Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Microtremor measurements in the disastrous areas by the 1990 Philippine earthquake

Masashi Hayashi
Shibaura Institute of Technology, Tokyo, Japan

Takao Nishikawa
Tokyo Metropolitan University, Japan

Kyouhei Saimi
Nikken Sekkei Corporation, Tokyo, Japan

Yasumasa Miyauchi
Takenaka Corporation, Tokyo, Japan

Kazuyuki Kasai
Toyo Construction Corporation, Tokyo, Japan

ABSTRACT: As members of the damage investigation team of Architectural Institute of Japan, we surveyed structural damage to buildings suffered from the Philippine Earthquake of 16 July 1990 at several disastrous areas in the northern Luzon Island: Baguio, Agoo, and others, from 20th to 30th of September 1990.

In order to know the dynamic characteristics of the buildings suffered damage and of the ground, and to know what cause the damage, we made microtremor measurements on the buildings with different levels of damage as well as on their ground, in parallel with detailed investigation of damage to the structures.

In this research, we report the results of the microtremor measurements. And based on the results, predominant periods of damaged structures, ground conditions and the relationships between structural damage and their characteristics are also discussed.

1 INTRODUCTION

We know that the earthquake damage to the structure is affected heavily by the ground conditions from the past experiences of disastrous earthquakes. For example, damage level of structures suffered are quite different among similar type built in the same area. It depends on many causes, there is no doubt that natural periods of structures, predominant periods of grounds and relationships between them are very important factor.

There are many ways to know the ground condition and dynamic characteristics of structures, and microtremor measurements is one of the most economical and simple methods for this purpose.

To pursuit the causes of structural damage by this earthquake, microtremor measurements were made on and around the buildings suffered from the earthquake, parallel with examination of damage in detail.

2 MEASURING AND PROCESSING

Two moving-coil type portable velocity sensors, with natural period of 1 sec. were used. Displacement wave forms were obtained by using integrating amplifiers and recorded. It is desirable to make measurement at night to avoid undesirable noises from traffic and other man-made noises, but because of various reasons, the measurement was done during the daytime. Each measurement was done for 5 minutes or more to obtain stable wave forms. Relatively stable portions of the measured wave forms for 160 sec. long were selected and were digitized at the intervals of 0.01 sec..

The Fourier spectra for 2048 data-span were calculated from those data by shifting span for analysis for half span to get 15 spectra. And spectrum of ensemble mean was obtained from those spectra. Spectral ratio between 2 measurement sites were also calculated. Dynamic characteristics of the structures and ground conditions can be estimated from simple Fourier spectra, mean spectra, and spectral ratios.

3 MEASUREMENTS IN BAGUIO

Microtremor measurements were conducted on and around 7 structures in Baguio; Export Processing Zone Authority factories (EPZA), Baugio Country Club, Montepino Condominium, National Life Insurance Bldg. (NLI), St. Louis School Center, Two-story wooden house, and Seminario Major Recollectos. Figure 1 shows location of these buildings with other heavily damaged buildings not inspected at this time.

Baguio was located in the mountainous district and the center of the city was also hilly then almost of buildings aforementioned were on site of the slope or built

on the readjusted land: banking or cutting.
EPZA had two 3-story RC buildings with the similar plans. The south one which had been built on the banking had collapsed and fire had occured simultaneously that caused serious loss of lives. Another one on the north on the cutting natural ground was damaged heavily but was able to avoid disruption.
Microtremor measurements were made on the remaining north building, and on the ground close to both north and south buildings. When measurements were done, it was very noisy by traffic and by the machinery in this factory. Recorded wave forms of the buildings in Baguio are shown in Figure 2 and averaged spectra of these in Figure 3. Fundamental periods were read from the spectra, but they never reflected the value of uninjured condition before the earthquake. From the Spectra of 2 site of grounds, it could be guessed that south banking ground was slightly superior at about 1 sec. and 0.3 sec. comparing with north cutting ground. In Table 1, names, number of stories, and damage level of the buildings investigated in this research are mentioned. And fundamental periods of the buildings and predominant periods of the ground estimated from the results of the analyses are also inserted in this Table.

Baugio Country Club was located on the hill. A building of 7 stories collapsed, resulting of fracture of columns on the soft 3rd story portion, that story was used as restaurant and upper 4 stories were used as hotel rooms floors. The restaurant floor looked like the first level from one side but looked like the 3rd story from the opposite side. On the other hand, another building adjacent to it had little damage to the structure. It had almost the same plan with collapsed building but had 6 stories, one floor less than the other one. Measurements were made on this remaining building. It was estimated from the spectra that predominant period of the ground was about 0.5 sec. and fundamental period of this structure was 0.3 sec.. Further more, it was guessed that natural period of the disrupted building had been longer than this structure and closer to the ground's.

Montepino Condominium was heavily damaged especially columns on the first story but escaped to collapse. Measurements were done on the 2nd and the 5th floor, and on the peripheral ground. The spectra of the ground (Fig. 4) showed peaks about 0.5-0.3 sec. and that of the injured structure gave the peak value about 0.7 sec. as shown in Figure 3. It was guessed that predominant period of this structure before the earthquake had been closer to the period of the ground.

National Life Insurance Building, which was built on the edge of a precipice, had 7 stories. It was seen from facing street as a 4-story building, but was seen as a 7-story when looked up from opposite side of the building. Face bricks of walls had been fallen partially but damage of frames were not so marked by appearance except the portion of the penthouse.
Measurements were made on the rooftop made by concrete and the 2nd floor in both directions; longitudinal and transverse.
It was difficult to clarify the ground conditions because of traffic noise, but characteristics of the structure was distinct from the wave forms (Fig. 2) and the spectra (Fig. 3). Amplitude of the wave forms was very large comparing with others. Then We estimate that this structure had

Table 1. Location of microtremor measurements and their predominant periods

No.	NAME		Number of stories	Damage	PERIODS (sec.) BUILDING TRANS.	BUILDING LONG.	GROUND
a-1	EPZA (Baguio)		3	serious	0.48	0.59	0.33-0.50
a-2	Baguio Country Club		4(B2)	slight	0.33	0.33	0.50 *
a-3	Montepino Condominium		11	serious	0.77	0.67	0.43-0.52
a-4	National life Insurance Bldg.		7(B2)	serious	0.50	0.32	0.37-0.40
a-5	St. Louis School Center		3	slight	0.42	0.29, 0.33	0.40-0.50
			3	non	0.26	0.26	0.40-0.50
			3	serious	0.26	0.31	0.40-0.50
a-6	Two-storied wooden houses		2	non	0.32	0.34	---
a-7	Seminario Major Recollectos		3	slight	0.27	0.22	0.40-0.50
b-1	Don Marcos Memorial	Library	2	serious	0.40	0.42	0.27-0.30
	State Univ. (Agoo)	Main blg.	2	slight	0.21, 0.26	0.22	0.20-0.29
b-2	IRE Training Center		2	non	0.56*	---	0.36
b-3	Agoo	0M	(the foot of eastern		mountain)	---	0.38
	DONA TORIBIA	200M			---	---	0.37
	ASPIRAS ROAD	500M			---	---	0.31, 0.38
	& CASES BLVD.	800M			---	---	0.31, 0.38
		1200M	(the Crossing)		---	---	0.83
		1550M			---	---	0.36, 0.83
		2050M	(western end)			---	---
c-1	National Library (Manila)		4	slight	0.57, 0.93	0.64, 0.79	0.67

* not clear

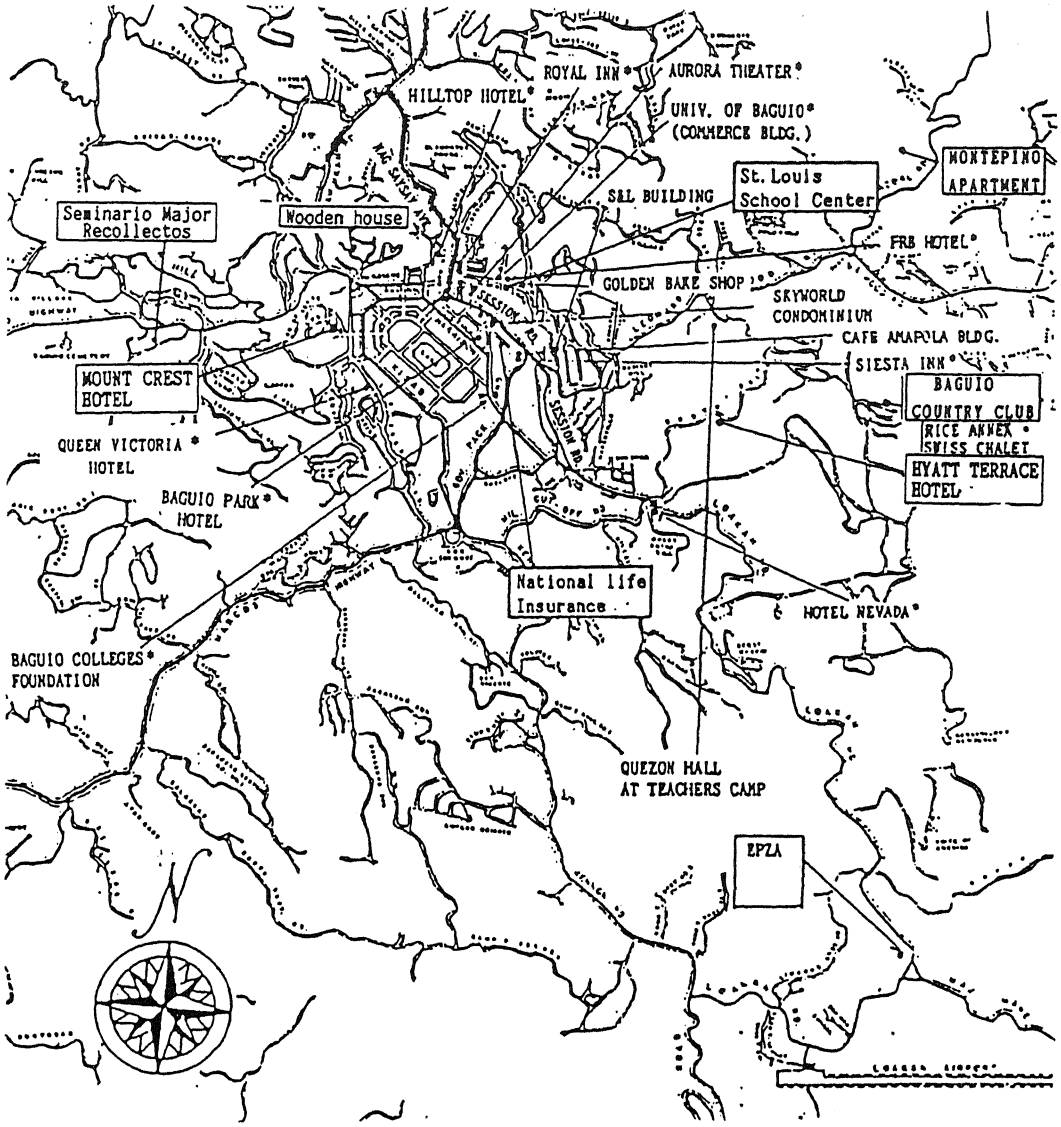

Figure 1. Location of damaged buildings & microtremor measurement sites in Baguio

soft property and had relatively long natural period. Therefore, it might be thought that there were some causes in this to avoid serious damage.

St. Louis School Center was located on the hilltop and was close to the Baguio University, which collapsed at middle stories, and close to FRB Hotel collapsed entirely. In this school, measurements were taken on the 3 school buildings. One of them closest to the destructed buildings was damaged at corner columns because of slide of banking. The other buildings were damaged lightly or little.

From the results of spectra, predominant periods of the ground in this area were about 0.4 sec. and structures measured had shorter period than the ground .

A two-story wooden house located on the relatively an easy slope at the north-west from the center of Baguio was measured to know the characteristics of wooden house and of the ground. It was consisted of the brick basement and wooden single story and was little damaged. Measurements were done on the basement floor and on the first wood floor.

The result of the measurement suggested that brick portion was stiff and wooden structure at the 2nd story was very soft inversely. It was estimated the period of the ground was not different from the other in Baguio.

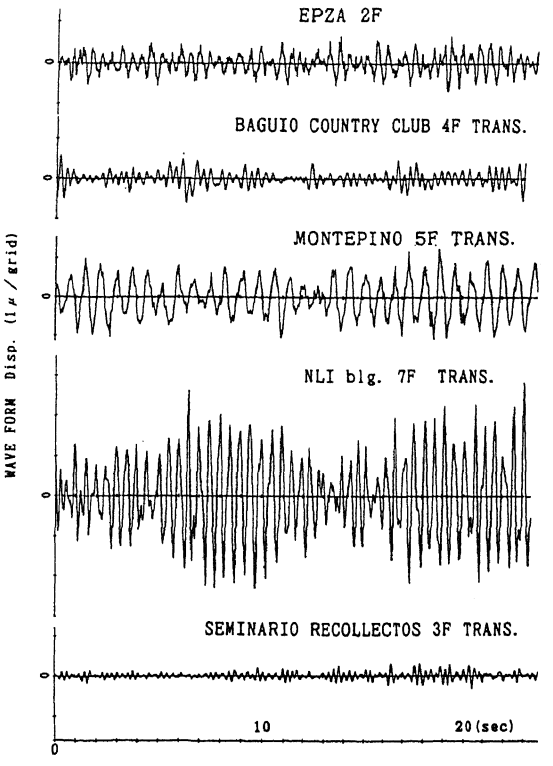

Figure 2. Microtremor records of structures in Baguio

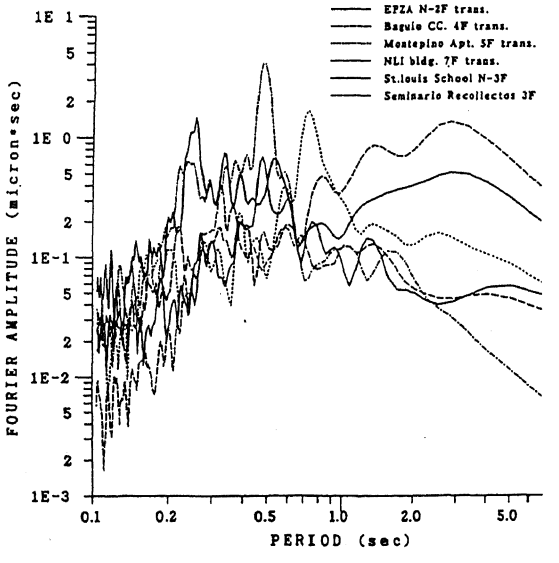

Figure 3. Fourier spectra of the structures in Baguio

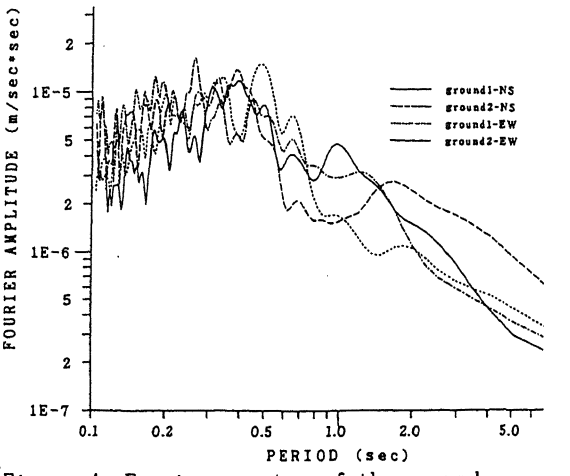

Figure 4. Fourier spectra of the ground at Montepino Condominium

Seminario Major Recollectos was located on the hill, the south-west in Baguio. The hall on the slope was badly damaged but the dormitory close to the hall on the flat ground had minor damage. Measurements were taken in the dormitory. The wave forms (Fig. 2) and the spectra (Fig. 3) indicated that this structure was very rigid and ground characteristics was not so soft.

In this case, we guessed that configuration of the ground where structures built might have influenced at the earthquake more or less. We observed many serious damage cases under similar situation like this in Baguio. But this tendency could not be seen in the results of the microtremor measurements.

4 MEASUREMENTS IN AGOO AND IN MANILA

In Agoo, microtremor measurements were made on and around 3 buildings; Don Marcos Memorial State University (DMMSU) and International Rural Electrification Training Center (IRE). Further more, measurements on grounds were conducted along the road. Location of the measurement sites are shown in Figure 5.

Don Marcos Memorial State University (DMMSU) was located in the east part of Agoo and on the flat plane at distance about 500 m from the east rock mountains. Peripherals of the campus was seen as marsh-land. Three RC buildings with 2 stories straggled on the campus. The library and the dormitory suffered serious damage and the main-building having relatively complex floor plan was damaged slightly.

Measurements were made on the library and 2 sites on the ground near the buildings in the campus. The observed wave forms in Agoo and their averaged spectra are shown in Figure 6. Results of the measurements suggested that ground of this campus was not so soft against our prospects. The periods of

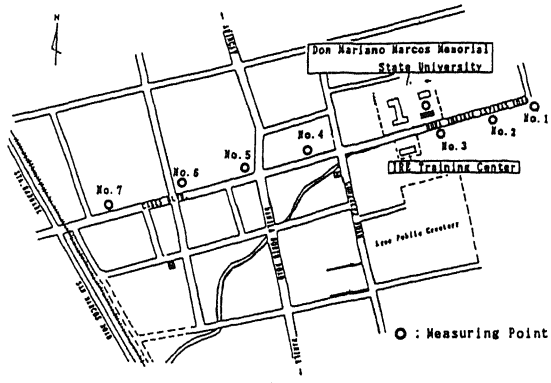

Figure 5. Location of microtremor measurements in Agoo

the suffered library obtained from measurements were longer than that of the peripheral ground. From the results, it was guessed that at the time of the earthquake, as the progress of the destruction of the structural and non-structural member, the fundamental period became longer and then collapse was avoided.

The structure which suffered a minor damage and had many partition walls showed rigid property and its periods were shorter than that of the ground.

IRE Training Center having 2 stories was damaged a little. IRE building and DMMSU stood in the opposite direction. Top roof of this building was not made of concrete slabs but made of wood or steel, this roof type were frequently observed through this inves-

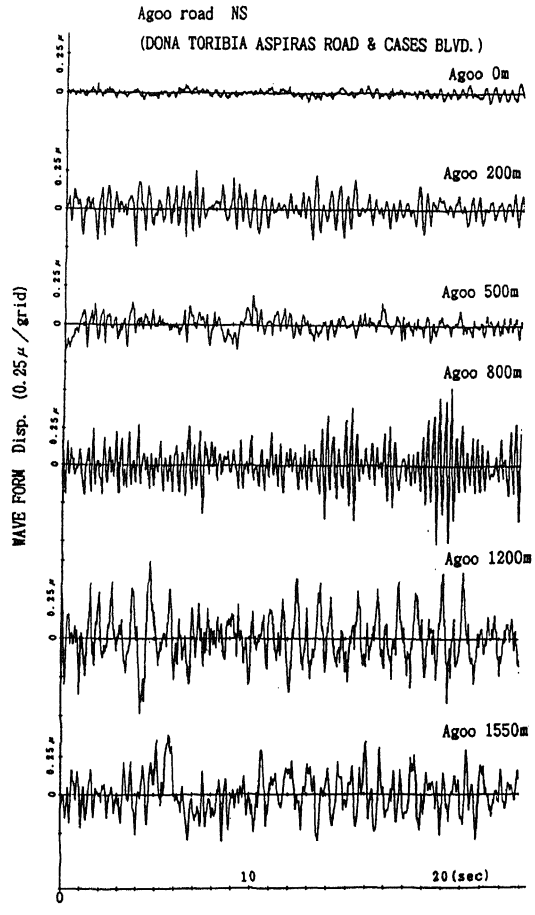

Figure 7. Microtremor records measured along DONA TRIBIA ASPIRAS ROAD in Agoo

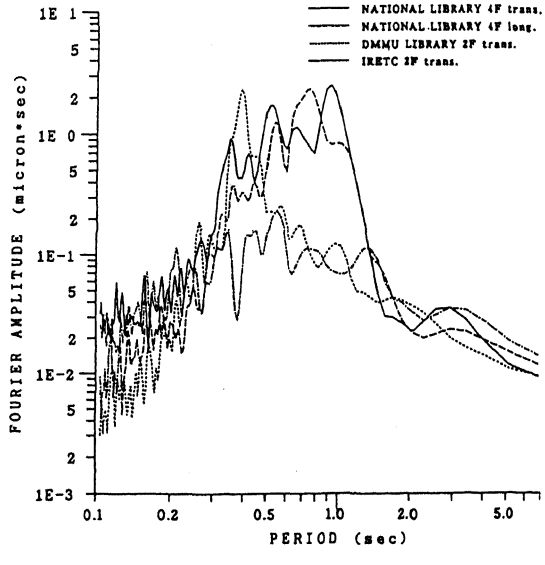

Figure 6. Fourier spectra of the buildings in Agoo and in Manila

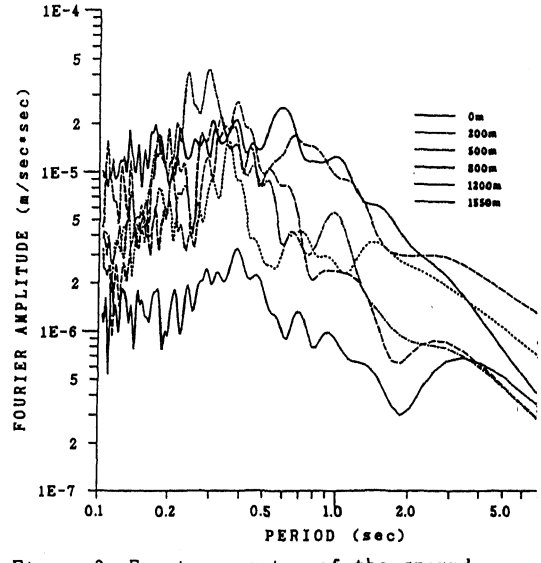

Figure 8. Fourier spectra of the ground in Agoo

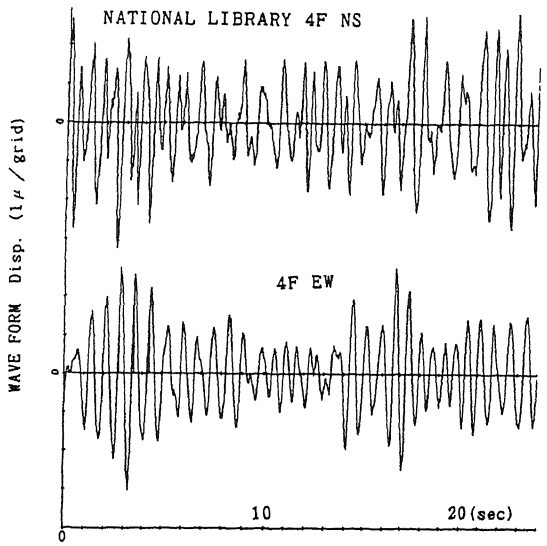

Figure 9. Microtremor records on the National Library in Manira

tigation in Philippine. This building had high rigidity because of the light weight and supported by well balanced configuration of walls. The measurement results of the ground was almost same as that of DMMSU.

We also took measurements at 7 sites on the ground along a east-west measurement line over than 2 km in length on the DONA TORIBIA ASPIRAS ROAD & CASES BLVD. (Fig. 5). The far-east site on the road was at the boundary between the east rock mountains and the flat land reaching to the sea. The far-west site was near the fields where sand-boils had been observed at the time of the earthquake was on the flat land. The center of the measurements line was the intersection of the national road; MANILA NORTH ROAD where the center of Agoo and there were some relatively large size structures near the intersection, and its vicinity was very noisy because of traffic. The observed waveform are shown in Figure 7 and spectra in Figure 8. Shapes of the wave forms and of the spectra were changed considerably between the east side (hill side) and west side (sea side) of the national road which ran from north to south; at the west side, predominant periods were as long as Ø.8 sec., and there were no large structure. On the other hand, periods at the east side was about Ø.4 sec..

Finally in Manila, we made measurements in the National Library. It had 4 stories and had mezzanine floors between each floor. Then it substantially had 8 floors and had height equal to standard 8 story buildings. At the earthquake it was damaged lightly on the core shear walls. The walls had made by concrete blocks were damaged in previous strong earthquake of 1968. And Then the walls were replaced with reinforced concrete walls. Cracks were observed on the boundary portions between frames and repaired walls but not inspected at this time.
It was seen from the wave forms (Fig. 9) and spectrum (Fig. 6) that the fundamental periods of the structure were Ø.8-Ø.9 sec. and values of the ground were smaller than that of the structure.

5 RESULTS

Table 1 shows the names of buildings and measurement points on the ground. The fundamental periods of buildings and predominant periods of ground on Table 1 were read from the averaged spectra and spectral ratios. The predominant periods of the ground in the affected area were around Ø.4-Ø.5 sec. in Baguio. Almost of the measured structures were constructed on the slope, or on the banking or cutting ground in this area. At several structures, cracks by the landslide were seen on the ground near the buildings. But direct relationship between the damage to structures and land-slide was not known in this investigation. In Agoo, the predominant periods along the road considerably changed between east side and west side of the national road. The structures we measured were on sites of the east area, their grounds were hard.

6 CONCLUSIONS

The ground of these areas consisted of relatively hard soils, then the soil layers did not amplify the ground motions severely. The fundamental periods of heavily damaged buildings were sometimes longer than the predominant periods of the ground. These buildings, however, might have been stiffer than they were before the earthquake; their fundamental periods were much closer to the predominant periods of the ground. We observed many cases in this investigation that non-structural walls made by concrete blocks had fallen down to the out of plane. This phenomenon could make changes the fundamental period dynamically and would affected largely to the final conditions of the structures, and the anchorages of the wall to the frame could affect that seriously too.

ACKNOWLEDGMENTS

We thanks members of Philippine participants :Mr. Wilfred S. Lopez of Department of Public Works and Highways, Mr. Carlos Villaraza and Mr. Rodolofo C. Cabael of Philippine National Oil Company for cooperation in making the microtremor measurements, also Mr. Hiroyuki Kanai of Tokyo University for cooperation to this research.