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ON RELATIONSHIP BETWEEN THE ESTIMATED STRONG MOTION CHARACTERISTICS OF SURFACE LAYER AND THE EARTHQUAKE DAMAGE - CASE STUDY AT INTRAMUROS, METRO MANILA -

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SUMMARY

It is important for the countermeasure against earthquake damage not only to know the earthquake damage history of a particular site and any structures built on it, but also to correlate this knowledge with dynamic seismic characteristics. Recently, the use of the H/V spectral ratio technique has become a popular method to investigate site characteristics. The H/V technique has also been extended further to estimate to the vulnerability of the ground. In this paper, these techniques are applied for Intramuros, the old walled city of Metro Manila, which has been repeatedly affected by earthquakes in the past. The surveys were conducted at two different time periods and the results show stability within a long time interval. More importantly, the results of microtremor measurement correspond to past earthquake damages.

INTRODUCTION

It is important for earthquake disaster prevention to understand the dynamic characteristics of urban infrastructures as well as the ground. Recently, it has been a popular technique to use H/V spectral ratio [1] for ground has been a popular method all over the world. Later on, the use of vulnerability index, Kg to relate ground amplification factor and predomination frequency has been developed to correlate with earthquake damage [2]. The term vulnerability index, Kg is defined as equal to Ag^2/Fg, where Ag and Fg are the amplification factor and the predominant frequency determined from microtremor, respectively.
This study conducted microtremor measurements in Metro Manila, Philippines to verify the use of microtremor and vulnerability index to determine correlation with past earthquake damages. This study selected the area of Intramuros, the old walled-city of the city of Manila. Previous researchers [3-5] had also conducted microtremor measurement in this area in 500 m to 1 km meshes and their results roughly

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determined the predominant frequency distribution in this part of the metropolis. However, it is still necessary to determine the detailed distribution of the dynamic characteristics to be able to compare the earthquake damages for ground and structures directly. This study further supplements previous studies by conducting measurements within much closely survey area.

STUDY AREA

The study area of this research is Intramuros, the old walled city of Manila, which frequently suffered earthquake damage in the past [6-8]. The 1990 Luzon earthquake although about 120 km away from Manila, caused considerably damage to some 15 RC-buildings in the metropolis. Omachi and Nakamura conducted microtremor measurements to compare microtremor with damage [9]. The results of the microtremor measurement in 1990 show that the low frequency values of around 1 Hz with the amplification factor as high as 3 to 8 predominated in the reclaimed area where the earthquake damages were also rather serious. Meanwhile, to verify stability of microtremor through time, a series of microtremor measurements were conducted by this study from 2002 - 2003.

ON MICROTREMOR MEASUREMENT

Overview of Measurement

Figure 1 shows the distribution of measurement points in the study area. In and around this area, there were ten points surveyed in 1990 (shown by red circles), fourteen points in 2002 (shown by blue circles) and thirty points in 2003 (shown by green circles). Some points were resurveyed in 2002 and 2003 for the purpose of comparing results of the 1990 survey.

At each site, microtremor was recorded for 4,096 samples in 100 Hz sampling. This procedure was repeated three times for each site. This methodology was also adopted for the 1990, 2002 and 2003 measurements. There were also five sites done during the 1990 measurements and one site during the 2002 measurement outside of the ancient wall.

Figure 1 Distribution of Measurement Points.

Method of analysis and results

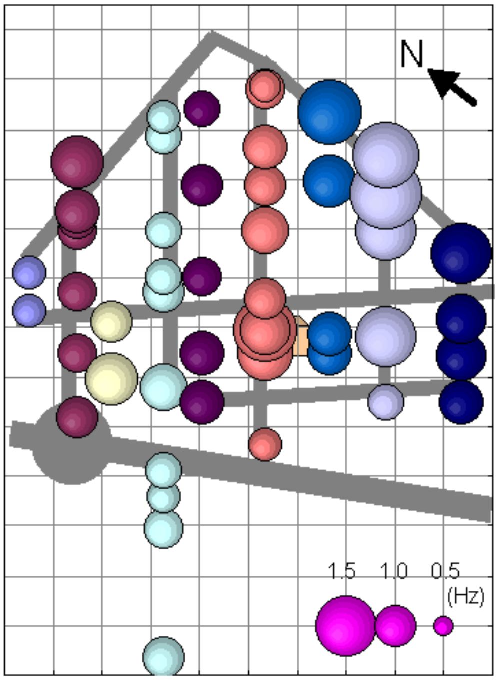


Figure 2 Distribution of Fg.

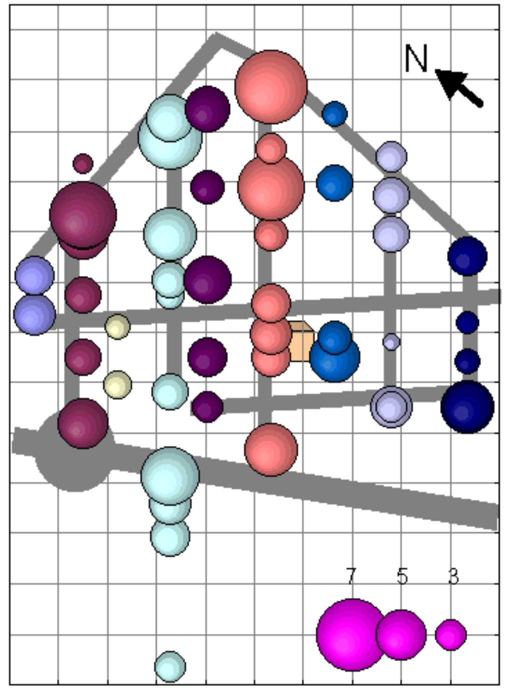


Figure 3 Distribution of Ag.

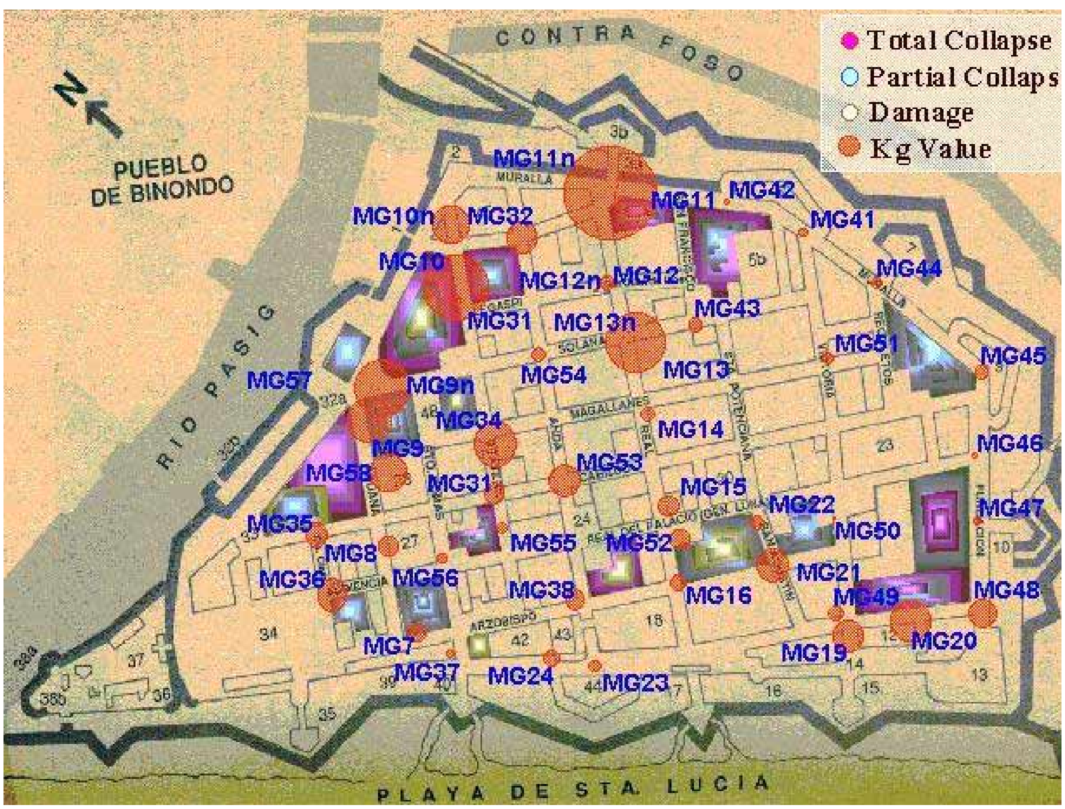


Figure 4 Distribution of Kg Value and Damage History

Figure 2 and 3 shows the results of measurement in terms of the predominant frequency Fg (Hz) and amplification factor Ag derived from H/V spectral ratio of recorded microtremor.
H/V spectral ratio was derived from the averaged horizontal to vertical Fourier spectrum. Smoothing was done using a Hanning window of 80 times (bandwidth is 0.4 Hz). Figure 4 shows the comparison between Kg values and major damages of past earthquakes on detailed map. In Figures 2, 3 and 4, the diameter of the circle indicates measurement point corresponds to the Fg, Ag and Kg values.
Although the predominant frequency is almost stable for the study area, amplification factors show variation. Three sites (MG5, MG6 and MG17) show high Kg values. These are located on the reclaimed land near the ditch. Meanwhile, MG1, MG3 and MG4 have relative low Kg value. It seems that it depends on the age of reclaimed area.

Examination on Stability of Microtremor with a Long Time Difference

Three points MG9, MG10 and MG11 conducted in 1990 locate close to MG9n, MG10n and MG11n conducted in 2002, respectively. By comparing with the results, MG9 and MG10 give approximately similar frequency and amplification. However, in the case of MG11, the shapes of spectrum are almost similar, but the peak values differ from each other. We investigated the possible cause and we found out that a sewer has recently been constructed near this observation site. The operation of this structure may have caused the change of site condition.

COMPARING WITH THE DETAILED DAMAGE AND MICROTREMOR

Figure 5 shows the overview and damage situation of San Agustin Church after the July 18, 1880 earthquake, located inside Intramuros and considered as one of the world heritage sites in the world. This church repeatedly suffered earthquake damage. Figure 5(b) shows its picture in 1880 after this earthquake caused one of the bell towers to fall.

(a) Present Condition

(b) Past Damage Condition

Figure 5 Overview of San Agustin Church

Around this church, microtremor was measured at points MG15, MG16, MG21 and MG22. Since depth of soil layer is another important criterion for determining earthquake damage, we tried to determine the estimated depth of soil layer using the following formula,

$$H = V_b / 4 A_g F_g$$

Where, H : Estimated depth of the surface layer (m),

V_b : Shear wave velocity,

A_g : Amplification factor, and

F_g : Predominant frequency.

Here, V_b is assumed to be 600 m/sec. Figure 6 shows the estimated depth of the surface layer. Figure 7 shows the soil profile one block away from the church [10]. By comparing the depth with the soil profile, it seems that the estimated depth of the surface layer corresponds to the fine-grained sand layer at 34m depth.

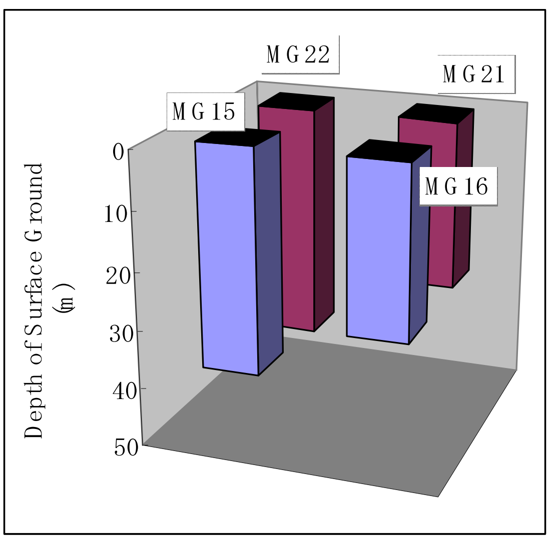


Figure 6 Estimated depth of surface ground

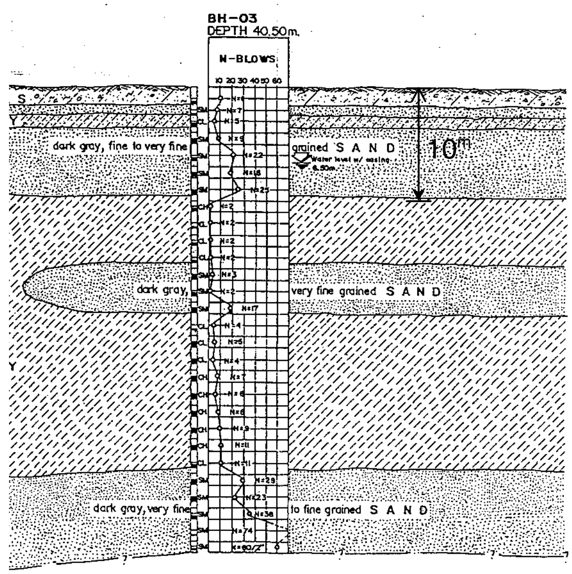


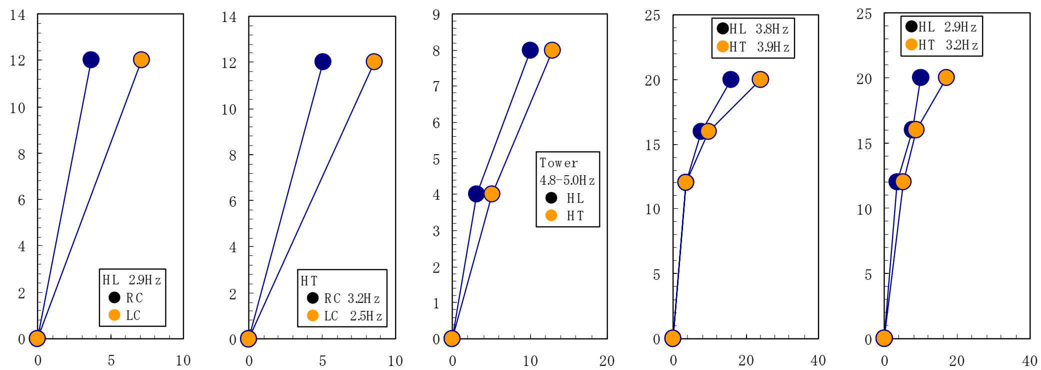
Figure 7 Soil profile near San Agustin Church

Figure 6 shows that the base ground is leaning and the deepest site is MG15, near to the left (lost) tower of this church. The influence of a base ground inclination is considered to be a large factor for estimating the potential damage of this structure. However, considering that other building abuts on the another surviving tower, it is supposed that the influence of an adjoining building is also large. In order to clarify such a damage factor, a thorough understanding of the dynamic characteristic of the ground and the characteristic of the structures are necessary.

Damage Estimation from Microtremor on the Structure

To grasp the dynamic characteristics in detail, microtremor measurement was also conducted inside the church., both for the main building and the bell tower shown in figure 5. Here the height of the main building and the bell tower assumed to 12 m and 8 m, respectively. Measurement points were installed on the grand floor and the top for the main building and on the bottom, middle and top of the bell tower.

From the microtremor on the ground, the predominant frequency and amplification factor is a little higher than 1 Hz and 2-4 times, respectively, so Kg value is less than 20.



(a) The main building **(b) Tower** **(C) Unified of the main building and the tower**

Figure 8 Mode diagrams of the San Agustin

Figure 8 is the mode diagram for the main building, the tower and unified of the main building and the tower.
The predominant frequency of the main building is around 3 Hz in general for both HL and HT direction. Here HL and HT direction corresponds to the direction along the long and transverse axis of the main building, respectively. But in detail, in case of HL direction, predominant frequency is 2.9 Hz for both left and right side but the amplification factor of left side is several times more than that of right side. In case of HT direction, predominant frequency is 3.2 Hz and 2.5 Hz for left and right side, respectively, and the amplification factor of left side is 5 times or more than that of right side. Of course it is impossible to avoid the effect of dead load to keep the balance for the lost left tower, it seems to be damaged on the left side. On the tower, there are two predominant frequencies, around 3 Hz and less than 4 Hz. Former seems to be the characteristics consist of the main building and thew tower. Latter is thought as the characteristics effected by the tower. For both cases, HT component has high amplitude two times or more than HL component, and the damage had been caused toward this direction.

CONCLUSIONS

This paper shows the microtremor measurement and vulnerability index can explain past earthquake damages. The results also show that microtremor measurements provide almost stable results with long time intervals. This technique can be used to identify possible areas or structures that may be damaged in the future by earthquakes. At the same time, the technique can be used for monitoring a structure’s state of health through time.

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