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

Kazuo Konagai[1)*], Masayuki Yoshimi[2)], Kimiro Meguro[1)], Miho Yoshimura[1)], Paola Mayorca[1)], Masasuke Takashima[1)], Alireza Farahani[1)], Hossein Tahghighi[1)] and Mohammad Keshavarz[3)]

1) Institute of Industrial Science, The Univ. of Tokyo

2) Active Fault Research Center, National Inst., Advanced Industrial Science and Technology

3) The International Institute of Earthquake Engineering and Seismology, Iran

Abstract

The Bam earthquake of December 26, 2003 (Mw6.5) occurred around the city of Bam in the southeast of Iran. Since the earthquake happened early in the morning at 01:56:56 (GMT, 05:26:26 local time), most of the reported victims of 43,100 were killed in their dwellings. In Iran, strong ground motion networks are very dense to describe seismological features of earthquakes, but yet very sparse for the damage distribution analysis. Actually, the damage differed from street block to street block, while only one seismometer was available in the city. 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 as this structure. This report provides 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. Though the moderate moment magnitude of 6.5 (Building and Housing Research Center, Iran) – 6.6 (USGS) calculated for this earthquake was not surprisingly large as contrasted with those major earthquakes that ever occurred in this country, Bam, an oasis city in a desert, was seriously ravaged. About 43,100 people were reportedly killed and 30,000 injured making this earthquake the worst that Iran has ever had in the past century..

The city had about 100,000 residents according to official figures. Shortly after the earthquake, the officials announced that the possible deaths would be 28,000. The number was revised down to 26,500 on January 3, but as the 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 between 30,000 and 35,000, and up until now the death toll has been increased up to 43,100. Since the earthquake happened quite early in the morning, the majority of the casualties were killed in their dwellings, mostly adobe, un-reinforced and/or confined masonry structures.

Since the effect of the earthquake was seriously large in amount and broad in scope, it turned out that several organizations in Japan were dispatching their 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 for a wide expertise. After some discussions, a joint engineering team was organized for an efficient reconnaissance survey. Although the major counterpart organization was the International Institute of Earthquake Engineering and Seismology (IIEES), the Building 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. 16–25

* e-mail: konagai@iis.u-tokyo.ac.jp (4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan)

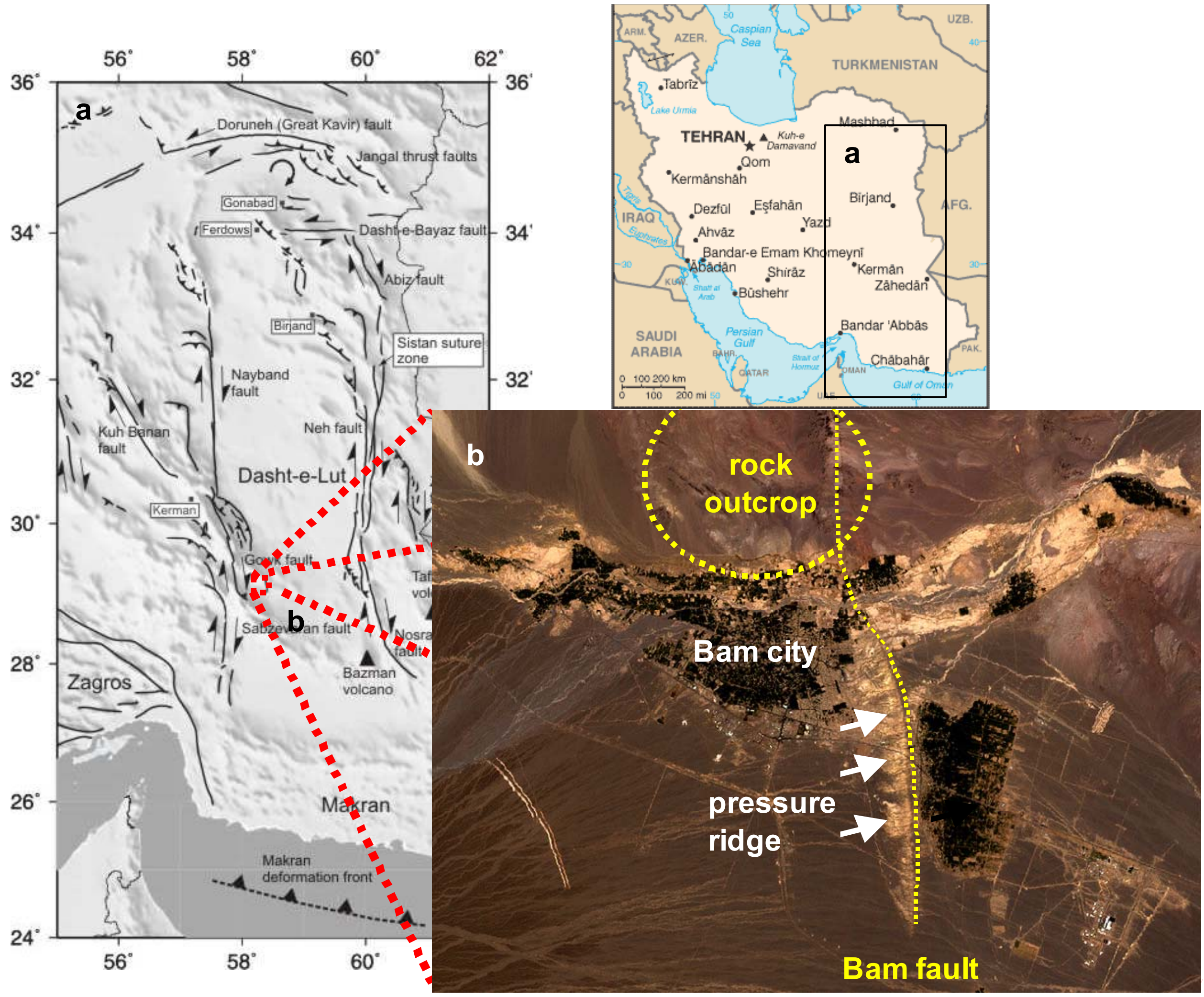


Fig. 1 Location of Bam and its satellite imagery: Bam fault take up basically right-lateral shear in this area. However some shortening component has been responsible for forming a pressure ridge along the fault. Bam city spreads behind the pressure ridge on the hanging wall side. (Satellite imagery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

and Feb. 23–March 5, respectively, stressing on the evaluation of damage to dwellings, description of the 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 of widespread active faults (Fig 1a) that take up basically 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. 1b). The presence of a pressure ridge suggests that there are shortening (thrusting) components associated with the strike-slip movement of the fault.

Fig. 1b 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 Bam fault, which extends from north to south. The 2 km wide pressure ridge has stopped sand, soil and other suspended matters that rivers from mountains have carried over centuries. The area is thus rich of underground water. Taking this advantage, Bam, an old oasis city has been developed with no reported great historical earthquake before this event.

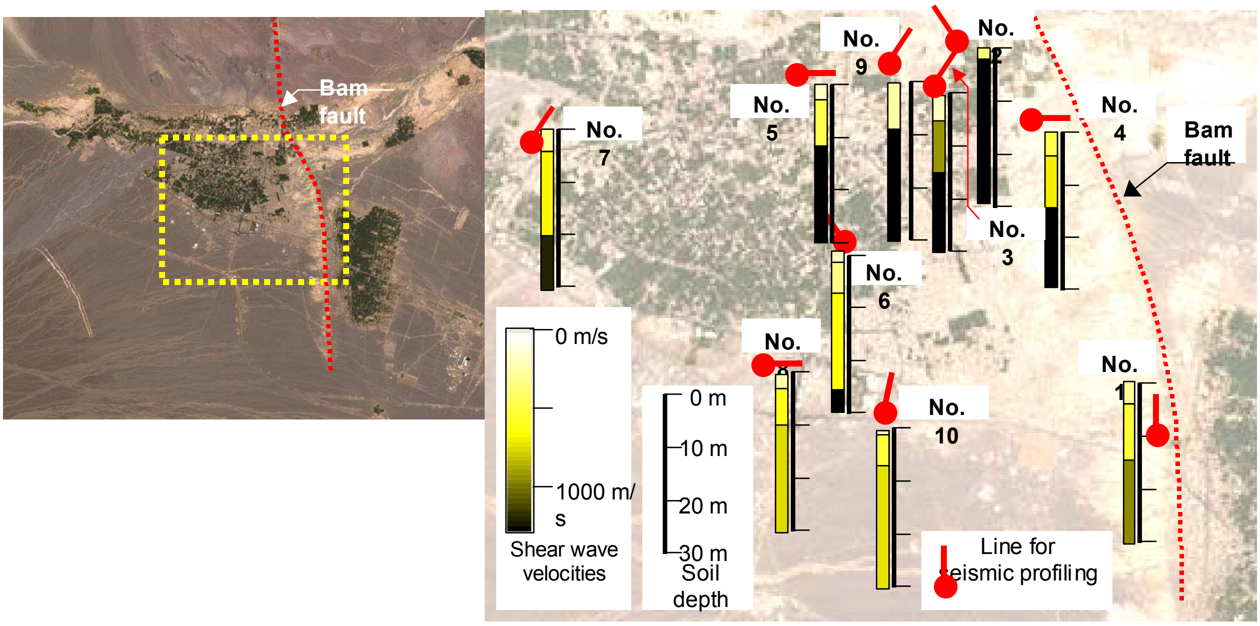


Fig. 2 Seismic soil profilings in Bam: Each marks with a circle on its one end show a line taken for seismic profiling. Circle denotes the point where a blow was given. (Original data from IIEES).

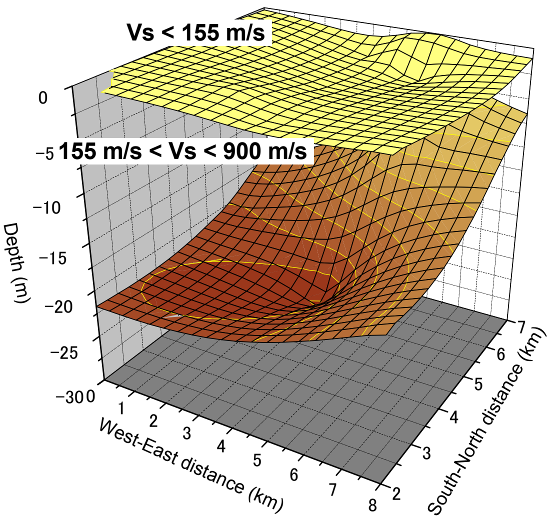


Fig. 3. Inferred layer boundaries of shear wave velocities 155 m/s and 900 m/s respectively.

The city spreads 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 total 10 lines taken in the city after the earthquake. Color bars in Fig. 2 show average soil profiles at these lines. Alluvial soil covers thick 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 variation of soil profile in Bam city.

3. Strains Remaining on Utility Poles

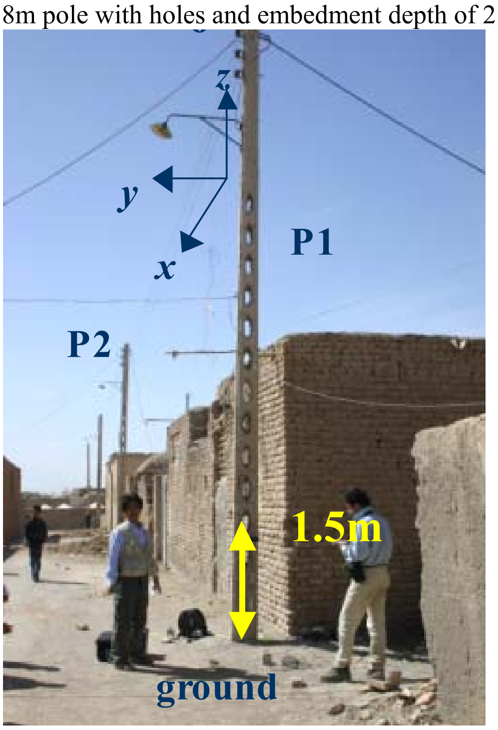
For oasis cities near active faults to be prepared for possible future earthquakes, damage caused by the Bam earthquake is to be discussed in terms of strong ground motion features that dwellings have experienced. However, as was often the case, damage differed from street block to street block, while only one seismometer was available in the city. In countries such as Japan and Iran ranked as the most seismic hazard prone zones in the world, strong ground motion networks are often very dense to describe seismological features of earthquakes, but yet very sparse to describe damage distribution frustrating many attempts for learning 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 as this structure. Poles differ in their dimensions from area to area, but a thin pole type, with holes for climbing on, were the most widely used in the city (Fig. 4(a)) and, thus, chosen as the target.

In order to examine the dynamic features of this pole type, 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.

Table 1. Characteristics of the surveyed poles

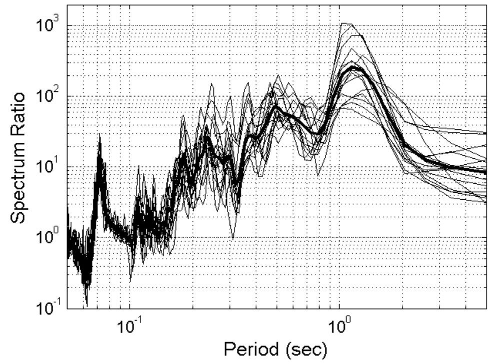
Name	Height (m)	Remarks
P-1	6.6	Pole with hexagonal holes
P-2	6.6	Pole with hexagonal holes filled with concrete

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

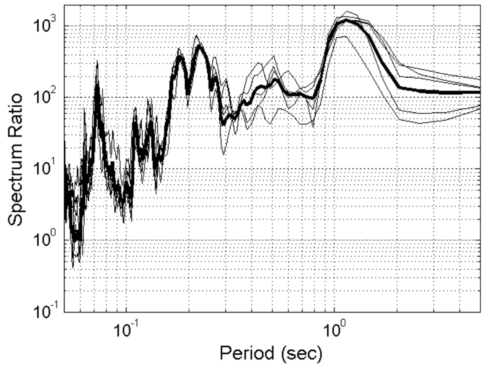


(b) Poles P-1 and P-2

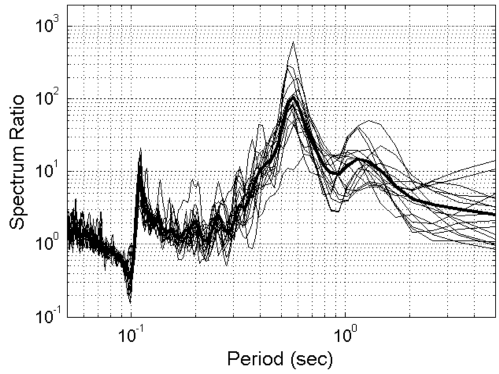
Fig. 4 Poles taken in Bam



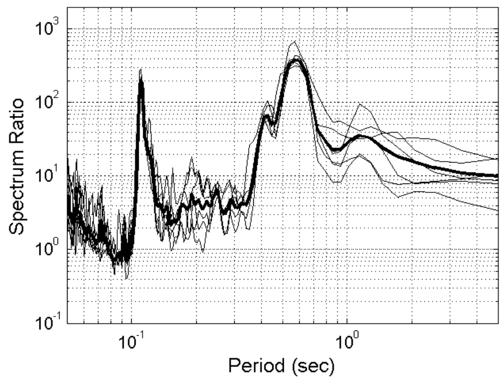
(a) Pole-X/Ground-X for ambient response



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

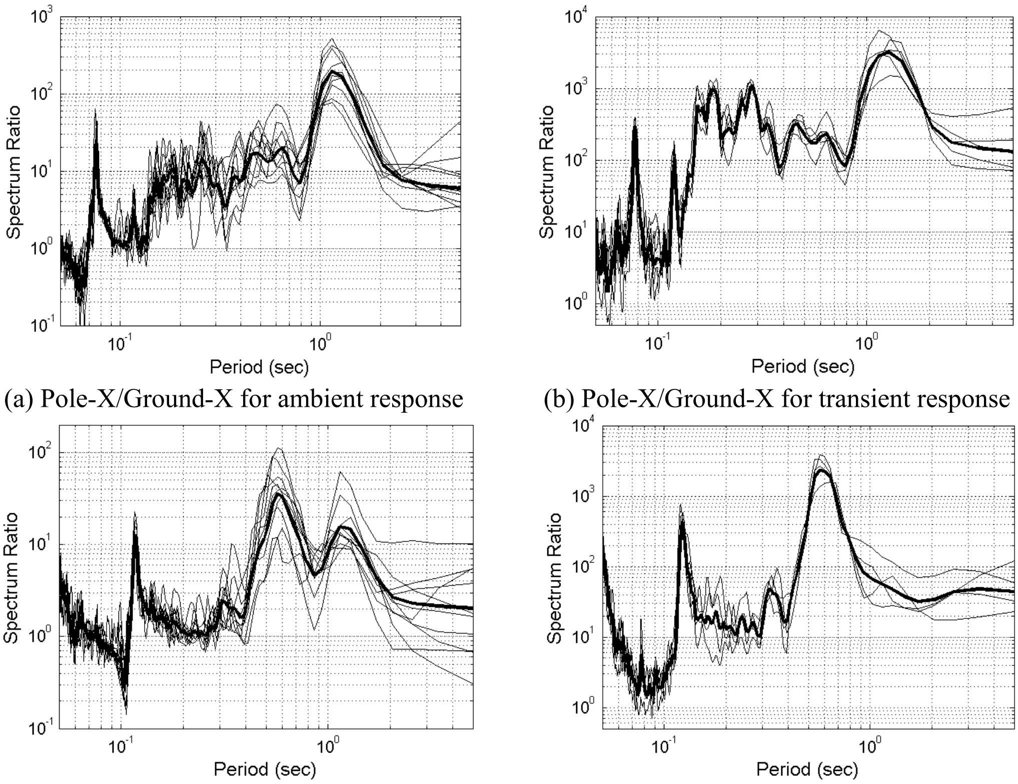


(c) Pole-Y/Ground-Y for ambient response



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

Fig. 5. Transfer functions for pole P-1



(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

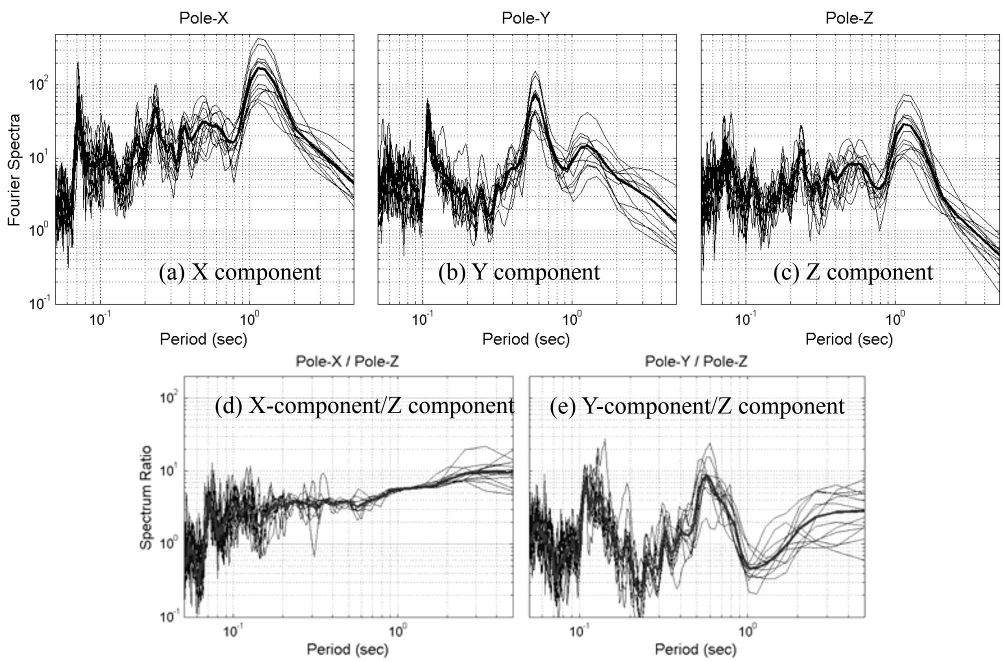


Fig. 7. Comparison of P-1 spectra in three directions

A pair of 3-components velocity sensors was used for the measurement, one on the ground and the other strapped to each pole at the height about 1.0 to 1.5m 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) hit in X-direction; and c) hit in Y-direction.

Each time history of the tremor was divided into several

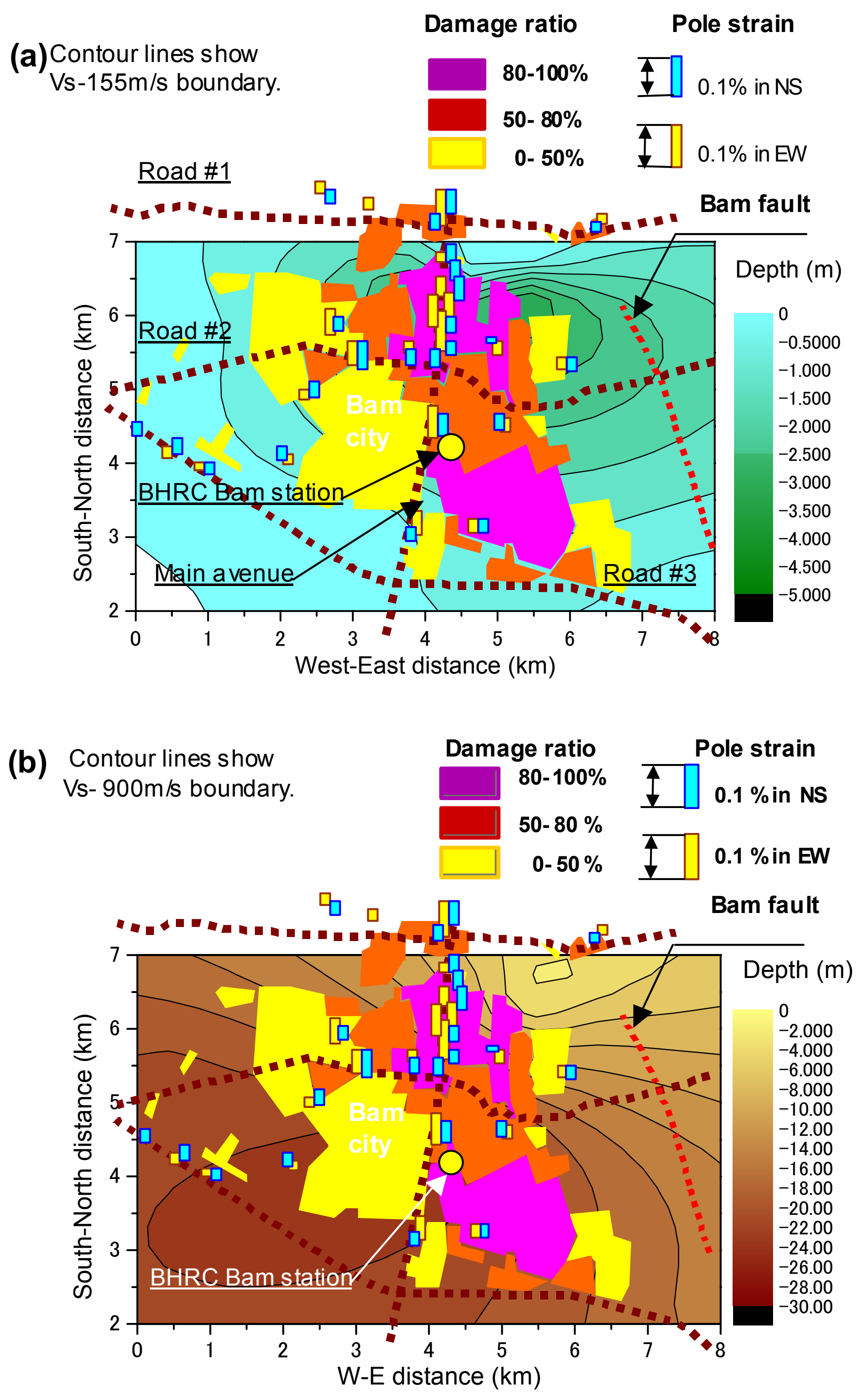


Fig. 8b Strains remaining in poles: (Damage ratio provided by NCC of Iran, 2004)

10.24sec pieces. Fourier spectra of all pieces were then calculated and averaged for each time history. In order to obtain transfer functions in the frequency domain, spectra measured on the pole were divided by those on the ground.

Fig. 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 0.57sec, with the main difference being the peak relative amplitudes. When the structure is hit, the lower period amplitude becomes higher.

Poles exhibits quite different vibration features in X-direction (Compare Figs 5(a) and 5(b) with 5(c) and 5(d)). As for ambient vibration cases, two peaks at 0.07 and 1.10 sec are distinguished among the others at 0.18,

(a) Near the main avenue
N29º07’00.5” E58º21’41.5”　77º

(b) East of the city
N29º06’23.3” E58º22’36.7”　88º

(c) Along the Street #2
N29º06’24.6” E58º21’13.1”　74º

Fig. 9.　Damage to dwellings in Bam

0.21, and 0.6. When the structure is hit, two clear peaks appear at 0.18 and 0.21s in addition to 0.07 and 1.10s, but 0.6s peak is not clearly seen suggesting that this peak is the crosstalk from Y-component of the pole vibration.

Fig. 6 shows the transfer functions for P-2 pole. The functions have similar shapes as those for P-1 pole in all cases, suggesting that mortar filled in 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 that the spectra for X and Z components are similar with each other, while Y component exhibits some different shape. 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 effect of transmission lines, the cracks caused by poles’ motion in Y direction. For each pole, crack openings were added up over about 2m distance near the lower pole end, and then the total openings were divided by the distance to obtain average strain remaining on the pole. Total 270 poles were taken both in the city and its suburbs. The poles were then divided into several tens clusters in such a way that each cluster includes at least one crossing in it. Since the poles in one cluster line up at least two roads crossing each other, both north-south (NS) and east-west (EW) average strains were obtained cluster-wise. Fig. 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 (Fig.9a) and it faded out quickly as we go some street blocks away from the avenue (Fig. 9b). 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. 9c). The strain distribution thus seems to be consistent with the overall damage distribution pattern. However, a 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). The further discussion will turn up in a future publication.

4. Summary

In countries such as Japan and Iran ranked as the most seismic hazard prone zones in the world, strong ground motion networks are often very dense to describe seismological features of earthquakes, but yet very sparse to describe damage distribution frustrating many attempts for learning lessons from tragedies. Measuring traces of strong ground motions remaining in structures, which are seen everywhere and have common features, will provide useful pieces of information for discussing spatial distribution of damage. RC utility poles were taken as the target structures in Bam, the city flattened in the December 26, 2003 earthquake. Total 270 poles were taken 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. 9c). Dwellings along these roads were the most seriously damaged and in general, the distribution of cracked poles seems to have a good correlation with the 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 really necessary to provide fragility curves of adobe structures for letting people know possible scenario of serious destruction, and for improving seismic performance of their dwellings by retrofitting them. Unfortunately, the poles do not show directly any seismic intensity measures but just strains, though the obtained strain distribution was seemingly consistent with the overall distribution of damage to dwellings. A calibration is necessary and this will turn up in a future publication.

Acknowledgement

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References

NASA: Destructive earthquake near Bam, 2004, http://www.parstimes.com/spaceimages/bam_landsat.html (Photo, taken on October 1, 1999)

National Cartographic Center of Iran, Damage distribution to dwellings, Bam, 2004, http://www.ncc.org.ir/bam/BAMfinal_H_e.jpg

Walker, R., J., and Baker, C., 2003, Surface Expression of Thrust Faulting in Eastern Iran: Source Parameters and Surface Deformation of the 1978 Tabas and 1968 Ferdows Earthquake Sequences, *Geophysical Journal International*, **152**, 749-765.