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BASE-ROCK ELEVATION MEASUREMENT USING SINGLE AND ARRAY MICROTREMOR INVESTIGATION

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ABSTRACT: Site-specific ground motion analysis is a method for developing surface ground motion and surface spectral acceleration models. The analysis is performed by conducting propagation analysis from base-rock to surface elevation. The important information needs for site-specific ground motion analysis is the position of base-rock or bedrock below the surface level. This paper presents the investigation results of base-rock elevation at the Diponegoro University Semarang, Indonesia. The background reason for the base-rock investigation of this university area is because this area is located close to three seismic sources (Semarang, Lasem and Demak shallow crustal faults). Seismic microzonation caused by all three seismic source scenarios are still on-going. One of the important analysis used for seismic microzonation at the study area is site-specific ground motion analysis. The base-rock elevation prediction in the study area was performed using a combination of single and array microtremor tests and soil boring investigations. The base-rock elevation prediction developed using microtremor tests was verified using the soil profile developed from soil boring investigation. Based on soil boring and microtremor investigations, the base-rock elevation at the university area was predicted at 30 to 60 m below the surface level.

Keywords: Base-rock, Ground Motion, Microtremor, Propagation Analysis, Shallow Crustal Fault

1. INTRODUCTION

Site-specific ground motion analysis is a method for developing surface ground motion, usually in terms of displacement, acceleration, and velocity-time histories. Surface response spectral acceleration and amplification factor can also be calculated or obtained using this method. The analysis is conducted as a complementary analysis for ‘buildings and other structures’ resistance design and evaluation against seismic forces. Surface spectral acceleration for building design in Indonesia is usually performed using amplification or site factor and multiplying this site factor by spectral acceleration at base-rock elevation.

ASCE/SEI 7-16 [1] introduced the requirement of site-specific ground motion analysis for buildings located on soft soil (site class SE) and medium soil (site class SD) having a specific minimum Risk Targeted Maximum Considered Earthquake (MCE_R) S_S and S_1 spectral acceleration. ASCE/SEI 7-16 states that all structures located on-site class SD and SE having an MCE_R-S_1 less than or equal to 0.2 g shall be evaluated using site-specific ground motion analysis. One of the important information needs for performing site-specific ground motion analysis is obtaining the base-rock elevation. The base-rock elevation can be obtained or predicted using typical invasive soil boring investigation and non-invasive microtremor tests, either using single or array microtremor investigations.

This paper explains the base-rock investigation research at Diponegoro University area. The study area is located in the southern part of Semarang, the capital city of Central Java Province, Indonesia. Based on the New Indonesian Seismic Hazard Map 2017 [2], the university area is located closed to three different seismic sources, Semarang, Lasem and Demak crustal fault traces. The base-rock investigation in this area is part of seismic microzonation research for the university area. Seismic vulnerability analysis due to a specific scenario earthquake motion study is still ongoing. The study is being performed because most of the buildings within the university area were designed and constructed following the old version of Indonesian seismic code. The base-rock prediction level was conducted using a combination of single and array microtremor tests and soil boring investigations. Figure 1 shows the position of the university area against the three closed seismic sources. All seismic sources are located less than 10 kilometers from the university area.

Based on the New Indonesian Seismic Code 2019 (SNI 1726:2019) [3], the MCE_R-S_S and MCE_R-S_1 spectral response accelerations of the study area are between 0.87–0.891g and 0.373–0.38g, respectively. Figure 2 shows the 2019 MCE_R-S_S map. Figure 3 shows the 2019 MCE_R-S_1

map. Based on these two spectral MCE_R accelerations, a site-specific ground motion was analyzed at the university area as a complementary analysis using surface response spectral acceleration.

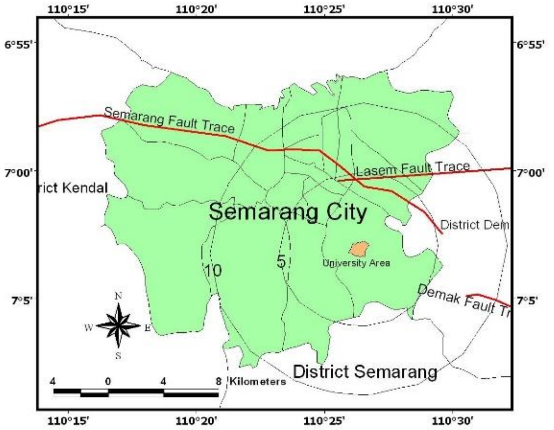


Fig.1 Seismic source positions and the corresponding distance to the university area

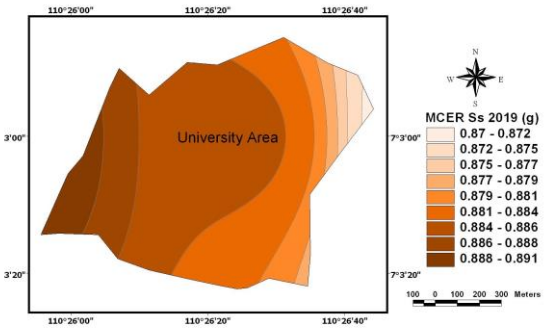


Fig.2 MCE_R-S_S 2019 map of the university area

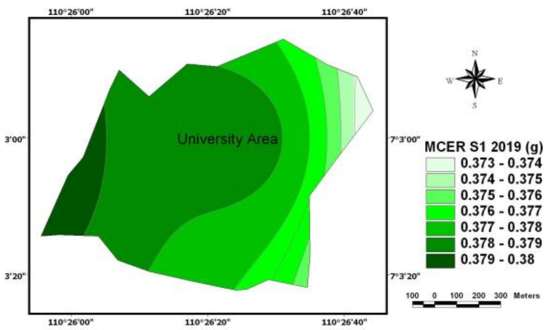


Fig.3 MCE_R-S_1 2019 map of the university area

2. METHODOLOGY

Base-rock elevation prediction at the university area was performed as part of the same research conducted in the whole area of the city. This research was conducted as part of the seismic microzonation research of Semarang City which started in 2015 and is still on-going [4]. The base-rock investigation for the whole city area was started by conducting 241 single station seismometer investigations and following the same method proposed by [5, 6 and 7]. The purpose of this investigation was to obtain the dominant frequency of soil sediment at the microtremor equipment position. Figure 4 shows the position of the 241 single station microtremor investigations [8]. The dominant frequency for each microtremor position was calculated using the Horizontal to Vertical Spectrum Ratio (HVSR) formula developed in [9, 10]. Figure 5 shows two examples of HVSR curves developed in the study area. The dominant frequency (F_o) obtained from the HVSR curve was used for base-rock prediction [11–15]. The base-rock prediction elevation in this study was calculated following the empirical formulae developed in [16, 17]. Equation 1 shows the formula used for predicting the base-rock elevation [16, 17]. The variable "Z" in Eq. 1 represents the thickness of the soil sediment above the base-rock elevation. Table 1 shows the "m" and "n" constant values used for sediment thickness calculation. The Z values obtained at all single microtremor positions surrounding the study area were used for developing the base-rock elevation map of the study area.

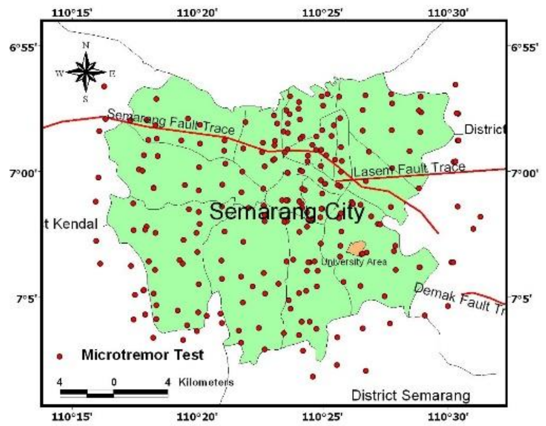


Fig.4 Single station seismometer investigation at Semarang

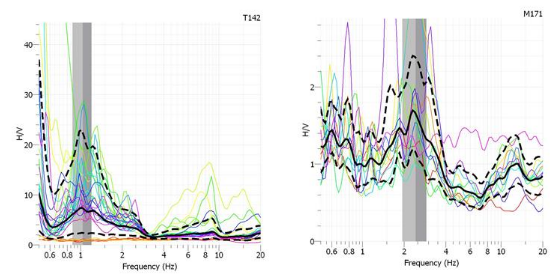


Fig.5 Two example HVSR analysis results at two point within the university area.

$$Z = mF_o^{\ n} \tag{1}$$

Table 1 Constant value "m" and "n" used for sediment thickness calculation

References	m	n
[16]	96	-1.388
[17]	108	-1.551

Following the single station seismometer investigation, array microtremor investigations were performed in the university area. The purpose of these investigations was to find the predicted soil profile in terms of shear wave velocity (Vs) profile at the study area. Based on the Vs data or Vs profile, the base-rock elevation can be predicted following the standard criteria described by [1, 3]. SNI 1726:2019 [3] and ASCE/SEI 7-16 [1] states that the minimum Vs = 750 m/sec (rock) and minimum Vs=1500 m/sec (hard rock) can be used for adjusting rock properties. The basic concepts of array seismometer analysis are almost equal to single station seismometer analysis. All data developed using single seismometers were analyzed as an array data.

Fourteen boring investigations were conducted in the study area. The purpose of this investigation was to find the soft rock or hard rock elevation at the boring position. All boring investigations in the study area were conducted to a maximum of 30 m depth. Figure 6 shows the array microtremor and soil boring investigation positions.

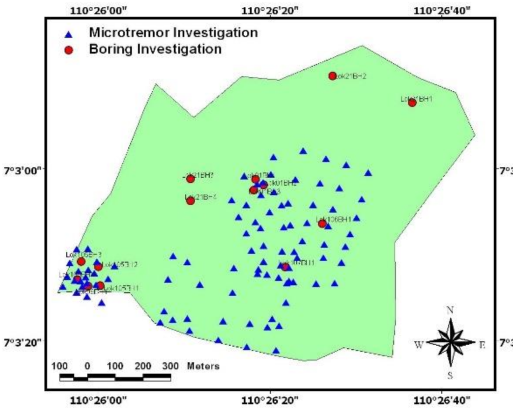


Fig.6 Array microtremor and soil boring investigations at the study area

3. RESULT AND DISCUSSION

Single station microtremor investigation conducted at the university area produce a dominant frequency (F_o) map. This map was created by conducting spatial analysis. Figure 7 shows the spatial analysis results for the dominant frequency map in the study area. All dominant frequencies (F_o) data obtained from single station seismometer tests in the study area were used for base-rock elevation prediction. Figure 8 shows the base-rock elevation prediction results conducted in the study area. The base-rock elevations in the study area are divided into two different elevation 0-30 m (area 1, red area) and 30-60 m (area 2, green area). Due to the restriction of soil boring investigations, the base-rock elevation is divided into two different depths. All boring investigations were executed to a maximum of 30 m depth. Five boring investigations were located in area 1 and another nine boring investigations are located in area 2.

Based on the information related to base-rock elevation, array microtremor analysis was then performed in the study area. Figure 9 shows four different cross-section positions for developing array microtremor analysis and developing Vs profile. Figures 10 to 13 show the four different results of the soil profile in terms of shear wave velocity (Vs) profile. Based on Fig. 10 and Fig. 12 base-rock elevation was predicted at minimum -40 m depth below the surface level. However, according to Fig. 11 and 13, the based-rock elevation is predicted a minimum -60 m depth below the surface level.

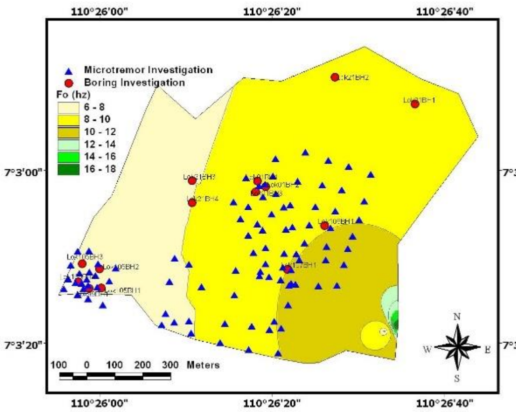


Fig.7 Dominant frequency (F_o) map of the study area

Based on four different cross-section positions, the base-rock elevation can be proved using boring investigation results at cross-section no 3. From the Vs profile, the base-rock or hard-rock layer with a minimum 1500 m/s shear wave velocity can be found at 30 m or maybe less than 30 m below the surface level. The Vs profile developed at cross-section no 3 will make base-rock level easy to predict. Based on Fig. 10 or cross-section no 1 the base-rock elevation can be predicted at 50 m below the surface level. However, it is difficult to predict the elevation of base-rock based on cross-section 2.

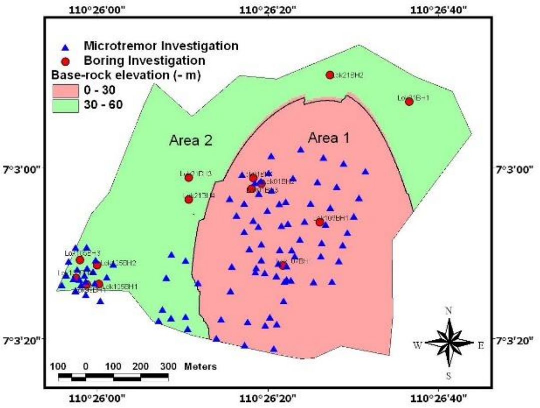


Fig.8 Base-rock elevation map of the study area

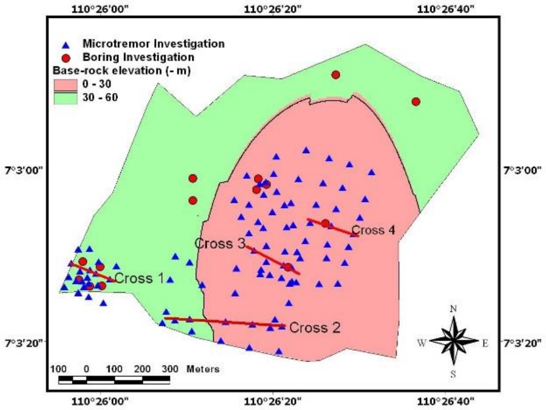


Fig.9 Cross-section positions

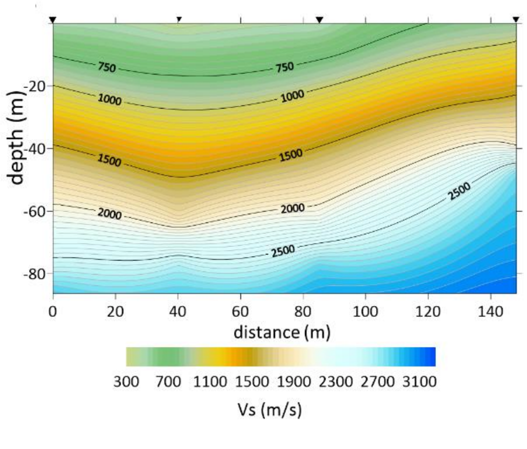


Fig.10 Vs profile at cross-section no 1

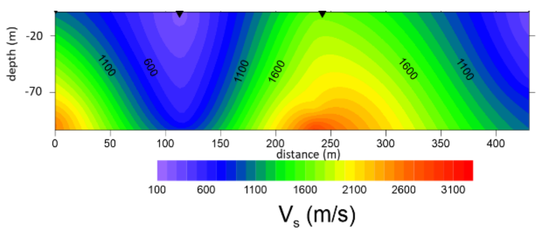


Fig.11 Vs profile at cross-section no 2

To verify the base-rock elevation, 14 boring investigations were performed in the study area. Figure 13 shows two different boring investigation results collected from boring no Bh1 (Fig. 13 (a)) and Bh2 (Fig. 13 (b)), two example boring-log data points collected from area 1 and area 2, respectively. A good correlation between soil boring investigation and array microtremor investigations results were measured in this research, especially in the university area. As can be seen in Fig. 13 (a) the base-rock elevation is easily to predict by conducting the minimum shear wave velocity of 1500 m/sec. The base-rock elevation was observed at approximately 30 m below the surface level (cross-section no 3). A sand-stone sample was observed at the boring no Lok01Bh1 at 25 to 30 m below the surface level. Base-rock elevations were observed at three boring locations in area 1. However, no rock samples were obtained from the nine boring positions in area 2. Fig 13(b) shows an example of boring-log record from area 2 (cross-section no 1). Figure 14 shows the correlation of N-SPT (Standard Penetration Test) result and Vs profile developed at boring no BH1. Figure 15 shows the correlation of N-SPT data and Vs profiles at boring no Bh2.

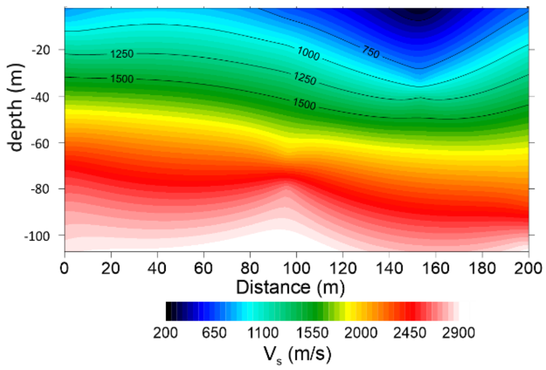


Fig.12 Vs profile at cross-section no 3

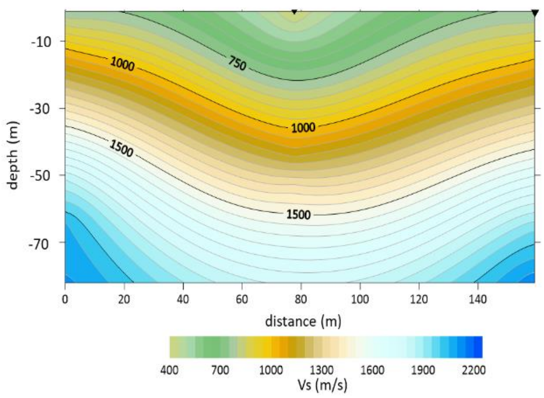
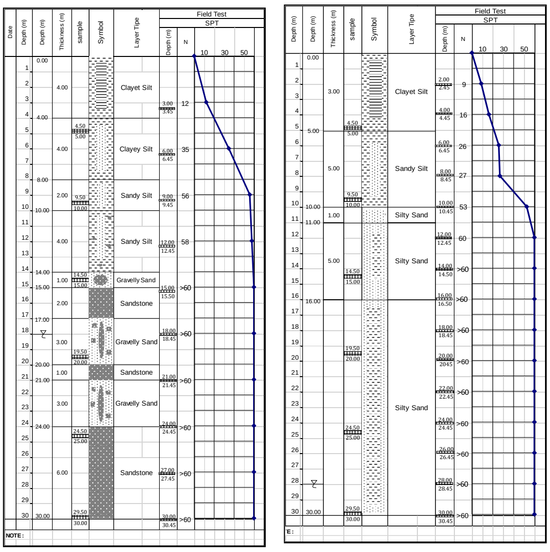


Fig.13 Vs profile at cross-section no 4

Figure 14 shows the correlation of Vs profiles developed from array microtremors with 4 geophones and soil boring investigation results. The analysis was conducted at cross-section no 3 position. Based on the Vs profiles, the maximum Vs value obtained at 30 m below the surface level was 2502 m/sec and the minimum Vs value at this level was 843 m/sec and the average Vs value was 1913 m/sec. The average Vs value from 25 m to 30 m was greater than 1500 m/sec. Following [1] and [3] the hard rock samples will be obtained at minimum 26 m below the surface level. Based on the boring-log result conducted at this array position as can be seen in Fig. 13(a), the sand stone sample was obtained from 26 to 30 m below the surface level. The N-SPT profile was also obtained from the same boring position. However, it is difficult to evaluate the hard rock position based on the N-SPT data. Due to the capability of the N-SPT spoon sampler apparatus, for all N-SPT greater than 60, the boring master will stop the blowing process and write the N-SPT record ">60" into the boring-log. Sand stone samples were also observed at other two boring investigation positions. A good output performance for base-rock investigation was observed at area 1.



(a) (b)

Fig.13 Two sample boring log results at area 1 (a) and area 2 (b)

Figure 15 shows the same Vs and N-SPT correlation conducted at array 1 position. Five geophones were installed for ambient vibration measurements at this position. On average, no Vs value at 30 m below the surface level reached 1500 m/sec. The average Vs value collected from five geophones is less than 1500 m/sec. Based on the average Vs data, it is difficult to obtain the base-rock samples at this array investigation position. Based on the boring-log report, no soft rock or hard rock samples were obtained from the soil boring investigation. As can be seen in Fig. 13 (b), the N-SPT values obtained from 12 m to 30 m below the surface level were greater than 60. Fig. 16 and Fig. 17 shows the predicted distribution of base-rock elevation developed in the Engineering Faculty area. The base-rock elevations were predicted using Vs minimum 1500 m/s.

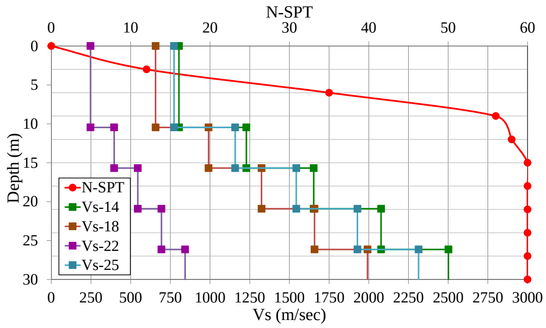


Fig.14 N-SPT and Vs correlation at cross-section 3

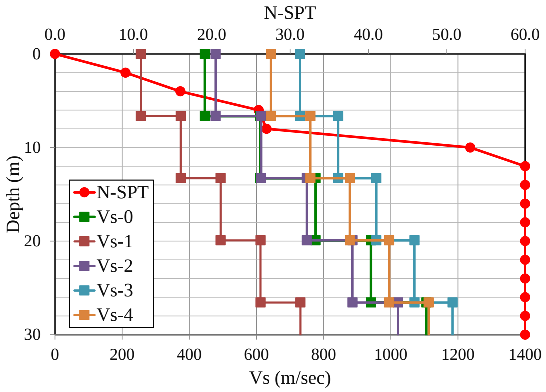


Fig.15 N-SPT and Vs correlation at cross-section 1

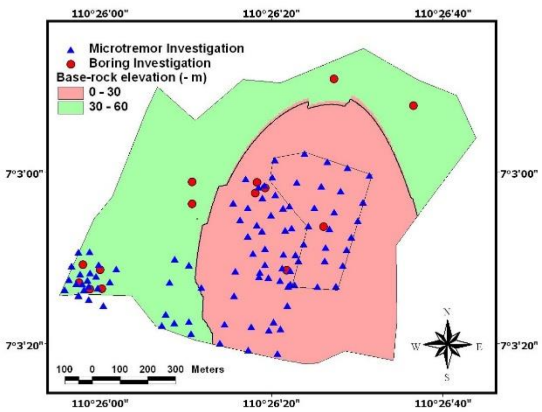


Fig.16 Based-Rock Elevation Prediction at Area 1 (Engineering Faculty)

Based on the microtremor and soil boring investigations conducted in the University area, base-rock elevation can be predicted using single and array microtremor investigations. Base-rock elevation can be predicted when the Vs data observed by microtremor equipment reaches a minimum of 1500 m/sec.

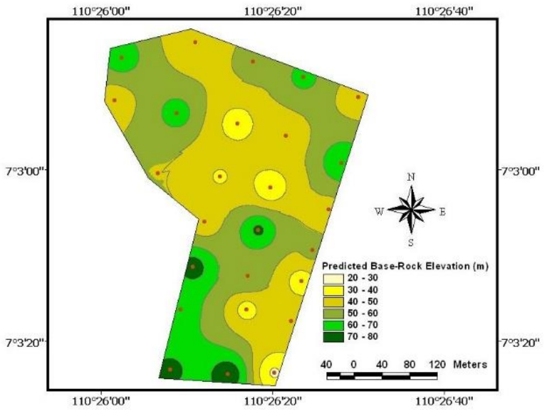


Fig.17 Predicted Base-Rock Elevation Based on Vs minimum 1500 m/s in Area 1 (Engineering Faculty)

4. CONCLUSIONS

Development of base-rock elevation is one of the most important process needs for seismic hazard analysis and site-specific ground motion analysis. Base-rock elevation can easily be predicted using single and array microtremor or seismometer investigations. Following the microtremor investigation, in terms of base-rock elevation, the study area was divided into two different sub-areas, the first area had a maximum of 30 m and the second area was predicted to have a maximum of 60 m base-rock elevation.

Based on fourteen boring investigations results for verifying the base-rock elevation, sand stone (hard rock) samples were observed at three boring positions, with maximum 30 m depth (first area). However, no hard rock samples were observed at the other eleven boring positions (first and second area).

Single and array microtremor investigations can be used as complementary methods in predicting base-rock measurements. Boring investigations shall be conducted to verify the microtremor investigation results. A minimum of 1500 m/sec of shear wave velocity values should be applied for base-rock elevation measurements. However, if the Vs value obtained on-site is less than 1500 m/sec, predicting the base-rock elevation is difficult. For verifying base-rock elevation located at a minimum 100 m depth, the soil boring investigation will spend a lot of money and time.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] ASCE/SEI 7-16: Minimum Design Loads and Associated Criteria for Buildings and Other Structures. American Society of Civil Engineers, 2017.

[2] National Center for Earthquake Studies: Indonesian Seismic Sources and Seismic Hazard Maps 2017, Centre for Research and Development of Housing and Resettlement, Ministry of Public Works and Human Settlements, ISBN 978-602-5489-01-3, 2017, pp. 1-377.

[3] SNI 1726:2019, Seismic Resistance Design Code for Buildings and Other Structures, Jakarta, 2019, pp. 1-238.

[4] Partono W., Prabandiyani S.P.R., Irsyam M. and Maarif S.: Seismic Microzonation of Semarang Indonesia based on Site Response Analysis using 30 m Soil Deposit Model. Jurnal Teknologi, Vol. 78:8-5, 2016, pp. 31-38.

[5] Claudet S.B., Baise S., Bonilla L.F., Thierry C.B., Pasten C., Campos J., Volant P. and Verdugo R., Site effect evaluation in the Basin of Santiago de Chile using ambient noise measurements, Geophys. J. Int., 176, 2009, pp. 925-937.

[6] Johansson J.A.T., Mahecha E.A.L., Acosta A.T.T. and Arellamo J.P.M.: H/V Microtremor Measurements in Pisco, Peru after the 2007 August 15 Earthquake, The 14th World Conference on Earthquake Engineering, Beijing, China, (2008).

[7] Nogoshi, M. and Igarashi, T.: On the amplitude characteristics of microtremor, Part 2, J. Seism. Soc. Japan, 24, 1971, pp. 26-40.

[8] Partono, W., Irsyam M., Asrurifak M., Sari U. C. and Sumarsono: Improvement of Structural Analysis by Modification of Site Response Analysis and Earthquake Force Direction, Int. Journal of Geomate, Vol. 19, Issue 75, 2020, pp. 115-121.

[9] Nakamura Y.: A Method for Dynamic Characteristic Estimation of Subsurface Using Microtremor on The Ground Surface, Quarterly Report of Railway Technical Research Institute, vol. 30, 1989, pp. 25-33.

[10] Sun-Woo M., Palanidoss S., Yunhoa Z., Ganapathiraman V. and Taeseu K.: Bedrock depth evaluation using microtremor measurement in Singapore: empirical guidelines at weathered granite formation in Singapore, Journal of Applied Geophysics, 171, 2019, 103866, pp. 1-9.

[11] *John W. L., Gregory V S., Eric A. W. and James*

S. C.: Estimation of Bedrock Depth Using the Horizontal-to-Vertical (H/V) Ambient-Noise Seismic Method, Symposium on the Application of Geophysics to Engineering and Environmental Problems, September 2008,

[12] Sunaryo, Harti Umbu Mala, and Anom Prasetio, Earthquake Microzonation Study on Batubesi Dam Nuha, East Luwu, South Sulawesi, Indonesia, International Journal of Geomate, Vol 15, Issue 48, 2018, pp. 148 – 154.

[13] Yamanaka M., Hachimura T. and Hasegawa S., Distribution of Landfill by Geophysical Exploration Methods at Illegal Industrial Wastes Disposal Site, International Journal of Geomate, Vol 9 (17), 2015, pp. 1342-1347.

[14] Koesuma S., Ridwan M., Nugraha A. D., Widiyantoro S. and Fukuda Y.: Preliminary Estimation of Engineering Bedrock Depths from Microtremor Array Measurements in Solo, Central Java, Indonesia, Journal of Mathematical and Fundamental Sciences, Vol 49, No 3, 2017

[15] Chun H. K., Chun-Te C., Che-Min L., Kuo-Liang W., Jyun-Yan H., Shun-Chiang C., S-wave velocity structure and site effect parameters derived from microtremor arrays in the Western Plain of Taiwan, Journal of Asian Earth Sciences, Vol. 128, 2016, pp. 27-41.

[16] Ibs-von Seht, M. and Wohlenberg, J.: Microtremors measurements used to map thickness of soft soil sediments, Bulletin of the Seismological Society of America, v.89, 1999, pp.250-259.

[17] Parolai, S., Bormann, P., and Milkert, C.: New relationships between Vs, thickness of sediments, and resonance frequency calculated by the H/V ratio seismic noise for Cologne Area (Germany), Bulletin of the Seismological Society of America, v.92, 2002, pp. 2521-2527.