Building damage evaluation in Bam City in the aftermath of the December 26th 2003 Bam Earthquake

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1. Introduction

On December 26th 2003 at 5:26AM (local time) a Mw6.5 earthquake stroke Bam City and its vicinities. As of February 9, 2004, the death toll was approximately 43,200 and the number of people receiving medical care, 15,000. Nearly 49,000 houses were damaged leaving 76,000 people homeless [1]. The shake caused almost the complete collapse of Arg-e-Bam, a huge adobe citadel more than 2000 years old, which was designated world heritage site by UNESCO.

The earthquake, whose epicenter was located 8km below the ground surface, was caused by a strike-slip fault dislocation of Bam fault [2]. Peak ground accelerations at the Bam Station, located in Bam City, were 0.99g and 0.87g in the vertical and horizontal directions, respectively [3].

This paper presents the results of the survey carried out by part of the team sent by the Japan Society of Civil Engineers to investigate the damage in the area two months after the earthquake occurrence.

2. Construction practice in Bam City and typical observed damage

Although the Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No. 2800 [4] prohibits the use of adobe buildings, this is by far, the predominant construction material in the region, especially in the older part of Bam city. Typical houses are one story height with thick walls, up to 900mm, and heavy roofs, which serve as insulation for both hot and cold weather. Adobes are prepared manually as shown in Fig.2 and its typical measures are 250mm×250mm×65mm. Natural fibers are sometimes included in the mud mix. Multi-wythe walls are the most common.

Unreinforced masonry, confined masonry, and steel buildings with masonry infill are also common in the area. Very few reinforced concrete structures are observed. Masonry bricks vary in quality and are produced through both artisan and industrial processes.

Adobe structures were badly damaged as in many previous experiences. Fig. 3 shows a completely collapsed adobe house in the front whereas in the back, a confined masonry structure stands almost undamaged. Some masonry structures are provided with horizontal ties only, i.e. collar beams, as shown in Fig. 4. Although the complete collapse is prevented, the lack of vertical ties causes the failure of the wall corners.

3. Damage evaluation survey

Considering the damage evaluation by the National Geoscience Database of Iran [5], which was prepared based on aerial photographs, 33 locations covering Bam and Baravat cities were selected. At each location, three surveyors evaluated two damage levels: complete collapse and non-collapse, corresponding to D5 and D0-D4 damage levels in the EMS-98 scale [6], respectively. The surveyed area approximately corresponded to a circle with radius equal to 50-100m. The surveyed buildings were typified as: adobe houses, adobe walls, unreinforced masonry, confined masonry, steel, and reinforced concrete. The number of buildings of each type and

Fig. 1 Overview of Darzin City near Bam

Fig. 2 Adobe preparation

Fig. 3 Completely collapsed adobe house

Fig. 4 Heavily damaged partially confined masonry house

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the collapse rate was recorded. Four levels of collapse rate were considered: >80%, 50-80%, 20-50%, and <20%.

As part of the survey, microtremors were measured at all the locations were damage was evaluated in order to estimate the dynamic properties of the underlying soil deposit. Additionally, microtremors were recorded at typical undamaged constructions to determine their fundamental periods. The sensors, with a frequency range 0.5-20Hz, recorded velocities in three directions. Four to six 40.96sec measurements were taken at each location.

4. Results and discussion

At first the results of the microtremors measured at the building structures are discussed. The data was processed by choosing the portions of the records with fewer disturbances. The Fourier Spectrum of at least 8 windows of 10.24sec were calculated and smoothened with a 0.3Hz width Parzen window. The so-obtained spectra were averaged to evaluate the structure dynamic properties.

Figure 5 shows one of the surveyed adobe houses in Darzin City. The structure height is approximately 3.8m and the average wall thickness 800mm. The sensor was placed on top of the roof coinciding with a wall alignment.

Figure 6 illustrates the analysis results. The blue lines show the spectra of different measurement windows whereas the red line represents the average. The fundamental periods in the longitudinal and transverse directions are 0.1 and 0.09sec, respectively. It is clear that the structure is slightly stiffer in the transverse direction along which several walls were aligned. The transverse direction spectrum shows a peak at 0.1sec, which coincides with the vibration period in the longitudinal direction. This may suggest some torsional vibrations in the structure.

Similar measurements were carried out at other structures. Generally, adobe predominant periods varied between 0.09 and 0.11 sec. On the other hand, masonry houses had typical periods of 0.07 to 0.09sec.

Figure 7 shows the results of the adobe house damage evaluation plotted on the damage distribution map published in [5]. From the graph it is clear that the adobe construction predominance is related to the city evolution. The closer the surveyed point is to Arg-e-Bam, the city origin, the larger the number of adobe houses. It can also be observed that the newer the structure, i.e. further from Arg-e-Bam, the lower the collapse rate.

As expected the adobe performance was poor. Among 18 observed points where these structures were present, 13 sustained more than 80% collapse rate and 16 sustained more than 50% collapse rate. Very few adobe houses survived the earthquake in the city downtown.

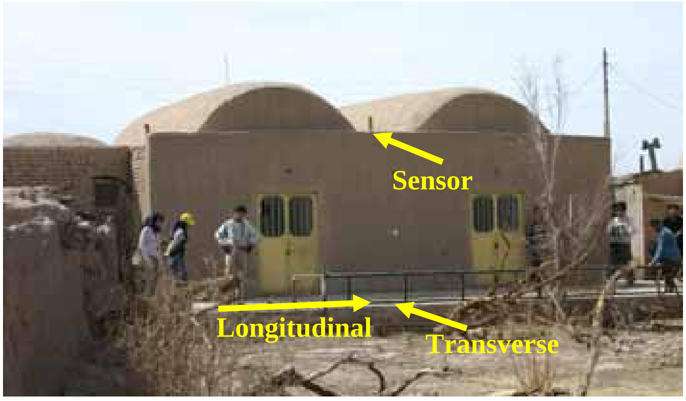

Fig. 5 Measured adobe house in Darzin City

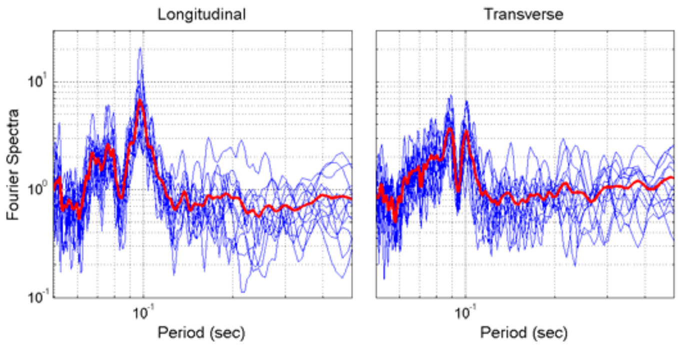

Fig. 6 Typical adobe house microtremor Fourier Spectra

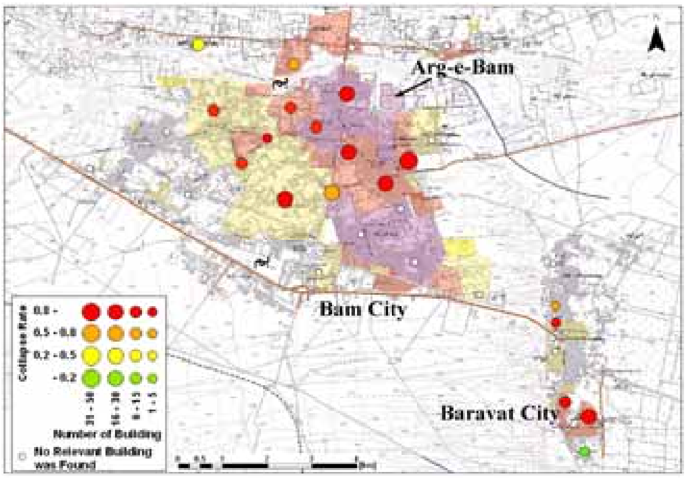

Fig. 7 Adobe building damage

5. Concluding remarks

The December 26, 2003 Bam Earthquake was yet another evidence of the high seismic vulnerability of adobe and unreinforced masonry structures. It also showed the very good seismic performance of confined masonry. Although it is possible to ban the use of adobe as a construction material, which was actually done by the Iranian Government, this measure is inapplicable as many people with limited resources will continue to use it. Several constructions practices for improving the seismic performance of new adobe structures have already been devised as well as retrofitting methods for existing structures. Unfortunately, these have not been implemented due to a lack of appropriate information spreading campaigns. This fact underscores once more the stress that should be put not only on technical issues of earthquake engineering but also on the social ones.

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