A SDSS-BASED EARTHQUAKE DAMAGE ASSESSMENT FOR EMERGENCY RESPONSE: CASE STUDY IN BAM

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ABSTRACT:

Lack of reliable, up to date, available and qualified geospatial data is one of the problems we are faced to have a proper response to natural disasters. On the other hand, complexity of earthquake phenomena from time, position and intensity, makes it a very uncertain phenomenon to assess. Furthermore, there is no comprehensive spatial analysis tool to support decision making under such disasters. Therefore, development of spatial decision support system (SDSS) to support processing and analyzing geo-spatial data for disaster management and damage estimation is of extreme importance. Previous research shows that about 70 % of Iranian urban areas are suspect to earthquake, therefore, Iran is located in an extremely earthquake risk prone areas in the world.This paper outlines a methodology to assess damage estimation due to an earthquake using SDSS. The methodology is based on quantifying number of buildings destroyed due to an earthquake using high resolution remotely sensed images and other spatial data to be integrated in a SDSS.An inventory of buildings in Bam city before the earthquake happened in Dec. 2003 was prepared. The number of destroyed buildings, due to the earthquake was evaluated. An object-based classification and segmentation methods have been used for damage estimation. Out of 18872 buildings in Bam city, 6473 buildings (34 %) were collapsed due to the earthquake. Preliminary assessments indicate an overall accuracy for the classification to be about 80.5%.The results of this paper can assist decision makers to allocate rescue forces to the damaged areas based on their degree of destruction.

1. INTRODUCTION

Research to date on earthquake damage assessment 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 buildings collapsed, and a mapping system to display and disseminate earthquake-related multimodal geospatial data (Eguchi *et al*., 1999, 2000a,b; Huyck and Adams, 2002).

This paper outlines a methodology to assess damage estimation due to an earthquake using spatial decision support system (SDSS). The methodology is based on quantifying number of buildings destroyed due to an earthquake using high resolution remotely sensed images and other spatial data to be integrated in a SDSS.

Remote sensing technology is increasingly recognized as a valuable post-earthquake damage assessment tool. Identification of ways in which post-earthquake response and recovery activities can be improved through the integration of remote sensing technologies, geo-spatial data for disaster management and damage estimation in SDSS is the main objective of this paper.

At 05:26 A.M on December 26 2003, a magnitude of 6.6 Richter earthquake struck the historic city of Bam, in the south eastern Iranian Province of Kerman (USGS, 2004). 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 disaster in Iranian history. According to recent reports, the death toll has reached 26,200 with a further 75,600 left homeless (IFRC, 2004). Initial reports from aid organizations in Bam estimated that between 70-95% of buildings were destroyed.

Some related works on earthquake damage assessment is introduced in section 2. Section 3 describes our methodology for remote sensing processing. Section 4 demonstrates the statistical classification method as the case study undertaken. Finally section 5 demonstrates conclusion and future direction for the research.

2. BACKGROUND

Over the past decade, the value of optical remote sensing technology for city-wide damage assessment has been increasingly recognized. As very high-resolution commercial imagery has become available from sensors such as Quickbird and IKONOS, it is now possible to identify damage to individual structures (Adams *et al*., 2003, 2004). 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 earthquake urban damage detection and emergency response (Eguchi *et al*., 1999, 2000a, 2000b, 2003; Huyck and Adams, 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.

3. METHODOLOGY

A SDSS is an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial problem (Sprague and Carlson 1982). It is designed to assist the spatial planner with guidance in making land use decisions. A system which models decisions could be used to help identify the most effective decision path. Our proposed methodology shown in Diagram 1 outlines the stages of the development of a SDSS-based earthquake damage assessment for emergency response. Based on this methodology, there are 7 steps. The first 4 steps are implemented based on the method proposed in Samadzadegan *et al.* 2007. The output of their work is a classified image that we used in this article. We summarizes an "object-oriented" methodology ((De Kok *et al*., 1999; Benz *et al*., 2004; Bitelli *et al*., 2004)) for counting the number of buildings collapsed in Bam - a valuable statistic that was unavailable in the aftermath of the event. In theoretical terms, this approach focuses on the analysis of "objects" within the imagery (in this case buildings), rather than individual pixels. Analytically, this approach differs from traditional "pixel-based" optical analyses used to develop damage maps following the 1995 Kobe, Japan (Matsuoka and Yamazaki, 1998), 1999 Marmara,Turkey (Eguchi *et al*., 2002; Huyck *et al*., 2004), and 2001 Boumerdes, Algeria (Adams *et al*., 2003; Yamazaki *et al*., 2003) earthquakes.

3.1 Remote Sensing Processing

As a strong earthquake, like what happened in Bam can cause extreme damages to buildings, evaluating damaged buildings due to earthquake is vital for allocating rescue forces to damage areas and damage estimation. One of the fastest ways to extract information about damaged places and to measure the amount of demolition especially in urban areas is using satellite images to compare images of before and after earthquake. Recent developments in remote sensing techniques made automatic extraction of this information from satellite images possible. In this article, we employed high-resolution standard product Quickbird satellite imagery, collected before and in the immediate aftermath of the Bam earthquake.

Figures 1 and 2 show the extent of Quickbird satellite coverage of Bam. The first image is dated September 30, 2003 – approximately 3 months before the earthquake struck with resolution 0.6 m on Panchromatic band. The second one, taken one week after the earthquake on January 3, 2004 with resolution 2.4m on Multispectral band, shows widespread changes associated with buildings collapse.

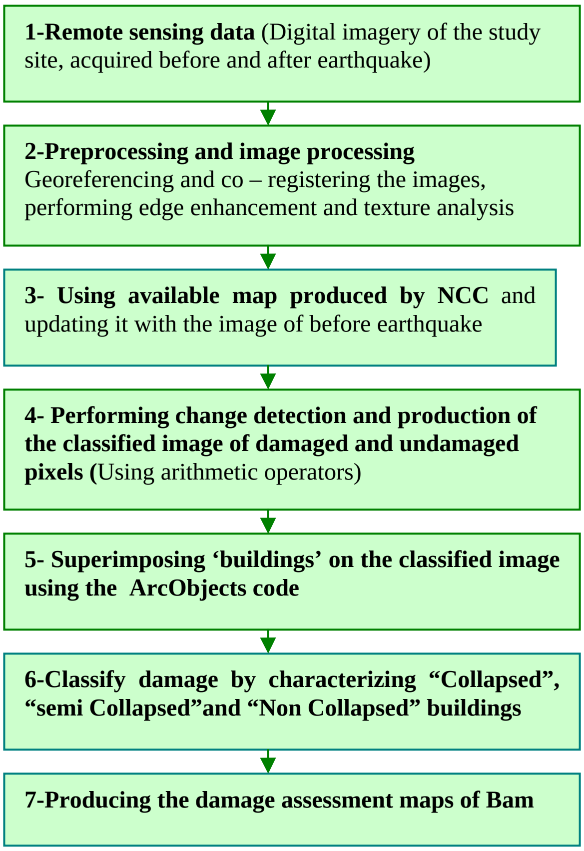

Diagram 1. The stages of the development of a SDSS-based earthquake damage assessment for emergency response

To maximize spatial correspondence between the multi-temporal scenes the "after" event image was registered to the "before" image, using a series of ground control points with a first order polynomial transformation. Result of the analysis is a raster layer, which values of its pixels are 0, 1, 2 in accordance to non-parcel pixels, parcel's damaged pixel and parcel's undamaged pixels.

There are different methods for extracting these information (i.e. classification of pixels with comparison between the multi-temporal scenes of "after" and "before" earthquake).
Here we describe a method that uses geostatistics and artificial neural network. Classification has been undertaken on texture properties of the images. In statistical view, texture of an image has two components: local variable and spatial correlation. Local variable can be apparent using variance but it does not show spatial correlation of variables. However geostatistics quantify these two variables using main parameter of geostatistics that is semivariance (Samadzadegan *et al*., 2007):

$$\gamma(h)=\frac{1}{2N(h)}\sum_{\alpha=1}^{N(h)}[t(u_\alpha+h)-t(u_\alpha)]^2 \qquad (1)$$

where t = numerical value of pixels used for classification
h = distance between each of two pixels
N=the number of dual pixels are in h distance from each other

γ = semivariance calculated for different values and different directions (direct Variogram)

Semivariances for different values and different directions summarized using semivariogram.

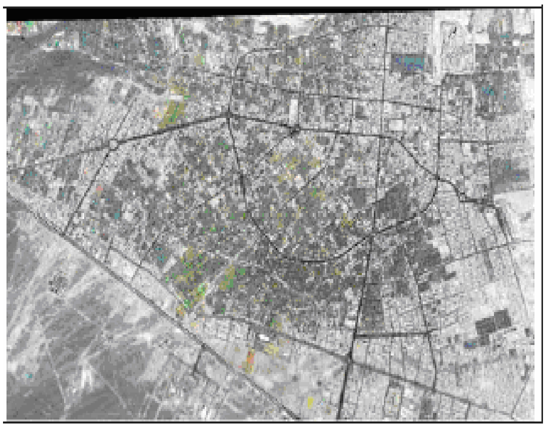

Figure 1. Quickbird satellite imagery of Bam, acquired before the December 26th 2003 earthquake

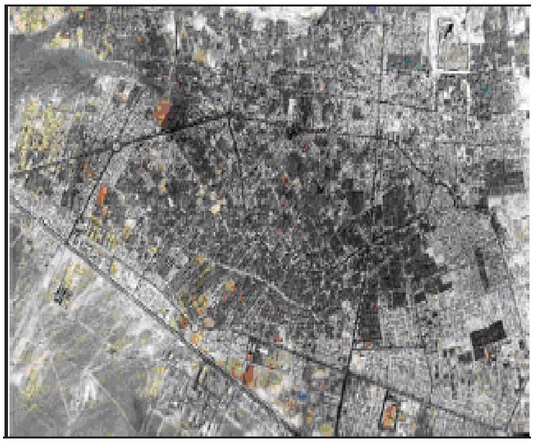

Figure 2. Quickbird satellite imagery of Bam, acquired after the December 26th 2003 earthquake

For classification of these extracted information (values of semivariances), artificial neural network (ANN) analysis has been employed. Here a multi layer perceptron network that is a supervised method for classification is used. For this network we used some pixels as training data that their demolition is obvious and finally all pixels of images classified (Samadzadegan *et al*., 2007).

A classified image and a parcel's vector layer at a scale of 1:2000 are input data for an ArcObjects code written by the authors. The parcel's vector layer of Bam is acquired by the ground surveying. In this image, values of 0,1,2 are in accordance to non-parcel pixels, parcel's damaged pixels and parcel's undamaged pixels. Figure 3 shows the classified image and the parcel's vector layer of Bam.

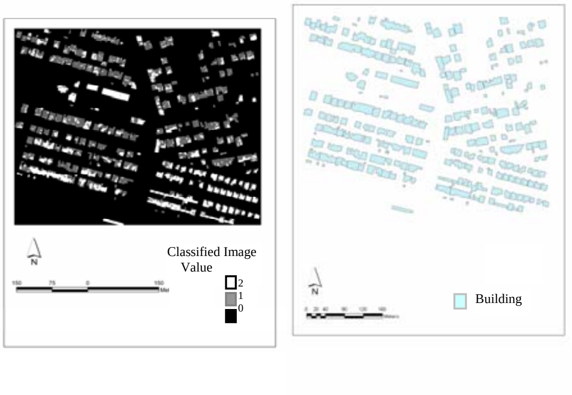

Figure 3. The left image is the classified image. The right image is parcel's vector layer of Bam

3.2 The Statistical Classification Method

We are going to specify demolition state of each parcel with due attention to the number of pixels of 0,1,2 values. It identifies building collapse in terms of the unique statistical characteristics of intact versus damaged structures within the "after" scene, rather than the degree of change between pre- and post-event images (Gusella *et al*., 2005). We assume three criteria for this specification:

- The parcel's state is non-collapsed when the number of pixels with 1 value relative to total pixels of the parcel is smaller than 0.3.
- The parcel's state is semi-collapsed when the number of pixels with 1 value relative to total pixels of the parcel is bigger than or equal to 0.3 or smaller than 0.6.
- The parcel's state is completely-collapsed when the number of pixels with 1 value relative to total pixels of the parcel is bigger than or equal to 0.6.
-

Notably, this approach to damage classification differs from the "change detection" analyses previously employed by Adams *et al.* (2004) and Huyck *et al.* (2004).

This project is implemented in two different statuses of processing in vector and raster format. The output of the former is a vector- based demolition map and the output of the later is a raster-based demolition map. The output of the former is the same parcel's vector layer of Bam with an additional field in its attribute table together to suitable symbology indicating demolition state of parcels. The output of the later is the raster layer with value attribute table (VAT) together to suitable symbology indicating demolition state of parcels.

Figure 4 depicts output raster layer and Figure 5 demonstrate the vector layer results.

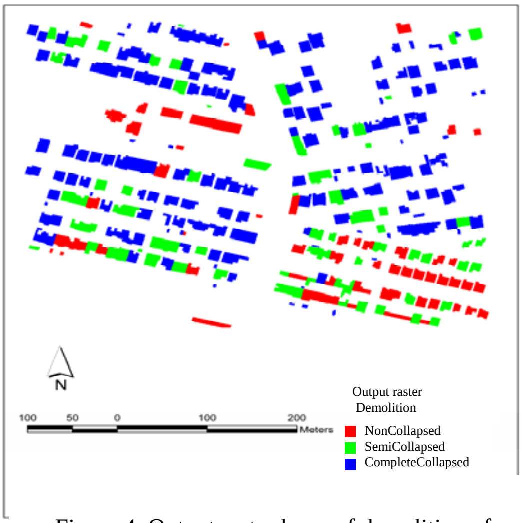

Figure 4. Output raster layer of demolition of buildings in Bam earthquake

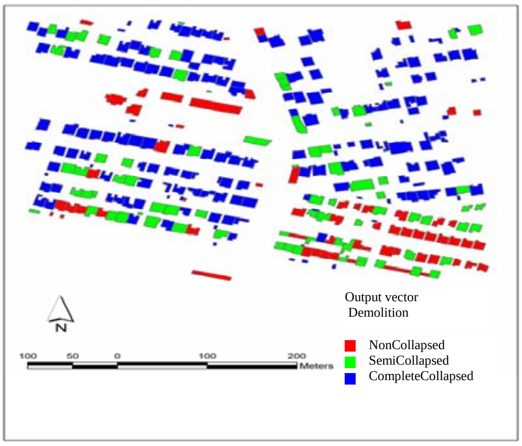

Figure 5. Output vector layer of demolition of buildings in Bam earthquake

4. CONCLUSION

Results from this research 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 for 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 to support the monitoring of recovery operations. An object-based classification and segmentation method has been developed and successfully tested regarding Bam earthquake. Out of 18872 buildings in city of Bam, 6473 buildings (34 %) were collapsed due to the earthquake. Preliminary assessments indicate an overall accuracy for the damage classification to be about 80.5%. Using this methodology we can allocate rescue operations to high risk prone regions after earthquake.

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