Evaluation of Bam Earthquakes impacts (Iran) using remote sensing

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Abstract: Earthquakes are a natural hazard that causes extreme damage to property and life. The Bam, Iran earthquake has been considered as one of the largest disasters that ever occurred between 2000-2011. With an estimated loss of $15 billion in property and 26,000 loss of lives, there is no doubt that measures have to be taken by Iran in order to reduce the impacts of natural hazards such as an earthquake risk reduction plan should another earthquake hit the nation. The research employed the Case Study Method wherein the Bam, Iran earthquake was used to identify the possible measures for earthquake impact reduction. Gathering of secondary materials and data from books, magazines, and journals was also employed to acquire additional information on the incident. From the research done, it has been found out that disaster preparedness has to be practiced such as the use of GPS (Global Positioning System) in order to monitor crustal movements that signal the coming of an earthquake a geographical mapping can also be employed in order to identify fault lines and other earthquake-prone areas. There should also be a geophysical investigation of areas in order to pinpoint the kind of soil where the buildings are to be erected. This is important since the strength of the soil to hold the building up during an earthquake can help reduce the impacts of earthquakes. The use of Fiber Reinforced Polymer (FRP) to Unreinforced Masonry (UTM) should also be made imperative. The addition of FRP greatly increases the strength of the buildings.
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1. Introduction

Earthquakes are a natural occurrence. These are geological events that occur inside the earth that produce vibrations. Once these vibrations reach the surface, the earth shakes. These shakes often cause damage to property including natural and manmade objects. In worse situations, earthquakes can even lead to loss of life. Though there are a number of causes of this phenomenon, the most common is the movement along a fault (Gale Encyclopedia of Science June 2001).

Earthquakes happen to almost all countries in the world. Iran has not been spared. The Iranian Plateau is where most types of tectonic activity happen. In fact, Iran has a long history of experiencing devastating earthquakes. These earthquakes have killed thousands of people and have led to loss of property and hunger among its people. Iran has experienced a series of large damaging earthquakes especially within in the 20th century. In records, there have been 126,000 deaths due to 14 earthquakes of magnitude 7 and 51 earthquakes of 6.6-6.9 magnitude (Manuel Berberian, Ph.D. L&CPG, M.NYAS).

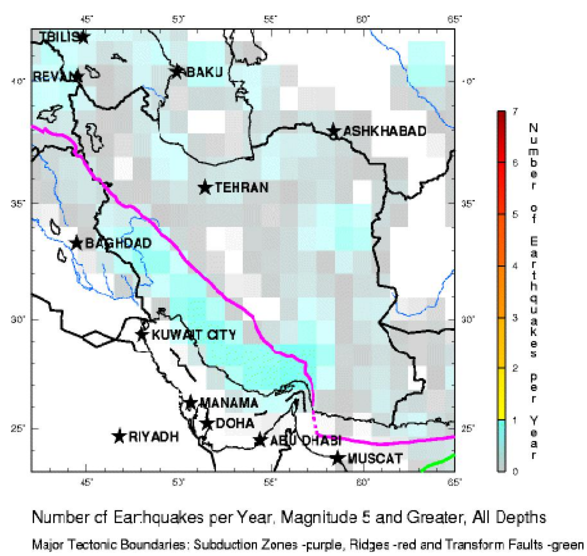

Figure 1. Earthquake Density Map

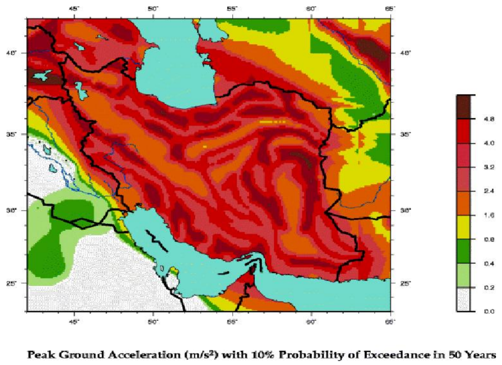

Figure 2. Seismic Hazard Map of Iran (US Geological Survey)

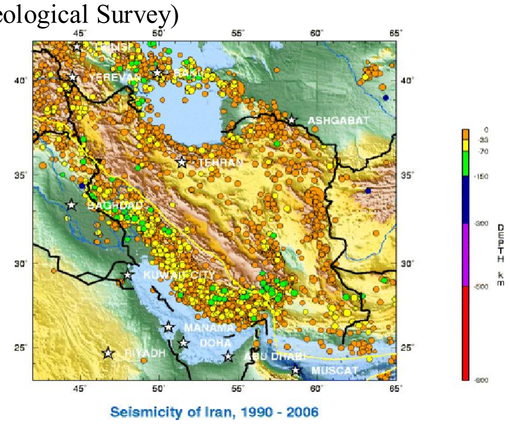

Figure 3. Seismicity Map of Iran (US Geological Survey)

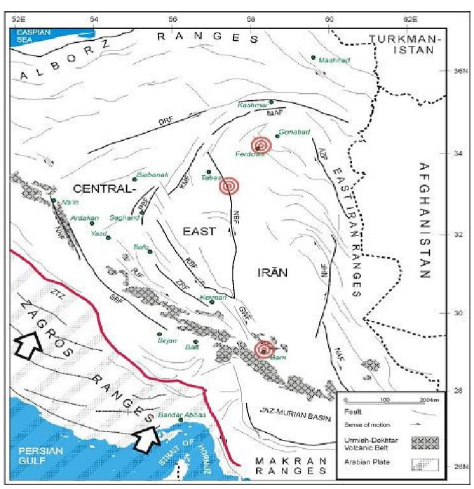

Figure 4. The simplified structural map of Central-East Iran showing the location of major faults. Red line represents the boundary between Arabian and Eurasian plates. Large arrows indicate the direction of plate motion. Compiled from Berberian, 1981; Jackson and McKenzie, 1984; Haghipour and Aghanabati, 1989; Alavi, 1991. AZF = Abiz Fault, DRF = Doruneh Fault, GWF = Gowk Fault, KBF = Kuhbanan Fault, KMF = Kalmard Fault, MAF = Mehdiabad Fault, NAF = Nostratabad Fault, NHF = Nehbandan Fault, NNF = Na'in Fault, RJF = Rafsanjan Fault, SBF = Shahre-Babak Fault, ZRF = Zarand Fault, ZTZ = Zagros Thrust Zone.

Table 1. The Richter Magnitude Scale (Wikipedia)

Richter magnitudes	**Description**	**Earthquake effects**	**Frequency of occurrence**
Less than 2.0	Micro	Micro earthquakes, not felt.	About 8,000 per day
2.0–2.9	Minor	Generally, not felt, but recorded.	About 1,000 per day
3.0–3.9		Often felt, but rarely causes damage.	49,000 per year (est.)
4.0–4.9	Light	Noticeable shaking of indoor items, rattling noises. Significant damage unlikely.	6,200 per year (est.)
5.0–5.9	Moderate	Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings.	800 per year
6.0–6.9	Strong	Can be destructive in areas up to about 160 kilometers (100 mi) across in populated areas.	120 per year
7.0–7.9	Major	Can cause serious damage over larger areas.	18 per year
8.0–8.9	Great	Can cause serious damage in areas several hundred miles across.	1 per year
9.0–9.9		Devastating in areas several thousand miles across.	1 per 20 years
10.0+	Epic	Never recorded; see below for equivalent seismic energy yield.	Extremely rare (Unknown)

One of the most disastrous earthquakes that ever hit Iran was the Bam Earthquake in 2003. On the 26th day of December 2003, at 5:27 in the morning, a 6.6-magnitude earthquake hit southeast Iran. The historic city of Bam was at its epicenter. The Bam Citadel or Arg-e Bam was severely damaged. According to Structural Engineer, Farzad Naeim, of the Earthquake Engineering Research Institute, the Bam earthquake has been by far the worst earthquake to ever hit Iran in history (Campi, Giovanni. "The

Bam earthquake: the tragedy of a cultural treasure 'depicted in the faces of people, 2004).

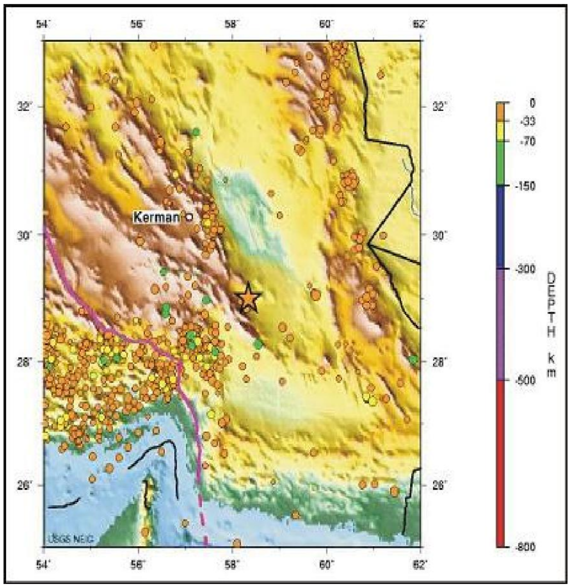

Figure 5. Record of seismicity in southeastern Iran from 1990 to 2003. Location of the December 26, 2003 Bam earthquake is marked by a star (from USGS National Earthquake Information Center).

The loss of lives and damage to property caused by the killer quake cannot be undermined. It was a lesson learned for both the people and the government of Iran to adopt a more effective and efficient risk reduction or crisis management plan in order to be more prepared should another tragedy occur. After all, over ten earthquakes have hit the country in the 20th century alone.

Crisis management could have played a great role at reducing the impacts of earthquakes in Iran. This is especially true when the Bam earthquake occurred. However, it can be noted that there had been a lot of instances when a crisis management plan were ignored and/or failed. Manuel Berberian, Ph.D. L&CPG, M.NYAS Najarian Associates, discussed a few of these points in The Thoughts of Bam Earthquake.

Programs that were initiated by the United Nations International Decade for Natural Disaster Reduction, The UN/IDNDR/ICSUS Global Seismic Hazard Assessment Program, and the Global Alliance for Disaster Reduction (GADR) for disaster mitigation were not implemented successfully in Third World Countries. Results have shown that to make these measures become effective, there should first be the move to bridge the cultural, social, and political gaps existing among countries today.

There are obstacles that have to be removed from technical and professional people. These people can very well make significant contributions to the reduction of impacts of natural hazards should their roles be properly labeled.

There is no road map for relief to mitigate disaster-resistant communities. Natural hazard mitigation plans are not evaluated and implemented.

Governmental and corporate social responsibilities in mitigating disasters are lacking.

Table 2. Earthquakes in Iran during the 21st Century

Date	**Epicenter**	**Magnitude**	**Coordinates**	**Official title**
Dec 20, 2010	**Hosseinabad**	**6.5**	**28.491°N 59.117°E**	**2010 Hosseinabad earthquake**
Aug 27, 2010	**Damghan**	**5.9**	**26°44′34.8″N 55°49′40.8″E**	**2010 Damghan earthquake**
Sep 10, 2008	**Qeshm**	**6.1**	**26°44′34.8″N 55°49′40.8″E**	**2008 Bandar Abbas earthquake**
March 31, 2006	**Borujerd**	**6.1[4]**	**33°34′51.6″N 48°47′38.4″E**	**2006 Borujerd earthquake**
November 27, 2005	**Qeshm**	**6.0[5]**	**26°47′2.4″N 55°50′49.2″E**	**2005 Qeshm earthquake**
February 22, 2005	**Zarand**	**6.4[6]**	**30°44′27.6″N 56°52′37.2″E**	**2005 Zarand earthquake**
May 28, 2004	**Māzandarān**	**6.3[8]**	**36°16′12″N 51°34′30″E**	**2004 Māzandarān earthquake**
December 26, 2003	**Bam**	**6.6[9]**	**29°0′14.4″N 58°20′13.2″E**	**2003 Bam earthquake**
June 22, 2002	**Qazvin**	**6.5[10]**	**35°40′8.4″N 48°55′58.8″E**	**2002 Bou'in-Zahra earthquake**

2. Material and Methods

Earthquakes are a very dangerous natural hazard. Its effects extend to damage to property and loss of lives in extreme cases. Its occurrence is something that all nations fear. However, this fear should be the motivating factor for countries and governments to prepare themselves and their people when this hazard hits.

This is precisely the aim of this research paper. That is, to identify measures to reduce the impacts of earthquakes especially in Iran. And in order to do this, the method to be used is the Case Study Method wherein a sample incident will be looked deeper into in order to identify what measures were lacking during that time as basis for the adoption of measures to reduce the impacts of earthquakes.

Another method that will be used is gathering of secondary data from books, journals, magazines, and existing researches in order to provide more data on the damage caused by the Bam, Iran earthquake.

For this research, the Bam, Iran earthquake will be the subject of the case study; it being the worst earthquake to ever hit the country in recent times.

3. Results

The earthquake that shook Iran on the morning of December 26, 2003 was a major earthquake that struck Bam and the surrounding Kerman province of southeastern Iran. The widely accepted estimate for the magnitude of the earthquake estimated by the United States Geological Survey is a moment magnitude (Mw) 6.6. The death toll amounted to 30,000. Injured people reached 50,000 and around 100,000 people were left homeless (fifth class, English section Economy, Prof.: A. WYKES).

The earthquake had taken a total of 15 billion or $1.9 billion in damages, according to the Housing and Urban Development Ministry in Tehran The financial damage to housing costs $7 billion and the human-related compensation is at $5 billion. Much worse, the cost for reconstruction is greater than the cost of the damage itself.

The intensity of the damage caused by the earthquake has put it among the largest world disasters of 2000-2011. In a research conducted by Khalil, et.al, it was discovered that the distribution of the damage showed a microzonation that was serious in some parts of the city especially along the fault. This is especially true where there is thick, fine, medium, and loose soil and sediments. In general, the damage increased from west to east across the city. The entire city's average level of destruction was -75% while the eastern part of the city reached 100%. The major factors that influenced the damage and destruction to the city include distance of the site from the seismic source, the quality of the foundation soil, and the types of buildings. Most of the buildings located near the epicenter were made of mud bricks using mud cement (Rezaei, Khalil, et al, 2009).

4. Discussions

Though many countries around the world have experienced one or more earthquakes in this lifetime, the impacts of such occurrences are still overwhelming. It is a fact that there is already a good number of risk reduction measures implemented by these countries. However, these measures may not be applicable to certain areas or that, perhaps, the strategies are not updated and tested. With the data that were gathered on the extent of the damage caused by the Bam earthquake, some risk reduction measures are suggested.

The measures that can be implemented in order to reduce the impacts of earthquakes in Iran are the following: Improve Unreinforced Masonry (URM). Since the building found in the city of Bam were old and made of brick mud from mud cement, it may be advised to use stronger materials to make the structures more resistant to vibrations. The use of unreinforced masonry (URM) may not be enough.

Primarily structural weakness, overloading, vibrations, settlements, and deformations cause the failure of URM. These URM were very common in the Bam area. It is said that houses built of URM, usually made of hollow clay, bricks, tiles, stone, concrete blocks, or adobe, are easily damaged during earthquakes. This is because the mortar holding the masonry is usually not strong enough to withstand an earthquake.

As a solution to this, the use of Fiber Reinforced Polymer (FRP) is suggested. FRP is a new class of composite material made from fiber and resin. It has been proven effective and efficient and even economical for the repair and development of structures in civil engineering.

The FRP has been proven to stay durable even as the material ages and it has been used for the strengthening of structural members. The design and behavior of beams that have been reinforced internally with FRP bond together and develop length ("Reinforced concrete design with FRP composites." SciTech Book News (2007).

Furthermore, when an FRP specimen was tested for strength, it was seen that the FRP returned to its original size when the load was removed. Therefore, it can be concluded that FRP can withstand axial stress.

FRP composites can be acquired in laminates or fiber sheet form or in bars. The fiber sheet is convenient for irregular surfaces since the fibers can be oriented in any desired way. Furthermore, it is also lightweight. The bar, on the other hand, is more convenient to use because of anchoring and aesthetic requirements.

FRP comes in two applications for strengthening walls using laminates and bars. FRP laminates are formed by manual laying it up onto the structural member being strengthened. However, before the fiber ply is installed, the masonry may have to be prepared by sandblasting, application of a primer, and puttying. A first coat of resin is applied, then the fiber ply, and then a second coating of resin is applied. When this hardens, the fiber ply becomes an integral part of the member. The second manner of application is by applying a pre-impregnated fiber ply directly onto the masonry surface. Two coats of resin are applied. The second application of resin is brushed onto the surface after it has been adhered to the wall.The output when used in structures can better withstand the impacts of earthquakes.

2. Geological Mapping of an Area

In order to investigate the surface and subsurface of an area, geological mapping has to be done. If this mapping is done accurately, it will be able to predict an earthquake; thus, reducing the impacts of the said occurrence. Geoinformatics, the revolution of such investigations, explores remote sensing, geographical information system, and global positioning system technologies as sources of timely information on natural resources management as well as environmental protection ("Geoinformatics for natural resource management." SciTech Book News (2009)). This, therefore, can also be used for reducing the impacts of earthquakes.

3. Crustal Deformation Studies by the Use of GPS

Crustal deformations are also a cause of earthquake activity. GPS is now very useful in the study of crustal movement. The Global Positioning System (GPS) is a space-based navigation system that consists of a constellation of 24 satellites. These are located in six orbital planes with an inclination of 55° to the equator. The satellites are positioned at a height of around 20,200 km with 12 hours of orbital period. The United States Department of Defense (DOD) for accurate determination of position, velocity, and time is operating these. All the GPS satellites are being controlled by system tracking stations, ground antennae, and a master control station With this, the slightest instance of crustal movement which may signal an earthquake may be detected the soonest time possible.

In fact, the Southern California Earthquake Center (SCEC) project seeks to detect or predict the occurrence of earthquakes. To do this, it will install 250 GPS receivers on towers that are 6 miles apart all over Southern California. The data that will be generated will be used to measure distortions on the earth's crust (Lais, Sami. 1997).

Nothing can keep a nation more ready for a disaster than predicting its coming.

4. Geophysical Investigation of Areas

With the issue on the soil type of the Bam City area where the damage trend was seen moving from west to east, a sediment logical, geological, geotectonic, geotechnical, paleoseismological, and geophysical investigation in urban areas must be done. By doing so, a detailed knowledge of the subsurface structure may be utilized for the accurate and precise seismic hazard assessments for effective earthquake protection planning (Rezaei, Khalil, et al). The height, weight, and load capacity of a building may be specified to avoid movements of the soil. Furthermore, certain areas may be set with limits as to the type of buildings that may be built there. The Bam, Iran earthquake's impacts could have been reduced had the country been more ready. However, it is never too late to implement such recommended measures to reduce the impacts of such natural hazard. The researcher humbly hopes that other scholars, experts, and students may do further research in order to come up with more risk reducing measures.

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