STATISTICAL STUDY TO DETERMINE JMA EARTHQUAKE INTENSITY BY QUESTIONNAIRE SURVEY IN 2003 BAM (IRAN) EARTHQUAKE

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ABSTRACT:
After the destructive Bam earthquake of December 26, 2003 (Mw = 6.6), the present survey was conducted about two months after the earthquake as a part of damage investigation by Japan Society of Civil Engineers (JSCE) earthquake damage investigation team. Questionnaire survey developed by Ohta has long and widely been used in Japan and has been conducted for recent major earthquakes in Japan to get the detailed distributions of seismic intensities. The questionnaire is to inquire how objectives around people have been shaking and how people feel during earthquake. In this paper, based on the survey carried out at nearly 20 locations by collecting some 100 questionnaires through direct interview with residents in Bam city, earthquake intensities in JMA (Japan Meteorological Agency) scale are determined and discussed through statistical analysis of the questionnaires at the locations. Findings clarify that the method though developed in Japan on the basis of its lifestyle arose somehow in the questions has promising results in Iran as well in spite of lifestyle difference between them.

KEYWORDS:
questionnaire survey, JMA earthquake intensity, Bam Earthquake

1. INTRODUCTION

A sever earthquake (29.004 N, 58.337 E, M_w=6.6, depth=10 km) occurred at 5:26A.M. (Local time) on 26 December 2003, near the city of Bam in southeastern Iran (Figure 1). Over 26,200 people were killed and about 30,000 were injured during and after the earthquake (Ghafory-Ashtiany 2004). In addition to such devastating human loss, the local economy was also heavily damaged, especially by the collapse of Arg-e-Bam, an old citadel of mud bricks constructed more than 2,000 years ago and registered as a UNESCO World Heritage Site since 2004.

Reconnaissance was conducted from 18 to 22 February 2004. To estimate the local intensity in Bam, a questionnaire survey were conducted at 18 locations in Bam and Baravat. These 18 observation points are shown in Figure 2.

As shown in Figure 2, the observation points are set along two segments, which intersect at Point No. 2 and cover the most severely damaged areas in Bam.

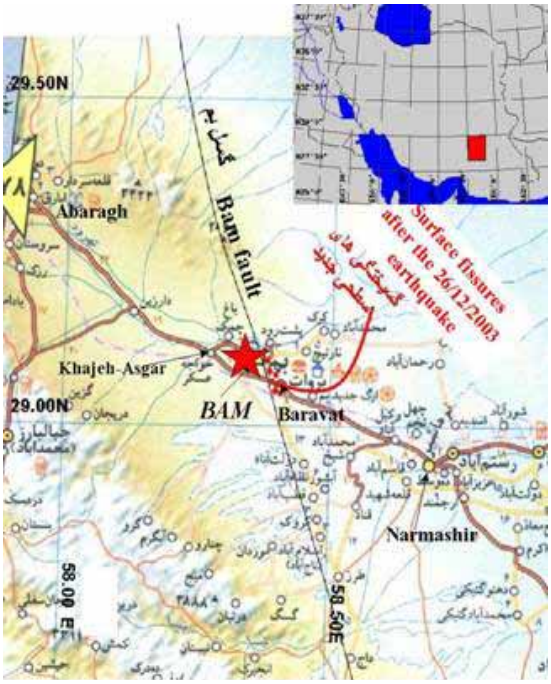

Figure 1. Map of Iran and location of Bam

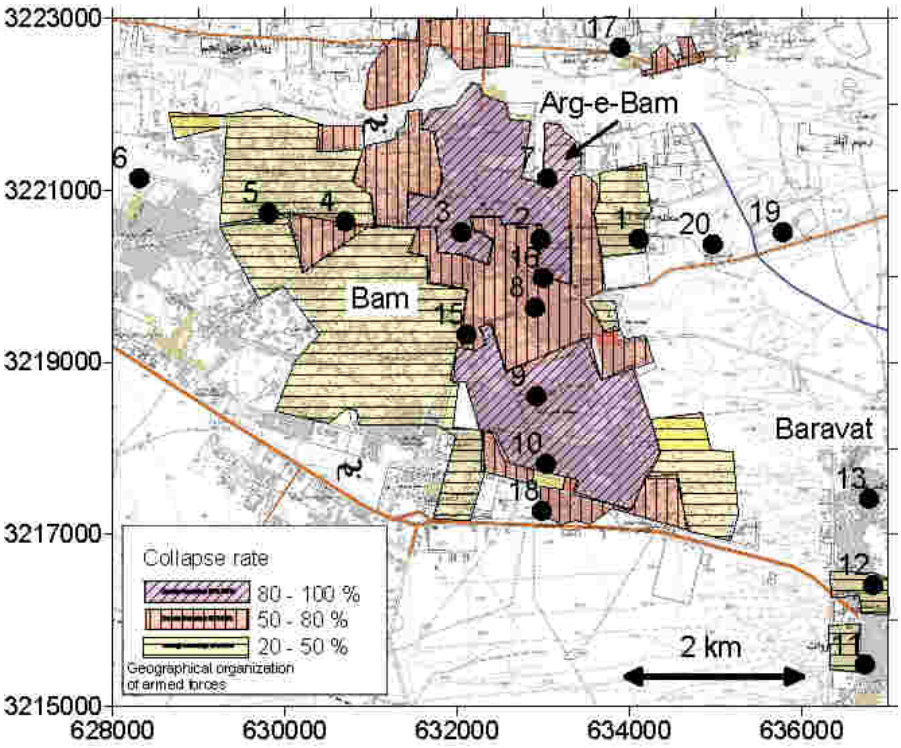

Figure 2. Observation points in Bam and Baravat, Iran (National Cartographic Center of Iran 2003)
(At Point No. 15, the strong motions shown in Figure 3 were recorded.)

2. RECORDED STRONG GROUND MOTION

No major earthquake had been recorded near Bam before the event of 26 December 2003 (Zare 2006). The strong motions shown in Figure 3 were recorded on the first floor of the two-story Bam county building (Point No. 15 in Figure 2), only 14 km away from the epicenter (BHRC 2003). Peak ground accelerations were about 0.8 and 1.0 g for the lateral and vertical components, respectively. As Zare and Hamzehloo (2005) point out, the strong-motion records are representative of a very strong, but short, earthquake that had large vertical and fault-normal near-field effects. The dominant frequency is about 7 Hz. However, there is a large peak near 1 Hz in the horizontal records, which may be due to the fault-rupturing process. Based on the strong-motion waveform, the instrumental JMA seismic intensity was calculated to be 6.1 (Miyajima et al. 2004, Fallahi et al. 2004, and Tobita et al. 2007).

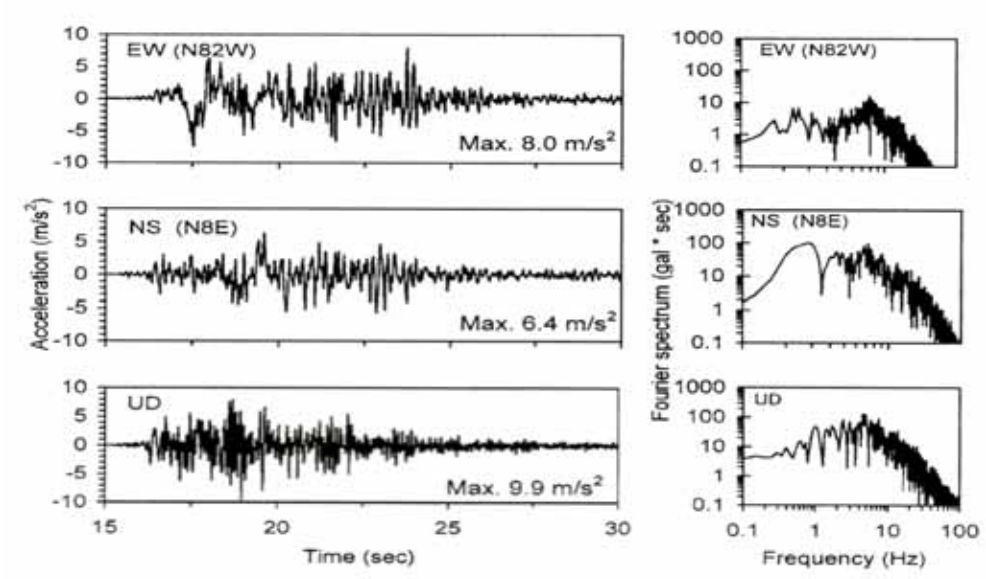

Figure 3. Acceleration records observed at the Bam county house (BHRC 2003)

3. ESTIMATED LOCAL SEISMIC INTENSITY

3.1. Questionnaire Survey

A questionnaire survey to estimate seismic intensity in the area affected by the 2003 Bam, Iran earthquake was conducted about two months after the main shock. People who had lived near the observation points were interviewed using the questionnaire (Ohta and Omote 1977, Ohta et al. 1979, Ohta et al. 1986). During the limited reconnaissance time, at least four people at each observation point and 98 people in total contributed to our survey. Although some objects in the survey questions are found only in Japanese lifestyle (e.g., paper siding doors), the original sentences from Ohta et al. (1979) are translated directly from Japanese into Persian without any modification except language. This is because the statistical data and procedures to obtain the intensity are optimized using Japanese case histories. At each observation point, the residents living near that observation point before the earthquake were interviewed for about 10 to 15 minutes. The method was originally developed by Ohta et al. (1979), and has been applied to many major earthquakes to obtain seismic macro or micro zoning maps, e.g., in Japan (Ohta et al. 1998, Tsurugi et al. 2000), India (Murakami and Katta 2001), and Indonesia (Honda et al. 2005). The questionnaire has 35 items: nine of these are to obtain a respondent's location and floor number in a building at the time of the earthquake and the geomorphology of the surrounding area; 21 are closely related to the seismic intensity, e.g., one's reaction towards the shaking, observation of surrounding objects, and the impression of the shaking; and the remainder can be used for other purposes. A typical question looks like this:

Question No. 12: Did you see any motion of water in the kitchen, or in a goldfish bowl, etc.?
(1) Did not pay attention, (2) not moving, (3) moving slightly, (4) moving, (5) moving strongly, (6) Water spilled out

A respondent may choose, for example, the answer or category number (3), "moving slightly". After gathering the data, seismic intensity is evaluated as follows.

3.2. Estimation of JMA Seismic Intensity

For estimation of JMA seismic intensity in this paper used from seismic coefficient matrix proposed by Takada and Ueda (1998). In each observation point 4 to 7 persons were interviewed and filled its relevant questionnaire. The JMA seismic intensity calculated for each questionnaire then the average of them assumed for the intensity of that observation point.

The process of calculation of JMA seismic intensity for each questionnaire in an observation point and determining the intensity there is described as follows:

1. Obtain the questionnaire seismic intensity, I_Q by below equation:

$$I_Q = \frac{1}{N_e} \sum_{i}^{n_q} \beta_i(m_i) \qquad (3.1)$$

Based on a category number, m_i, chosen by a respondent for the ith question (i=12 and m_{12}=3 in the above example), a seismic coefficient $\beta_i(m_i)$ whose values were determined statistically for each category number mi is put into Equation (3.1) to obtain the questionnaire seismic intensity, I_Q. In Equation (3.1) N_e is the number of questions that had valid response. For example, if a respondent chooses the answer (1), "Did not pay attention," in the above question, this response does not contribute to the intensity estimation and is not counted as a valid response. And, n_q is the number of efficient questions of each questionnaire.

2. The questionnaire seismic intensity is converted into the JMA seismic intensity, I_{JMA}, as follows:

$$I_{JMA} = 2.958 \times (I_Q - 1.456)^{0.547} \qquad (3.2)$$

3. JMA seismic intensity of each observation point is average of JMA seismic intensities of its questionnaires.

4. DISCUTION AND CONCLUSSIONS

Figure 4 shows the gender ratio and Figure 5 shows the age ratio of interviewees. The JMA seismic intensity in each observation point is listed in Table 1. It is seen that maximum and minimum intensities are 5.6 and 6.5, respectively; and average value is 6. The large intensities estimated at point 3 in old part of city, points 4 and 6 in west part of city, point 9 in south and point 17 in north. The small intensities estimated at points 1 and 8 in center and east of the city. The contour map of JMA seismic intensity is illustrated in Figure 6. The JMA intensity derived from the questionnaire survey near the strong-motion recording station, 6.2, matches the JMA seismic intensity derived from recorded waveforms, 6.1. The average or mean intensities in each observation point listed in Table 1 are shown in Figure 7; also shown is mean-plus-one-standard-deviation intensities. Furthermore, the probability distributions are shown schematically at three selected observation points, indicating that the coefficient of variation (= standard deviation/mean value) varies with location of observation points. This statistical analysis leads to much better results if the large quantities of questionnaires are applied in each observation point. However, based on the above mentioned findings the method though developed in Japan on the basis of its lifestyle arose somehow in the questions has promising results in Iran as well in spite of lifestyle difference between them.

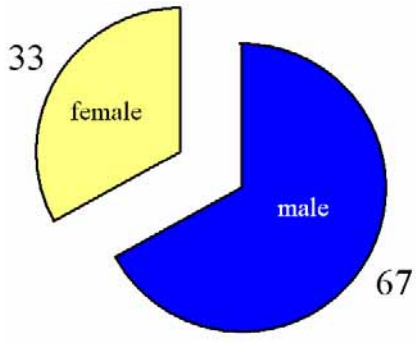

Figure 4. Gender ratio

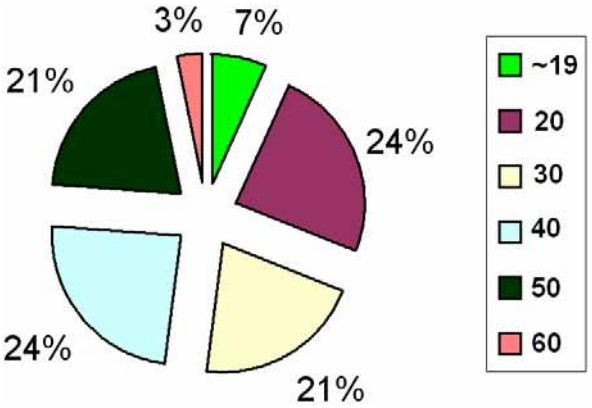

Figure 5. Age ratio

Table 1. I_{JMA} estimated for observation points

Observation Point	I_{JMA}
1	5.8
2	6.3
3	6.5
4	6.4
5	6.0
6	6.5
7	6.2
8	5.6
9	6.5
10	6.3
11	6.2
12	6.1
13	6.1
15	6.2
16	6.2
17	6.4
18	6.3

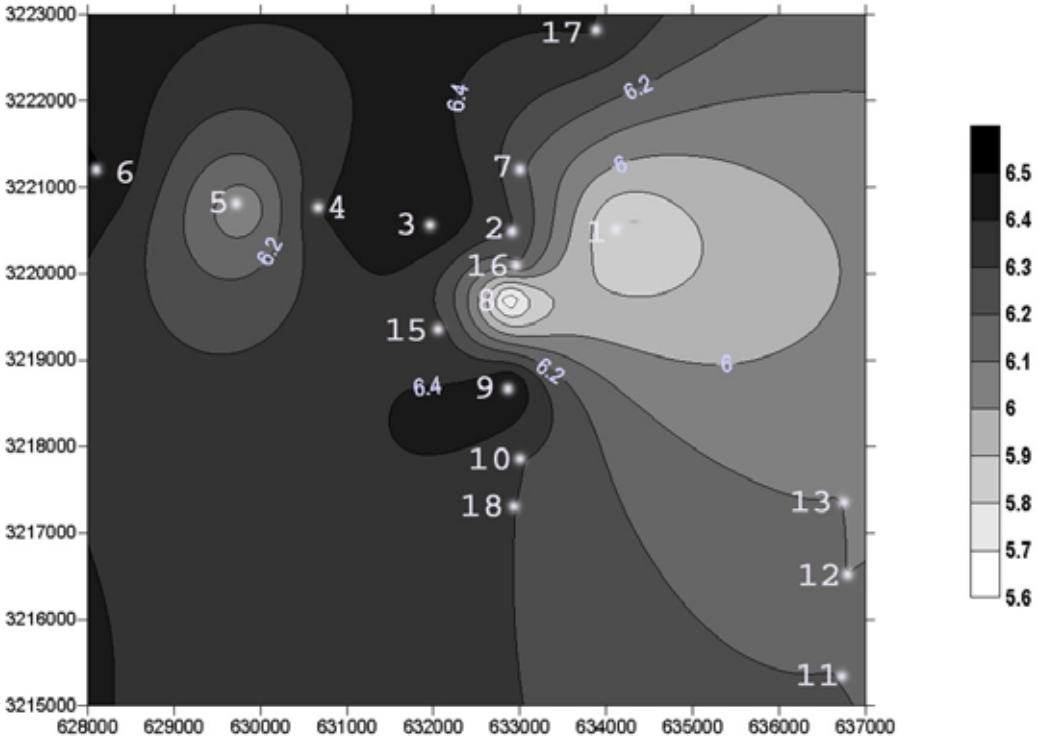

Figure 6. Contour map of JMA seismic intensity

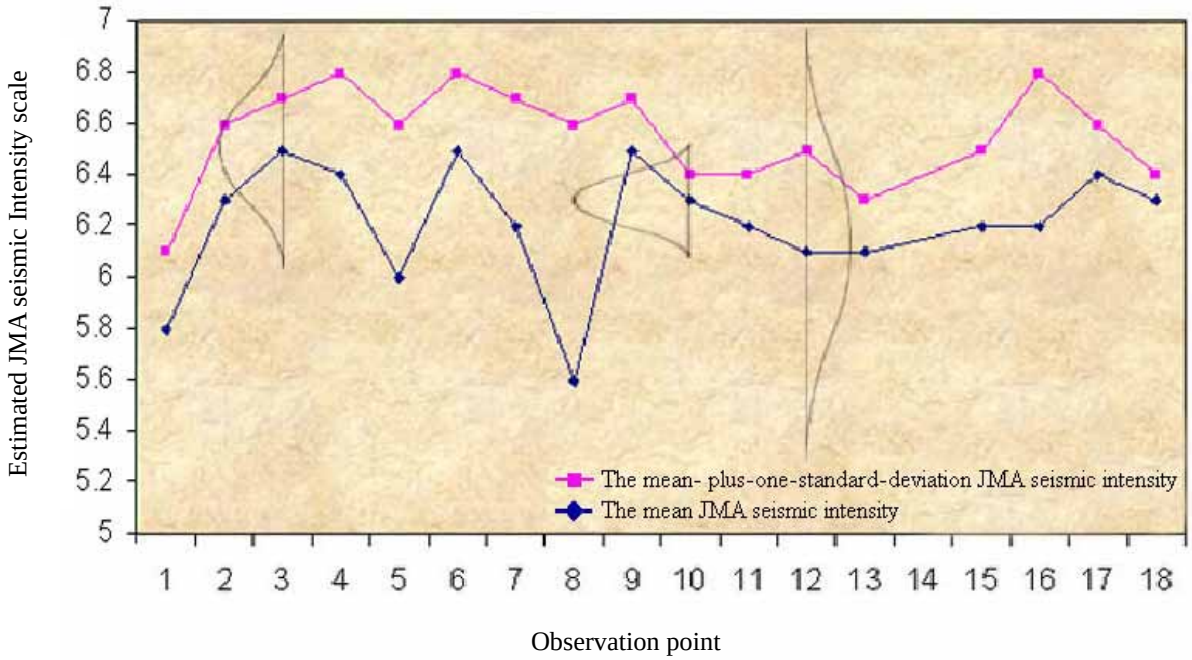

Figure 7. The mean JMA seismic intensity and the mean- plus-one-standard-deviation JMA seismic intensity in each observation point, and the probability distributions at three selected points

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