RECONSTRUCTION MONITORING OF BAM CITY AFTER THE 2003 EARTHQUAKE BASED ON SATELLITE IMAGES, STATISTICAL DATA AND FIELD OBSERVATIONS

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ABSTRACT

The renewal of buildings and other urban infrastructures such as electricity networks, gas and water pipelines, roads and bridges soon after the Bam earthquake in the southeast of Iran in 2003 were started. There are a few questions about the progress trend of this case of reconstruction. To what extent were these planned projects appropriate for the Bam city reformation from different points of view? Up to now, how much public and governmental attentions have been made for the urban reconstruction and development of that city to achieve the goals? What kind of fundamental changes and developments can be detected in the satellite images? In this research, we have studied the process of Bam reconstruction during the last ten years of the post-earthquake period. We have collected three series of photos of the similar locations in Bam city immediately after the earthquake in early 2004, in 2007, and ten years later in 2014 in order to compare the transformation and redesign of the landscape. We also have gathered two sets of satellite images of two parts of city before earthquake in 2003 and in 2012 to investigate the significant changes of the buildings, roads, vegetation cover and land use. Moreover, we have made an analysis of housing census data in 2001, 2006 and 2011 acquired from the governmental statistical center of Iran, which is collected every 5 years. This study is followed in two distinct stations. The results of renewal and reconstructions have been considered to trace the trend of progress in the project.

Key Words: Monitoring, Reconstruction, Earthquake, Bam city, Satellite Image

INTRODUCTION

Iran is an earthquake-prone country that has experienced many earthquakes over the past centuries. The earthquake of Bam city, which occurred on 26 December 2003 with an estimated magnitude 6.6, was one of the most destructive ones. Bam is a very old city located in the southeast corner of Kerman Province of Iran. Although the 2003 earthquake lasted for only few seconds, more than 22,391 people were killed in this city (Eshghi et al. 2004). This earthquake damaged almost all the brick buildings, the famous historical citadel Arg-e Bam, which was more than 2000-years old, and even modern buildings and city establishments. Fig. 1 shows the satellite images of Bam city in three different times, before earthquake in September 2003, immediately after the earthquake in January 2004, and in August 2012. Soon after the Bam earthquake, a considerable number of studies investigated the damages and impacts of this disaster (Chiroiu 2005, Gusella et. al 2005, Kohiyama and Yamazaki 2005). However, very few researches have been done regarding the renewal and reconstruction of the city to evaluate the disaster recovery during the past ten years followed to the earthquake (Ghafory-Ashtiany et al.2008). Understanding the process of reconstruction is a valuable measurement for the evaluation of government's performance because it demonstrates the governmental authority's efforts and capability to alleviate the hardship of a disaster and establish social and economical satisfaction for survivors (Murao et al. 2013).

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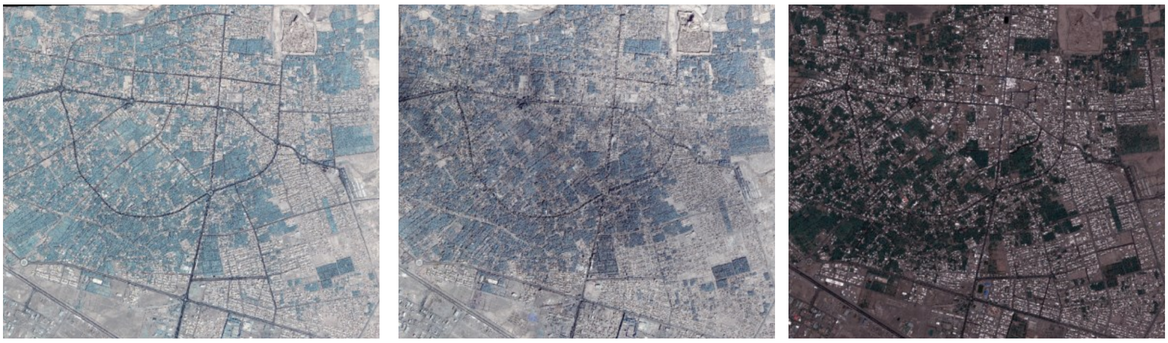


2003 2004 2012

Figure 1. Bam city before earthquake in December 2003, immediately after the earthquake in January 2004, and in August 2012

Through monitoring this process, we can also identify the technology and materials used in the construction of new buildings. More importantly, we can get insights whether the status and role of the city in the surrounding region has changed and were the previous inhabitant willing to live again in the city or have left their homes. This paper attempts to evaluate the renovation and reconstruction of Bam in the post-earthquake interval of ten years, by examining the current situation of the city including residential buildings, public establishments and other city infrastructures.

FRAMEWORK OF THE RESEARCH

In this research work we have employed a procedure which has divided into four parts. First, an examination of official statistics and reports provided by the authorities regarding the extent of damage to buildings and fatalities were collected. The status of buildings and their facilities before and after the earthquake, the type of structural frames used in each building before and after the earthquake were also collected. Second, we conducted a field survey of reconstructions based on the sets of field photos taken at three different times after the earthquake from the same locations, in order to compare the landscape and particularly observe performed changes in the physical environment. Following to that, we analyzed and compared two satellite images of the city regions before the earthquake, immediately after the earthquake and the present time to investigate significant changes in buildings, roads, vegetation covers and land use. Finally in the last section, we discussed the obtained results and findings to conclude and acknowledge weaknesses and shortcomings as well as strengths and ratings.

STATISTICAL DATA

Statistical analysis was conducted based on the data and information prepared by the Bam's Statistical Survey Center under the supervision of Iranian Statistical Center (2004). Urban planning and design of the city in the pre- and post-earthquake times were also evaluated based on the comprehensive and master plans provided by the Bam's municipality.

According to the information available in the records of Civil Engineering Organization of Bam regarding number of buildings pre- and post-earthquake, there were a total number of 28625 buildings before earthquake. Immediately after the earthquake in 2004, 26111 buildings were reported completely destroyed, 2381 buildings were partially damaged and 133 remained intact. Starting in 2004 after earthquake up to March 2014, 33126 permissions for construction of new buildings have been issued among which 26540 were executed. Also in 2011, Iranian Statistical Center has announced a number of 26708 residential units in the city of Bam. This significant number of units in this year indicates the broad extent of the reconstructions during seven years after earthquake and the huge amount of budget allocated to this project. Table 1 and Table 2 show number and percentage of the facilities and type of structures for all of the residential buildings respectively. Since the Civil Engineering Organization of Bam claimed that they had monitored the construction process of new buildings, it is expected that these structures show more resistance against similar level of earthquake in the future.

Table 1 Number and percentage of residential units on the basis of existing facilities

Electricity	Tab Water	landline Telephone	Gas Pipeline	Toilet	Bath Room
26647 (99.8%)	26553 (99.4%)	11891 (44.5%)	491 (1.8%)	25720 (96.3%)	24200 (90.6%)

Table 2 Number and Percent of ordinary residential units by type of materials

Steel frame Structures	Reinforced concrete Frame	Other (Adobe, Mud, Clay, Wood, Cement Blocks, Brick)
21504 (87%)	2327 (9%)	1068 (4%)

FIELD SURVEY

A field survey in Bam was carried out during a research trip by the first author in March 2014. The photos of city reconstructions were collected in different locations by driving and walking in the city. The photo locations were selected based on the reference images that were previously prepared by different groups of investigators during the first month after the earthquake, and in May 2007 by the second author. We tried to match the geographical locations so that the landscape comparison becomes possible.

The field survey revealed four main points.

1. The debris could still be seen in some damaged areas. (Fig. 2a). In addition in some regions, especially in the center and northern part of the city, debris had been removed, but construction has not been taken place and there are still bare lands. (Fig. 2b)

(a) (b)

Figure 2. (a) Desolate building in the northeast of Bam and (b) bare land in the center of Bam

2. Except for a few cases, almost all of the important public buildings, mosques, banks and other governmental offices were reconstructed. (Fig. 3)

3. Some of the buildings that have been highly damaged but not destructed have been repaired and reused with the existing conditions.

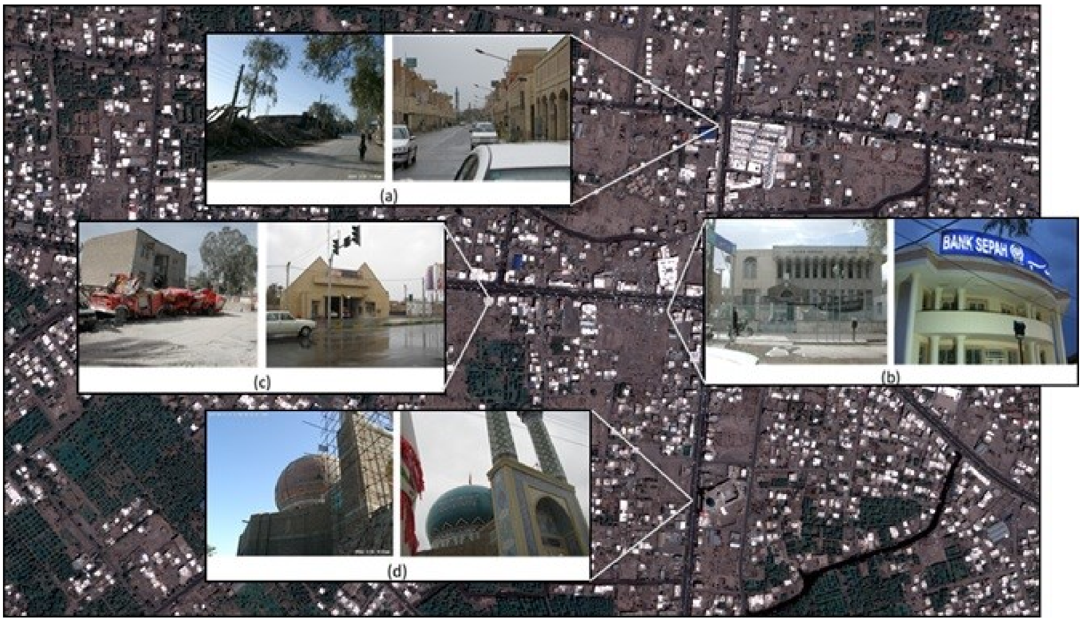


Figure 3. Comparison of some reconstructed buildings after the earthquake and in 2014. (a) Bam Bazar in January 2004 (left) and March 2014 (right). (b) SEPAH Bank in January 2004 (left) and March 2007 (right). (c) Fire station of Bam in January 2004 (left) and March 2014 (right). (d) Mosque in January 2004 (left) and March 2007 (right).

4. New buildings that not exist before the earthquake as a sport stadium, medical university, commercial-administrative complex, library and cultural center, and also a new residential region in the east and southeast of the city.

SATELLITE IMAGES

We compare two sets of satellite images that captured the area including Bam city by QuickBird on September 30, 2003 and by GeoEye-1 on August 11, 2012. The regions of the city that were covered in this study were selected based on the previous work done by Hisada et al. (2004). They chose eight different aftershock observation stations in the city and evaluated the damages to buildings around the stations based on the EMS-98 criteria, and classified the buildings into five groups, G1 to G5, with respect to the degree of damages.

Out of these stations, two stations (Fig. 4) that were partially damaged (station 1) and severely destructed (station 2) were selected. The estimation of damage in these two stations were consistent with the other studies (Yamazaki et al. 2005, Kohiyama and Yamazaki 2005, Rathje et al. 2005). Then the satellite images around the stations before (2003) and 8 years after (2012) the earthquake were compared to detect the changes in three major urban land covers: *buildings*, *vegetation* and *ground*. Subsequently, we classified the changes in land-covers into ten different categories, that are *old building to new building*, *old building no change* (remained from 2003), *old building to vegetation*, *old building to ground*, *vegetation to new building*, *vegetation no change* (remained from 2003), *vegetation to ground*, *ground to new building*, *ground to vegetation*, and *ground no change* (remained from 2003).

Fig. 5 shows the satellite images covering the station 1 in 2003 and 2012. The area and percentage for the three land-covers are presented under each image. A clear increase in the percentage of buildings and a decrease of ground in 2012 can be observed.

Similarly, the changes in land-covers around the station 2 are depicted in Fig. 6. In this area, which was extensively destroyed after the earthquake, the land-covers for buildings and vegetation were decreased and those for ground increased significantly. In this area, located in the north part of

the city, the amounts of empty lands are quite large, in other words, reconstruction is slow. Although debris had been removed and the lands were smoothed, reconstruction has not yet started.
Fig. 7 shows the changes in land-cover before and after the earthquake in the two study areas.

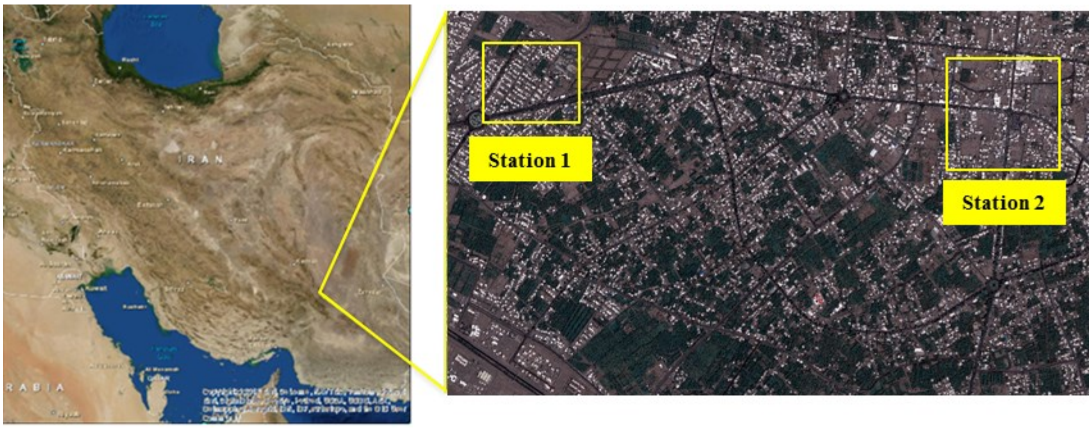


Figure 4. Location of Bam in Iran and two selected study areas around aftershock stations

(a) (b)

	2003		2012	
	area (m²)	percentage	area (m²)	percentage
Vegetation	42396	14	32712	12
Ground	90291	30	41976	15
Building	168608	56	207041	73

(c)

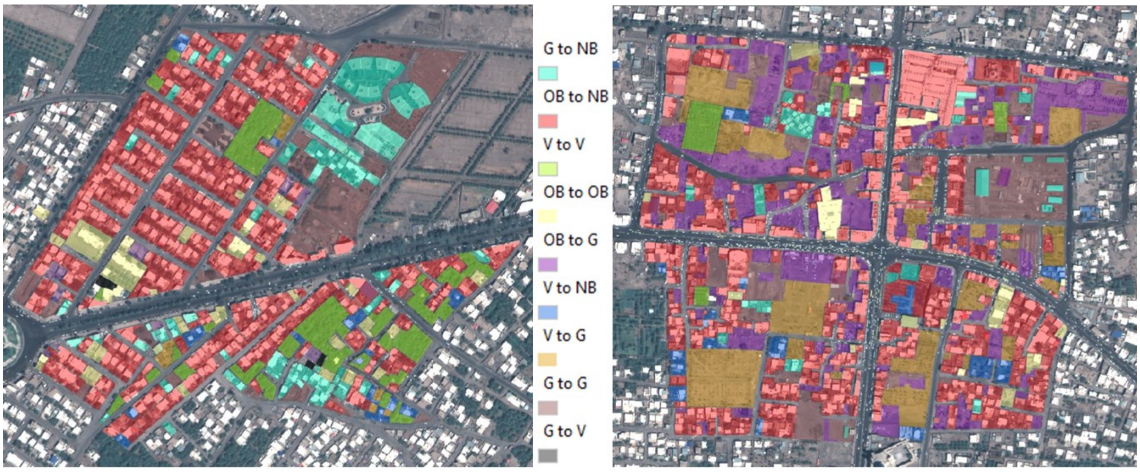
Figure 5. (a) Satellite image and land-covers at the station 1 in 2003 and (b) those in 2012. The area (m²) and percentage of *buildings*, *vegetation* and *ground* in (c) 2003 and (d) 2012.

(a) (b)

	2003		2012	
	area (m²)	percentage	area (m²)	percentage
Vegetation	80214	18	9982	3
Ground	65809	14	192467	45
Building	305946	68	222315	52

(c)

Figure 6. (a) Satellite image and land-covers at the station 2 in 2003 and (b) those in 2012. The area (m²) and percentage of *buildings*, *vegetation* and *ground* in (c) 2003 and (d) 2012.



(a) (b)

Figure 7. Changes in land-cover from *old building*, *vegetation*, *ground* in 2003 into *new buildings*, *old buildings*, *vegetation* and *ground* in 2012 are shown in colors at two locations: around (a) the station 1 and (b) the station 2.

The total areas associated with each of these changes are tabulated in Table 3. The considerable changes of old buildings and ground into new buildings were again confirmed around the station 1.

On the other hand, around the station 2, the large amount of land-cover changes from old buildings and vegetation into ground were recognized.

Table 3. Corresponding area changes (m^2) from 2003 to 2012 at the two locations

(a) around the station 1

2003 \ 2012	New Building	Old Building	Vegetation	Ground
Old Building	172395	12486	0	98058
Vegetation	14437	----	8466	61354
Ground	13845	----	0	55013

(b) around the station 2

2003 \ 2012	New Building	Old Building	Vegetation	Ground
Old Building	142125	18639	0	4783
Vegetation	6215	----	30108	2485
Ground	36381	----	996	37201

DISCUSSION

The observation from the field surveys and the satellite images indicated major findings. Firstly, most of the damaged structures have been reconstructed again in the previous locations. Meanwhile some of the buildings that were not seriously damaged were completely renewed. Also, new buildings (such as sport gym, commercial complex and etc.) have been established in the empty lands that provided new land use to the region. In some areas, vegetation and open green spaces have been destructed, most of where no construction has taken place and gardens changed to bare lands.

It can be seen that although the total number of approved and reconstructed units in the city has increased in 2012 compared to 2003, the area of the empty lots and vacant lands, especially around the station 2 has vastly expanded. Despite the statistics there are still many vacant lands in the center and northern part of the city (Fig. 6b) that were previously inhabited however they have been left empty after the earthquake. This can be explained by the increase of unit numbers and population density in reconstructed areas. Most of the old buildings consisted of a single or two units, however after reconstruction, new buildings with more floor levels and units were established. Therefore the total number of constructed units has increased compared to the pre-earthquake time, even though the area of empty lands has also become larger. Specifically at the station 2, the amount of land converted from old buildings (OB) and vegetation (V) to empty ground (G) compared to the total area of vegetation (V), ground (G) and old buildings (OB) that converted to new buildings (NB) was considerably smaller than expected (almost half), which states the fact that reconstruction has not fully taken place.

Furthermore, although parts of vegetation have converted into new buildings (Fig. 7b), the amount of this change is not to that extent to be concerned about. The more concerning issue is the considerable amount of vegetation land that has become empty ground after the earthquake. With regard to the value of farms and gardens and the profits that could be made from these areas, and also considering the fact that most of the destroyed gardens are located in the largely-damaged areas such as (G4+G5)> 70% in Hisada et al. (2004), we can say that probably the owners of these lands were killed in the earthquake and thus nobody can restore and maintain the conditions of these gardens.

CONCLUSION

Urban reconstruction after an earthquake is the most important part of disaster management that is performed by governments. Studying on reconstruction processes is important for the evaluation of government's efforts and achievements. In this paper, the authors conducted a study on the reconstruction of Bam city in two designated areas after the earthquake of 2003, to monitor and evaluate this process. Results showed that at one study are, which was partially damaged, the total area of buildings has increased while the area of empty lands decreased and the area of green space did not changed. We can conclude that this region has not only fully restored but has also been developed and improved.

On the other hand, at another study area that was severely damaged, the total area of the buildings has decreased after the earthquake while the area of the vacant lands has distinctly increased. This increasing amount of bare lands is due to the destruction of gardens and also due to the lack of reconstruction of new houses.

The results of the comparison between two satellite images taken in 2003 and 2012 indicated that there are significant differences in the reconstruction of the studied areas. This could represent either a miscalculation or a failure in the estimation of damages in the region or it could be due to another factor such as the grants or low-interest loans provided by the government that encouraged citizens to renovate their buildings. The latter seems more probable. In future, further monitoring of other areas of Bam is necessary to discover more details about the recovery process.

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