

The Bam (Iran) Earthquake of December 26, 2003: Preliminary Reconnaissance Using Remotely Sensed Data and the VIEWS (Visualizing the Impacts of Earthquakes with Satellite Images) System

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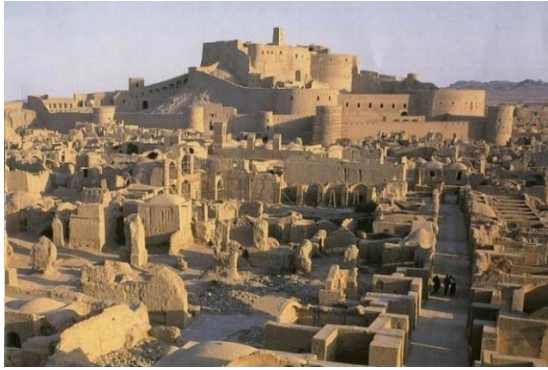
Many residents in the historic city of Bam were still sleeping at 05:26 on December 26, 2003, when the magnitude 6.6 (USGS, 2004a) earthquake struck. Their traditional mud-brick and clay homes put up little resistance to the violent shaking, and as walls and roofs crumbled and collapsed, tens of thousands of victims were trapped beneath the rubble.

The earthquake was centered approximately 10km to the southwest of Bam (IIEES, 2004), which borders the Dasht-e-Lut desert, in the Iranian province of Kerman (see Figure 1). Initial investigations suggest that the event occurred on the Bam fault, and was caused by northward motion of the Arabian plate against the Eurasian plate (USGS, 2004b). A full seismological report is available at USGS (2004a), with seismotectonic background of the Bam area provided by Eshghi and Zare (2003). For a pre-earthquake seismic hazard assessment and bibliography, see Tavakoli and Ghafory-Ashtiany (1999) and ISG (2004).



Figure 1 Schematic map, showing the location of the earthquake epicenter (29.01°N, 58.34°E) relative to the historic city of Bam, bordering the Dasht-e-Lut desert in the south-east Iranian province of Kerman.

Damage was concentrated in a relatively small area, of roughly 16km radius, around Bam - a tourist destination on the old Silk Road, famed for its 2,500-year old citadel Arg-e-Bam (Figure 2a). According to recent reports, the death toll has reached 41,000 (IFRC, 2004c), with a final expected figure closer to 45,000. The Government of Iran estimates that a further 45,000 people have been displaced from their homes (USAID, 2004), which may rise to 75,000 as residents staying elsewhere with friends and relatives, begin to return.



a



b



c



d



e



f

Figure 2 Photo mosaic of the Bam Citadel and surrounding urban districts. (a) The Citadel before the earthquake struck; (b) the Citadel after the December 26, 2003 earthquake; (c) residential city blocks razed by the earthquake; (d) mud-brick houses reduced to rubble; (e) sand-colored building debris smothered victims and crushed cars; (f) the 10% of structures still standing recorded 40-60% structural damage. (Photographs courtesy of <http://activistchat.com/gallery/albums.php>)

In terms of human cost, the Bam earthquake ranks as the worst recorded disaster in Iranian history; a tragic statistic in a nation already ranked as the World's 4th most disaster prone country (IFRC, 2004a). Although Bam itself had no prior record of significant earthquake damage, within the surrounding 100km, during the 50-year period from 1948-1998, 14 earthquakes were recorded measuring magnitude 5 or greater on the Richter scale (Eshghi and Zare, 2003). Within the nation as a whole, the 20th century saw 65 major events (magnitude ≥ 6.0), claiming 126,000 Iranian lives (for further details, see Berberian,

2004). According to historic records, earthquakes have razed other cities, including Tabriz, Ray and Nishapur (Berberian, 1997). Such devastation and massive loss of life is largely attributable to poor construction methods in a society where it is traditional for people to build their own homes. According to (F. Naiem, cited in Online NewsHour, 2004), building codes have proved difficult to enforce for modern structures, and are largely absent for older dwellings.

Post-earthquake Urban Damage Detection

A United Nations damage assessment team estimated that 90% of buildings in Bam sustained 60-100% damage (WFP, 2003) - some 25,000 of the 29,500 structures within the city center and surrounding villages (UN, 2004). The remaining 10% of building stock recorded 40-60% damage. Figure 2b through Figure 2f 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 94 health homes, 14 rural and 10 urban health centers; and 131 schools and 3 universities severely damaged (IFRC, 2004b).

In the immediate aftermath of an earthquake, experiences from the 2003 Algeria (Adams *et al.*, 2003a, 2003b) and 1999 Turkey events (Eguchi *et al.*, 2003) have demonstrated that satellite images could make a significant contribution to post-earthquake damage assessment. Remote sensing coverage acquired by earth-orbiting satellites offers a birds-eye view of urban damage. Today, commercial satellites provide a close-up view of family houses, or tents used for temporary housing. This makes them an excellent tool for seeking out the hardest hit areas and monitoring the progress of recovery efforts.

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 the Impacts of Earthquakes using Remote Sensing Images) system.

VIEWS

Running on a notebook computer for portability in the field (Figure 3), VIEWS enables reconnaissance teams to compare satellite images acquired before and after an earthquake. The system directs responders to the hardest hit areas, using a preliminary regional damage assessment (Adams *et al.*, 2003b). For more detailed damage information, collapsed buildings are easily identified on the high-resolution satellite coverage.



Figure 3 The VIEWS (Visualizing the Impacts of Earthquakes using Remote Sensing Images) system being tested prior to deployment in Bam with the EERI reconnaissance team.

The imagery 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 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 information 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 following sections present the VIEWS satellite coverage of Bam, together with the quick-look regional damage assessment used by the EERI reconnaissance team. VIEWS excerpts used to visualize building damage in the Bam citadel and surrounding residential districts are also included.

Preliminary Regional Damage Assessment

Figure 4 shows the extent of ‘Quickbird’ satellite coverage of Bam, acquired by the University of California at Irvine (UCI), and the Earthquake Engineering Research Institute (EERI) as part of their *Learning from Earthquakes* Program. The first image is dated September 30th 2003 – approximately 3 months before the earthquake struck. Visual comparison with the second image, taken just over one week after the earthquake on 3rd January 2004, reveals widespread changes. Many of the differences are caused by building collapse, although seasonal variations in vegetation may also be present.

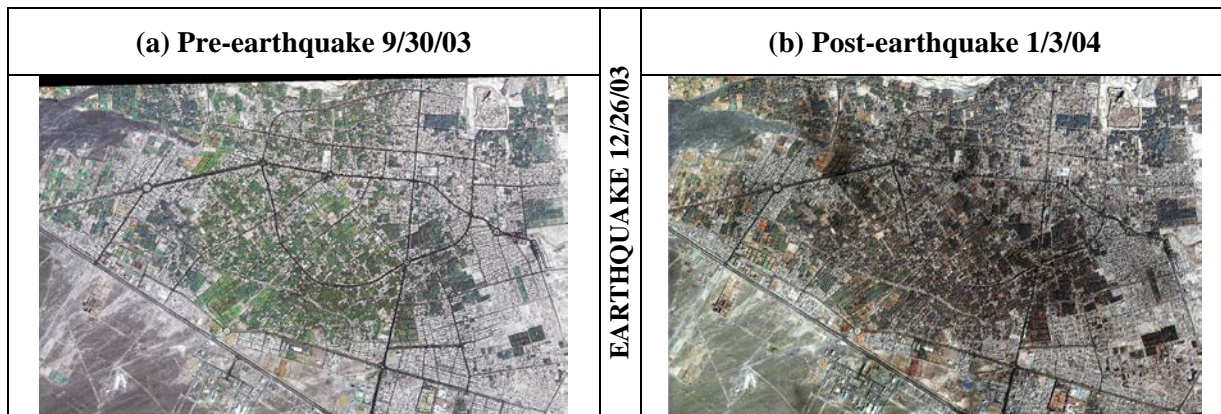


Figure 4 Pan-sharpened QuickBird satellite coverage of Bam, acquired: (a) in September 2003 ‘before’ the earthquake; and (b) in January 2004 ‘after’ the earthquake. In addition to differences between the scenes due to urban damage, the greenness of vegetation has changed because of seasonal effects and sensor look angle variation. Imagery courtesy of DigitalGlobe, www.digitalglobe.com.

These changes were quantified using a texture-based change detection algorithm originally developed for the 2003 Algerian earthquake. In the resulting building damage map (Figure 5), red and orange areas are associated with extreme changes where structures have collapsed. These zones are concentrated within eastern districts of Bam, a distribution which corresponds closely with preliminary results of a ground-based damage assessment (National Cartographic Center of Iran, 2004).

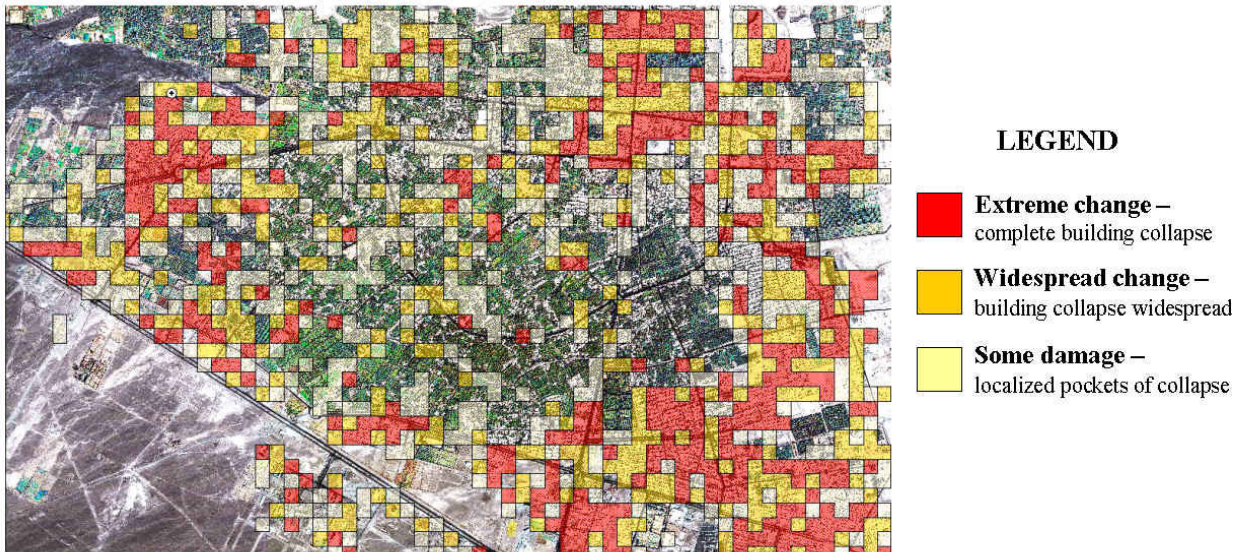


Figure 5 Preliminary VIEWS damage assessment for Bam, obtained using texture-based change detection. Red and orange areas correspond with pronounced changes between the ‘before’ and ‘after’ scenes, which are primarily associated with collapsed buildings. To aid visualization, results are overlaid with QuickBird coverage from 30th September 2003. Imagery courtesy of DigitalGlobe, www.digitalglobe.com.

Building Damage Visualization

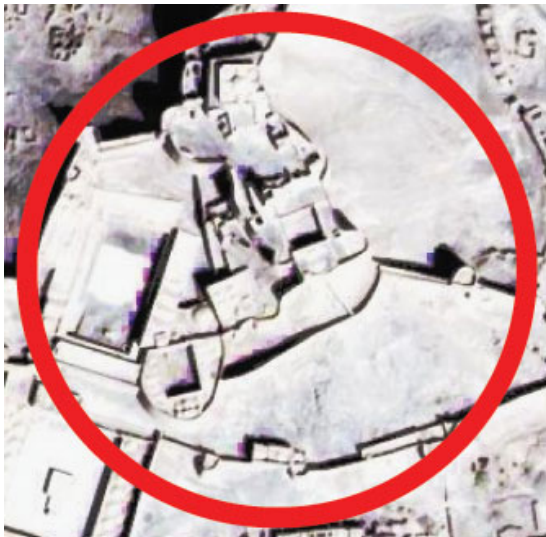
Figure 6 and Figure 7 provide a close-up view of damage within selected areas where the regional damage assessment recorded extreme changes. Identifying and visualizing building collapse in this way could guide search and rescue teams to the probable location of trapped victims.



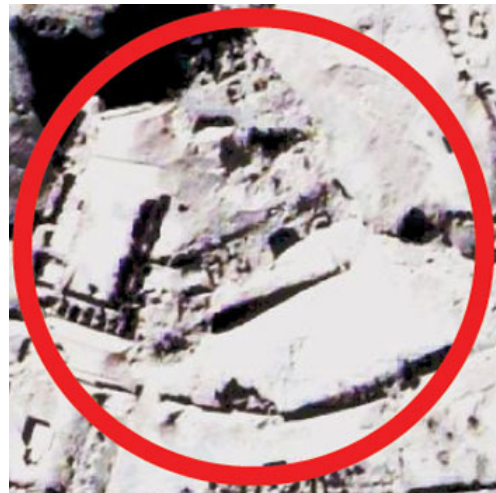
a



b



6a close up



6b close up

Figure 6 Visual comparison of (a) before and (b) after QuickBird satellite imagery reveals widespread devastation within the Bam citadel. Reports indicate that the December 26th 2003 earthquake destroyed the main fortress (see annotation), together with 95% of surrounding buildings. Imagery courtesy of DigitalGlobe, www.digitalglobe.com.



a before



b after



c before



d after



Figure 7 Building damage within eastern residential districts of Bam, visualized by comparing the ‘before’ and ‘after’ QuickBird satellite imagery. Imagery courtesy of DigitalGlobe, www.digitalglobe.com.

According to field reports, up to 95% of buildings collapsed within the ancient Bam citadel. From Figure 6, the eastern wall of the fortress has collapsed (see also Figure 2b). Surrounding dwellings that were clearly defined in the before scene are replaced by indistinct piles of debris, where their walls and roofs have collapsed.

Within residential districts of Bam (Figure 7), entire blocks of family homes have been destroyed. Their distinct footprint and white roof in the before image, is replaced by chaotic piles of brown rubble (see also Figure 2c through Figure 2e). With buildings constructed from local materials, the sand-colored debris is difficult to distinguish from the sandy ground surface.

Future Research

This research program will continue working towards an end goal of robust damage detection algorithms that can be rapidly deployed in future earthquakes to aid response and recovery efforts. 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. In particular, the integration of SAR satellite imagery would enable 24/7, all weather damage assessment. While damage detection algorithms presently map the general occurrence of building collapse, future research will explore a refined scaling that expresses damage severity and extent. 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.

Acknowledgements

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