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Strain Induced in Cracked Utility Poles and Damage to Dwellings from the Dec 26, 2003, Bam Earthquake

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Abstract

The Bam earthquake of December 26, 2003 (Mw6.5) occurred around the city of Bam in southeast Iran. Because the earthquake happened early in the morning at 01: 56: 56 (GMT, 05: 26: 26 local time), most of the reported 43,100 victims were killed in their dwellings. In Iran, there are dense strong ground motion networks for describing the seismological features of earthquakes, but very sparse networks for damage distribution analysis. Actually, damage differed from street block to street block, and only one seismometer was available in the city. Measuring traces of intense shakes remaining in structures, which are seen everywhere and have common features, can be very effective. The authors used utility poles in Bam for this structure. This report provides a spatial distribution of strains induced in these poles, and compares them with damage distribution in the city.

Key words: Bam earthquake, local site effect, utility poles, microtremors, adobe dwellings

1. Introduction

An intense earthquake occurred in southeastern Iran at 5: 28 local time, December 26, 2003. Although the moderate moment magnitude of 6.5 (Building and Housing Research Center, Iran) - 6.6 (USGS) calculated for this earthquake was not surprisingly large when contrasted with major earthquakes that have occurred in this country, Bam, an oasis city in a desert, was ravaged. About 43,100 people were reportedly killed and 30,000 injured, making this earthquake the worst Iran has experienced in the past century.

The city had about 100,000 residents according to official figures. Shortly after the earthquake, officials announced that the possible deaths would number 28,000. The number was revised downward to 26,500 on January 3, but as rescue crews continued to pull out dead bodies from debris, the death toll increased. On Jan. 15 the official estimates put the number of casualties at between 30,000 and 35,000, and to date the death toll has increased to 43,100. Because the earthquake happened quite early in the morning, the majority of the casualties were in their dwellings, mostly adobe, unreinforced and/or confined masonry structures.

Because the effects of the earthquake were quantitatively serious and broad in scope, several organizations in Japan dispatched teams. They included the Japan Association for Earthquake Engineering (JAEE), Japan Society of Civil Engineers (JSCE), and the Ministry of Education, Culture, Sports, Science and Technology (MEX). The MEX team was made up of several sub-teams with wide-ranging expertise. After some discussions, a joint engineering team was organized to undertake an efficient reconnaissance survey. Although the major counterpart organization was the International Institute of Earthquake Engineering and Seismology (IIEES), the Building

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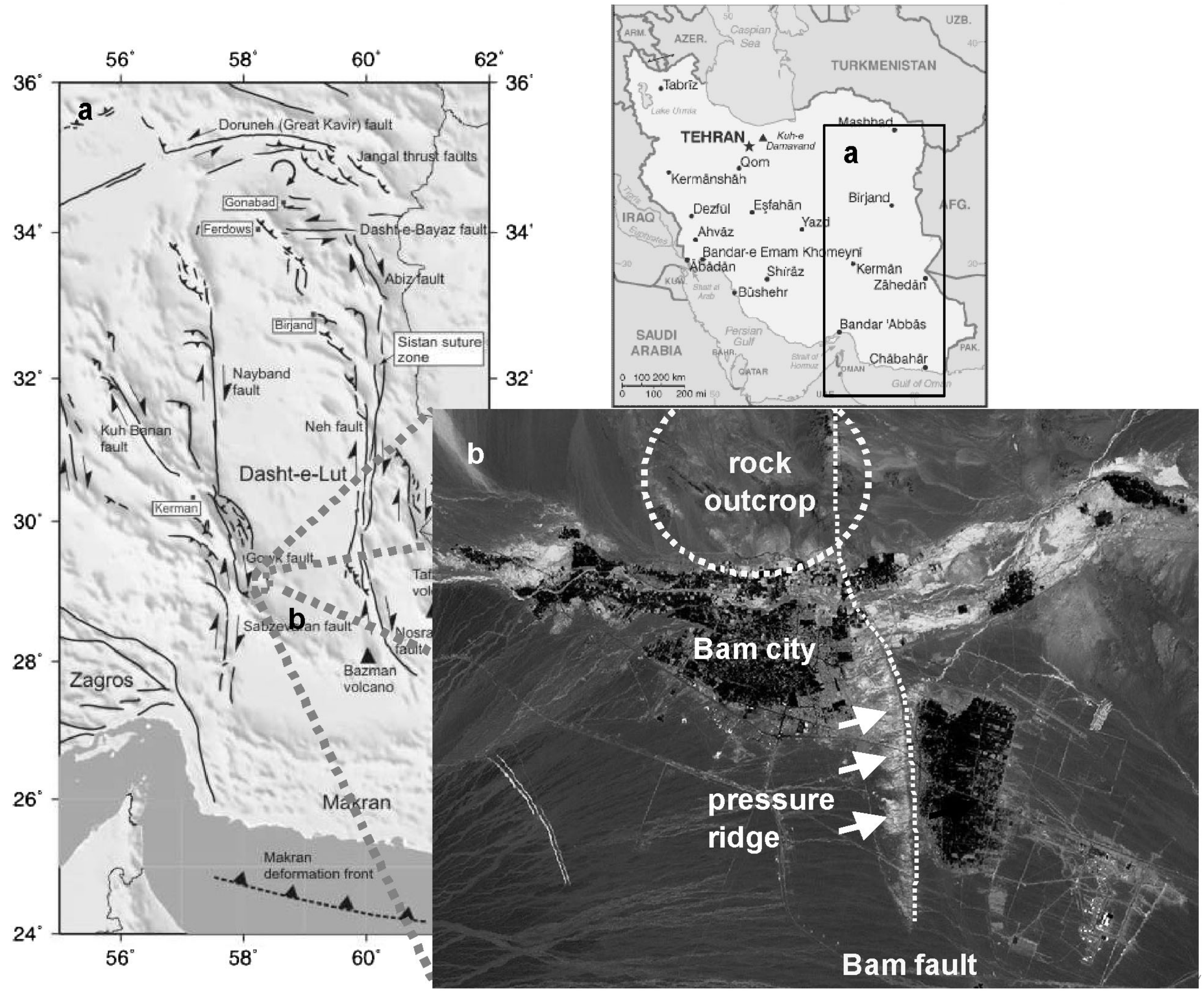


Fig. 1. Location of Bam and its satellite imagery: The Bam fault take-up is basically a right-lateral shear in this area. However, some shortening components have been responsible for forming a pressure ridge along the fault. Bam city is spread behind the pressure ridge on the hanging wall side. (Satellite imagery from LANDSAT, (NASA, 2004), October 1, 1999), Fault map from Walker *et al.* (2003).

and Housing Research Institute (BHRC) and the University of Tehran (UT) also collaborated during the field survey. The joint team made the first and second reconnaissance trips on Feb. 16-5 and Feb. 23-March 5, respectively, stressing the evaluation of damage to dwellings and description of damage in terms of possible intensity distribution, which might have been affected by local and geological site conditions.

2. Source Parameters and Geological Structure

Southeastern Iran is a region with widespread active faults (Fig. 1 a) that basically take up a right-lateral shear in this area. The Bam Earthquake, measuring 6.6 on the Richter scale, occurred on December 26, 2003 at 05: 28 local time, with its epicenter located at 29.004 N, 58.337 E, on a predominantly right-lateral strike-slip fault. The focal depth was located 7 to 12 km directly underneath Bam city spreading west behind a pressure ridge formed along Bam fault (Fig. 1 b). The presence of a pressure ridge suggests that there are shortening (thrusting) components associated with the strike-slip movement of the fault.

Figure 1 b shows satellite imagery from LANDSAT (NASA, 2004) covering Bam. A volcanic rock outcrop can be seen just north of the city, which dips to the south. The rock is cut in half by the Bam fault, which extends from north to south. The 2-km-wide pressure ridge has stopped sand, soil, and other sus-

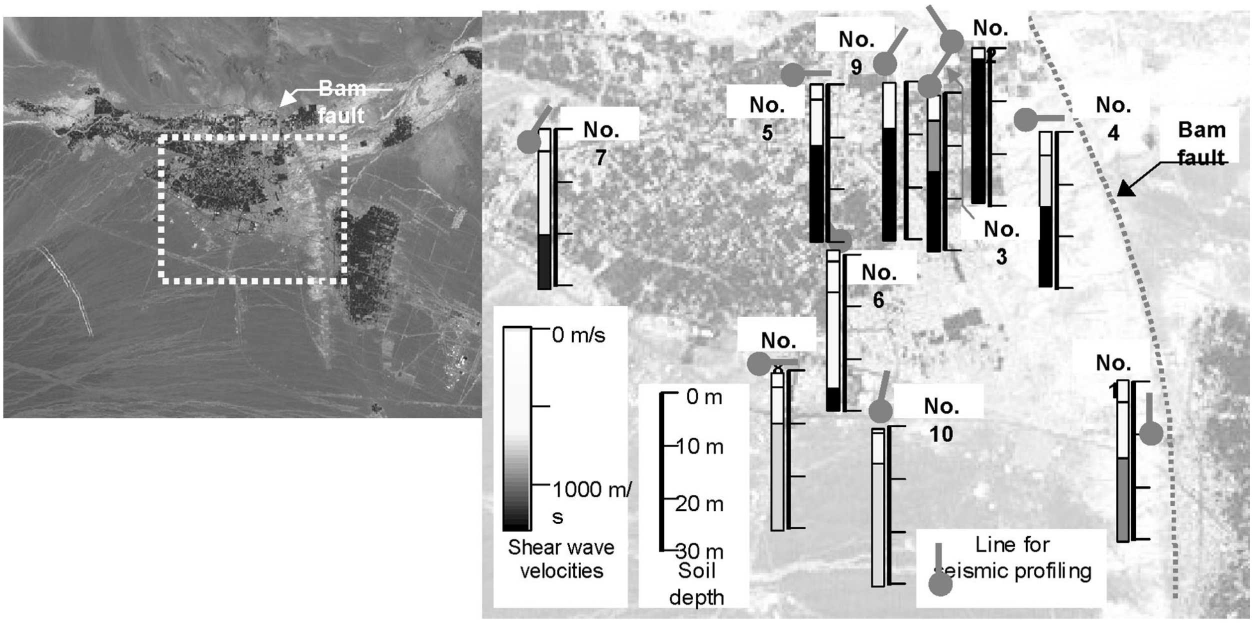


Fig. 2. Seismic soil profiling in Bam: Each mark with a circle at one end shows the line taken for seismic profiling. A circle denotes the point where a blow was given. (Original data from IIEES).

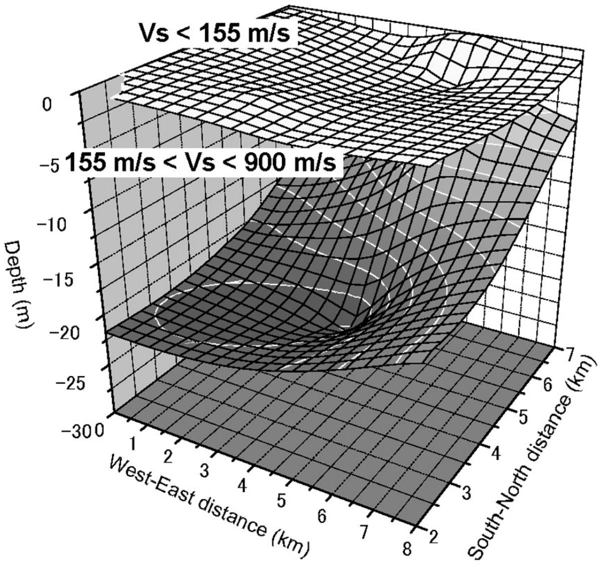


Fig. 3. Inferred layer boundaries of shear wave velocities 155 m/s and 900 m/s respectively.

pended matters that rivers from mountains have carried over the centuries. The area is thus rich in underground water. Taking advantage of this, Bam, as an old oasis city, has developed with no reported great historic earthquakes before this event.

The city extends about 6 km from north to south and 8 km from east to west on the hanging wall side.

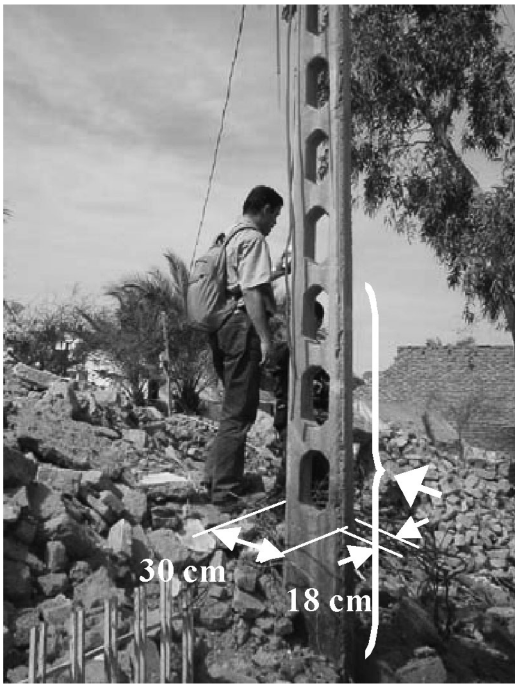
The International Institute of Earthquake Engineering and Seismology (IIEES) did seismic profiling along a total of 10 lines in the city after the earthquake. Bars in Fig. 2 show average soil profiles at these lines. Alluvial soil thickly covers the mid- to southern part of the city area, while the soil becomes thinner as we go north. Fig. 3 shows inferred layer boundaries of shear wave velocities 155 m/s and 900 m/s respectively, both showing rich variations of soil profile in Bam city.

3. Strains Remaining on Utility Poles

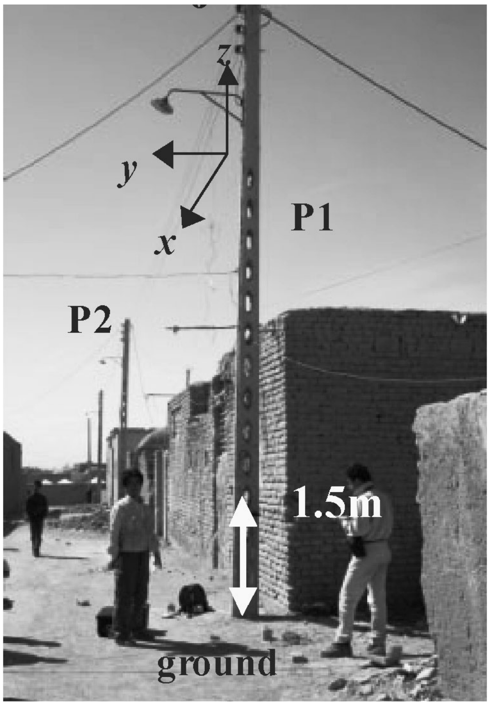
For oasis cities near active faults to be prepared for possible future earthquakes, damage caused by the Bam earthquake is discussed in terms of strong ground motion features that dwellings have experienced. However, as is often the case, damage differed from street block to street block, and only one seismometer was available in the city. In countries such as Japan and Iran, which are ranked among the most seismic hazard prone zones in the world, strong ground motion networks are often very dense for describing the seismological features of earthquakes, but are very sparse for describing damage distribution, frustrating many attempts to learn lessons from tragedies. Among possible breakthroughs, measuring traces of intense shake remaining in structures, which are seen everywhere and have common features, can be very effective. The authors used utility poles in Bam for this structure. Poles differ in their

Table 1. Characteristics of the surveyed poles

Name	Height (m)	Remarks
P-1	6.6	Pole with hexagonal holes
P-2	6.6	Pole with hexagonal holes filled with concrete



(a) 8 m pole with holes and embedment depth of 2 m.



(b) Poles P-1 and P-2.

Fig. 4. Poles used in Bam.

dimensions from area to area, but a thin pole with holes for climbing were the most widely used in the city (Fig. 4(a)), and thus, were chosen as the target.

To examine the dynamic features of this type of pole, microtremors were measured at two poles (Fig. 4 (b)). Their characteristics are summarized in Table 1. Bottom holes on P-2 pole were filled in to prevent theft.

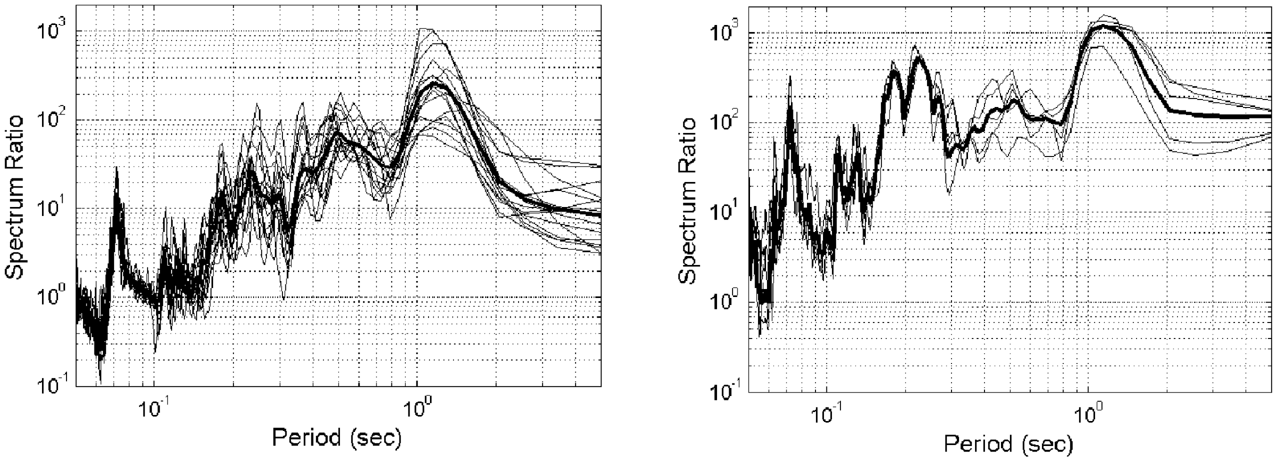
A pair of 3-component velocity sensors was used for the measurements, one on the ground and the other strapped to each pole at a height of about 1.0 to 1.5 m above the ground. In each case, the X-axis was taken along the transmission line. Tremors were measured with poles a) subjected to ambient vibration, basically wind; b) striking in X-direction; and c) striking in Y-direction.

Each time the history of the tremor was divided into several 10.24 sec segments. Fourier spectra of all segments were then calculated and averaged for each time history. To obtain transfer functions in the frequency domain, spectra measured on the pole were divided by those on the ground.

Figure 5 shows the transfer function for P-1. It is clear in Y-direction that there is little change of the predominant periods between the ambient and hit cases. In both cases, clear peaks are found at 0.105 and 0.57 sec, with the main difference being the peak relative amplitudes. When the structure is hit, the lower period amplitude becomes higher.

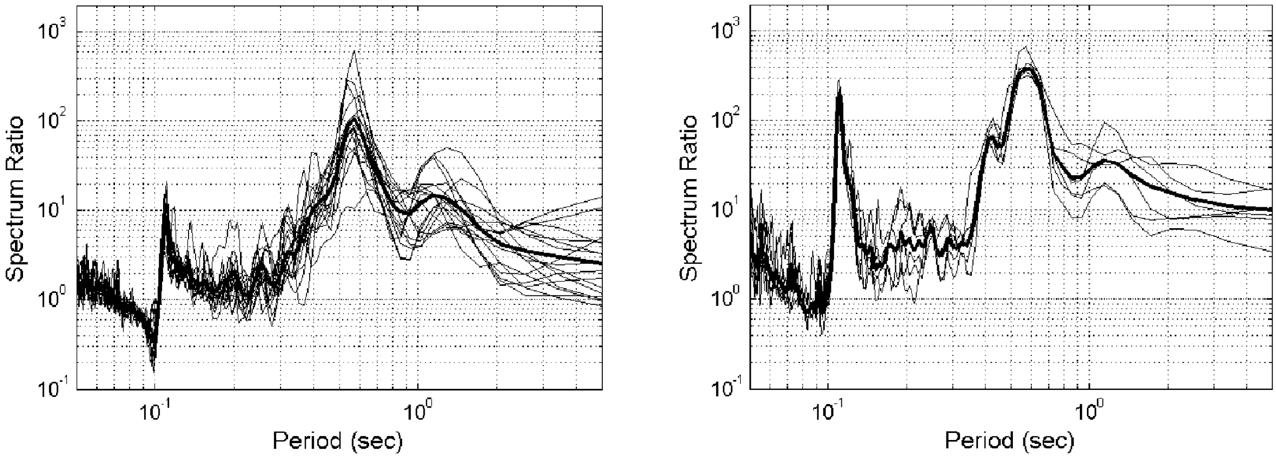
Poles exhibit quite different vibration features in the X-direction (Compare Figs. 5 (a) and 5 (b) with 5 (c) and 5 (d)). As for ambient vibration cases, 2 peaks at 0.07 and 1.10 sec are distinguished among the others at 0.18, 0.21, and 0.6. When the structure is struck, 2 clear peaks appear at 0.18 and 0.21 s, in addition to 0.07 and 1.10 s, but the 0.6 s peak is not clearly seen, suggesting that this peak is crosstalk from the Y-component of the pole vibration.

Figure 6 shows the transfer functions for the P-2 pole. The functions have similar shapes to those for the P-1 pole in all cases, suggesting that mortar filled in the holes had little effect on the dynamic behavior of the pole. Fig. 7 (a), (b) and (c) show X, Y, and Z components of the pole vibration spectra. It is noted



(a) Pole-X/Ground-X for ambient response

(b) Pole-X/Ground-X for transient response



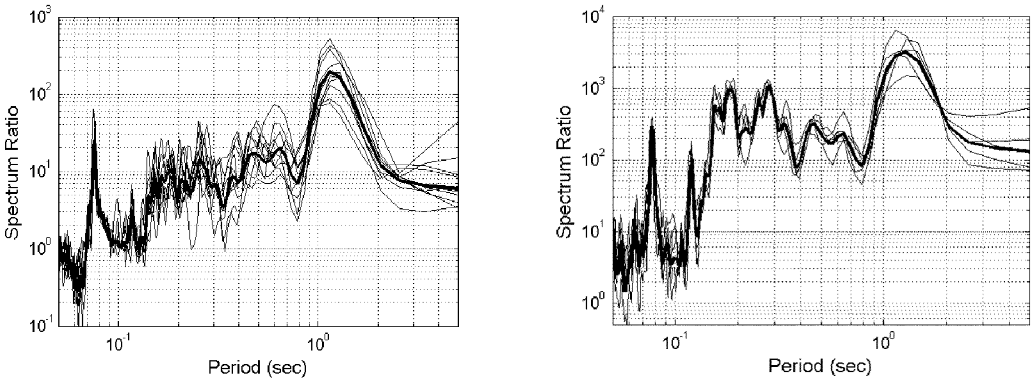
(c) Pole-Y/Ground-Y for ambient response

(d) Pole-Y/Ground-Y for transient response

Fig. 5. Transfer functions for pole P-1.

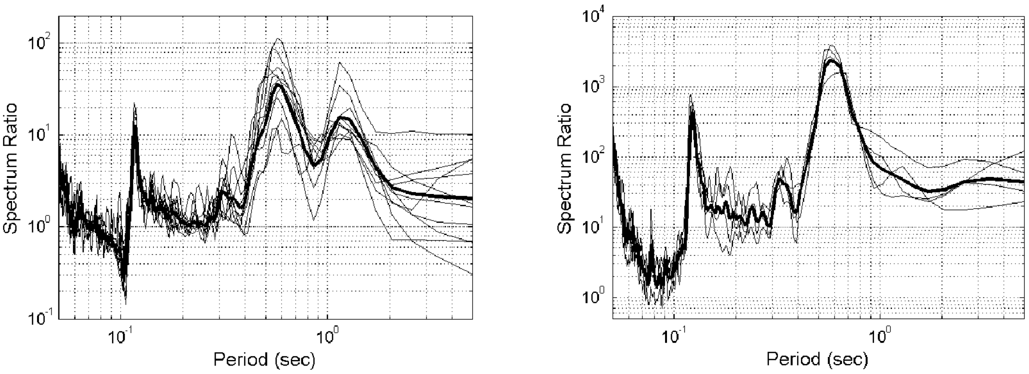
that the spectra for X and Z components are similar to each other, while the Y component exhibits some different shapes. Fig. 7 (d) shows X/Z and Y/Z spectra ratios to highlight this feature. Assuming that the vertical vibrations of the pole were mainly induced by cable oscillations, it may be concluded that a cable has an important effect on the pole's motion along the cable.

For this reason, crack openings on pole sides without holes were taken to minimize the effects of transmission lines, the cracks caused by the motion of poles in the Y direction. For each pole, crack openings were added up over about a 2 m distance near the lower pole end, and then all of the openings were divided by the distance to obtain the average strain remaining on the pole. A total of 270 poles were used in both the city and its suburbs. The poles were then divided into several tens of clusters in such a way that each cluster included at least one crossing in it. Because the poles in one cluster line up at least two roads intersecting each other, both north-south (NS) and east-west (EW) average strains were obtained cluster-wise. Figs. 8 (a) and 8 (b) show the distribution of remaining average strains in the city. Contour lines in Figs. 8 (a) and (b) show inferred layer boundaries of shear wave velocities $V_s = 155\,m/s$ and $V_s = 900\,m/s$, respectively (see Fig. 3), and colored zones show percentages of damage to dwellings mapped by the National Cartographic Center of Iran (2004). In general, strains are large along the main avenue that runs through the city from north to south. Damage was also severe along this avenue



(a) Pole-X/Ground-X for ambient response

(b) Pole-X/Ground-X for transient response



(c) Pole-Y/Ground-Y for ambient response

(d) Pole-Y/Ground-Y for transient response

Fig. 6. Transfer functions for pole P-2.

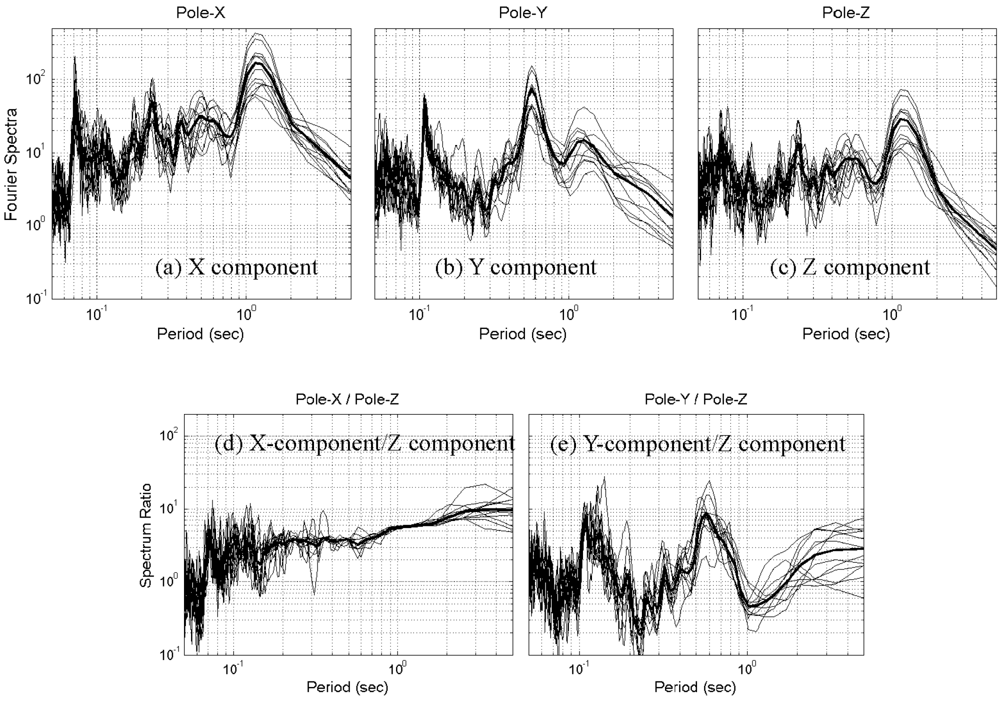


Fig. 7. Comparison of P-1 spectra in three directions.

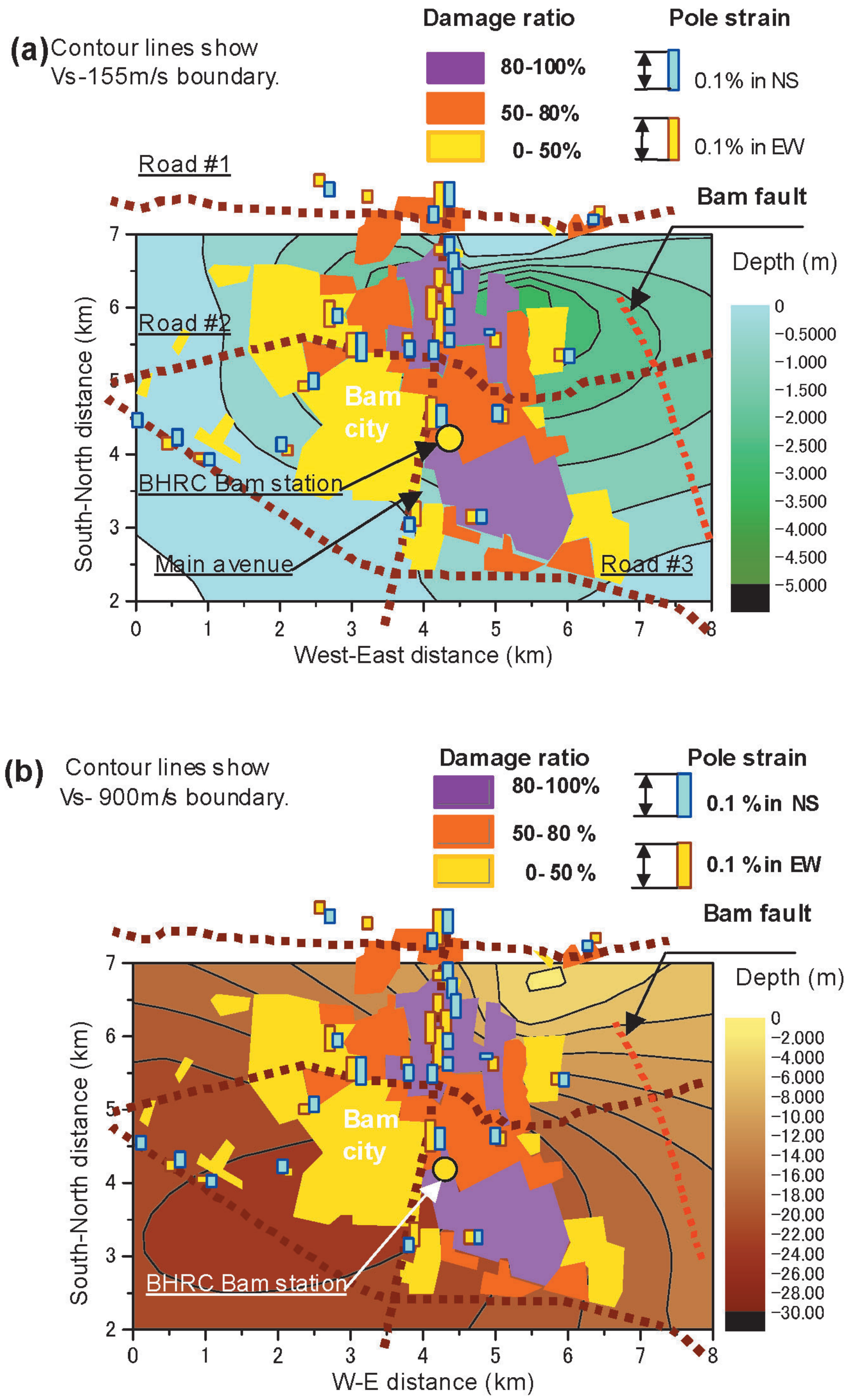


Fig. 8 b Strains remaining in poles: (Damage ratio provided by NCC of Iran, 2004).

(Fig. 9 a), and it faded quickly as we got some street blocks away from the avenue (Fig. 9 b). Some severe damage to dwellings was also found along Road #2, which used to be an old river trace, and goes through the city from East to West (Fig. 9 c). The strain distribution thus seems to be consistent with the overall damage distribution pattern. However, calibration is necessary to interpret the strain distribution pattern in terms of intensity, in spite of the fact that only one strong ground motion record was available in the city (see the location on the map Fig. 8). A further discussion will appear in a future publication.

(a) Near the main avenue.
N29° 07′00.5″ E58° 21′41.5″ 77°.

(b) East of the city.
N29° 06′23.3″ E58° 22′36.7″ 88°.

(c) Along the Street #2
N29° 06′24.6° E58° 21′13.1″ 74°.

Fig. 9. Damage to dwellings in Bam.

4. Summary

In countries such as Japan and Iran, which are ranked among the most seismic hazard prone zones in the world, strong ground motion networks are often very dense for describing the seismological features of earthquakes, but are very sparse for describing damage distribution, frustrating many attempts to learn lessons from tragedies. Measuring traces of strong ground motions remaining in structures, which are seen everywhere and have common features, provides useful information for discussing the spatial distribution of damage. RC utility poles were taken as the target structures in Bam, the city flattened in the December 26, 2003 earthquake. A total of 270 poles were used both in the city and its suburbs. Clusters of poles with relatively large strains were found mostly along (1) the main avenue that runs through the city from north to south and (2) along Road #2, which used to be an old river trace, and goes through the city from East to West (Fig. 9 c). Dwellings along these roads were the most seriously damaged. In general, the distribution of cracked poles seems to have a good correlation with damage distribution, which again showed the high seismic vulnerability of adobe and unreinforced masonry structures.

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. With this situation as a background, it is necessary to provide fragility curves of adobe structures to inform people of the possible scenarios of serious destruction, and to improve the seismic performance of their dwellings by retrofitting them. Unfortunately, the poles do not directly show any seismic intensity measures, just strains, although the strain distribution obtained was apparently consistent with the overall distribution of damage to dwellings. Calibration is necessary, and this will be discussed in a future publication.

Acknowledgement

The authors would like to express their sincere sympathy to the people affected by the killer earthquake. They are also grateful to all JAEE/JSCE reconnaissance team members and collaborators from Iranian organizations including the International Institute of Earthquake Engineering and Seismology (IIEES) as the key counterpart, Building and Housing Research Center (BHRC) and the University of Tehran. The initiative taken by Prof. Mohsen Ghafory-Ashtiany, President of IIEES, for organizing the joint reconnaissance team is highly appreciated. Prof. G. Heidarinejad, President of Building and Housing Research Center, kindly provided the team with necessary materials including digital data of strong ground motions from the Bam earthquake. Prof. R Alaghebandian and Prof. A. Ghalandarzadeh, University of Tehran, joined the reconnaissance and helped the team members providing geotechnical and architectural pieces of information. The authors wish to further collaborate with Iranian specialists on possible countermeasures, e.g., reconstruction of damaged structures, retrofitting of existing structures, and reducing earthquake hazards.

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