LESSONS LEARNED FROM THE BAM URBAN EARTHQUAKE

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ABSTRACT :

The Present active tectonics, deformation and seismicity in Iran are mainly under the influence of the moving plates in western Asia. Recent and historic data clearly show that not only large magnitude earthquakes but also even medium sized earthquakes leave catastrophic live losses and great economical impacts for many years in the country. Within the recent shocks one can mention to the Ipak 1962; Rudbar-Tarom 1990; Avaj 2002 and Bam 2003. The 26 December 2003 Bam urban earthquake devastated historical monuments, poorly mud constructed buildings and modern engineered structures. Although the general quality of earthquake management procedures for responding to earthquakes happened in Iran has been improved, especially after the Rudbar-Tarom 1990 earthquake, but looking to the Bam urban earthquake can provide a lot of new useful information because it can be used as a model for a probable occurrence of an earthquake in the capital city of Tehran (as there are some faults under the urban area of this city, also). So in this paper we have collected the available data about this earthquake from different aspects especially different management phases: mitigation, preparedness, response, and recovery and what has been happened before and after it to discuss the situation and to make some new suggestions for improving future urban earthquakes management in Iran.

KEYWORDS: Urban earthquake, Bam earthquake, earthquake management, mitigation, preparedness, response.

1. INTRODUCTION

Iran is located at the intersection of the southern-northern regional plates on the Alpine-Himalayan orogenic belt. High elevated topographies, volcanism and active faulting are some of the characteristics of the country. Geological studies show that reverse faulting is a major type of faulting between active and recent faults. The dominance of reverse faulting in Iran in under the influence of its location between the surrounding regional plates. The knowledge of seismicity and active faulting is important for seismic hazard studies. Seismic activity of the Persian Plateau may be classically divided into the shocks happen in: Alborz, Zagros, Central-Iran, Makran and Kope-Dagh. These regions have natural characteristics that are reflected in the parameters like seismicity patterns and focal mechanisms. Kerman province (which Bam is located within) is on of the active seismic provinces of Iran. Many recent and historical catastrophic earthquakes have destroyed different parts of this province from time to time. Based on the seismic macrozonation hazard map of Iran, most of the province cities are located within the high and very high relative risk areas (BHRC). The construction quality especially in small villages and towns is usually poor. The residences and other constructions are generally built without considering seismic design regulations, so they are highly vulnerable. As is shown by previous earthquakes they will collapse even under shakings caused by moderate earthquakes. Different catastrophic earthquakes have been destroyed the cities and the villages but the great Bam earthquake was the worst one. The Bam earthquake revealed that how negligence in constructing buildings, especially residences, can increase loose of human life. So in this paper we have studied this earthquake from different aspects especially different management phases: mitigation, preparedness, response, and recovery and what has been happened before and after it to discuss the situation and to make some new suggestions for improving future urban earthquakes management in Iran.

2. SEISMICITY

In comparison to the neighboring Lut block the Kerman Plateau is a high elevated region. There are not reliable estimations of the slip rates on the faults of this province, but a rough estimate will suggest about several millimeters per year (Berberian et al., 2001). Although precise earthquake location is a necessity for detailed seismotectonic and seismic risk studies but the event location in Iran still suffer from inaccuracies, mainly because of improper distribution of stations. Errors greater than 100 km are reported for some small-to-medium sized quakes located by local stations. Different authors and organizations have reported different locations and magnitudes for the earthquakes of Iran. The best reference for historical and pre-1964 earthquakes of Iran is the two books by Berberian 1995, and Ambraseys and Melville 1982. In this paper we have mainly used these books for historical and early instrumental earthquakes, although we have used data from ISC and USGS plus IGUT (Institute of Geophysics, University of Tehran) also.

2.1. Historical Seismicity

The historical seismicity of the Kerman province is limited to the earthquakes reported after 1800 A.D. by Ambraseys and Melville, 1982 and Berberian, 1995. Based on Berberian, 1995 there might be evidences of historical earthquakes around Koohbanan, Zarand, Kerman, Bam and Mahan caused by active faults near them. Figure 1 show the historical seismicity of the Bam and Kerman. Important earthquakes are Nosrat-Abad earthquake (1838), Hoorjand earthquake (Nov., 1854), Chatrood earthquake (Jan., 17, 1864), Chatrood earthquake (Aug., 4, 1871) and Sirch earthquake (1877). The $M_s=7.0$ Nosrat-Abad earthquake was a great shock which was followed by aftershocks for about two years. The $M_s=5.8$ and $I_{MM} = VII^+$ Hoorjand earthquake destroyed some villages located north-east of Kerman. The Koohbanan fault may be responsible for this event. This fault is suspected also to be responsible for the damaging seismic events of the 1864 and 1871 Chatrood earthquakes. The calculated magnitude and the intensity for mentioned quakes is about $M_s=6.0$, $I_{MM}=VIII$ and $M_s=5$, $I_{MM}=VIII$ respectively. These events have destroyed Chatrood and surrounding area while the first one has destroyed some residences in Kerman city too. Mozafari, Maalek and Qob-e-h Sabz mosques have been damaged by the 1864 earthquake. The $M_s=5.7$ Sirch earthquake has also made some destruction to the surrounding epicenteral area. Lack of information has made it difficult to draw a clear picture of the historical seismicity of Kerman. So it is reasonable to study the archaeological sites/data in the region and try to find seismic effects. However it is better to do a comprehensive study including different aspects of geophysical-archaeology.
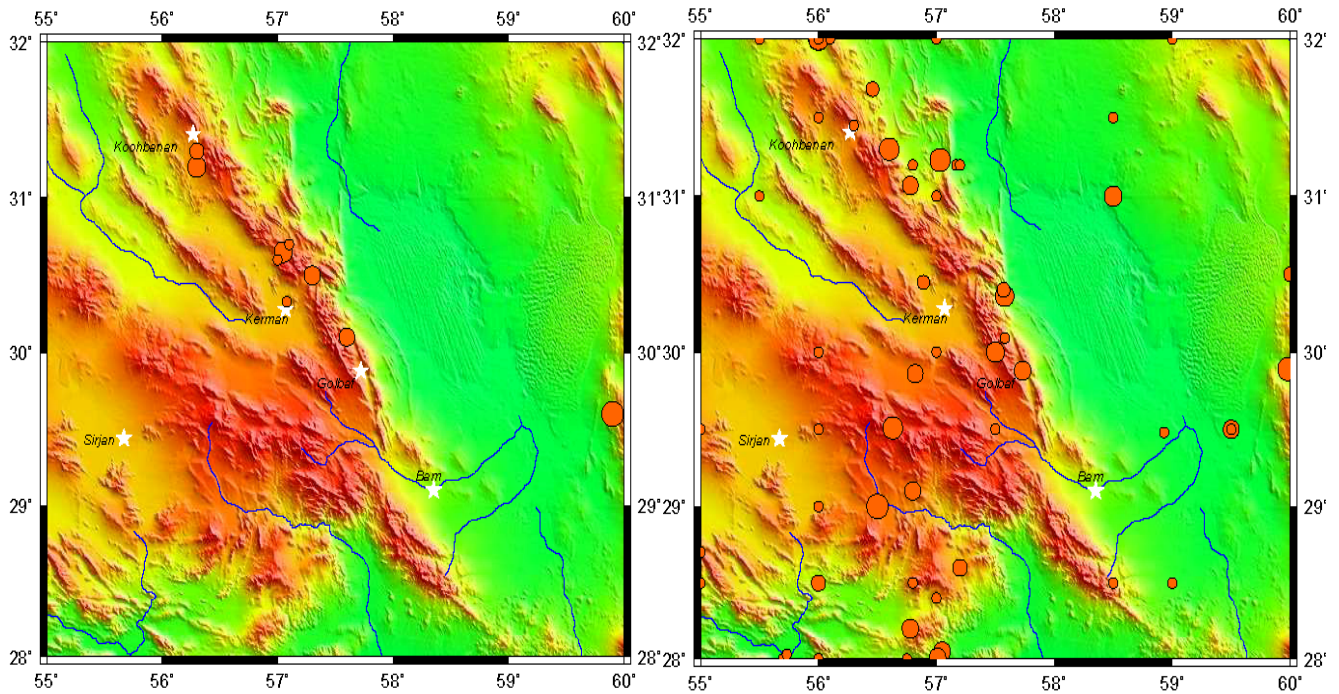
Figure 1 Regional historical seismicity of Bam Pre-1900.

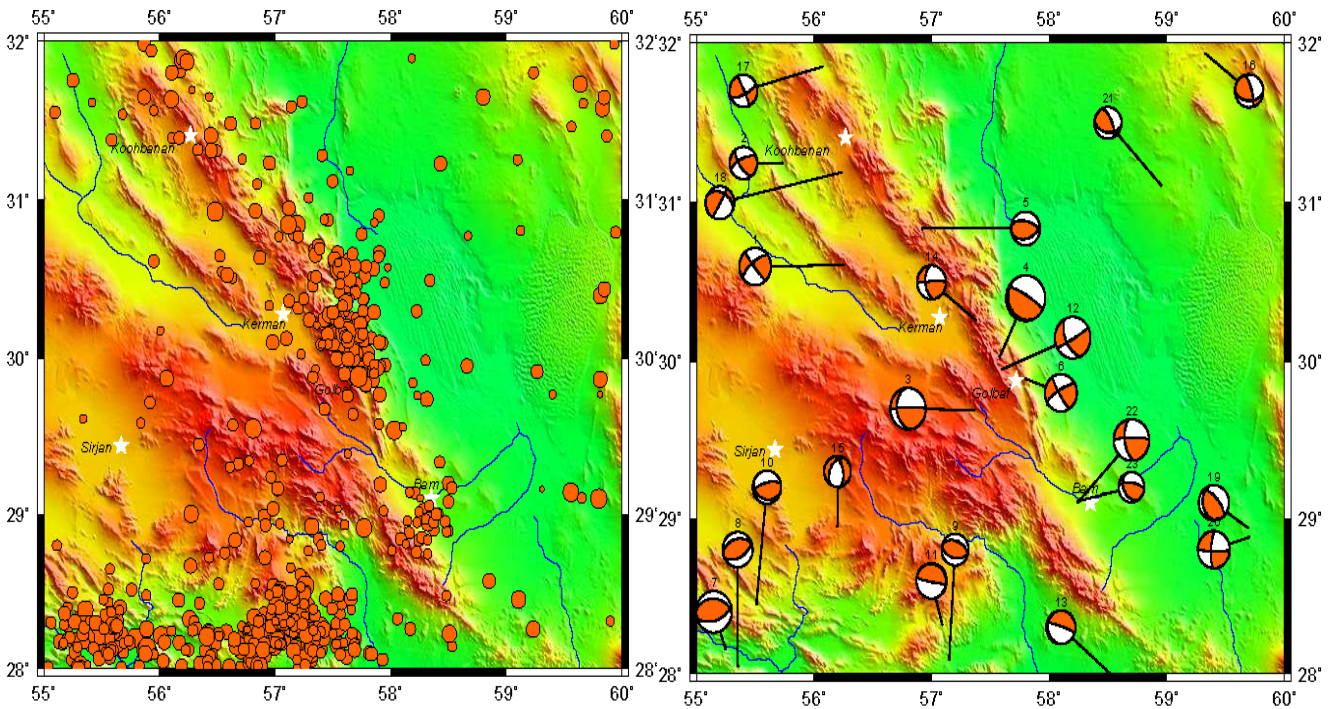Figure 2 Regional instrumental seismicity of Bam 1900-63.

Figure 3 Regional instrumental seismicity of Bam 1964-2004.

Figure 4 Regional CMT solutions in Bam.

2.2. Instrumental Seismicity

Regional instrumental seismicity of Bam and surrounding area is divided into two periods. Early instrumental earthquakes from 1900 to 1963 (figure 2) and modern instrumental earthquakes from 1964 to early 2004 (figure 3). Because of large location errors macroseismic data are of great importance for the first period. However the location error of modern instrumental data has been improved by increasing the number and improving the coverage of the global/local seismic stations. Earthquake faults of the region that may be considered as the seismic sources are the Anar, Rafsanjan, Jorjafak, Koohbanan, Sabzevaran, Lakarkooh, Gowk, Nayband, Shahdad, Kahurak, Laleh-Zar, Mahan and Bam faults. All of these faults are nearly north-west-south-east ward. It seems that Koohbanan, Lakarkooh and Nayband faults tie (around Golbaf) to continue as the Gowk fault toward south. As it is shown in Figure 3 there is an increase in seismicity around this tie, while there are some catastrophic earthquakes reported there, also. The historical and instrumental seismicity show that the Koohbanan, Lakarkooh, Nayband, Shahdad and Gowk faults and the region between them is experiencing different levels of seismicity. On the other hand it seems that the Rafsanjan, Anar, Sabzevaran, Kahurak and Laleh-Zar faults are showing lower levels of seismicity. One would consider that there is not a local seismic network in this province and the presented data are mainly collected from regional and global networks. Then we have not precise knowledge about microseismicity of the area and hypocenteral parameters so we can not clearly talk about the seismogenic layer. To better understand the regional seismic sources and their interaction with each other in terms of regional seismotectonic we have presented CMT solutions in figure 4. The CMT (Harvard University) solutions present that compressive and strike-slip motions are the main regional feature. There are tectonic ties formed by south-west structural trends with northwest-southeast trends. The northwest-southeast trends are nearly sub-parallel with Zagros. Many medium-great sized earthquakes have been occurred around these ties. The intersection around Golbaf is related to the Gowk fault system. Four recent earthquakes at: 11/6/1981, 28/7/1981, 20/11/1989, 14/3/1998 and 18/11/1998 have been occurred around there. They are shown by beach balls no. 3, 4, 6, 12 and 14 in figure 4. They all show right-lateral movement expect CMT no 4 (nearly pure compressive, which may be considered as a mechanism initiated on a sub-fault in this fault system after 11/6/1981 earthquake). CMT no 2 and 18 belong to the shocks happened at 12/19/1977 and 6/8/1984 (right-lateral and reverse motions). The great bam earthquake and its subsequent aftershock (beach balls no. 22 and 23) follow the same pattern of motion. Compressive CMT solutions in the south west of the province are under the control of the motion in Zagros (e.g. CMT no. 7, 8, 10) while the CMT no. 15 may be a motion on a sub-fault there. The solutions in the middle-south of the figure no. 5 may explain the subduction in Makran (i.e. 11 and 13). Figures 1 to 4 has been drawn by GMT.

3.0 LESSONS LEARNED FROM THE BAM EARTYHQUAKE

On 26 December 2003 at 05:26 GMT the Bam urban area was severely destroyed by a M_w=6.6 earthquake, however the impact of such a moderate sized earthquake was unexpected. The source of the earthquake has been under the city, focal depth about 8 km and nearly strike-slip with small reverse mechanism. Based on the recorded accelerograms the vertical acceleration was about 1g and the horizontal acceleration was about 0.8g (BHRC). The earthquake has been discussed thoroughly elsewhere (e.g. Berberian 2005). Almost all the Bam was devastated although the damage was concentrated in a 15 km radius about the city. It also caused considerable loss to man made constructions, lifeline infrastructures, such as hospitals, cultural centers, the water supply system, power lines, educational buildings etc… . Spence 2007, compared Iran, Japan and USA for yearly earthquake death rate during three temporal periods and concluded that while Japan and USA have been reduced their yearly rates, Iran's status has been worsening. Earthquake management can be divided into two phases: pre-earthquake and post-earthquake that is more dividable into: preparedness, mitigation, prevention, relief and rescue, rehabilitation and reconstruction. The aim of this paper is to try to learn some lessons from the Bam earthquake especially in four sections: role of community, medical care and public health, damage survey and reconstruction and Socio-economical consequences.

3.1 Role of Community

The public awareness of the earthquake risk is still low in Iran (Tierney et al., 2005), so public education can play a key

role in different earthquake management phases. McEntire et al., 2002, identified four models in this regard: the disaster-resistant community, the disaster-resilient community, sustainable development/sustainable hazards mitigation, invulnerable development and they presented comprehensive vulnerability management in their paper also. They have compared the models in terms of type, phase of disaster, the approaches to the disaster management and the academic dimensions of the approaches. Based on the results from the Bam earthquake Bamdad 2005, proposed the disaster knowledgeable community model by including the internal and external dimensions of knowledge which relies on the distribution of the knowledge among the communities in order to improve people/community engagement in disaster management. The model identified four post disaster waves following the Bam earthquake: physical, social, economic, political, and medical waves. It suggests that the main concern for the Iranian society to cope with disasters is the public education.

3.2 Medical Care and Public Health

Earthquakes like all other disasters have common medical and public health consequences, however they differ in the extent to which these consequences happen and disturb the normal medical/non-medical infrastructures. Emergency assistance includes: providing urgent treatment centers, evacuation of the injured people and activities to maintain public health (providing temporary public health facilities, effective disease surveillance, provision of adequate shelter, supplies of food and water). As medical and health necessities usually exceed the existing capacities after great earthquakes the participation of non-local help providers should be considered for: search and rescue, triage and initial stabilization and definitive medical care. Search-and-rescue support should originate from neighboring provinces and/or countries. Triage should be conducted at three levels: on-site, medical and evacuation. The main suggestion is that medical and health care services should arrive very fast after the event in order to be effective. On the other hand the help providers must be self-sufficient and must have the suitable capabilities to provide the actual needs of the affected people (Abolghasemi et al., 2006).

3.3 Damage Survey and Reconstruction

Survey of the damaged structures affected by the Bam earthquake showed that: (1) Adobe and unreinforced masonry structures are very susceptible to earthquake damage and should not be used in seismically active areas. The existing stock of these kinds of structures should be seismically retrofitted using currently available and appropriate technologies. (2) Because of the poor choice of construction material and the poor quality of workmanship steel and reinforced concrete structures did not perform as expected. (3) Improved structural design and detailing, appropriate use of construction materials and competent construction inspection is very important in seismic zones. (4) Bam earthquake damage to structures should be included into the future revisions of the present BHRC code (Mehrabian et al., 2005). In a different approach to the reconstruction of Bam, the social aspects has been considered, including: preserving the city identity in urban design, strengthening the new houses against the national building code and active participation of householders in various aspects of physical, environmental, social and economic issues. Providing financial and construction material and the local participation are two important factors contributing to the success of the reconstruction program. On the other hand offering training in building safety techniques is needed for both mitigation and reconstruction programs to improve the overall local construction techniques (Fallahi, 2007). However effective construction control specially for private housing and small projects should be take into consideration (Manafpour, 2005).

3.4 Socio-economical Consequences

The Bam earthquake has intensively affected on the lives of the city people either directly or indirectly although it is difficult to accurately measure it. Approximately all the city especially residences and infrastructures in addition to the Arg-e-Bam, an invaluable cultural heritage has been destroyed. Crude estimates of economic loss from the earthquake are about 1.5 milliard USD, including direct damage of 1.2 milliard USD and indirect damage 0.3 milliard USD. Based on government agencies the reconstruction of the city may take between 2 to 3 years, while the previous experiences

have shown that it might take even a decade or more to complete the reconstruction (Manafpour, 2005). One of the noticeable economical earthquake consequences was the damage to Qantas that had made a severe impact on the economy of the agricultural communities of Bam. So seismic rehabilitation of the Qantas is a comprehensive project and technically strong rehabilitation plans should be designed for this purpose (Mehrabian et al., 2005).

4. CONCLUSIONS

The earthquake causalities have been primarily seen at the developing countries and with no doubt that the major cause of death is building collapse. Several strong earthquakes during recent and historical times have been occurred in Iran and the country will continue to be hit with more strong earthquakes in the near future. But the country appears powerless in considering the earthquake risk and it seems that the seismic damage has been increased in place of decrease for recent decades (Spence, 2007). Great death tolls and financial losses are still the main characteristics of the Iranian earthquakes. Just four days before the Bam earthquake a similar magnitude earthquake occurred in California with only a few of the killed people, so the knowledge of protecting human life against earthquakes exists and the international community would provide this knowledge to high seismic risk countries of the world in order to minimize and mitigate the risks (Manafpour, 2005). During recent time memories of the Buien-Zahra, Dasht-e Bayaz, Tabas, Golbaf and Manjil-Rubar earthquakes (as strong devastating earthquakes) have not been forgotten but the obvious lessons of these earthquakes are being ignored. The periodical nature of the strong earthquakes should not impose the culture of ignorance and acceptance of such earthquakes and their consequences and preventing the responsibility of society. The Bam earthquake showed that fundamental earthquake hazard reduction needs to engage national consciousness at all levels of society and also revealed again the problems in the disaster preparedness system and the deficiencies in current construction practice.

REFERENCES

Abolghasemi, H., Radfar, M., Khatami, N., Saghafi Nia, N., Amid A. and Briggs, S. M. (2006). International medical response to a natural disaster: Lessons learned from the Bam earthquake experience. Prehospital and Disaster Medicine, **21:3,** 141-147.

Ambraseys, N. N. and Melville, C. P. (1982). A history of Persian earthquakes. Cambridge University Press, UK.

Bamdad, N. (2005). The role of community knowledge in disaster management: The Bam earthquake lesson in Iran. Institute of Management and Planning Studies, Iran.

Berberian, M. (1995). Natural hazards and the first earthquake catalogue of Iran, historical hazards in Iran prior to 1900, Vol. 1, A UNESCO/IIEES publication during UN/IDNDR, IIEES, Iran.

Berberian, M., Jackson, J. A., Fielding, E., Parsons B. E., Priestly, K., Qorashi, M., Talebian, M., Walker, R., Wright, T. J. and Baker, E. (2001). The 1998 March 14 Fandoqa earthquake (Mw 6.6) in Kerman province, southeast Iran: re-rupture of the 1981 Sirch earthquake fault, triggering of slip on adjacent thrusts and the active tectonics of the Gowk fault zone. Geophysical Journal International, **146:2,** 371-390.

Berberian, M. (2005). The 2003 Bam urban earthquake: A predictable seismotectonic pattern along the western margin of the rigid Lut block, south-east Iran. Earthquake Spectra, **21:S1,** s35-s99.

BHRC: www.bhrc.ac.ir.

CMT: www.cmt.harvard.edu.

Fallahi, A. (2007). Lessons learned from the housing reconstruction following the Bam earthquake in Iran. The Australian Journal of Emergency Management, **22:1,** 26-35.

ISC: www.isc.ac.uk.

IGUT: www.geophysics.ut.ac.ir.

Manafpour, A. (2005). THE BAM, IRAN EARTHQUAKE OF 26 DECEMBER 2003. Field Investigation Report, Halcrow Group Limited.

McEntire, D. A., Fuller, C., Johnston, C. W. and Weber, R. (2002). A Comparison of Disaster Paradigms: The Search for a Holistic Policy Guide. Public Administration Review, **62:3,** 276-91.

Mehrabian, A. and Achintya, H. (2005). Some lessons learned from post-earthquake damage survey of structures in Bam, Iran earthquake of 2003. Structural Survey, **23:3,** 180-192.

Spence, R. (2007). Saving lives in earthquakes: successes and failures in seismic protection since 1960. Bulletin of Earthquake Engineering, **5,** 139–251.

Tierney K., Khazai B., Tobin T. and Krimgold F. (2005). Social and policy issues following the 2003 Bam Iran earthquake, in Bam. In: Naeim et al. (eds.): 2003 Bam Iran earthquake reconnaissance report. Earthquake Spectra Publication No. 2005–04.

USGS: www.neic.usgs.gov.

Wessel, P. and Smith W. H. F. (1995). New version of the Generic Mapping Tools released. EOS Transactions AGU, **76,** 329.