Bam (SE Iran) earthquake of 26 December 2003, Mw6.5: A Preliminary Reconnaissance Report

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1. Introduction

The Bam earthquake of December 26, 2003 (Mw6.5) occurred at 01:56:56 (GMT, 05:26:26 local time) around the city of Bam in the southeast of Iran (Figure-1). The earthquake happened at 5:26 am local time when most of the inhabitants were sleeping, which could be one of the causes of the great life loss at the time of the preparation of this report (29/12/2003). The number of victims was officially declared to be more than 25000 .Also more than 50000 people are declared to be injured and about 100000 people remaine homeless.

The Kerman province is one of the largest provinces in Iran, with an area of 186,422 km^2, and is located in southeast of the country. The population of Bam was about 100,000 at the time of the earthquake in 2003.

The city of Bam is well-known by the historical citadel of Arg-e-Bam which is more than 2000 year old, and was destroyed in the 26/12/2003 Bam earthquake (Figure-2). Arg-e Bam is the largest mud-brick complex in the world. This historical monument is located on an igneous hill, on the verge of the Silk Road It has an area of some 240,000 square meters. The monument was constructed mainly from mud-brick and clay. The total area of this castle is about 6 km^2 . There is no information about the exact date of the construction but according to Persian history it goes back to more than 2000 years ago and has been repaired many times, and was residential till 150 years ago.

2. The seismotectonic of the Bam earthquake prone area

2.1. General features

The earthquake prone Bam area in SE Iran is an active seismic zone (Table-1). The Bam city itself had no reported great historical earthquake before the event of 26/12/2003. Towards the northwest of Bam, 4 major earthquakes with magnitudes of greater than 5.6 have struck the cities and villages in the period between since 1981 until 1998. The trends of the main faults (including the Bam fault) in this region are North-South, and NW-SE (Figure-3). These two systems intersect in western Lut area. The NW-SE faults (Kuhbanan and Ravar faults) and the north-south faults (Nayband, Chahar-Farsakh, Anduhjerd, Gowk, Sarvestan and Bam faults) have determined the border of the north-south structures in the Lut area with the NW-SE structures. These intersection zones were some of the main sources for the disastrous earthquakes. The Gowk fault system is recognizable for its surface ruptures during the 1981, 1989 and 1998 earthquakes as well as a hot spring system. In the west of the Golbaf-Sirch valley, there is the Lut depression, where a vertical topographic offset of more than 4000 meters has occurred. Four great earthquakes have struck the region during the recent years: The Golbaf earthquake of 11 June 1981, Ms6.6, the Sirch earthquake of 28 July 1981, Ms7.0, the South Golbaf earthquake of 20 November 1989, mb5.6 and the North Golbaf (Fandogha) earthquake of 14 March 1998, Mw6.6. The Golbaf earthquake of 11/06/1981 has struck the region of Golbaf in the southern parts of the Golbaf valley (with the strike of N5-15E). This earthquake which was associated with a fault rupture along the Gowk fault, caused 1071 fatalities . The event caused great damage in the Golbaf region. The Sirch earthquake of 28/07/1981 occurred 49 days after the Golbaf earthquake and caused 877 life losses. It seems that it was originated as the secondary faulting along the Gowk fault (N-S trend) or the triggering of the rupture from activation of the Gowk fault in the hidden continuation of the Kuhbanan fault (NW-SE trend), in their intersection zone. Such a situation might be the reason for the great earthquakes around Sirch in 1877 and 1981 (both with magnitudes greater than 7.0). The

South Golbaf earthquake of 20/11/1989 caused 4 fatalities and 45 injured and some damages in Golbaf. Some surface faulting and folding have been reported to be related to this event. The North Golbaf earthquake of 14/3/1998 caused 5 fatalities and 50 injured, and was associated with surface faulting (about 20km length) in northern Golbaf. The focal mechanism of these earthquakes shows the compressional and strike slip mechanisms along the Gowk and Kuhbanan fault systems.

2.2. Focal mechanism

The focal mechanism of the Bam 26.12.2003 earthquake was reported as strike slip fault (NEIC Web site, December 2003, Figure-3), which fits in well with the surface evidence of right-lateral strike slip movement of the Bam fault.

2.3. Source parameters

Based on a preliminary estimation of the seismic moment, a Mw=6.5 is assessed for the Bam earthquake. The focal depth of the Bam earthquake of 26/12/2003 is estimated to be 8km (based on a S-P estimation on the records obtained from the mainshock).

2.4. Surface fault ruptures

The Bam fault with a near north-south direction passes from the vicinity of the city of Bam (less that 1km distance to the east of Bam, and between the cities of Bam and Baravat (Figure-2). The surface fissures created after the Bam earthquake are observed around the Bam fault between the cities on Bam and Baravat (Figure-4). The fissures are created in the form of the sinkholes in the city of Baravat (Figure-5).

2.5. Seismic Gap

The existing records on historical seismicity indicate no major earthquake in Bam since the historical time. It seems that the Bam earthquake of 26/12/2003 has ended a seismic gap along the Bam fault. This seismic gap could be verified with the Arg-e Bam castle, which was constructed about 2000 years ago and since then, until the 2003 earthquake of Bam.

3. Strong Ground Motion

The strong motion in this event were recorded in stations of the national Iranian strong motion network (according to BHRC). The record obtained in the Bam station shows the greatest PGA of 0.8g and 0.7g for the east-west horizontal and north-south horizontal components, respectively, and 0.98g for the vertical component (all non-corrected values). The preliminary observations on the strong motion record obtained in the Bam station, as well as the observed damages in the region shows a vertical directivity effect. This effect can be assigned to the Bam earthquake fault rupture, while a strong fault-normal (east-west) motion is created during the mainshock as well. The demolished walls and building of Bam are representative for such effects in the up-down (vertical) and east-west directions (fault-normal). The Bam residents that survived the quake explained to the reconnaissance team members that they felt strong up-down displacements during the mainshock.

4. The macroseismic intensity and the isoseismal map and attenuation of the strong motions

The macroseismic intensity of the earthquake is estimated to be I_0=IX (in the EMS98 scale), where the strong motions and damaging effects seems to be attenuated very fast especially in the fault-normal direction (Figure-6). The intensity levels are estimated to be VIII in Baravat, VII in New-Arg (Arg-e Jadid) and the airport area. The intensity level was estimated to be around IV-V in Kerman and Mahan.

5. Structural Engineering Aspects

6. Behavior of Lifelines

7. Historical Monuments

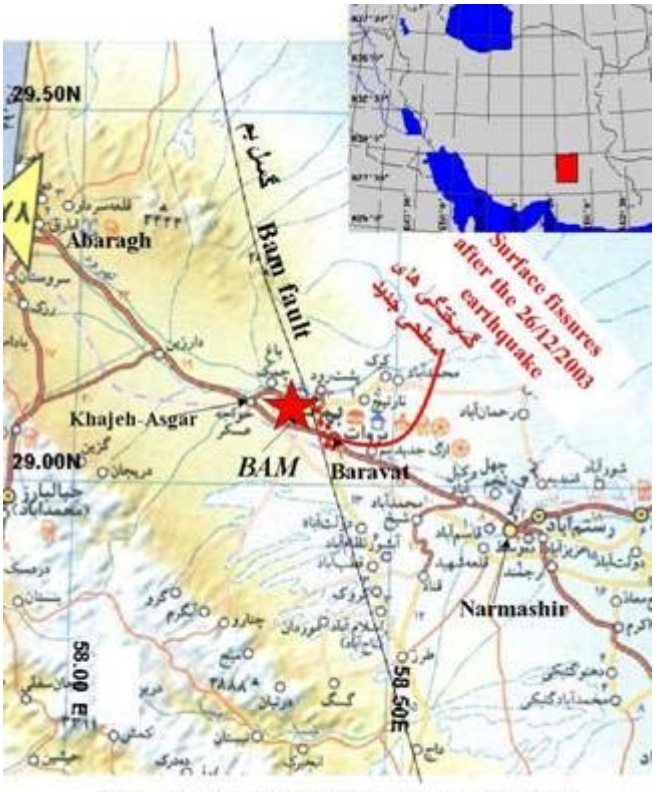
8. Disaster Management

Table-1 : Seismicity of the Bam region, whitin a 100km distance from the city of Bam:

Date			Time			Coordinates								
Y	M	D	HH	MM	SS	Lat.N	Lon.E	FD	mb	Ms	Mw	Efa	Ref	Region
1948	07	05	13	53		29.460	57.780	0	5.9	6.0	.0		Amb	Gowk

1962	09	29	06	54	00	28.290	57.480	83	5.5	.0	.0		N.US
1964	05	11	06	07	38	28.220	57.390	73	5.3	.0	.0		N.IS
1964	08	27	11	58	39	28.160	58.830	50	5.1	.0	.0		N.IS
1976	11	13	10	12	36	28.250	57.340	62	5.0	.0	.0		ISC
1981	06	11	07	24	25	29.895	57.718	30	6.6	6.0	.0	*	ISC Golbaf
1981	07	28	17	22	23	29.987	57.770	11	5.9	7.0	.0	*	ISC Sirch
1981	10	14	09	12	39	29.900	57.758	43	5.2	.0	.0		ISC
1982	10	15	02	53	55	28.280	57.398	83	5.0	.0	.0		ISC
1983	01	31	18	56	53	28.919	57.318	133	5.0	.0	.0		ISC
1984	10	11	05	09	27	29.539	58.030	48	5.1	.0	.0		ISC
1986	07	25	10	08	09	28.068	57.303	69	5.2	.0	.0		ISC
1989	11	20	04	19	04	29.880	57.721	18	5.5	5.7	5.9		ISC South Golbaf
1998	06	10	08	30	16	28.227	58.507	113	5.0	.0	.0		ISC

Figures:



Bam Earthquake of December 26, 2003, Mw 6.5

Figure-1: The location map of the epicenter and the reactivated Bam fault. The surface fissures created after Bam earthquake of 26/12/2003 are shown with dashed lines.

Figure-2: The historic site of Arg-e Bam in NE of the city of Bam (the image of the site Before the 26/12/2003 earthquake is inserted in the top-left of the picture).

.Figure-3: The fault map of the Bam earthquake prone area of the 26/12/2003 earthquake

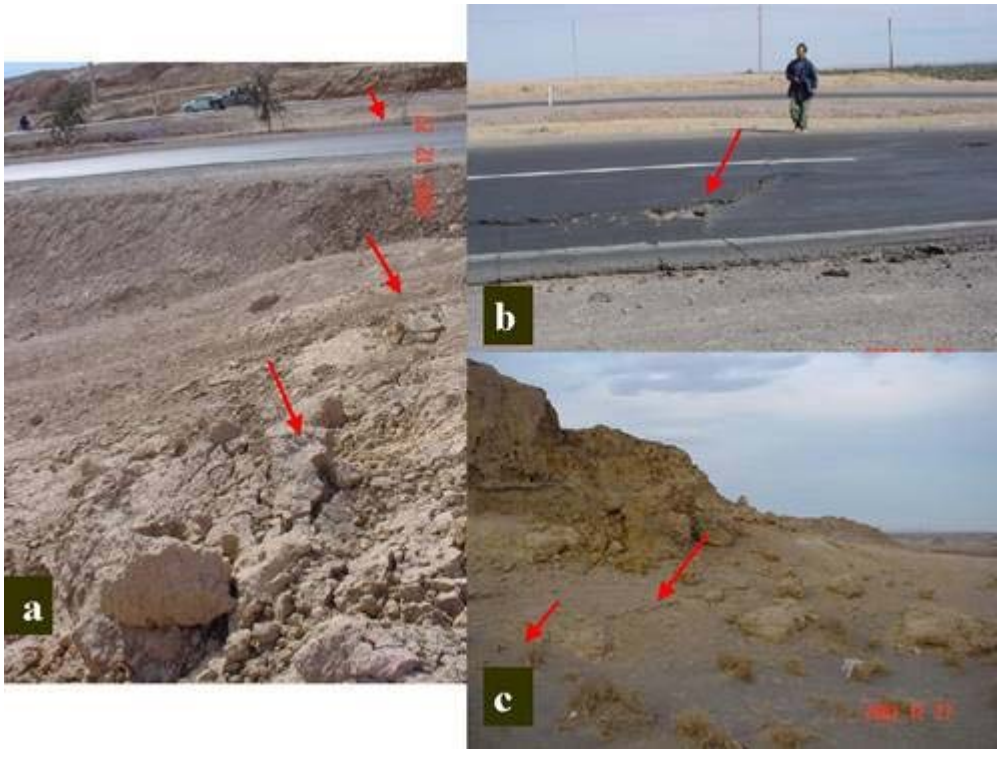


Figure-4: The surface fissures along the Bam fault (near Baravat) in the prone area of the 26/12/2003 earthquake). a) The fissures nearby Baravat, b) the fissure that ruptured the road from Bam to Baravat, and c) the fissures in the foot of the fault scarp of the Bam fault.

Figure-5: The sinkholes created during the 26/12/2006 earthquake in Baravat.

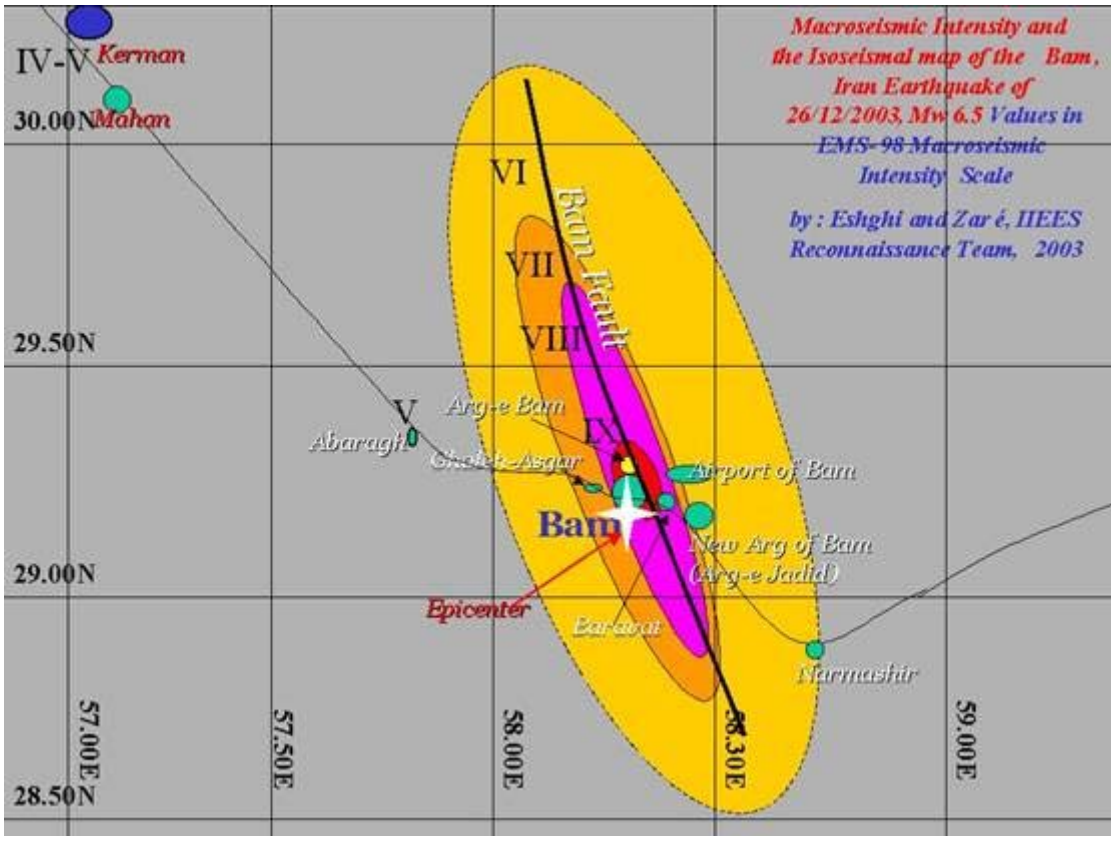


Figure-6: The Macroseismic intensity and the isoseismal map of the 26/12/2003 Bam earthquake.

Asian, Arabian, African plates

This earthquake occurred as the result of stresses generated by the motion of the Arabian plate northward against the Eurasian plate at a rate of approximately 3 cm/yr (about one inch per year). Deformation of the Earth's crust in response to the plate motion takes place in a broad zone that spans the entire width of Iran and extends into Turkmenistan. Earthquakes occur as the result of both reverse faulting and strike-slip faulting within the zone of deformation. Preliminary analysis of the pattern of seismic-wave radiation from the December 26 earthquake is consistent with the earthquake having been caused by right-lateral strike-slip motion on a north-south oriented fault. The earthquake occurred in a region within which major north-south, right-lateral, strike-slip faults had been previously mapped, and the epicenter lies near the previously mapped, north-south oriented, Bam fault. However, field investigations will be necessary to determine if the earthquake occurred on the Bam fault or on another, possibly not yet mapped, fault. The December 26 earthquake is 100 km south of the destructive earthquakes of June 11, 1981 (magnitude 6.6, approximately 3,000 deaths) and July 28, 1981 (magnitude 7.3, approximately 1,500 deaths). These earthquakes were caused by a combination of reverse-motion and strike-slip motion on the north-south oriented Gowk fault. http://www.olympus.net/personal/gofamily/quake/recent.html

The 6.7 Magnitude earthquake struck at 01:58 GMT 12/26/03. This was 05:28 am local time. The epicenter was in Bam, a city of 80,000, with 200,000 in the surrounding area, in southern Iran, 620 miles southeast of Teheran. The BBC reported within hours of the quake, "A huge relief operation involving ordinary Iranians, the army, Islamic volunteer groups and local rescue teams is under way." The death toll has been estimated at over 30,000 people with over 30,000 injured. Two hospitals collapsed in the quake and remaining ones were strained to help the thousands injured. Electricity and telephone service were knocked out. Over 70% of the houses in Bam are reported to be destroyed.

The quake had been preceeded the night before by a foreshock strong enough to cause some people to sleep out of doors. Undoubtably some lives were saved as people were not inside when houses collapsed. People have continued to sleep outside due to the many aftershocks, which are typical after a major quake. http://www.olympus.net/personal/gofamily/quake/recent.html