APPLICATION OF HORIZONTAL TO VERTICAL SPECTRAL RATIO METHOD FOR UNDERGROUND CHARACTERIZATION IN OYA

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1. INTRODUCTION

Shallow underground spaces are well known to be susceptible to seismic damage than deeper spaces. The damage intensity of the earthquake is dependent on epicenter, magnitude, direction and duration of the vibration; however, it has become apparent that the local geological condition (site effects) are the additional factors (Nakamura Y. , 2000). The local dynamic condition, has the influence, as it can amplify the motion caused by the earthquake. Therefore, it is essential to understand local dynamic characteristics of the shallow underground sites. A quick and inexpensive way of assessing the dynamic geological characteristics to obtain the dominant frequency is through the use of Nakamura's technique (Nakamura Y. , 1989), also known as the horizontal to the vertical spectral ratio (HVSR) (Pamuk, et al., 2017; Olszewska & Lasocki, 2004). Nakamura's technique has received much attention in estimating local site effects at the ground surface. In this case, the technique is used for assessing the dynamic characteristics (site and structural effects) of an underground quarry in Oya area, with roof depth of 40m, located in Tochigi prefecture, Japan. The HVSR initially comprises of measuring microtremors, which makes it suitable for low and high seismic areas. Since the area under investigation is located in a region of high seismic activity, it provides the chance to use both strong motions and microtremors for evaluating the dynamic characteristics. The results are then compared with the theoretical spectrum calculated by the transfer matrix method.

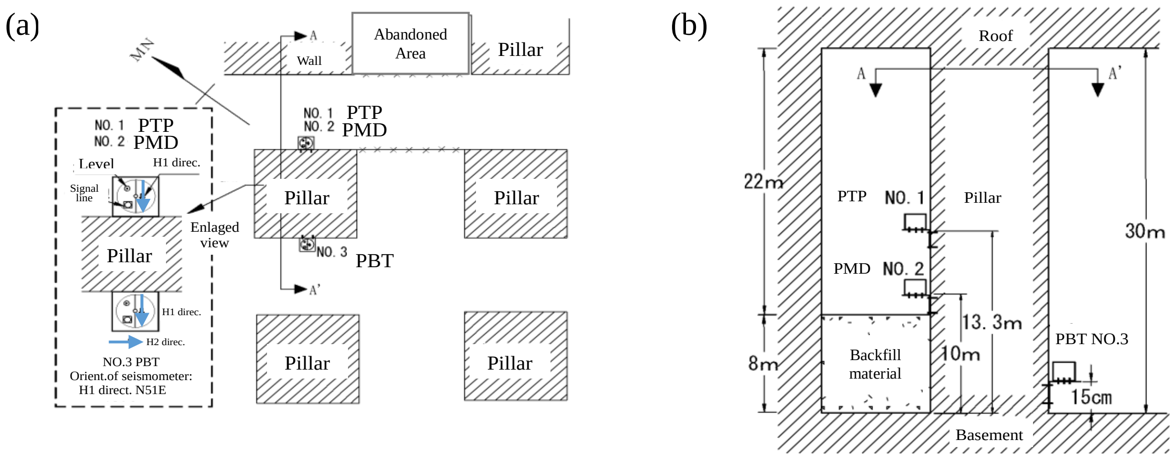

Fig. 1. Layout of underground quarry and locations of instruments, (a) plan view, (b) side elevation view.

2. METHODOLOGY AND DATA ANALYSIS

Measurements of the vibrations in the underground have been carried out using seismographs at three monitoring stations. Three seismographs are installed at 3 points along the vertical direction of the pillar in the quarry, as shown in Fig. 1. The seismographs have three-component velocity sensors; one vertical direction V and two horizontal directions lying at right angles H1 and H2. Note, H1 is parallel to N51E. The seismographs are denoted as PTP, PMD and PBT, fixed on the top part almost mid-height, middle (one third of the height) and bottom (15cm) respectively. In HVSR, it is demonstrated and accepted that the *S* wave would give more accurate readings. Bearing that in mind the *S* wave domain was selected from the data records of seismic events to calculate the HVRS with Parzen window function of 0.4Hz in bandwidth from the smoothened records. Each seismic event was recorded for a duration period of 90 seconds. The same procedure was repeated for the microtremor; however, this time taking domain records of the last 20 seconds to represent the microtremor. The seismograph registers data in a velocity-time signal, after that, using the Fast Fourier Transform (FFT) the signal is converted to the frequency domain. The recorded data for analysis consists of 20 earthquakes, including offshore shock records over a period of 1 month from 9 July to 7 August 2017. The average HVSR of the frequency domain is then defined as follows by Eq (1) (Nakamura Y. , 1989)

$$HVSR = \sqrt{NU^2 + EU^2}\ /2 \tag{1}$$

Where *NU* and *EU* are the ratios of the computed FFT spectrum with respect to the 3 components, H1/V and H2/V, respectively. From the obtained HVRS the peak frequency indicates the dominant frequency of the local site and the corresponding amplification factor. For the theoretical solution, the assumption was that the multilayer formation in Oya is horizontal. With the aid of borehole data, theoretical transfer function was then utilised to give the theoretical spectrum.

3. RESULTS AND DISCUSSION

Concerning the location of the epicenter, 20 seismic records originating from 5 different areas were selected and calculated average spectrum as shown in Fig 2. From the results, the peak value is predominant in a frequency ranging from 5 to 7Hz; thus no significant difference regarding the earthquake origin. For that reason, we present the averaged spectrum of individual

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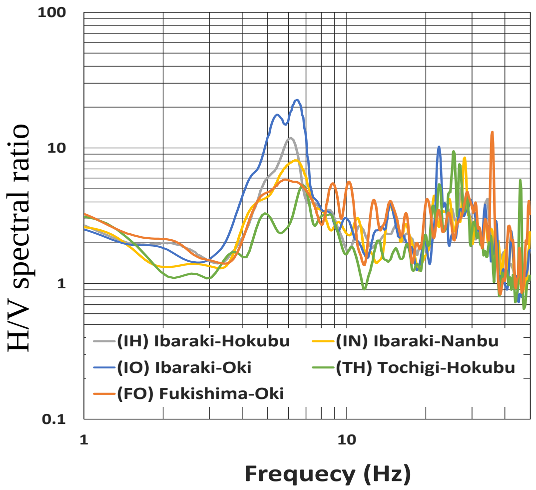

Fig. 2. H/V spectral ratio of 5 events recorded at PBT in Oya.

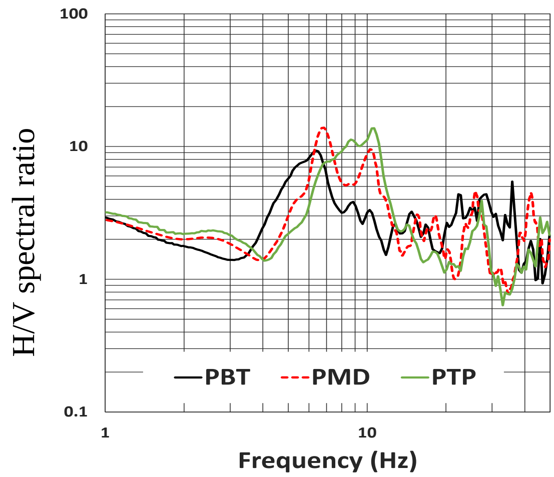

Fig. 3. H/V spectral ratio of measuring points at the pillar**.**

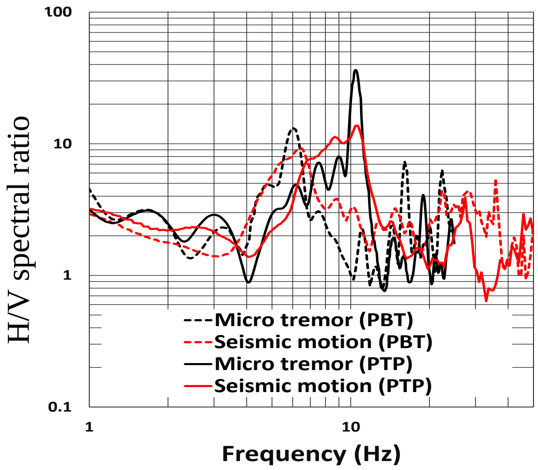

Fig. 4. Comparison of H/V spectral ratio of the seisimic motion and microtremor

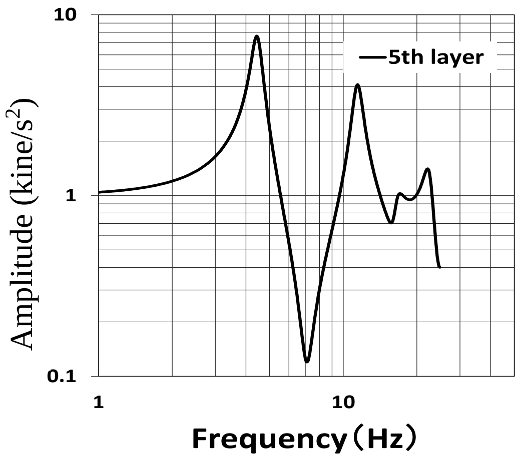

Fig. 5. Fourier spectrum of the 5th layer.

measuring points, as shown in Fig. 3. According to the HVSR results, the PBT (bottom of the pillar) vibrates at a frequency of 6Hz. However, PMB (the middle) and PTP (top) points vibrate at higher frequencies. The dominant frequency reaches up 10Hz at the top measuring point.

A further analysis, as shown in Fig. 4, shows that the computed HVSR for microtremor is almost the same with the HVSR of the earthquake, with a frequency of 6Hz at the bottom and 10Hz at the top. The results are in accordance with Nakamura's theory that the HVSR for microtremor and strong motion are supposed to yield same frequencies for a given site. Moreover, the difference in HVSR for an earthquake motion is negligible especially at the pillar bottom PBT in low frequency. Figure 5 presents the results of the theoretical spectrum of the 5th layer, where the quarry is located, and it is observed that the second dominant frequency is 11.4Hz, while the first is 4.4Hz, which is much closer to the bottom reading PBT of the seismic and microtremor.

4. CONCLUSION

There is no significant difference in the HVSR of the seismic data recorded in 5 different areas around Oya. However, the magnitude and the direction of the epicenters from Oya slightly affect the spectrum. It is clear that the dominant frequency at the bottom point is about 6Hz and approximately 10Hz at the top measuring point.

The dominant frequency of seismic motions and microtremors are in good agreement, both yield 6Hz and 10Hz at the bottom and top respectively. Also, it is realised that the slight variance in the HVSR of 5 different areas, is an outcome of magnitude and direction of the shock origin from the underground quarry.

The transfer function method showed that that the first and second dominant frequencies vary from 4.4Hz to 11.4Hz. As the first dominant frequency harmonises with the HVSR of the seismic and microtremors at the bottom point, an estimate of 4.5 to 6Hz concluded to be the dominant frequency of the ground quarry. The increment in spectrum peaks and frequency along the upward direction of the pillar suggests the structural effect. Even more so, the transfer function HVSR matches that of the PBT seismograph.

The supplementary investigation will be carried out using numerical simulation, where the number of monitoring points could be substantial to comprehensively seek out the site and structural effects in the underground quarry. After that, a potentially damaging frequency can be identified and counteracted.

REFERENCES

Nakamura, Y. (1989). A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface. Quarterly Report of Railway Technical Research Institute (RTRI).

Nakamura, Y. (2000). Clear identification of fundamental idea of Nakamura's technique and its applications. 12th world conference on earthquake engineering, 2656.

Olszewska, D., & Lasocki, S. (2004). Application of the horizontal to vertical spectral ratio technique for estimating the site characteristics of ground motion caused by mining induced seismic events. Acta Geophysica Polonica-Springer, 52, 301-316.

Pamuk, E., Ö zdag, Ö. C., Tunc¸el, A., Ö zyalın, S., & Akgun, M. (2017). Local site effects evaluation for Aliagˇa/I˙zmir using HVSR (Nakamura technique) and MASW methods. 887-899