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Local site effects detected by microtremor measurements on the damage due to the 1990 Philippine earthquake

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ABSTRACT: The 1990 Philippine earthquake caused damage to several cities such as Baguio, Dagupan, Agoo and Manila. The cause and effect of the earthquake damage was investigated by microtremor measurements, with a result indicating the local site effects on the damage features in each city. In Baguio City, for example, amplification of ground motion was not susceptible on the hilltops or sloping ground surfaces, but many multistory reinforced concrete buildings were likely to display resonant response to the ground motion.

1 INTRODUCTION

On July 16, 1990, an earthquake of magnitude 7.8 occured under the Luzon Island, Republic of the Philippines, killing over 1600 people. Many commercial buildings, roads, bridges, natural slopes were also sustained extensive damage by the earthquake and its aftershcks. The serious damage was mainly focused on several cities such as Baguio and Dagupan, and its major cause was found to be associated with strong ground motion, liquefaction and structural defects. Fig. 1 shows a location map of the area concerned.

With respect to the strong ground motion, since no strong motion records were available for the main event, ground motion intensity was only assessed from either general damage features or empirical attenuation equations obtained from previous case studies in other areas. Intensity VIII on the modified Rossi-Forel scale was assessed in an epicentral and seriously damaged areas. In such an assessment, much emphasis is inevitably placed on damage features which are closely related to both ground motion intensity and structural defects (or strength). From an engineering point of view, these two elements for the earthquake damage are preferably separated from each other.

For this reason, the authors made microtremor measurements at over 100 points in and around the areas affected by the Philippine earthquake in order to detect vibration characteristics of the ground (Nakamura 1989), as in the case of the 1989 Loma Prieta earthquake (Ohmachi, et al, 1991a). Though the areas include Ambuklao Dam, damage features and vibration characteristics in the above-mentioned four cities only are described here, because those of the dam have been described elsewhere (Ohmachi et al, 1991b).

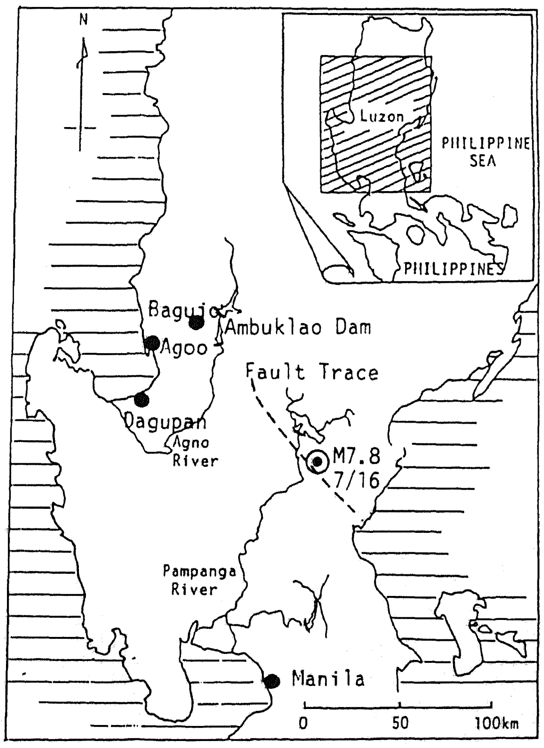

Fig. 1 Location map
A double circle indicates the epicenter of the 1990 Philippine earthquake, and closed circles indicate the cities where microtremor measurements were conducted. The measurement was also conducted at Ambuklao Dam which is shown above (Ohmachi et al, 1991b)

2 MICROTREMOR MEASUREMENTS AND ANALYSIS

An instrument named PIC87 developed by Railway Technical Research Institute was used. It consists of two sensor units, cables and a main body built in an alminium case which contains amplifiers, an A/D converter and a microcomputer. Dimensions and functions of the instruments are shown elsewhere (Ohmachi et al, 1991a, 1991b).

At each observation point, three components (two horizontal and one vertical) of microtremor were recorded at every 1/100sec for 40.96sec. The measurement was repeated three times at a point to secure the higher quality of recordings. For spectral analyses, three sets of 10.24sec long simultaneous recordings were selected from the three sets of the 40.96sec long recordings. Fourier spectra were calculated for the selected recordings and then smoothed five times by usig the Hanning spectral window. Finally, a frequency spectrum of one component of the microtremor was estimated by averaging the relevent three Fourier spectra.

The frequency spectra resulting from the above procedure are likely not only to reflect vibration characteristics of the ground itself, but those of particular driving sources such as running machinery and moving vehicles if any. To remove effects of the latter, an additional procedure was applied to the estimated frequency spectra. It calculates a spectral ratio between horizontal and vertical components. The spectral ratio provides a handy measure to estimate ground motion characteristics, and is temporarily called a spectral amplification factor of the ground.

3 BAGUIO CITY

3.1 Location and earthquake damage

Baguio is a summer capital located on highlands at about 1500 m above sea level, and has many ups-and-downs throughout the city. Two out of three major access-roads to Baguio were closed after the earthquake due to severe damage and imminent instability of road side slopes. Baguio Airport was also closed to the public because of damage to its runway, apron and terminal buildings. Photo 1 shows a measuring situation at the back of Hyatt Hotel, Baguio. From an attenuation equation, a peak acceleration of the main shock was estimated to be about 85 cm/s/s at a rock foundation in Baguio.

Many multistory reinforced concrete buildings collapsed or suffered serious damage, killing more than 600 people. Allegedly the damaged buildings had such structural deficiencies as insufficient reinforcement in columns, and weak connection between beams and columns. Besides, topographical effect on the ground motion was another candidate for the serious damage in Baguio, because most of severely damaged RC-buildings were, roughly speaking, located on either hilltops or steep slopes.

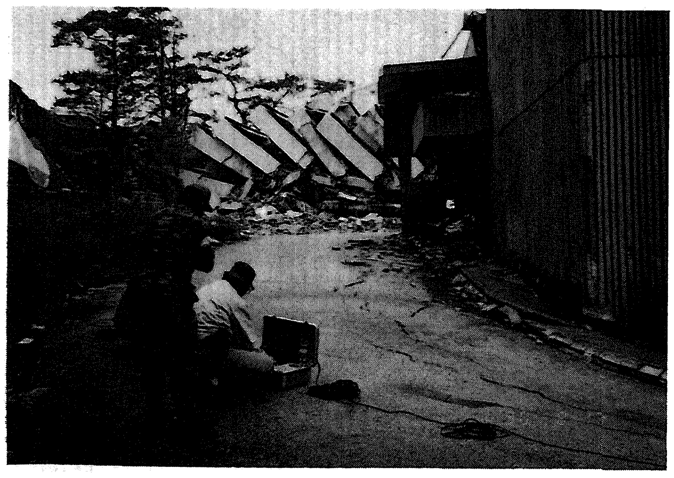

Photo 1 Measurement at Hyatt Hotel, Baguio

3.2 Ground motion characteristics

Special emphasis of the microtremor measurement in Baguio was placed on detecting topographical effects on ground motion characteristics if any. Thus, difference in an elevation at each observation point was measured by using an atmospheric pressure meter. Fig.2 shows a bird's-eye view of a northeastern part of the city, together with some severely damaged buildings and the observation points. In Fig. 2, the numbers before and after a slash indicate the respective numbers of story of a building above and below the cliff where the building was standing. The double figures in a parenthesis indicate an approximate elevation at the point when they are added to 1400m.

Fig. 3 exemplifies the spectral ratios between the horizontal and vertical components at the points BGO, 1, 2, 6, 7 and 18. From Fig.3 the peak frequencies and the ratios were read with a result shown in Fig. 4, in which difference in elevation of the points are plotted by open squares. In Fig. 4, the amplification factor estimated from the spectral ratio does not necessarily increase either on the hilltops or near the collaplsed buildings. Meanwhile, the peak frequency tends to decrease as the elevation increases. When a peak acceleration of 85 cm/s/s at a rock foundation is multiplied by the amplification factor which ranges from 3 to 7, a peak ground acceleration in this area was estimated to be 250 to 600 cm/s/s.

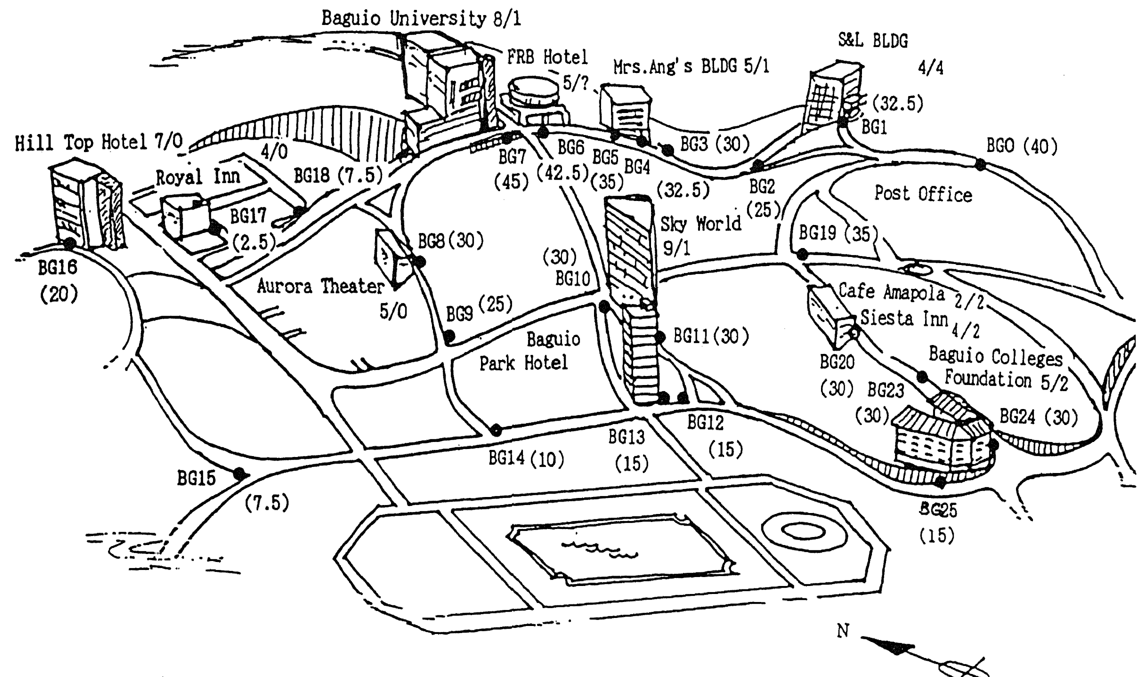

Fig. 2 Bird's eye view of a part of Baguio City including seriously damaged buildings and observation points

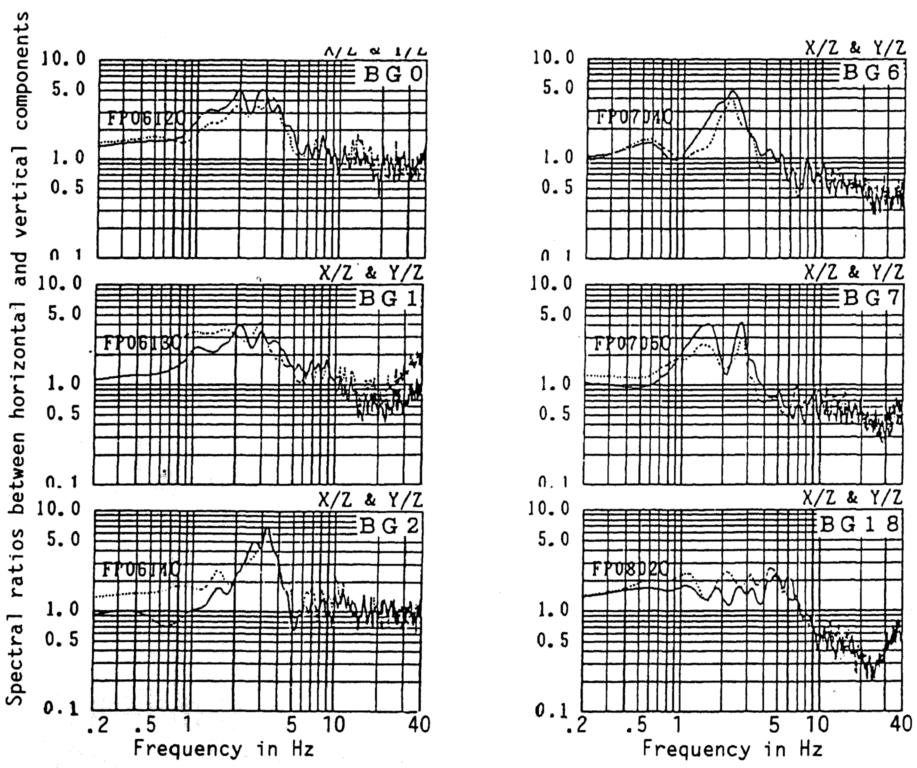

Fig. 3 Spectral ratios between horizontal and vertical components

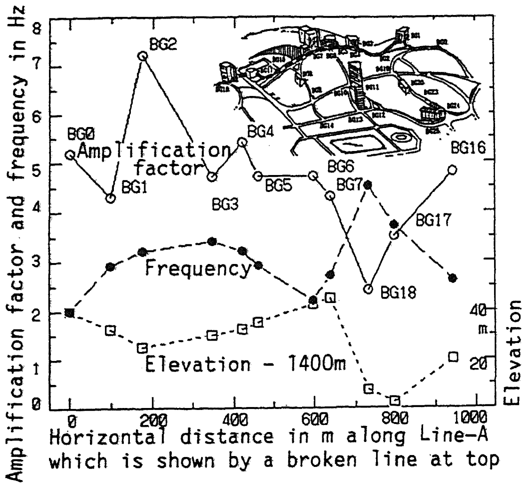

Fig. 4 Amplification factors, predominant frequencies and elevation along Line-A

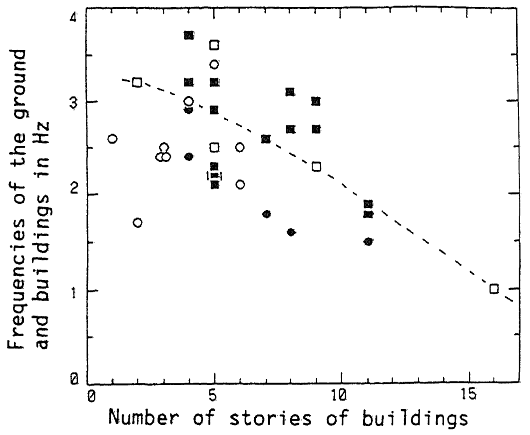

Fig. 5 Natural frequency of buildings (□), and of the ground close to undamaged, damaged and collapsed buildings (○, ●, ■)

In Fig. 5, open marks show the peak frequencies of the ground, and closed marks show natural frequencies of hardly damaged buildings that were observed in Minila, Dagupan and Baguio. This figure suggests that the frequency of the ground in the area ranging from 2Hz to 3Hz is roughly coincident with the frequency of the damaged buildings with 4 to 9 stories. In other words, it seems highly probable that the earthquake motion was remarkably amplified both by the subsurface ground and the buildings. Even if the amplification factor of the ground at the severely damaged buildings are estimated to be 4 or so, most of the buildings were located on steep slopes. It means that building structures located on the steep slopes may be particularly affected by special behavior of the steep slopes during earthquakes. More detailed results from the observation in Baguio can be found elsewhere (Ohmachi et al, 1991b).

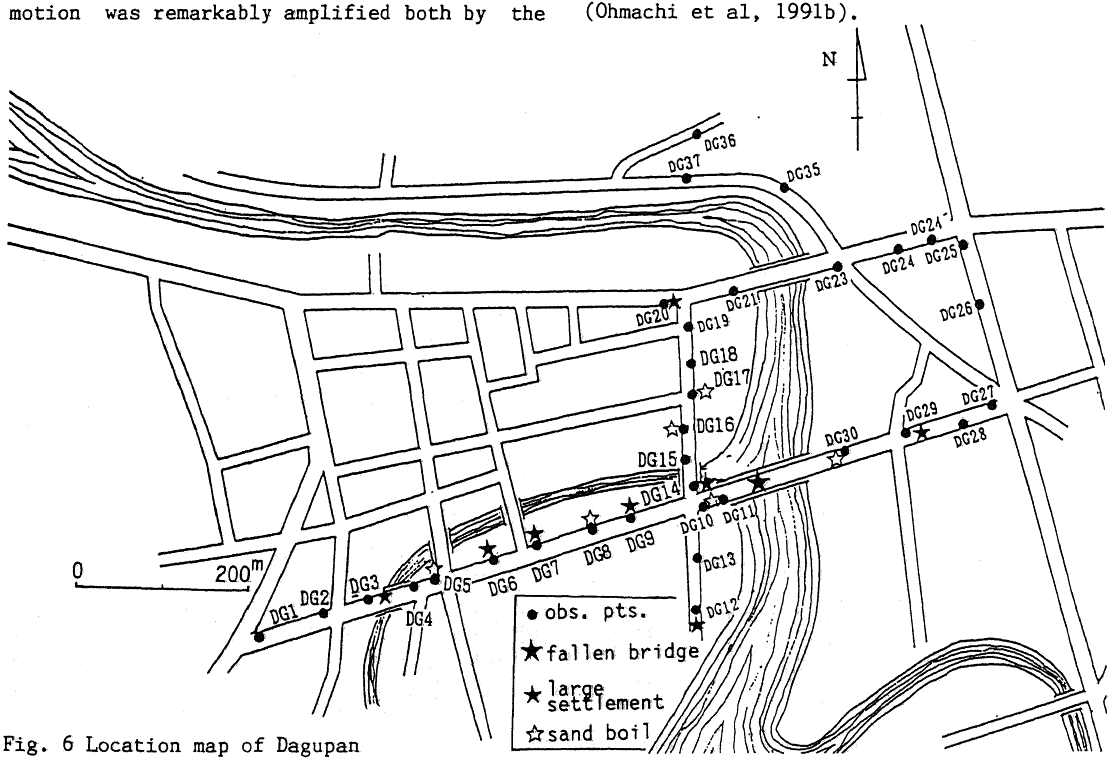

Fig. 6 Location map of Dagupan

4 DAGUPAN CITY

4.1 Outline of damage

Almost all the earthquake damage in Dagupan which was about 80 km distant from the epicenter, was mainly attributed to liquefaction of the ground. The liquefaction caused collapse of a seven-span RC-bridge named Magsaisai Bridge, and destroyed some 200 buildings beyond repair due to their foundation failure. In addition, the Pantal river was narrowed by the liquefaction-induced lateral spreading on both sides of the river. In comparison with the extensive damage to structures, loss of human lives was not so large in number; say, 13 persons in Dagupan, which contrasts well with much more fatalities in Baguio.

4.2 Ground motion characteristics

Fig. 6 shows a location map of the observation points in Dagupan. In the fugure, DG9, DG11 and DG25 are located at the nearest the places where we observed a most tilted building, the fallen Magsaisai Bridge and no damage, respectively. The peak frequencies and spectral amplification factors are shown in Fig. 7, from which most frequencies and factors are found to be 1 to 1.5Hz and 1 to 3, respectively. These suggest that the surface ground motion was little amplified, and that earthquake response of most buildings were not in resonance with the ground motion, which looks consistant with the general aspects of the earthquake damage in Dagupan.

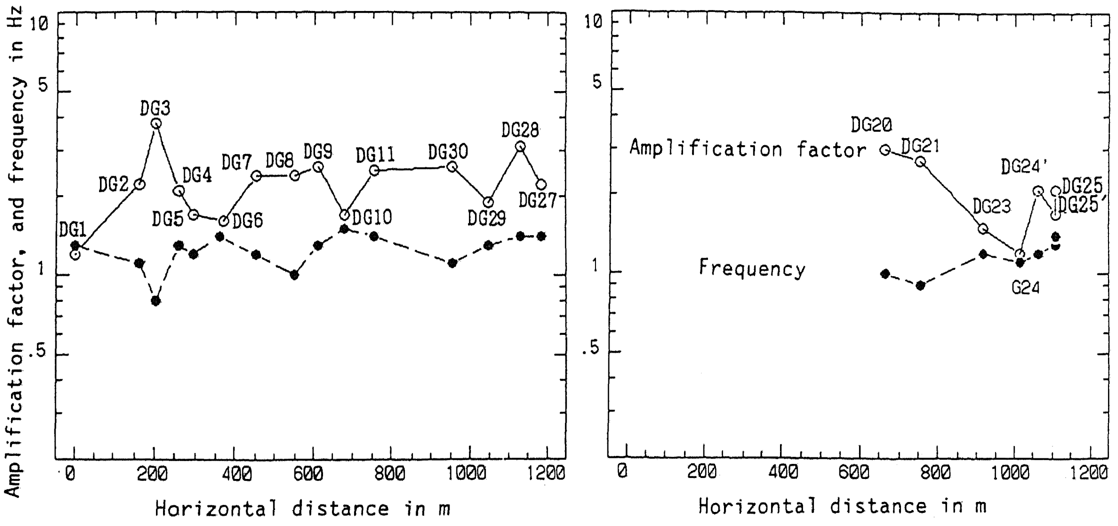

Fig. 7 Results of the measurement in Dagupan

5. AGOO AND MANILA CITIES

5.1 Agoo city

Majority of the earthquake damage in Agoo was collapse of low-rise buildings and RC-fences. Ground failure such as liquefaction was hardly found with an exception of minor cracks on road pavement. The damage seemed to be caused by strong ground shaking.

The measurement was conducted at 18 points along the main street running in parallel with the coast line, and along other two roads (Line-B and -C) crossing the main street. Fig. 8 shows results of the measurement along the two lines. The severity of the damage does not correspond well to the large amplification factor, but severe damage was limited in the area with the predominant frequency of 1 to 2 Hz.

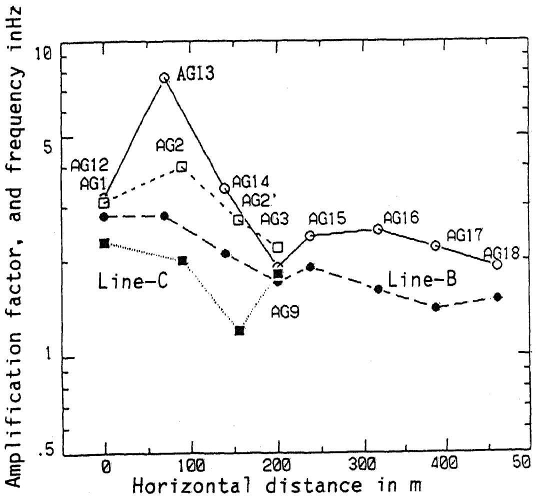

Fig. 8 Results of measurement in Agoo

5.2 Manila city

Although Manila was about 120 km distant from the epicenter, some people in buildings were reportedly so frightend that they felt somewhat fainted by the earthquake. Some 15 RC-buildings were damaged to a considerable extent. The microtremor was observed both on the filled land and in the old town that locate at the corner surrounded by the Pasig river and the Manila south harbor. Due to limitation of space, results are summarized in Fig. 9, suggesting that the amplification factor is larger or equal to 5 at the points where damaged buildings were observed.

6. SUMMARY AND CONCLUSION

Results of our postearthquake investigation in the areas affected by the 1990 Philippine earthquake is summerized as in Fig. 9, from which and those stated above we can draw conclusive remarks as follows:

1. In Baguio, the predominant frequency and the amplification factor of the ground ranged over 2 to 4 Hz and 3 to 7, respectively. Meanwhile, most of severely damaged buildings had 4 to 9 stories with their fundamental frequencies at around the similar frequency range. Thus, response of those buildings might be in resonance with the ground motion during the earthquake.
2. The ground motion was not always amplified considerably on the hilltops or sloping surfaces, but steep slopes probably affected structural stability during the earthquake.
3. In Dagupan, the frequency component of 1.0 to 1.5Hz predominated in the ground motion, but its amplification factor was 3 at most. The low values in both frequency and amplification factor seemed consistent with the earthquake damage which was largely attributed to liquefaction.
4. In Agoo, the predominant frequency ranged over 2 to 4 Hz, and the amplification factor was 2 to 4. These also seemed to be consitent with the earthquake damage which was largely attributied to extensive responses of structures, which contrasted well with that in Dagupan.
5. In Manila, the low frequency component of around 1 Hz with the amplification factor as high as 3 to 8 predominated in the ground motion of the so-called water-front area where the earthquake damage was rather serious.
6. With the above amplification factors, the peak acceleration on the ground surface was estimated for each city, as follows:

Baguio	250-550Gal	(2-4Hz)
Dagupan	100-250Gal	(1-1.5Hz)
Agoo	150-300Gal	(1-3Hz)
Manila(water-front)	150-400Gal	(around 1Hz)

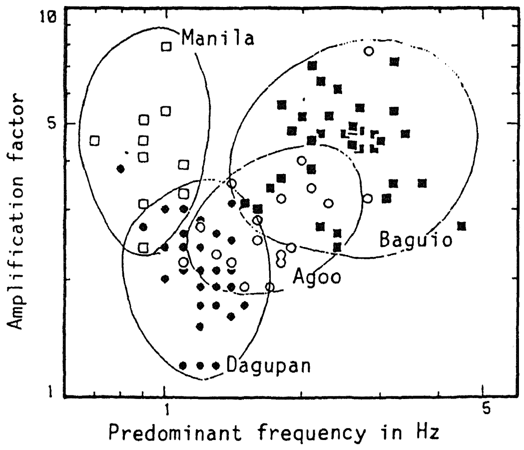

Fig. 9 Ground motion characteristics in four cities affected by the 1990 Philippine earthquake

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REFERENCES

Nakamura, Y. 1989. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface, QR of RTRI, vol. 30, No.1, pp25-33.

Ohmachi, T., Nakamura, Y., & Toshinawa, T. 1991a. Ground motion characteristics of the San Francisco Bay Area detected by microtremor measurements, Proc. 2nd Int. Conf. on Recent Advances in Geotech. Earthq. Eng. and Soil Dynamics, Paper No. LP08, 1991, pp.1643-1648.

Ohmachi, T., Nakamura, Y. & Nakamura, S. 1991b. Ground motion characteristics with reference to damage by the Philippine earthquake of July 16, 1990, Proc. 1st Int. Conf. Seism. Earthq. Eng., pp.347-356.