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STUDY OF SITE EFFECTS IN KOBE AREA USING MICROTREMORS

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ABSTRACT

During the Hyogoken-nanbu Earthquake of Jan. 17, 1995, the damage distribution that occurred in Kobe city was not uniform, indicating the existence of strong site effect. In this study an attempt was made to examine the effect of site condition on damage distribution in Kobe city area during this earthquake, by using measured microtremors. Measurement of microtremors was done between March 4 and 6, 1995. Both continuous and mobile measurements were made. The result of the continuous measurements showed some hourly variations, but the variations were within acceptable limits. The result of the mobile measurements showed site dependent variations. Stiff soil sites showed lower values of amplitude both in time history and spectral amplitude, while soft and deep soil formations showed higher values . The predominant periods also varied in relation to the soil formation in some of the cases. Damage distribution of building structures showed good relation with the characteristics of measured microtremors. The results indicated that carefully measured and properly interpreted microtremors could be used for site effect study in Kobe area.

KEYWORDS

Microtremors, Site effect, Kobe, Hyogoken-nanbu earthquake, soil formation, predominant period

INTRODUCTION

During the Hyogoken-nanbu Earthquake of Jan. 17, 1995, the number of recorded strong ground motion were not suitable enough for site effect study. In such cases the use of other methods(aftershock and microtremor measurements or analytical methods) is very essential to understand the site response during the strong ground shaking. After the pioneering works of Kanai and Tanaka in 1954 , 1961 and 1968, a lot of effort has been made to apply microtremors for site effect study. The use of measured microtremors for the study of site effects is based on the principle that, microtremors propagate in the ground and they are amplified at periods which are synchronous with the predominant period of the site due to features of selective resonance. The background for the use of microtremors for site effect study could be stated in a general way as follows: period distribution and spectral shapes of microtremors follow definite pattern for a particular site and resemble the strong ground motion at that given site. But the above conclusion has the following significant limitations: 1) Microtremors operate at a very low strain level when compared with strong ground motion which results in higher strain levels inducing non-linearity. 2) The effect of source on microtremors is significant. Short period microtremors less than 1s in period are substantially affected by direct source like traffic noise, while longer period microtremors are affected by environmental conditions like atmospheric pressure and sea waves. Removing the effect of these sources, specially those of short periods, is difficult 3) Microtremors are more difficult to apply when the subsurface formation is complicated. Irrespective of these short comings, microtremors showed site dependent variations when measured and interpreted carefully. Besides microtremors have an advantage over other methods used for site effect study because of simplicity, ease of use, low cost and shorter time required for observation and data analysis.

In this study, microtremor measurement was made in Kobe city between March 4 and 6, 1995.. In this measurement, two sets of continuous measurements were made every hour at two sites (CONT.1 and CONT.2) (Fig.1). (*Here after all location references to measurement points:CONT., J.,Q.,R.,S are as in Fig.1)* The purpose of the continuous measurements was to confirm if the stability of microtremors is consistent at different soil formations in the area. Besides the continuous measurements, four sets of line arrays of mobile measurements were made. Three of the arrays (J1-J5, Q1-Q10, R1-R10) run from foot of the Rokko mountain to reclaimed land area at different locations, while the fourth (S1-S10) runs perpendicular to R-arrays, an area which was heavily damaged by the Hyogoken-Nambu Earthquake.

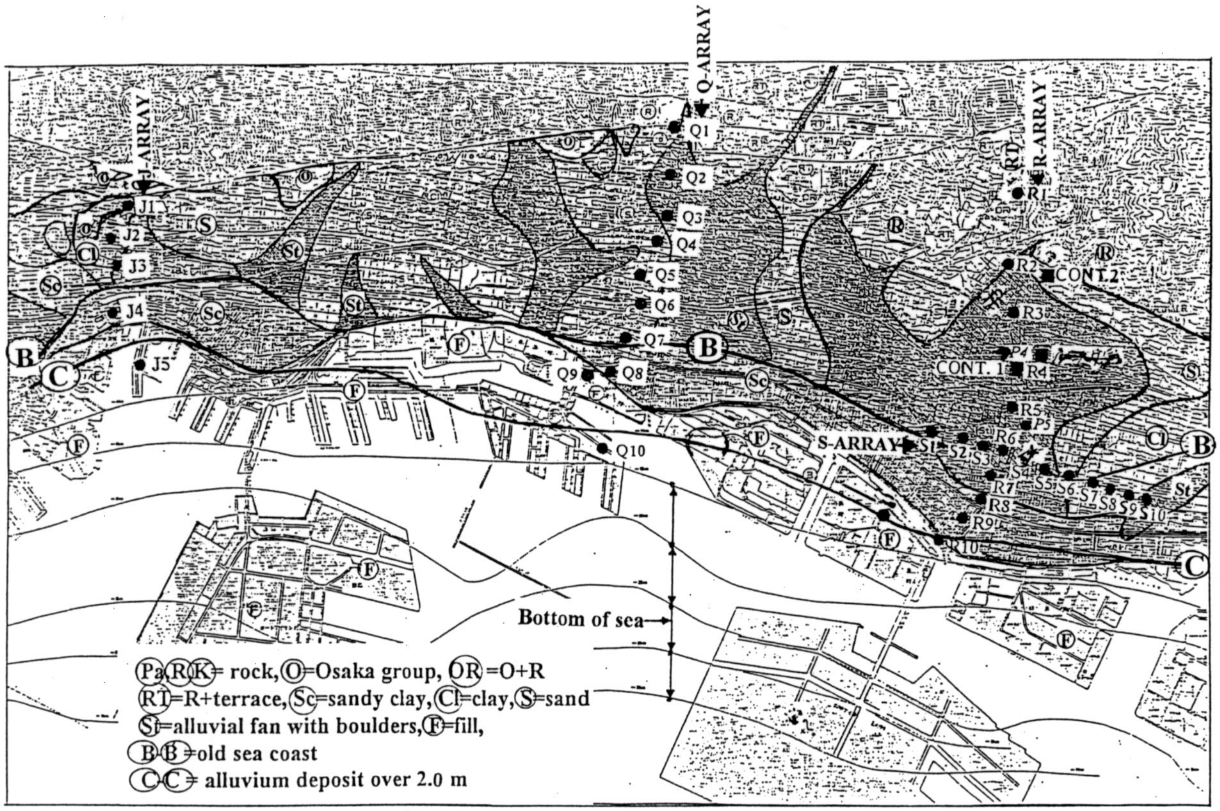
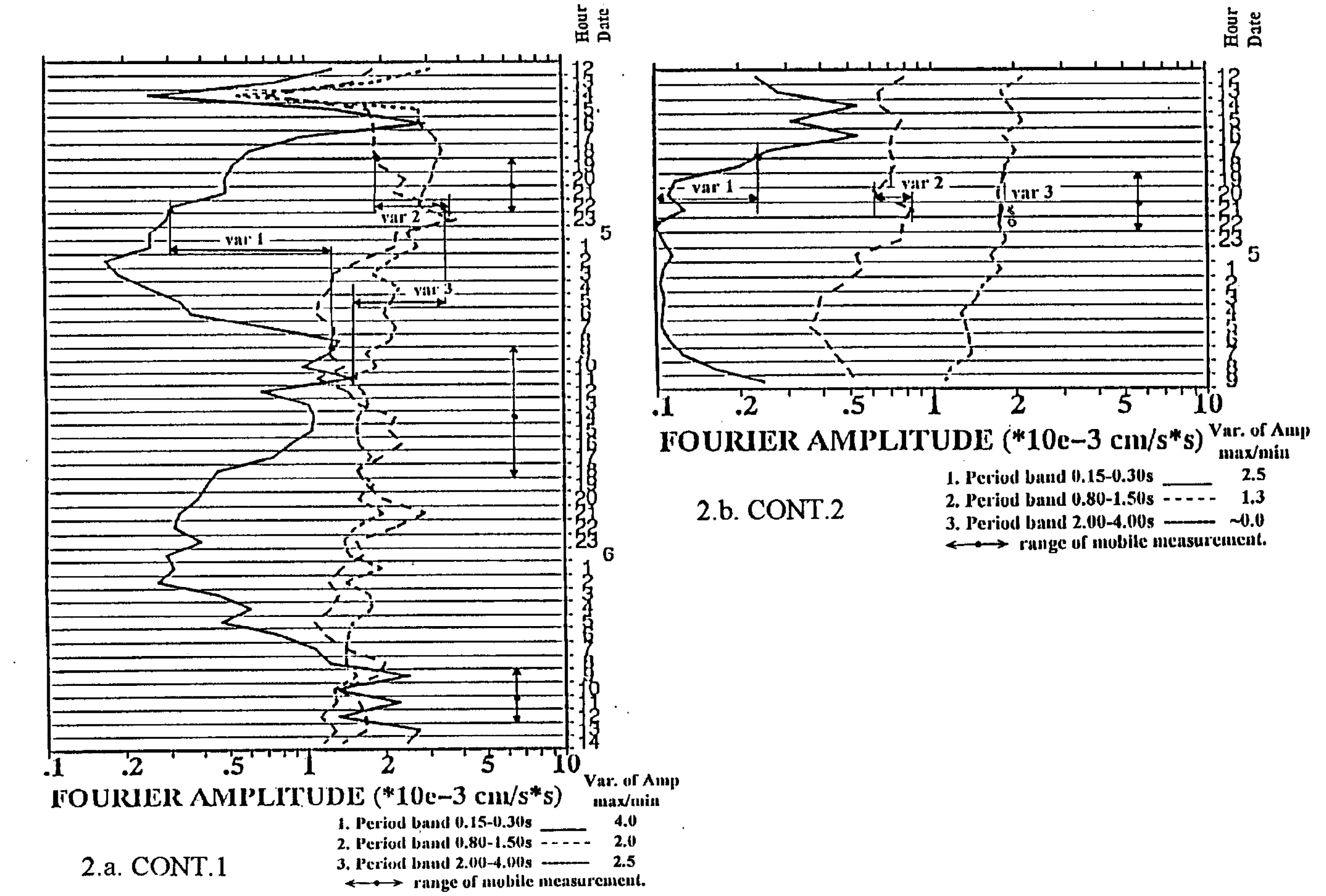


Fig.1 Location of microtremor measurement points in Kobe area. Points plotted on surface geology map.(adapted from Taisei, 1995)

During the measurement, highly sensitive seismometers, with three orthogonal components each, were used.. The natural period of the instruments used was 5 sec. They were intended to study including relatively deeper soil formations extending below hundreds of meters. The displacement amplitude of microtremors was measured. Each data at a point has a displacement time history of 300 s long. Fourier analysis was made by dividing each record into seven segments and taking the mean values. A segment with big direct noise from close source, like near by passing vehicles, was cut out and the stable part of the time history was used in further analysis. Smoothening was done by using Parzen window of 0.3 Hz wide. A two dimensional horizontal component (H2D) was computed by taking geometric averages with NS and EW components.

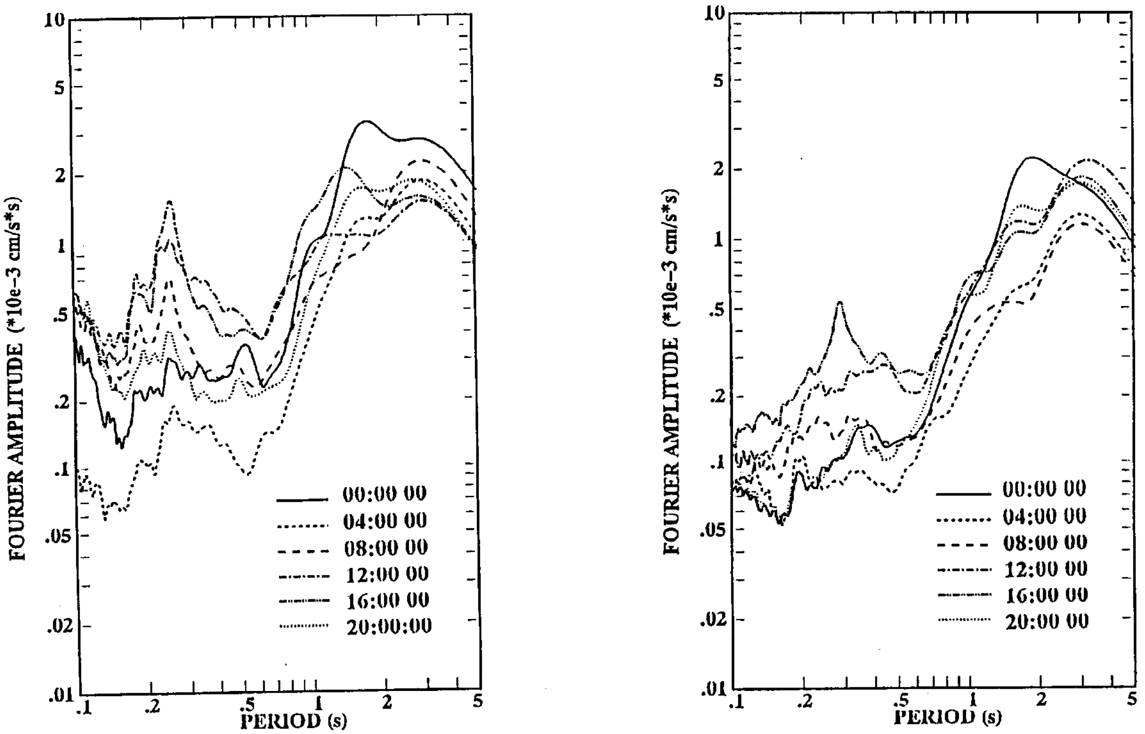
Two stationary continuous measurements were made every hour. The measurement at CONT.1 was made from March 4 , 12:00 to March 6, 14:00; on a diluvial soil formation overlain by a thin alluvial fun. The measurement at CONT.2 was made from March 4, 12:00 to March 5, 9:00, on a rock site overlain by slightly weathered rock. Within the range of hours corresponding to the mobile measurements (09:00- 21:00), (Fig. 2.a), the stationary continuous measurement at CONT.1 shows an amplitude variation up to 4 times in a limited band width within the short periods, reduces to 2 times at longer periods. Similarly the stationary continuous measurement at CONT.2 shows an amplitude variation of less than 3 times at shorter periods and reduces to about 1.3 times above 1s (Fig. 2.b). In both cases, the variations in shorter period range confirm well with the change in human cultural activity showing the minimum amplitude at early morning, increasing through morning and day time and falling in the evening. The variations in predominant period (Figs. 3a and b) were found to be stable.



2.a. CONT.1

2.b. CONT.2

Fig.2 Hourly variations of microtremor amplitudes plotted for every hour, for 3 selected period bands
The actual duration of measurements are shown by arrow ranges.



3.a CONT.1

3.b CONT.2

Fig. 3 The velocity Fourier amplitude spectra of hourly variations for continuous measurements.

The Fourier amplitude spectra for the mobile measurements are plotted (Figs.4a-d) for arrays J,Q,R and S respectively. To make the tracing of curves easier, every other data point is plotted, except for beginning and end point of arrays which are distinct rock and artificial fill sites. The daily variations were smaller than the variation between the different sites shown in Fig. 2. The variation of amplitude for short period (0.2s-0.5s) and long period above 1s receptively are about 4 and 3 times for J-array (Fig.4.a), 4 and 10 for Q-array (Fig.4.b), 80 and 10 for R-array (Fig.4.c), 5 and 1.5 for S-array (Fig.4.d) , respectively.

DISCUSSION OF RESULTS

1. The observation that the variations in amplitude between the different sites is much more than the hourly variations justifies the use of relative amplitude in comparing the different sites. The predominant periods were stable in all hours, hence microtremors in the area were considered stable for site effect studies.

2. All the arrays running from north to south (J, Q and R) showed relative amplification from north to south. This amplification is consistent with the soil formation, which starts on rock site at North, changes to diluvium, then to alluvium and artificial fill around the coast. The increase in amplification within the same type of formation, was understood as variation due to increase in thickness of sediment from the north to the south.

3. The S array showed de-amplification in the short period range as we move away from the Sumiyoshi river. This could be due to softer and younger deposits around the river at shallow depth. The small variation within S array in the long period could be an indication of a uniform structure along the array at deeper formations below the alluvium.

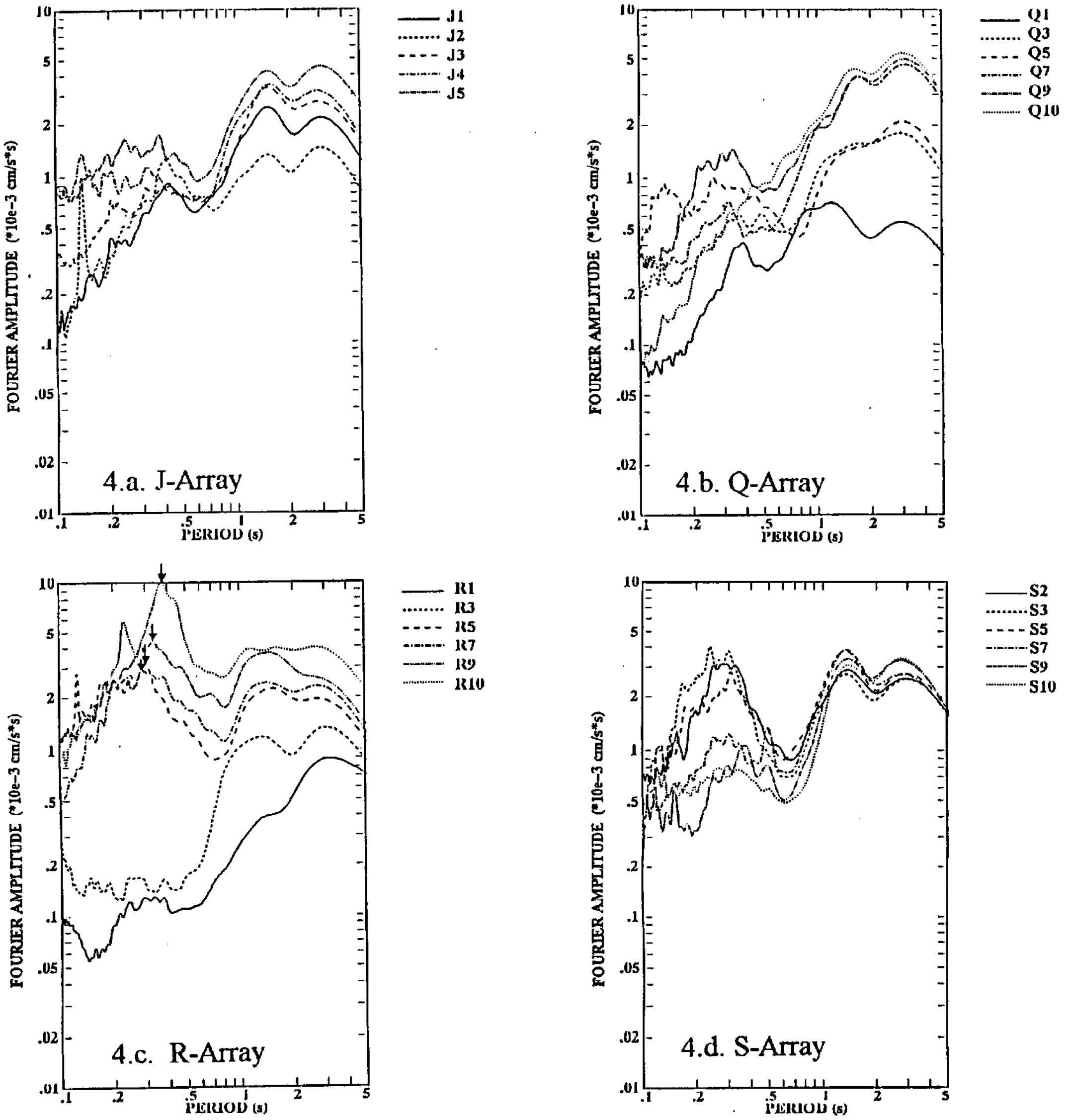
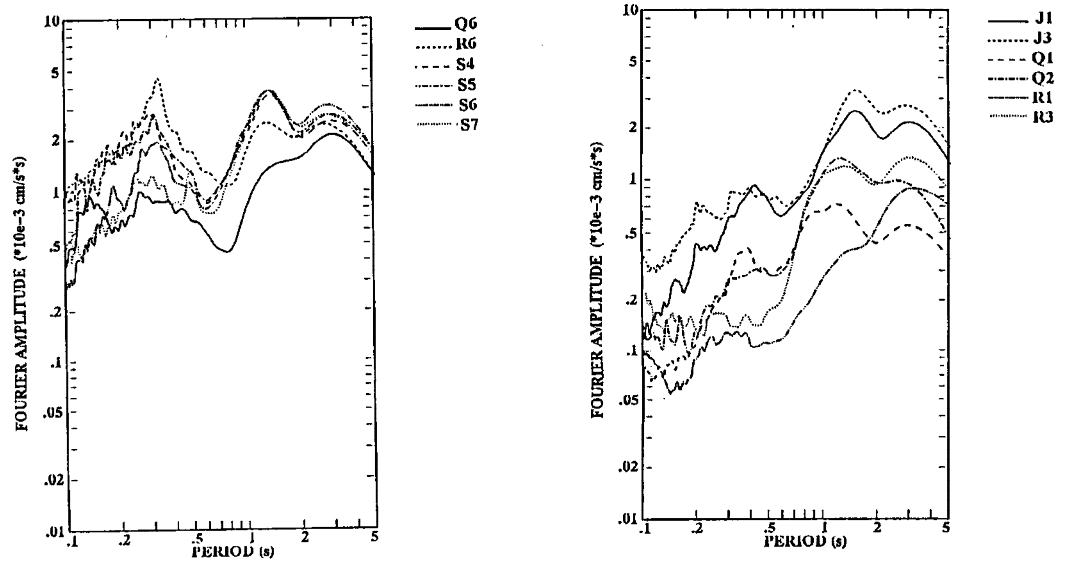


Fig. 4 The velocity Fourier amplitude spectra for mobile measurements.



5.a Heavily damaged area

5.b. Non damaged area

Fig. 5 The velocity Fourier amplitude spectra for mobile measurement plotted by arranging points based on damage distribution

4. Except for R array, in the short period range, the shift in predominant period is not so systematic and consistent as the variation in amplitude. This could be due to the alluvial fun and delta deposits, shown on the surface geology map in Fig. 1, which are understood to be very shallow and irregular, (AIJ, 1995). They are expected to influence the short period microtremors corresponding to their respective depth at each site. Generally microtremors are very sensitive even to small variations. In the longer period range, predominant periods appear almost at the same period irrespective of site, even if variation in amplitude is observed. As previous studies indicate, variations of predominant period in the longer period ranges appear more clearly when the contrast between deposit and underlying formation is significant. (Kobayashi *et al.*, 1986a and b). When such contrast does not exist, difference could be observed only in amplitude (Kagami *et al.* , 1982 and 1986). The result in Kobe resembles the later case.

5. The three arrays J, Q, R running parallel from the foot of Rokko mountain to the sea show marked difference when compared with each other. Considering the maximum value in spectral amplitude , the smallest value is for J-array, increases at Q-array and further increases at R-array. As could be seen from Figs. 16,17 and 18. Within J-array the maximum variation is about 4 and 3 times for short and long periods respectively, while is about 4 and 10 times for Q-array and is about 80 and 10 times for R-array. This confirms well with damage pattern in the respective areas. Around J-array, the damage is slight and the array is out of so-called intensity 7 anomaly in the area (AIJ, 1995).

6. Microtremor measurement and damage distribution showed good agreement. Microtremors in the highly damaged area, for low rise buildings which include wooden houses showed clear amplification around 0.3s (Fig.5.a). Other sites with no or little damage for such structures showed little amplification at shorter period (Fig.5.b). Though this short period is expected to shift towards longer periods during strong ground motion due to non-linear effect, it is assumed to coincide or be close with the natural period of the low rise buildings, which is also shifted due to non linearity during strong ground motions. Such coincidence of periods might have contributed significantly to damage.

CONCLUSIONS

1. The measured microtremers in Kobe area showed site dependent variation in time history and spectral amplitude . Stiff soil sites showed minimum values, while soft soil formations showed the maximum value. Within the same formation , amplification was observed as we move towards thicker soil deposits.

2. The predominant periods in most cases did not show very systematic variation.

3. The damage distribution in the area showed good agreement with the characteristics of measured microtremors.

4. During this measurement, observation of tidal waves or atmospheric condition was not done. Consideration was not made for attenuation due to distance from the sea. Irrespective of the above short comings, the measured microtremors showed good agreement with variation in ground formation and damage distribution.

5. A detailed and comprehensive survey with microtremor measurements in Kobe area could be one of the useful methods for seismic microzonation and disaster mitigation.

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