ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DETERMINATION OF SOIL THICKNESS BASED ON NATURAL FREQUENCY USING MICROTREMOR MEASUREMENT

Mohd Alias Mohd Noor and Mohd Effendi Daud
Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia
E-Mail: alias88.uthm@gmail.com

ABSTRACT

Ambient vibrations from microtremor measurement were carried out in the Universiti Tun Hussein Onn Malaysia (UTHM) using Lennartz 1Hz tri-axial seismometer sensor. Microtremor measurements have been conducted on 5 boreholes at UTHM, to study the correlation between the natural frequency (F_o) and depth of borehole. All of ambient vibration has been analysed using Horizontal to vertical spectral ratio (HVSR) method introduced by Nakamura (1989), where the natural frequencies of the site were estimated from the single peak of HVSR in the North-South (NS) and East-West (EW) directions. The reliability of natural frequency (F_o) values are distributed between 1.18 to 1.78 Hz in the both of the directions. Meanwhile, the soil thickness was calculated in the range between 34.13 to 37.90 m using by Equation 1.

Keywords: microtremor measurement, natural frequency, soil thickness.

INTRODUCTION

The most important factor in earthquake engineering is to determine the dynamic soil properties. Understanding of dynamic soil properties is of great importance to provide the information of the dynamic response of the soil-structure which needed in dynamic structural analysis of the superstructure. In this study, the dynamic soil properties are represented by the depth to bedrock or hard layer (soil thickness). Amplified or attenuated of seismic wave depending to soil thickness of a site (Dinesh *et al.*, 2010).

Borehole is the conventional method to determine the soil thickness based on Standard Penetration Testing (SPT-N) or N values. Commonly in Malaysia, boreholes are terminated when the N values are achieved50. Advantage of borehole is an accuracy of soil information because are obtained direct from the site. However, the information is limited for large site because this method is very expensive and time consuming.

As an alternative, microtremor measurement based on the ambient vibration of soil has been introduced to site exploration. Advantages of microtremor measurement are simple, much cheaper and noninvasive.

Nowadays, microtremor measurement is widely used for various applications, including seismic microzonation (Bour *et al.*, 1998), bedrock mapping (Seht and Wonlenberg, 1999) and shear wave velocity profile at 30 m depth (Scherbaum *et al.*, 2003). However, the information from microtremor measurement is cannot used as a single reference. It still needs supported by borehole information to minimize uncertainties in the site exploration.

Universiti Tun Hussein Onn Malaysia (UTHM) located on the unconsolidated soil deposits classified in the Quaternary deposits as a shown in Figure-1. The topography in this study area is relatively flat area.

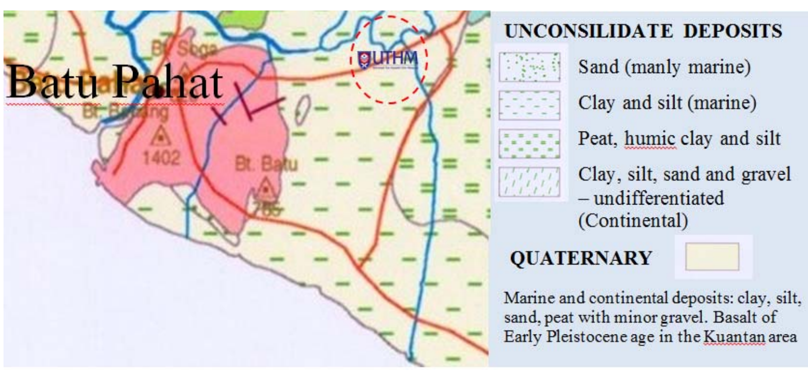

Figure-1. Geological map of the UTHM.

From the geotechnical information, was provided by Telaga Gerudi Sdn. Bhd, most of the depth of borehole in the range 30 to 39 m. SPT-N at the UTHM, mostly less than 10 until at depth of 30 m as a shown in the Figure-2(b). All of borehole are terminated when SPT-N is 50.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

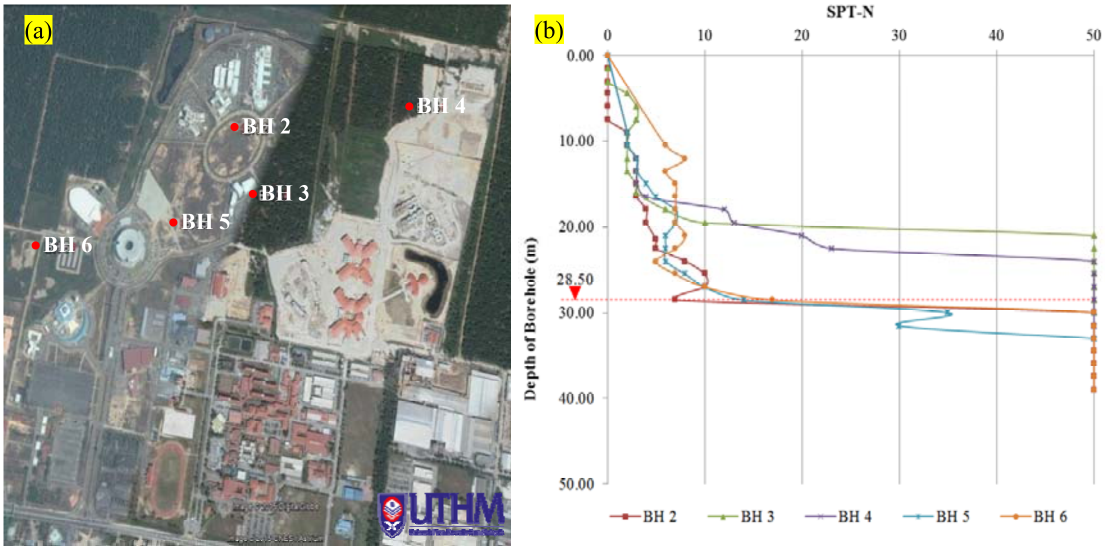

Figure-2. (a) Locations of boreholes at UTHM and (b) SPT-N versus borehole depth.

METHODOLOGY

Three units of Lennartz portable triaxial seismometer with 1 Hz eign frequency and one unit of CityShark II data logger are used to record all of ambient vibration on the field (see Figure-3(a)). All of the sensors are arranged in a triangular shape as a shown in Figure-3(b) and it is also located close to borehole location. At the same time, all of the sensors should be ensured away from the influence of the trees, the sound source is monochromatic, river, strong topography and underground structure such as a car park, sewer or pipes. The bubble of sensor must be in the middle of a circle that has been provided by adjusting the screw that attached at the bottom part of sensors, to make sure the sensor was leveled and the sensors must be aligned to the North direction that, guided by magnetic compass as shown by the arrow the sticker on top of sensor as shown in Figure-3(c). Microtremor measurements are recommended to repeat when the velocity of the wind more than more than 5 m/s and cannot to be continued on a rainy day.

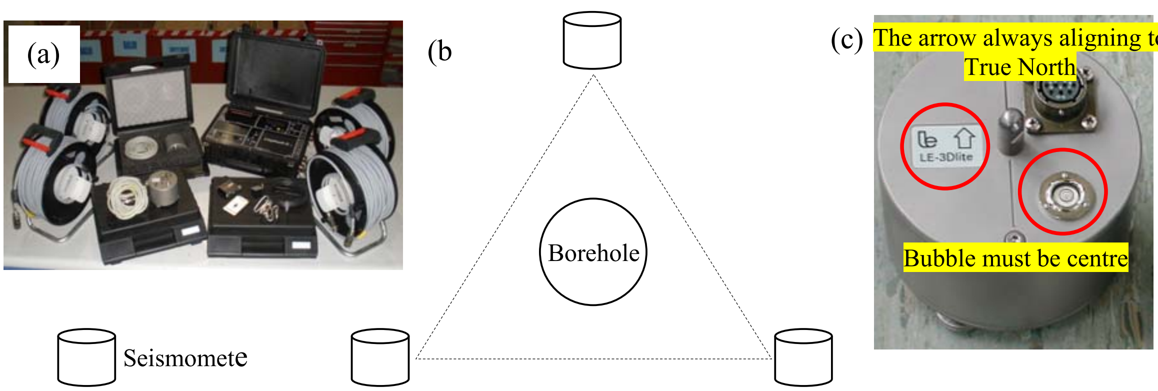

Figure-3. (a) Microtremor equipment, (b) position of the bubble and arrow on seismometer and (c) position of sensors on the fieldwork.

For the post processing, Fast Fourier Transform (FFT) algorithm based on Horizontal to vertical spectral ration (HVSR) method, through the Geopsy software has been used to analysis all of ambient vibration. All of ambient vibrations are automatically filtered to select the consistency signal. There are several parameters will be applied such as anti-STA/LTA trigger algorithm and tapered with a 5% cosine function is used before the computation of spectra. Konno-Omachi method is a used for the smoothed window and for the directional energy setting, all of ambient vibration has been analysed in the North-South (NS) and East-West (EW) directions. After that, all of ambient vibration data are checked the reliability and clarity provided by SESAME (2004) before accepted as natural frequency at the site.

RESULT AND DISCUSSIONS

Mean of HVSR curves from microtremor measurement on the 5 boreholes at the UTHM have computed in determining the natural frequency (F_o) in the North-South (NS) and East-West (EW) directions. The range of natural frequencies in the between 1.18 to 1.78 Hz and has a same values of F_o for both of directions and also all of the sensor. Table-1 shows the natural frequencies result at the UTHM.

Table-1. Natural frequencies (F_o) result.

Site	No. of borehole	Natural frequency, F_o (Hz)	
		NS	EW
Faculty of Civil and Environmetal Engineering	2	1.78	1.78
Faculty of Electrical and Electronic Engineering	3	1.45	1.45
Tun Fatimah Resident College	4	1.18	1.18
Tunku Tun Aminah Library	5	1.31	1.31
Sultan Ibrahim Hall	6	1.35	1.35

Based on Table-1, the natural frequencies at the UTHM mostly less than 2 Hz, and shows this site located on the soft soil area. It is consistent with the geological conditions at UTHM like shown in Figure-1. In addition, most of SPT-N values of the borehole at UTHM less than 10 to the depth at a 28.50 m (see Figure-2b).

As a known, natural frequency is a widely used as a one of parameter in determining the soil thickness today. According to Nakamura (1989), there are quantitative relationships between natural frequency was derived from HVSR method with the soil thickness at a site (Parolai *et al*., 2002). Meanwhile, Delgado *et al*., (2000) stated that it is possible to direct relationship between them, without knowing the shear wave velocity. The relationship between natural frequency and soil thickness has been reviewed in the many of previous studies.

Seth and Wohlenberg (1999) are among the earliest researchers that study the relationship between natural frequency and soil thickness at the western Lower Rhine Embayment (German). Parolai *et al* (2002) in the study case at the Colonge, Germany has been producing a regression line between soil thickness and natural frequency from the mean HVSR curve. Reasonable of natural frequency to determine the soil thickness of a site were accepted with a margin error less than 15% (Delgado *et al.,* 2000). In this study, equation (1) has been used to find the relationship between natural frequency and soil thickness (depth of borehole) at the UTHM area, as a shown in Figure-4.

$$y = 6.2854x + 26.712 \quad (R^2 = 0.1281) \qquad (1)$$

where "y" and "x" are represents the soil thickness and natural frequency. Equation (1) has been used to calculate the soil thickness based on the natural frequency of microtremor measurement. Table-2 shows the calculation to determine the soil thickness using by equation (1).

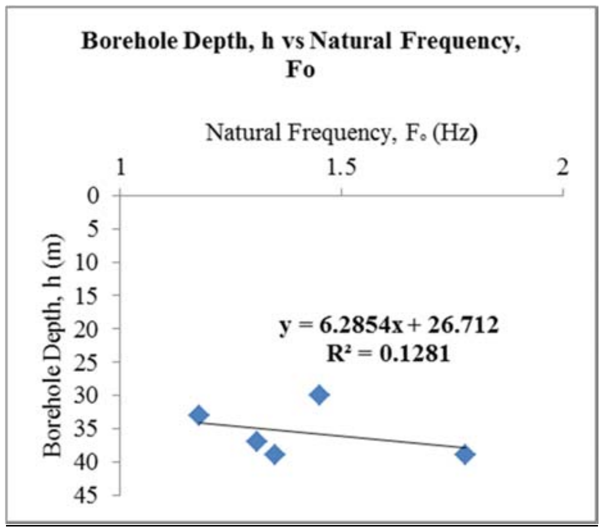

Figure-4. Regression line in correlating between borehole depth and natural frequency.

Calculation the soil thickness using by equation (1) shows there are slightly different between real of soil thicknesses from site investigation report. Firstly, at Faculty of Civil and Engineering Environmental shows the soil thickness at the depth 39 m and from equation (1) is a 37.90 m. Meanwhile, at the Faculty Electrical and Electronic Engineering shows the soil thickness from the equation (1) is a 35.83 m higher than real of soil thickness from the site investigation report.

A same situation like Faculty of Electrical and Electronic Engineering was happening at the Tun Fatimah Resident College, where the soil thickness from the equation (1) is higher than soil thickness from the site investigation report. In the meantime, the soil thickness at the Tunku Tun Aminah Library shows the soil thickness from the site investigation report is a 37 m compared with from the equation (1) is a 34.95 m. At the Sultan Ibrahim Hall shows the soil thickness from the equation (1) is a

VOL. 11, NO. 8, APRIL 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

35.20 m less than from a real of soil thickness from the site investigation report (39 m).

Differentiation of soil thickness between site investigation and from equation (1) show the minimum of soil thickness is at1.10 m and the maximum is a 5.83 m, where the percentage of margin error of soil thickness in the range 2.82 to 19.43%.

Table-2. Determination soil thickness based on natural frequency using Equation (1).

Site	No. of borehole	Natural frequency, F_0 (Hz)		Depth of soil to bedrock layer, h (meters)		Difference depth of soil to bedrock layer	
		NS	EW	SI Report	Eq. 1	(meters)	(percent, %)
Faculty of Civil and Environmental Engineering	2	1.78	1.78	39	37.90	1.10	2.82
Faculty of Electrical and Electronic Engineering	3	1.45	1.45	30	35.83	- 5.83	- 19.43
Tun Fatimah Resident College	4	1.18	1.18	33	34.13	- 1.13	- 3.42
Tunku Tun Aminah Library	5	1.31	1.31	37	34.95	2.05	5.54
Sultan Ibrahim Hall	6	1.35	1.35	39	35.20	3.80	9.74

HVSR curve image is a one of evidence used to show the geological formation at a site. But, it is cannot to be used to show directly the real geological formation of a site. However, HVSR curve image is still relevant to illustrate the geological formation indirectly. Figure-5 shows the HVSR curve images for all boreholes in UTHM area.

Based on Figure-5, most of HVSR curve images at UTHM are a single peak. Single peak of HVSR curve shows the possibility existence of deep soil thickness with large velocity contrast underneath of soil as a stated by Fahmy *et al*., (2014). Information from site investigation is consistent with HVSR curve images were obtained at UTHM.

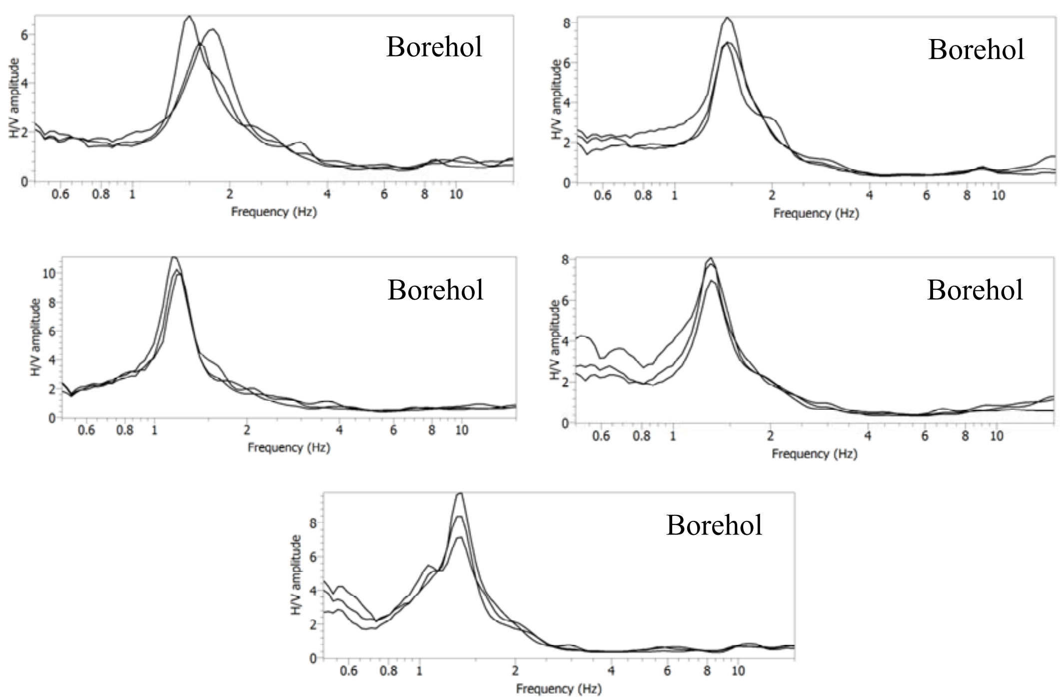

Figure-5. HVSR curve images from microtremor measurement of UTHM borehole area.

CONCLUSIONS

Natural frequencies of HVSR from microtremor measurements were used to determine the soil thickness at Universiti Tun Hussein Onn Malaysia (UTHM). The natural frequencies at UTHM in the range 1.18 to 1.78 Hz shows the UTHM located on the soft soil area like to information geological map. According to equation (1), the soil thicknesses have calculated in the range 34.14 to 37.90 m. It is slightly different compared to soil thickness from the site investigation report in the between 30 to 39

m. Calculation of percentage of margin errors is shows less than 20%. Meanwhile, HVSR curve images show a single peak at all of borehole. A single peak of HVSR curve image shows the probable existence the deep of soil thickness at UTHM. It is consistent with information from the site investigation, where the depth of soil thickness with SPT-N less than 10 achieve to 28.50 m.

ACKNOWLEDGEMENT

This study is supported by Ministry of Education (Higher Education) under FRGS, Vot 1229 as the main sponsor of this study. A great appreciation to Faculty of Civil and Environmental Engineering, UTHM for the instrumentations. Special thanks to colleagues who participated in this study and for their priceless co-operation and commitment.

REFERENCES

A. Fahmy, K., M. Effendi, D., Zainah, I., Azmi, I., M. Khairani, Y. and M. Alias, M. N., Estimation of Site Dynamic Characteristics from Ambient Noise Measurements using HVSR Method in Microzonation Study: Senggarang, Batu Pahat, Malaysia, Advanced Materials Research Vols. 931-932 (2014) pp. 803-807.

Bour, M., Fouissac, D., Dominique, P., and Martin, C. 1998. "On the Use of Microtremor Recordings in Seismic Microzonation", Soil Dynamics and Earthquake Engineering, Vol. 17, No. 7-8, pp. 465-474

Delgado, J., Lopez Casado, C., Giner, J., Estevez, A., Cuenca, A., and Molina, S. 2000. "Microtremors as a geophysical exploration tool: Applications and limitations", Pure and Applied Geophysics. Vol. 157, pp. 1445-1462.

Department of Minerals and Geoscience, Ministry of National Resources and Environment Geology of Peninsular Malaysia, 8th Edition (1985).

Dinesh, B. V., Nair, G. J., Prasad, A. G. V., Nakkeeran, P. V. and Radhakrishna,M. C., Estimation of sedimentary layer shear wave velocity using micro-tremor H/V ratio measurements for Bangalore city. Soil Dynamics and Earthquake Engineering, 30(11), (2010)1377-1382.

Nakamura, Y. 1989. "Method for Dynamic Characteristics Estimation of Subsurface Using Microtremor on the Ground Surface", Quarterly Report of RTRI (Railway Technical Research Institute) (30), Japan, pp. 25-33.

Parolai, S., Bormann, P., and Milkereit, C. 2002. "New relationships between Vs, thickness of sediments, and resonance frequency calculated by the H/V ratio of seismic noise for the cologne area (Germany)", Bulletin of the Seismological Society of America, Vol. 92, pp. 2521-2527.

Scherbaum, F., Hinzen, K. G., and Ohrnberger, M. 2003. "Determination of Shallow Shear Wave Velocity Profiles in the Cologne, Germany Area Using Ambient Vibrations", Geophysical Journal International, Vol. 152, No. 3, pp. 597-612.

Seht, M. I. V. and Wohlenberg, J. 1999. "Microtremor Measurements Used to Map Thickness of Soft Sediments", Bulletin of the Seismological Society of America, Vol. 89, No. 1, pp. 250-259.

SESAME. 2004. Guidelines For The Implementation Of The H / V Spectral Ratio Technique On Ambient Vibrations Measurements , Processing And Interpretation SESAME European research project, (December), 1–62.

Telaga Gerudi Sdn. Bhd., Laporan Akhir Penyiasatan Tapak untuk Cadangan Pembangunan Kolej Universiti Teknologi Tun Hussein Onn, Parit Raja, Johor, Malaysia, SI Report (2002).