemented following the Boumerdes and Bam earthquakes.

### Boumerdes, Algeria Earthquake

At 17:44 local time on May 21, 2003, a magnitude 6.8 earthquake struck Northern Algeria (USGS,

2003). Centered on the Boumerdes province (Figure 3a) some 50 km east of Algiers, the worst-affected urban areas included the cities of Boumerdes, Zemmouri, Thenia, Belouizdad, Rouiba and Reghaia, together with eastern areas of the capital. Deaths totaled 2,266, with a further 10,261 injuries (OCHA, 2003). Structural damage within urban areas was severe. From Figure 3b through Figure 3d, entire apartment blocks were reduced to piles of rubble. Civil structures, such as the police headquarters, were also damaged beyond repair.

Figure 4 shows the high-resolution Quickbird satellite



*Photographs courtesy of (b) AP Photo/Claude Paris; (c) Omar Kbemici and EERI; and (d) Reuters/Larbi.*

■ **Figure 3.** The May 21 2003 Boumerdes (Algeria) earthquake. Location of the earthquake epicenter; and building damage recorded in Boumerdes.

coverage acquired before and after the Boumerdes earthquake (courtesy of DigitalGlobe, [www.digitalglobe.com](http://www.digitalglobe.com)), purchased by the Earthquake Engineering Research Institute (EERI) as part of their Learning from Earthquakes Program. These ‘pan-sharpened’ images are a fusion of multispectral and panchromatic bands. The dataset includes a time series of imagery. The scene from April 22, 2002 serves as a baseline case, depicting the city as it used to appear before the earthquake struck. The second image is dated May 23, 2003 – just 2 days after the event. Third in the sequence, the coverage of June 18, 2003 records progress made with recovery efforts during the following month.

Constituting the initial TRS phase, Figure 5a shows the spatial distribution of severely damaged and collapsed buildings in Boumerdes, which were identified on the panchromatic Quickbird coverage, using the change detection methodology (see Figure 2). The scenes acquired before (4/22/02) and soon after the earthquake (5/23/03) were analyzed using the image processing software ENVI. In line with the high spatial

resolution of 60 cm, an additional texture-based pre-processing step was introduced to the change detection methodology. A 9x9 pixel Laplacian edge detection filter was initially applied to each co-registered scene, followed by a 25x25 dissimilarity texture measure. The resulting images were differenced on a per-pixel basis and the mean standard deviation about the image mean computed. An average standard deviation was then plotted within a 200x200 cell window. Mapping these block statistics in intervals of 1 standard deviation, highlights areas of potential building collapse, where textural change is consistently high. It remains for this city-wide damage map to be formally verified against ground based observations. This future work will draw on the building damage interpretation performed by Chiba University, Japan (see Yamazaki et al., 2003), as shown in Figure 5b.

In the meantime, a broad scale comparison can be drawn between observations and the damage map. Areas depicted in red and yellow in Figure 5a generally correspond with extreme textural changes accompanying building collapse.

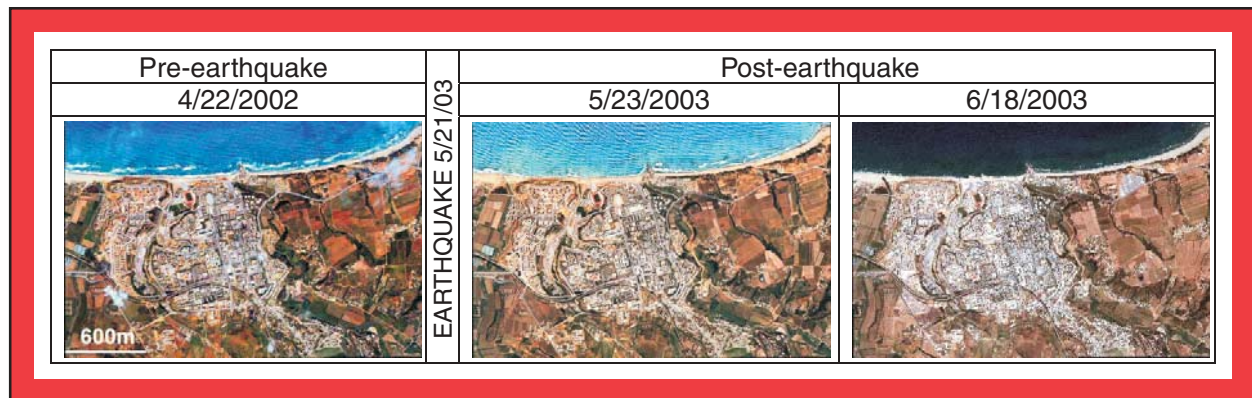
## **Collaborative Partners**

**Fumio Yamazaki**, Professor, Department of Urban Environmental Systems, Chiba University, Japan

**Masashi Matsuoka**, Deputy Team Leader, Earthquake Disaster Mitigation Research Center, Japan

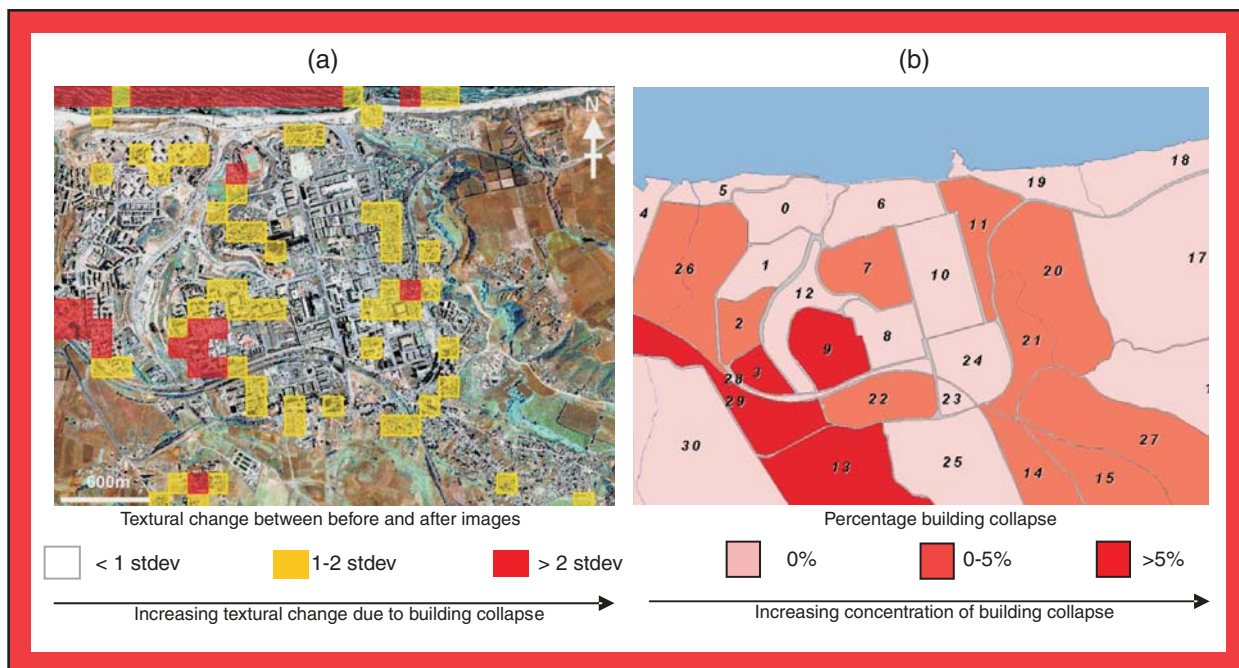
**Brett Thomassie**, Director of Civil and Government Programs, Digital Globe

**Marjorie Greene**, Learning from Earthquakes (LFE) Program Manager, Earthquake Engineering Research Institute



Images courtesy of DigitalGlobe, [www.digitalglobe.com](http://www.digitalglobe.com)

■ **Figure 4.** Quickbird satellite imagery of Boumerdes, acquired before and after the May 23, 2003 earthquake.



courtesy of F. Yamazaki

■ **Figure 5.** (a) Quickbird damage map for Boumerdes. High average block standard deviation from the image mean corresponds with extreme textural changes caused by building collapse. (b) Distribution of building collapse in Boumerdes

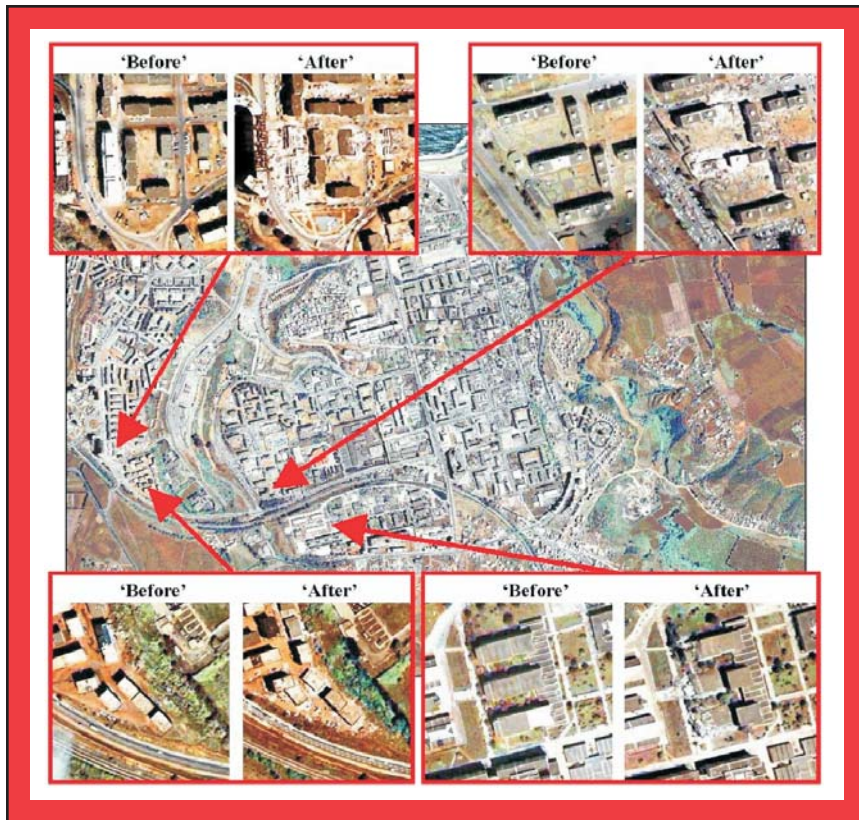
Concentrated damage in the south-west of the city aligns with zones 3 and 9 in the Chiba results (Figure 5b), where >5% of buildings collapsed. Extreme change within the coastal waters is probably attributable to textural variations in sea surface conditions.

Moving on to the second TRS phase, Figure 6 offers a detailed representation of neighborhoods sustaining severe building damage. From visual inspection of the 'before' and 'after' scenes, significant structural and geometric irregularities are apparent. Collapsed apartment blocks are readily distinguished by the bright yet chaotic appearance of debris. Where buildings have pancaked or toppled sideways, changes in shape and position are also evident. In the case of Boumerdes, a temporal sequence of 'after' images was available. In terms of monitoring progress with recovery operations,

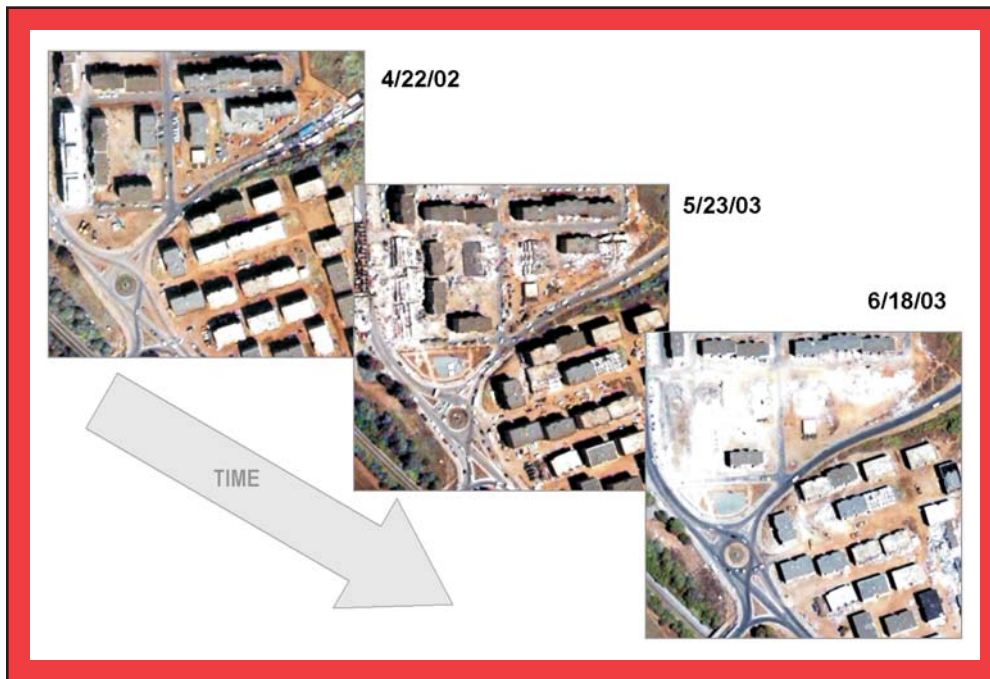
Figure 7 shows the full temporal sequence for an area of apartment blocks in western Boumerdes. The first image illustrates the buildings prior to the earthquake. The second shows their collapsed state, surrounded by debris. The third scene tracks recovery efforts, indicating that the site has largely been cleared.

### Bam, Iran Earthquake

At 05:26 on December 26 2003, a magnitude 6.6 (USGS, 2004) earthquake struck the historic city of Bam, in the Iranian province of Kerman (Figure 8a). The earthquake was centered approximately 10 km to the south-west of Bam. Damage was concentrated in a 16 km radius around the city, which is famed for its 2,500 year old citadel Arge-Bam. In terms of human cost, the Bam earthquake ranks as the worst recorded disas-



■ Figure 6. Visualization of building collapse in Boumerdes. The selected neighborhoods were identified as regions of extreme textural change in the damage map (Figure 5a)

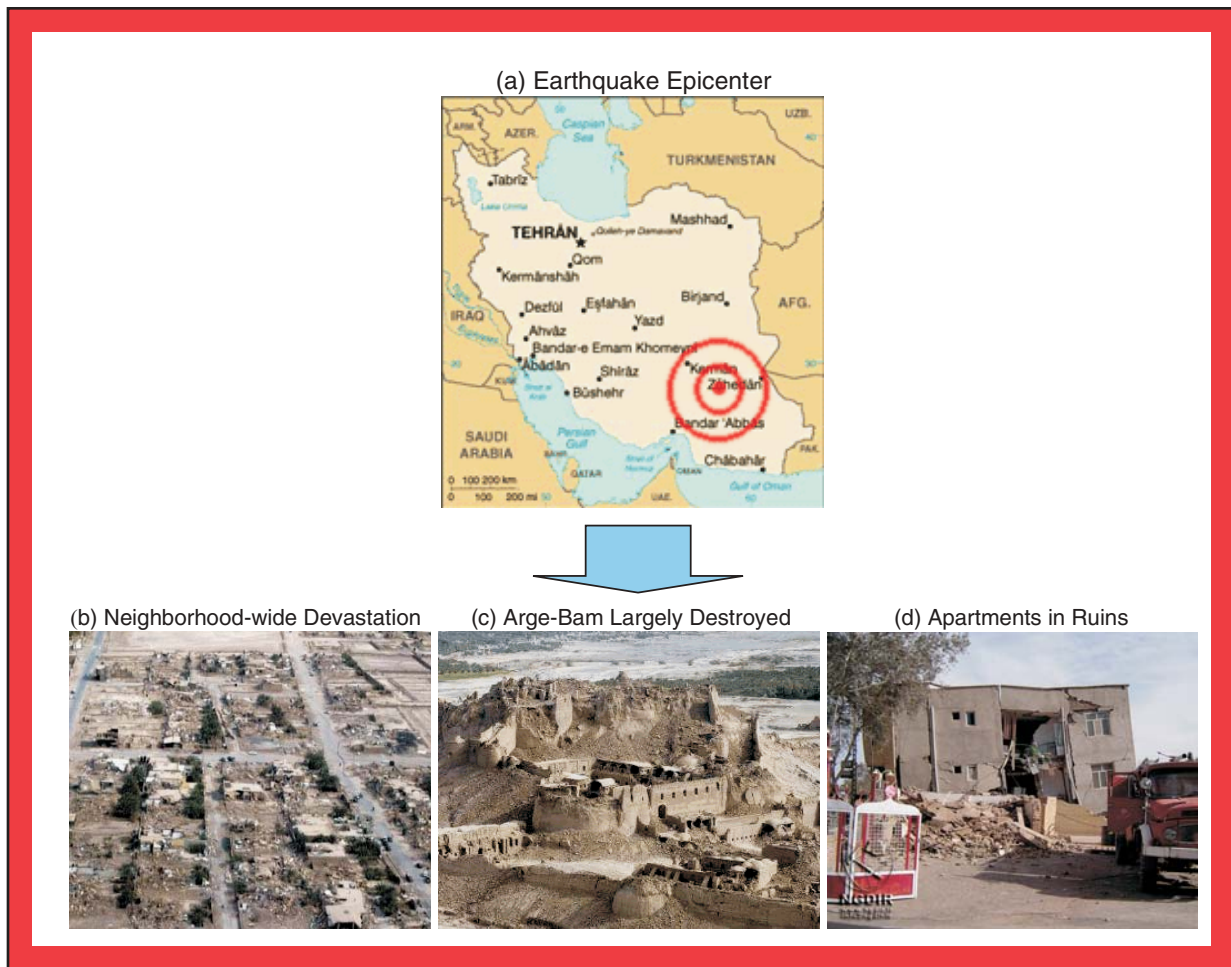


■ Figure 7. Time sequence of Quickbird images, showing apartments in western Boumerdes (1) prior to and (2) soon after the earthquake. Scene (3) acquired on 6/18/03, shows progress made with clean-up operations

ter in Iranian history. According to recent reports, the death toll has reached 26,200 (IFRC, 2004) with a further 75,600 left homeless. Initial reports from aid organizations in Bam estimated that between 70-95% of buildings were destroyed. Figure 8b through Figure 8d illustrate the nature and extent of damage: annihilation across entire city blocks; the historic city center and fortress in ruins; the main hospitals effectively destroyed, together with health homes, rural and urban health centers; 131 schools and 3 universities severely damaged.

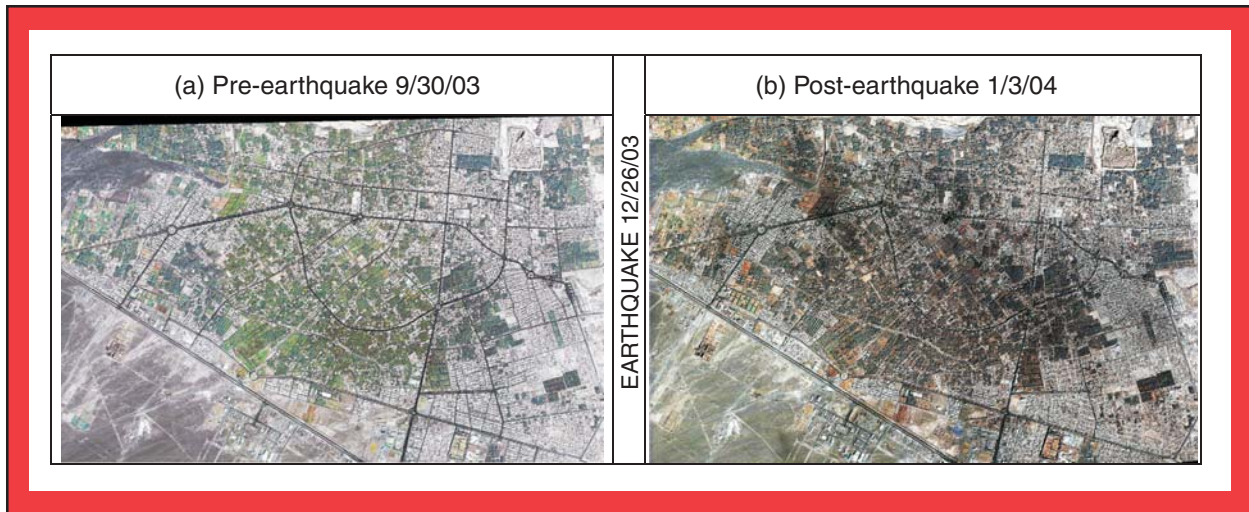
Figure 9 shows the extent of Quickbird satellite coverage of Bam (courtesy of DigitalGlobe, [www.digitalglobe.com](http://www.digitalglobe.com)), acquired by the University of California at Irvine, and the EERI as part of their Learning from Earthquakes Program. The first image is dated September 30, 2003 - approximately 3 months before the earthquake struck. The second, taken just over one week after the earthquake on January 3, 2004, shows widespread changes associated with building collapse.

For the initial TRS phase (see Figure 1), the same methodol-



Photographs courtesy of <http://activistchat.com/gallery/albums.php>

■ **Figure 8.** The December 26 2003 Bam (Iran) earthquake. Location of the earthquake epicenter; and examples of building damage recorded in the city and historic citadel Arge-Bam.

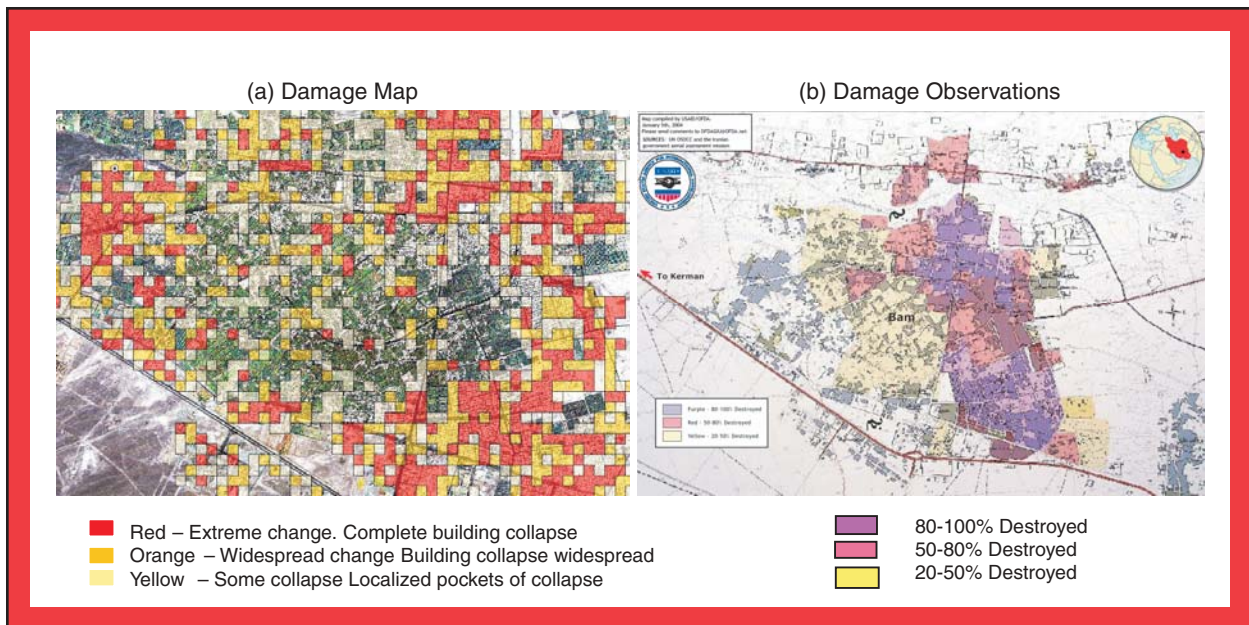


Images courtesy of DigitalGlobe, [www.digitalglobe.com](http://www.digitalglobe.com)

■ **Figure 9.** Quickbird satellite imagery of Bam, acquired before and after the December 26th 2003 earthquake.

ogy was employed here as for the Boumerdes event, with damage detected in terms of textural changes between the ‘before’ and ‘after’ scenes. The resulting city-wide damage map in Figure 10a shows the widespread occurrence of extreme changes (manifest as a high standard deviation about the

image mean) throughout Bam. The red and orange blocks corresponding with the highest concentration of collapsed structures, are widespread through eastern areas of the city and the Arge-Bam citadel. Visual comparison with the USAID damage map in Figure 10b, published in early January, indicates



courtesy of USAID

■ **Figure 10.** Quickbird damage map for Bam. Extreme textural changes caused by building collapse relate to a high average block standard deviation from the image mean (see also Figure 5) (b) Distribution of building collapse in Bam.

that 80-100% of buildings were destroyed in these areas. Formal verification of the damage map against these ground-based observations is a focus of ongoing research.

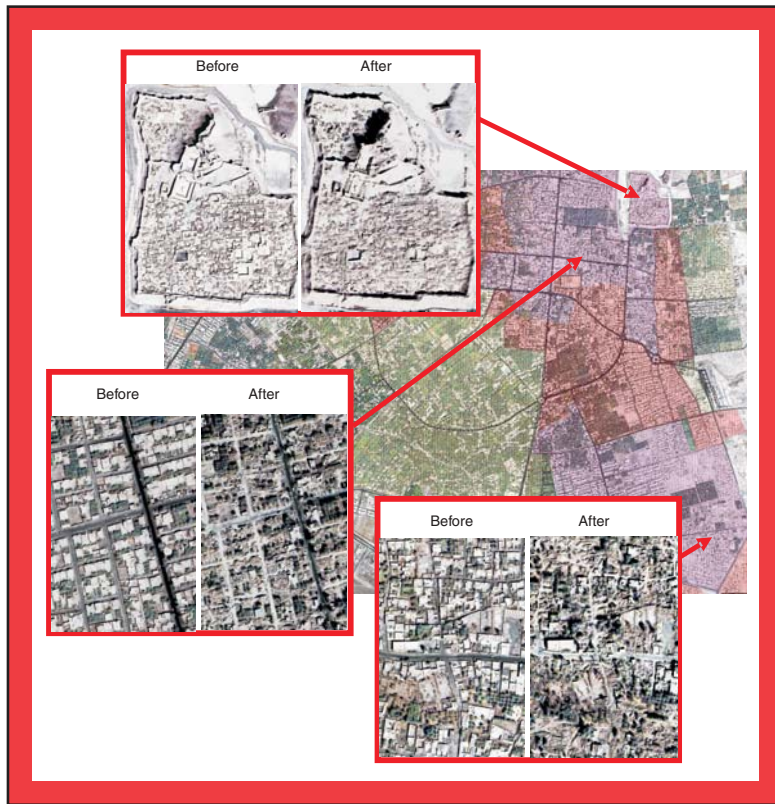
In terms of visual inspection, Figure 11 provides a close-up view of damage within a selection of areas on the damage map that record extreme changes. Collapsed buildings are evident throughout the ancient citadel. The eastern wall of the fortress appears to have collapsed. Many of the surrounding structures are no longer clearly defined as the walls and roofs have fallen in. In surrounding residential areas, building collapse is widespread; entire blocks of family homes have been destroyed. Their distinct footprint and white

roofs in the 'before' image, have been replaced by chaotic piles of brown rubble. Constructed from local material, the sand-colored debris is difficult to distinguish from the surrounding sandy ground surface.

## Deployment for Field Reconnaissance through VIEWS

Through MCEER funding, considerable effort has been invested in developing automated building damage detection methods, together with techniques for visualizing damage. The Bam earthquake marks their first deployment as a post-earthquake reconnaissance tool, within the VIEWS (Visualizing Impacts of Earthquakes With Satellites) system. Figure 12 shows the VIEWS interface, displaying 'before' and 'after' imagery of Bam.

Running on a notebook for portability, VIEWS enables reconnaissance teams to compare satellite images acquired before and after an earthquake. The system directs responders to the hardest hit areas, using the damage assessment map (Figure 10a). For more detailed damage information, collapsed buildings are easily identified on the high-resolution satellite coverage. This also serves as a basemap and orientation device for teams deployed to unfamiliar cities. To help users gain and maintain their bearings, VIEWS tracks their current position using a real-time GPS feed. The system also provides easy recall for observations made in the field. As users enter comments such as building damage descriptions and the ID number of their photographs, all informa-



■ **Figure 11.** Visualization of building collapse in Bam. The selected neighborhoods were identified as regions of extreme damage (80-100% collapse) on the USAID damage map (Figure 10b)

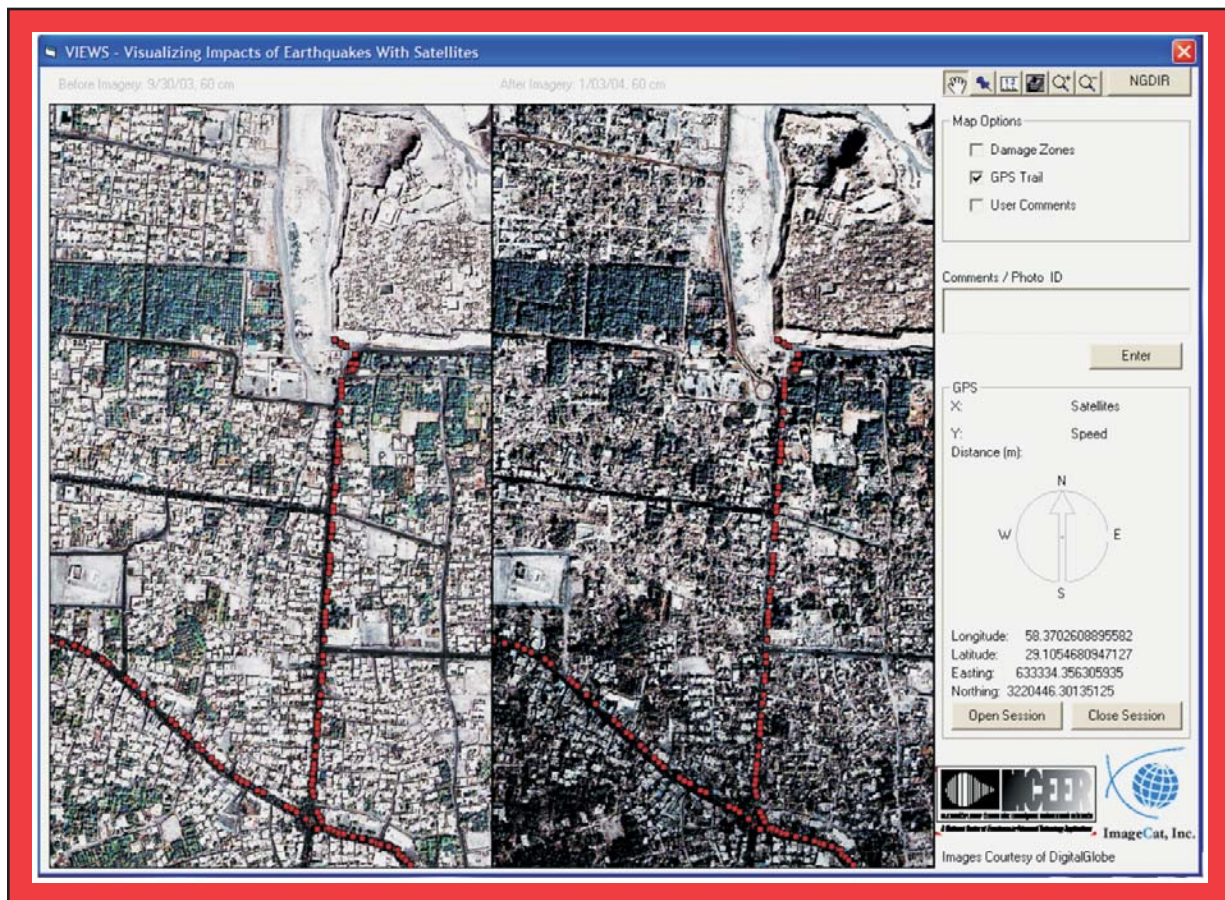
tion is automatically linked to the current GPS location. Back in the office, VIEWS datasets are readily transferred to a GIS environment, for further analysis.

The VIEWS system was deployed by the EERI reconnaissance team. During the course of reconnaissance activities in Bam, the GPS functionality was used to track routes followed through the city. Figure 12 illustrates one of the routes taken towards the citadel. The location of digital photographs was also recorded and their identification numbers and associated comments added as attributes. Following this initial trial, important lessons have been learned that will improve logistical and technical

aspects of VIEWS deployment for future earthquakes.

## Conclusion and Further Research

Results from the multitemporal change detection methodologies presented in this paper demonstrate that high-resolution Quickbird satellite imagery can be used to successfully determine the location and severity of post-earthquake building collapse. Compared with previous research completed for the 1999 Marmara (Turkey) earthquake (see Eguchi et al., 2003) using SPOT 4 optical data, the increase in spatial resolution to 60 cm necessitated additional



■ Figure 12. Screen-grab of the VIEWS (Visualizing Impacts of Earthquakes with Satellites) system, deployed in Bam with the EERI reconnaissance team. The GPS trail (red symbols) is shown for a route taken by the team during reconnaissance activities.

processing to distinguish damage associated with building collapse. When plotted as a damage map, the differenced edge detection and textural dissimilarity results successfully located blocks of extreme change. In this case, change was measured relatively rather than absolutely, in terms of the standard deviation about the image mean. The spectral signature of earthquake building damage differs around the World, as the building stock and construction materials vary. As such, devising universally applicable measures of change poses a considerable challenge.

While working towards an end goal of robust damage detection algorithms that can be rapidly deployed in future earthquakes to aid response and recovery efforts, this research program will concentrate on standardizing the methodology, so that building damage can be detected, irrespective of urban setting. From a methodological perspective, findings from the 1999 Turkey, and 2003 Algerian

and Iranian events, will be consolidated and existing optical damage detection algorithms refined and augmented with new capabilities. For example, the integration of higher resolution Radarsat SAR satellite imagery would enable 24/7, all-weather damage assessment. The use of unmanned airborne vehicles (UAVs) such as the MLB 'Bat' as part of reconnaissance activities, would enable the collection of imagery from remote locations with poor accessibility, or sites that are cut-off after an earthquake. The processing and integration of resulting high-resolution optical coverage will pose an exciting new research challenge.

In terms of research implementation, VIEWS technology will be extended to include these refinements, and on the basis of feedback from field reconnaissance teams, enhanced to optimize performance during future deployments. In achieving these objectives, collaboration will continue with U.S. and International research partners.

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