Microtremor Measurements

Conventional microtremor measurements with a three-component sensor were conducted on ground at eight sites, hereinafter called AKS and MNS in front of collapsed buildings at Akshavdip and Mansi complex in Ahmedabad, respectively, ANJ and BAC in front of town offices in Anjar and Bhachau, respectively, BJ0 near collector office in Bhuj, BJ1 in suburb of Bhuj, GND at a central part of Gandhi Dham, and KND in front of a gate of Kandla port. At each observation site, traffic density was not very heavy. The locations determined by using GPS at the sites are listed in Table 1.

Table 1. Locations of microtremor observation sites.

Site	Lati.(deg.)	Lati.(min.)	Longi.(deg.)	Longi.(min.)	Height(m)
BJ1	N 23	13.9162	E 69	39.0255	131.5
BJ0	N 23	14.3323	E 69	39.6156	100.5
ANJ	N 23	6.2788	E 70	1.7965	62.5
GND	N 23	3.7678	E 70	7.9044	19.2
KND	N 23	0.2280	E 70	13.1913	17.4
BAC	N 23	17.3444	E 70	20.7194	67.7
AKS	N 23	0.9911	E 72	33.4012	54.2

Evaluation errors of the locations could be less than 5-10 m in both horizontal and vertical directions. At Site MNS in Ahmedabad, GPS could not catch enough numbers of satellites, so location of the site was not determined.

The measurement system used consists of amplifiers, filters, 24-bit A/D converters, and a note-type computer, which are built in a portable case, with a three-component velocity sensor unit of which natural period is 2 s, and the system is shown in Photo 1.

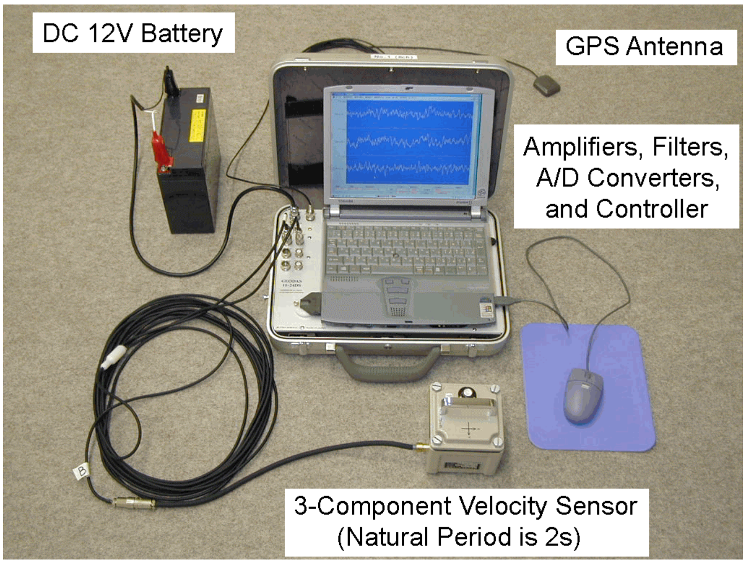

Photo 1. Test equipments used in microtremor measurements.

At each site, microtremor ground motions were measured for 5 minutes, and were digitized with equi-interval of 0.01 s. Figure 1 shows velocity time series of vertical and two orthogonal horizontal (N-S and E-W components) microtremor motions recorded at Site ANJ. Eight-16 sets of data with 2048 or 4096 points each are selected from the digitized motions excluding traffic-induced vibrations, and are used for the following analyses.

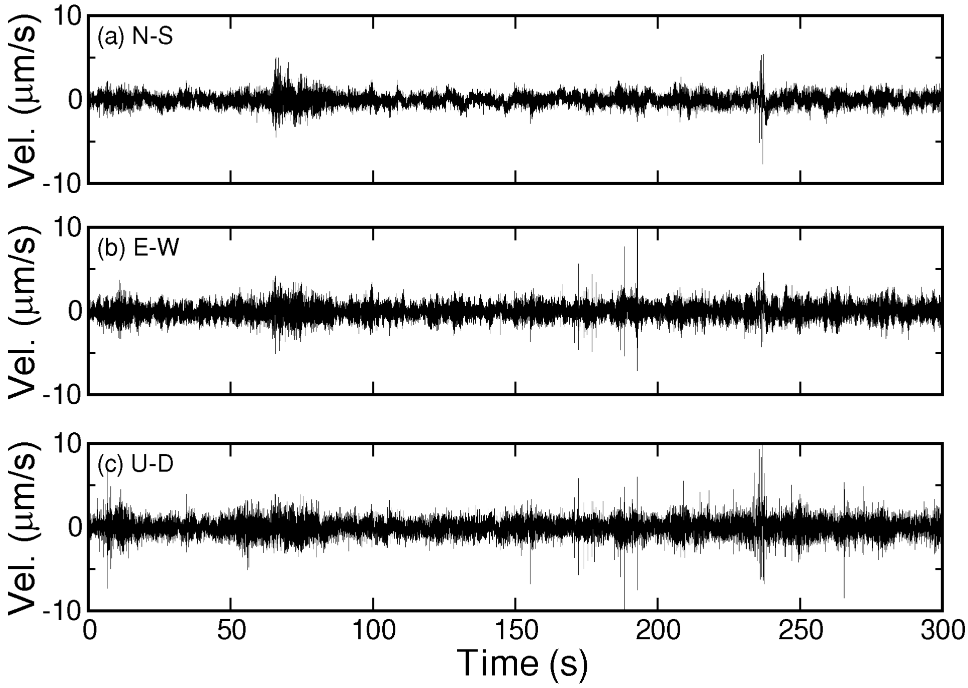

Figure 1. Velocity time series of microtremor ground motions at Site ANJ.

H/V Spectra of Microtremors

Horizontal-to-vertical (H/V) spectral ratio of microtremors, $(H/V)_m$, is defined as

$$(H/V)_m = (S_{NS}^2 + S_{EW}^2)^{1/2} / S_{UD} \qquad (1)$$

where S_{UD} is Fourier amplitude of vertical motion, and S_{NS} and S_{EW} are that of two orthogonal horizontal motions.

The observed microtremor H/V spectra at the sites are shown in Figure 2 in solid lines. Microtremor H/V spectra for the sites can be also found in the EDM / RIKEN homepage (http://www.miki.riken.go.jp/India2001/Survey1/1strec.html). At Site KND, the observed H/V spectrum has significant peaks, and the peak periods of H/V ratios are about 0.6, 0.9, and 1.5 s. Based on the past studies on microtremor H/V spectra, this indicates that Site KND could be on a sedimentary deposit, and ground motions at the site during earthquakes could be mainly controlled by soil structure around the site, i.e., “site effects.” At the other sites, however, no apparent peak exists in the observed H/V spectra, of which maximum values are less than 3. This suggests that bedrock could outcrop at the sites and/or there could be insignificant site effects on ground motions at the sites during earthquakes.

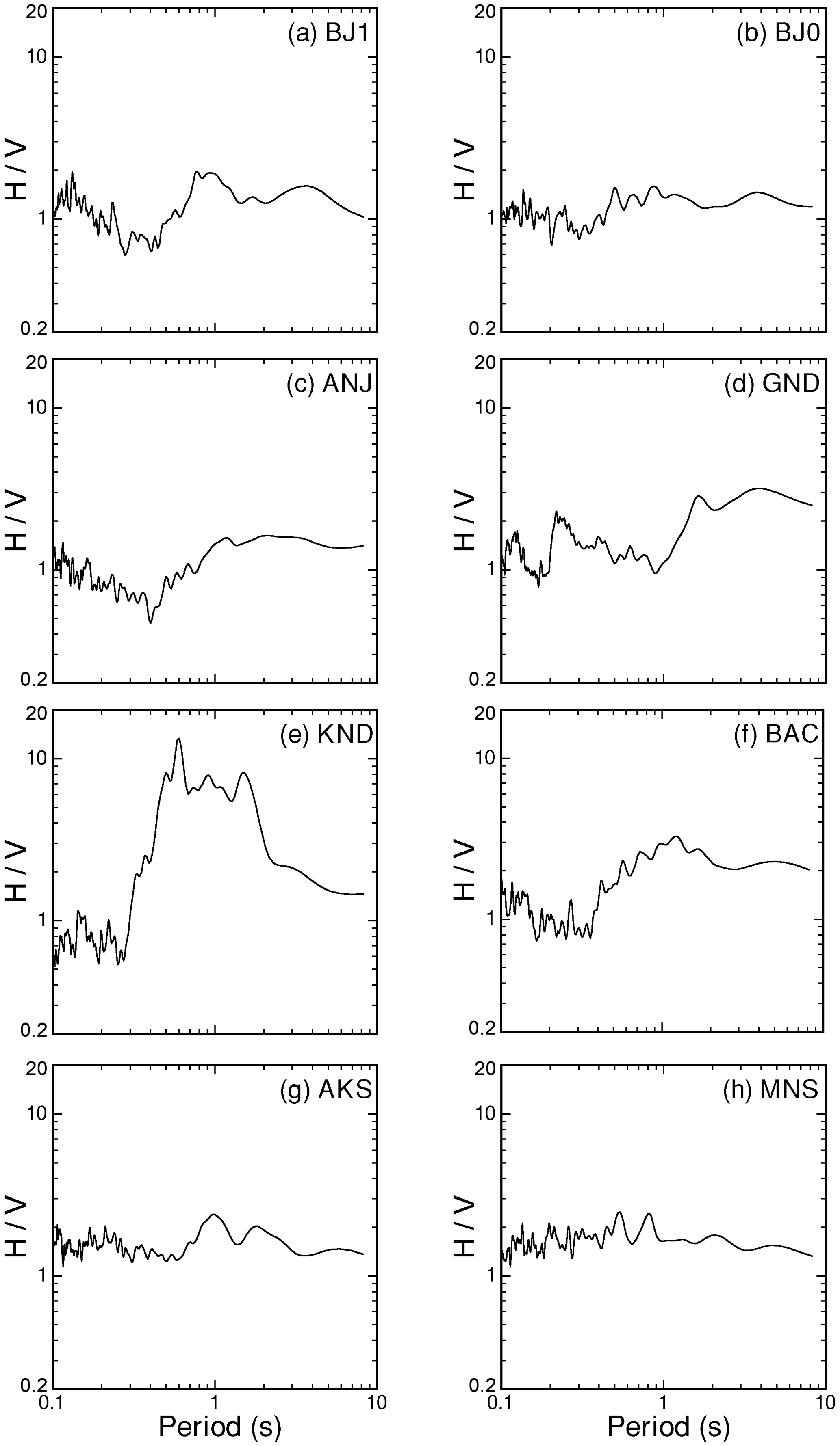

Figure 2. Microtremor H/V spectra at the eight sites.

Fundamental Periods of R/C Framed and Masonry Buildings

Microtremor measurements were also performed at two buildings for residential use, hereinafter called Buildings A and B (back and front ones in Photo 2, respectively), which are located very close to Site BJ1 in Bhuj. Figure 3 is a schematic map showing locations of the buildings and Site BJ1. These buildings are both two-storied, and Building A has reinforced concrete (R/C) framed structure with infill walls of hollow and/or stone bricks, but B has stone masonry structure. The heights of both buildings are 7.6 m. Building A was completed in 1981, but ground and 1st floors of Building B were in 1988 and 1999, respectively. During the main shock, Building A was slightly damaged but B was heavily damaged (see Photos 2-5). No inclination and subsidence could be observed on both buildings.

At the top and ground floors of the both buildings, horizontal X- and Y-component microtremor motions, which are in longitudinal and transverse directions of the buildings, were observed (see Figure 3). The test equipments, sampling conditions, and data processing used are all the same as those stated above.

Figures 4(a) and (b) show Fourier amplitude spectra of the observed horizontal X- and Y-component motions at the top and ground floors of the buildings. In the figures, the observed fundamental periods of Building A could be 0.23 s in X-direction and 0.20 s in Y-direction. On the other hand, those of Building B could be 0.23 s in X-direction and 0.34 s in Y-direction.

In the latest Indian building code in 1986, approximate fundamental period, T_a (s), of moment-resisting framed building with brick infill walls may be estimated by the empirical expression:

$$T_a = 0.09H / D^{0.5} \qquad (2)$$

where H is height of building, D is width of building in motion direction. On the other hand, approximate fundamental period of brick masonry building may be:

$$T_a \quad 0.1\,N \qquad (3)$$

where N is number of stories. Based on Eqs. (1) and (2), approximate fundamental periods of Building A might be 0.23 and 0.20 s in X- and Y-directions, respectively, and those of Building B be about 0.2-0.3 s. Figure 5 shows the relations between observed and approximately computed fundamental periods of the buildings. In Building A, the observed and computed fundamental periods show fairly good agreements, because damage to the building was insignificant. In Building B, on the other hand, the observed fundamental periods are larger than computed ones, especially, by a factor of 1.5 in Y-component, i.e., transverse direction. Assuming that the effects of soil-structure interaction on the observed microtremor motions are insignificant, it is indicated that fundamental period in transverse direction of Building B could change 1.5 times as that before the earthquake because of structural damage. Thus, it is also suggested that maximum response ductility of two-storied masonry building might be about/over 2 during the 2001 Gujarat-India earthquake.

Photo 2. Damaged buildings at which microtremor measurements were performed.

Photo 3. Damage to the buildings (from outside).


Photos 4 and 5. Damage to the buildings (inside of Building A).

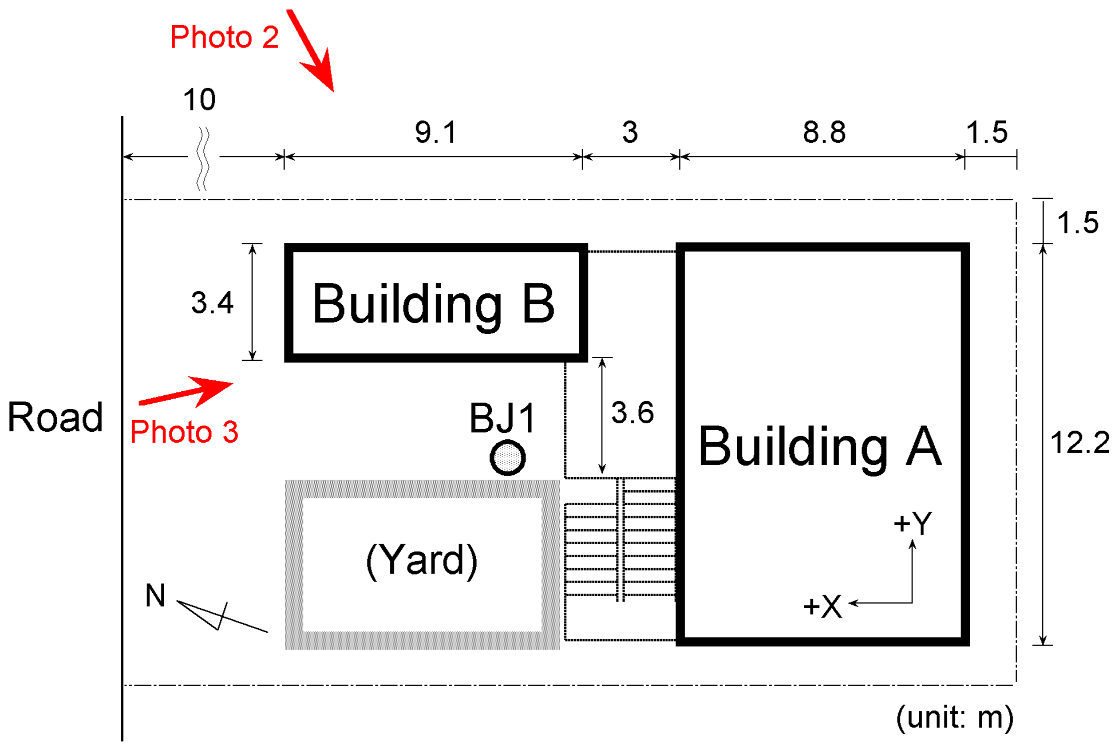

Figure 3. Schematic map showing locations of Buildings A and B.

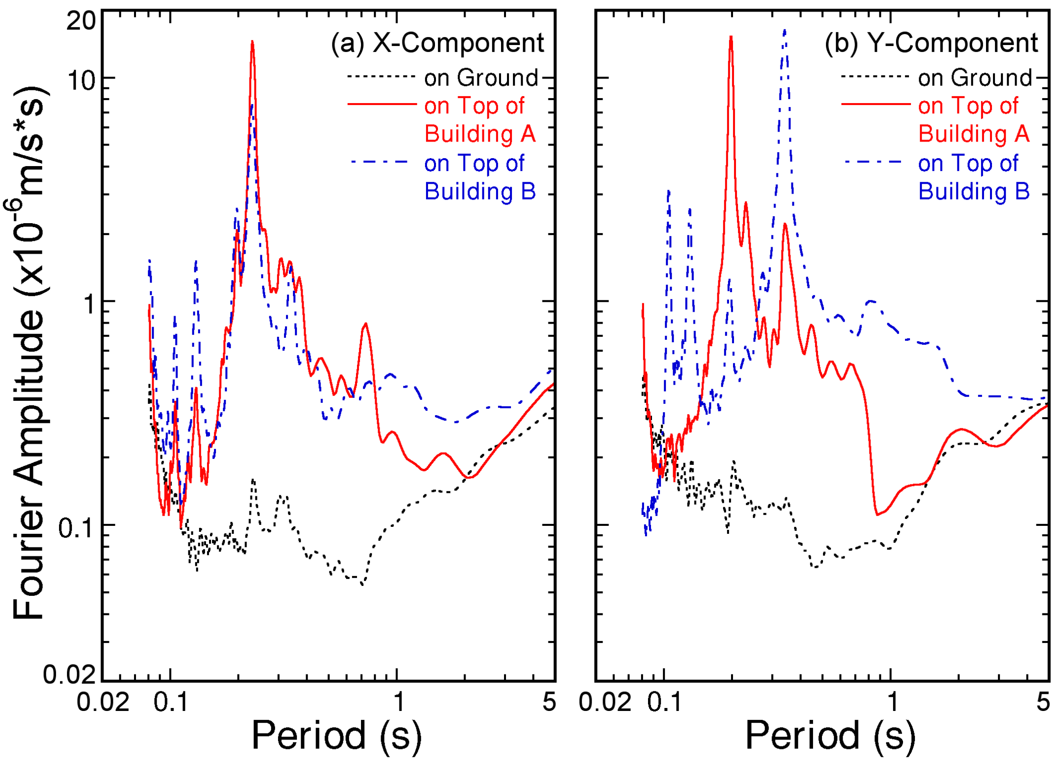

Figure 4. Fourier amplitude spectra of horizontal X- and Y-component microtremor motions at the top and ground floors of Buildings A and B.

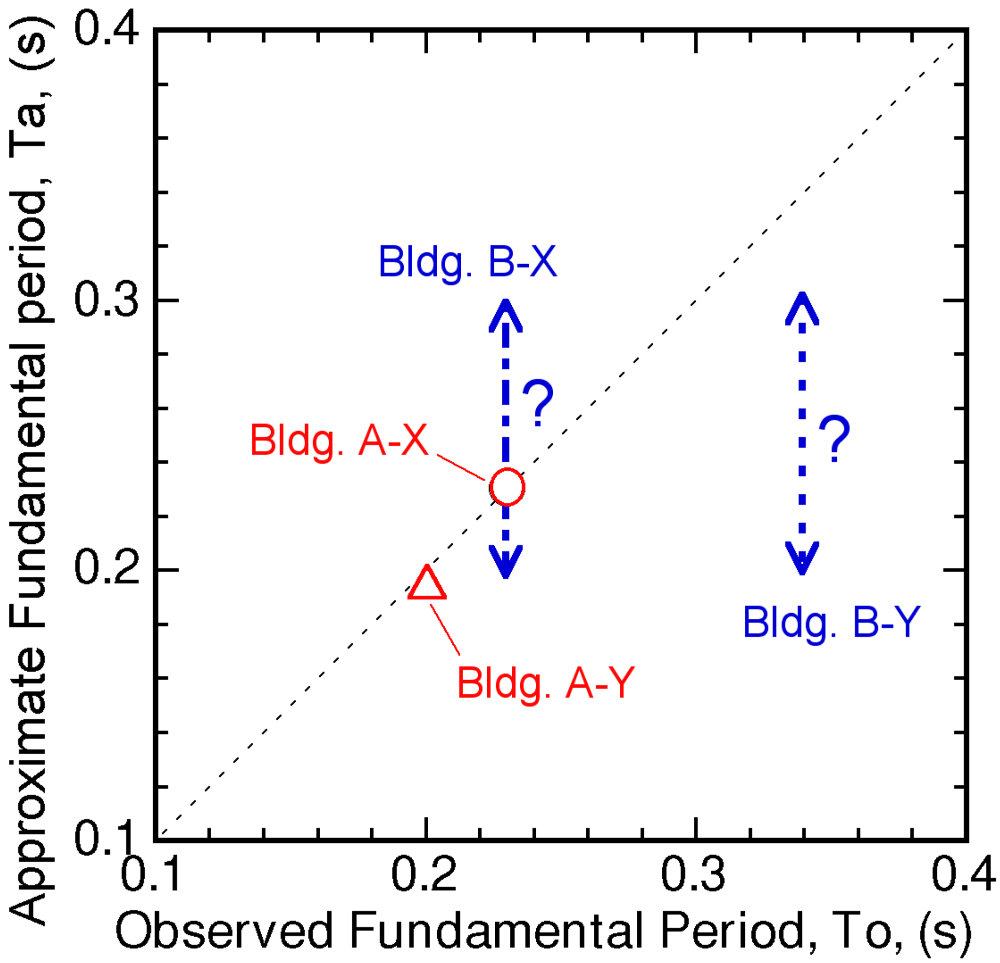

Figure 5. Comparison between observed and approximately computed fundamental periods of Buildings A and B.