Development of surface ground motion and spectral acceleration based on modified shear wave propagation analysis

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Development of surface ground motion and spectral acceleration based on modified shear wave propagation analysis

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1. Introduction

The new American code ASCE/SEI 7-16 (Minimum Design Loads and Associated Criteria for Buildings and Other Structures) [1] introduced a different concept for developing surface spectral acceleration especially for site class SE (soft soil). The site specific analysis or shear wave propagation analysis (SPA) shall be performed as an alternate method for obtaining the site factor. The site factors are usually used for developing surface spectral acceleration. The surface spectral acceleration can be obtained by multiplying spectral acceleration at bedrock elevation with the site factor. The development of SPA needs the information of bedrock elevation and soil profiles from the bedrock through surface elevation. The bedrock elevation can be observed using soil boring investigation and will time consuming and expansive. Another method that can be used or is often used for developing or predicting bedrock elevation is microtremor investigation (array or single microtremor). The soil density (γ), shear wave velocity (VS), damping ratio (ξ) and shear modulus (G) for each soil layer above the bedrock elevation are other four parameters used for SPA. The development of SPA for obtaining surface spectral acceleration is difficult for most of the civil engineers in Indonesia, compared to the previous method used or introduced by SNI 1726:2012 [2] and ASCE/SEI 7-10 [3]. This paper describes a comparative

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study for the development of SPA by conducting two different approaches. The first approach (Model-A) is conducted by using predicted bedrock elevation observed from microtremor investigation. However, the second approach (Model-B) is performed using soil boring investigation data. Two methods are introduced in this study, because of the limitation of soil data above the bedrock elevation. The soil boring investigation is usually performed for the foundation design and construction purposes. The final depth of soil boring investigation is usually not equal to the depth of bedrock elevation. The study was performed at the Engineering Faculty of Diponegoro University, Semarang, Indonesia. Figure 1 shows the study area. Three soil boring investigations were performed with maximum 30 metres of depth. The soil boring investigations were stopped at 30 metres of depth, because the maximum standard penetration test (N-SPT) values observed in this area was greater than 60 at 20 - 22 metres below the surface level. The single and array microtremor investigations were also conducted in this area. The bedrock elevation was also observed and predicted at 50 metres below the surface level.

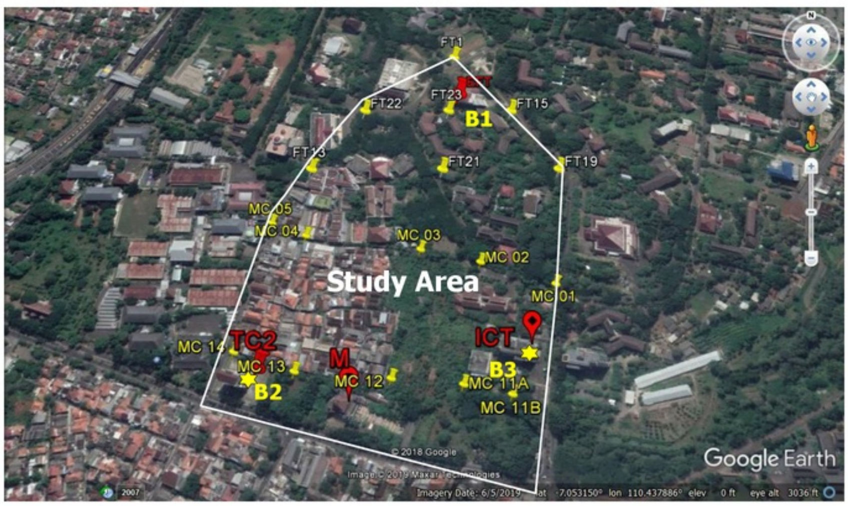

Figure 1. The study area

Figure 2 shows three example results of array microtremor investigation, N-SPT profile and shear wave velocity at the study area. This figure shows that the bedrock elevation can be predicted at 50 metres below the surface level. The hard soil data with N-SPT > 60 were observed at three boring positions B1, B2 and B3. Based on the Vs profile at two points, the rock elevation with Vs > 750 m/sec [2] was predicted at 30 metres below the surface level and the bedrock elevation with Vs > 1500 m/sec [2] was predicted at 50 metres below the surface level. Based on the data observed within the study area, the SPA was developed using two different models 50 metres (Model-A) and 30 metres (Model-B) soil profile models. Because of the limitations of soil or rock data below 30 metres, all data were arranged using the same data obtained from the soil boring investigation B1, B2 and B3.

2. Methodology

The development of surface spectral acceleration and surface ground motion is important for seismic resistance design and evaluation of buildings and other structures. The spectral acceleration can also be developed using SNI 1726:2012 or international code using amplification factor and spectral acceleration at the bedrock elevation. The developing of surface spectral acceleration and surface ground motion needs ground motion data, usually in terms of acceleration time histories. The acceleration time histories can be collected from national and international data base. The ground motion data used for

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SPA can be collected based on the earthquake events close to the building position. The information of seismicity data, for all seismic sources close to the building position, will be collected for SPA [4, 5]. If there is no earthquake data, caused by all seismic sources close to the building position, the data can be collected from other earthquake events by conducting response spectral matching analysis. The modified ground motion, developed based on the spectral matching analysis, can be used for predicting surface spectral acceleration and surface ground motion caused by a specific earthquake, having specific magnitude and epicentre distance. Based on the new Indonesian Seismic Hazard Maps 2017 [6], two important seismic sources are located close to the study area (Lasem fault and Semarang fault sources), having a minimum distance of less than 10 km. Another information described in these seismic maps, is the maximum magnitude (6.5 Mw) that should be taken into account for these two seismic sources. Based on these two information (maximum magnitude and distance), the ground motion data used for SPA for the study area were collected from earthquake events having magnitude ± 6.5 Mw and maximum epicentre distance of 10 km.

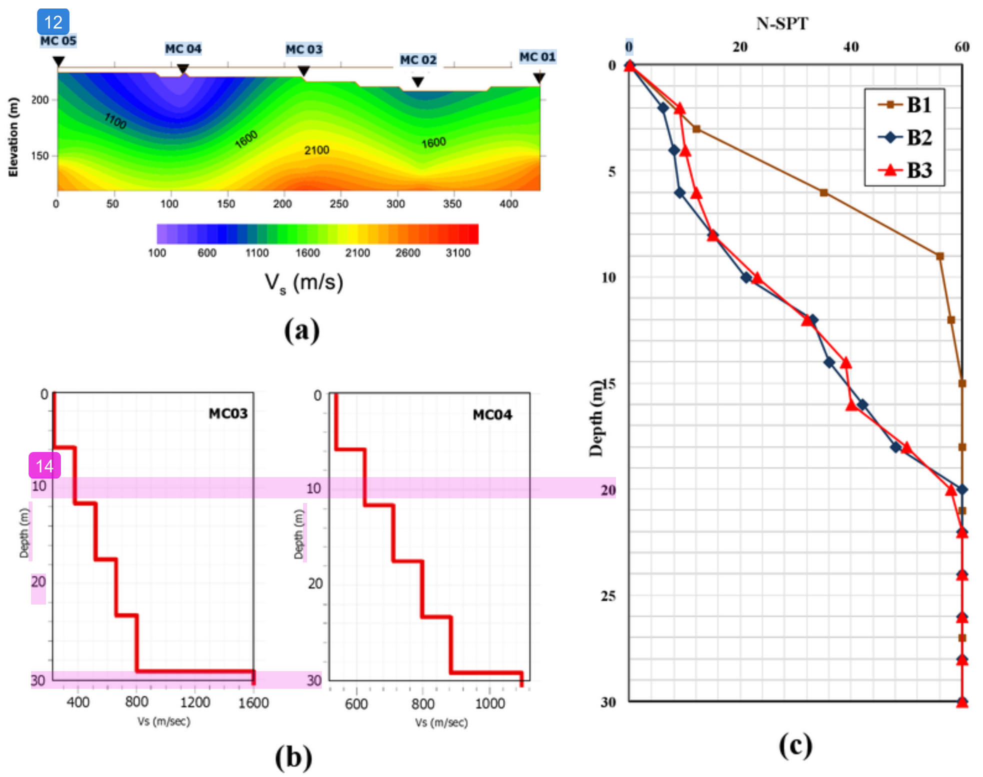

Figure 2. (a) Array Microtremor section MC01 – MC05, (b) shear wave velocity profile collected from different points and (c) N-SPT profile collected from boring no. B1, B2 and B3.

The surface spectral acceleration and surface ground motion for the study area were developed following two basic steps, such as response spectral matching analysis and SPA. The spectral matching analysis was performed for two directions of ground motion North-South (NS) and East-West (EW) directions. Figure 3 shows the spectral matching results for NS and EW directions of ground motion. The SPA is performed by conducting two different models. The soil profile from 0 through 30 metres depth is divided into 5 (five) layers with 6 m thickness for each layer. However, the thickness of soil or rock layer from 30 to 50 metres of depth is divided into two different layers. Figure 4 shows two different models used in this study. The Vs values used for each soil layer were developed using the average N-SPT data [7. 8, 9] from three different boring investigations and average Vs profiles obtained from 16 points microtremor investigation. The soil density used for each soil layer is calculated from the average of three boring investigations. Based on the soil boring investigations, all soil layers from 0-12 metres of depth is sandy silt, 12-24 metres of depth is hard soil and from 24-30 metres of depth is sandstone. Because of the limitation of soil or rock data from 30-50 metres of depth, the same sandstone parameter data were used at this layer.

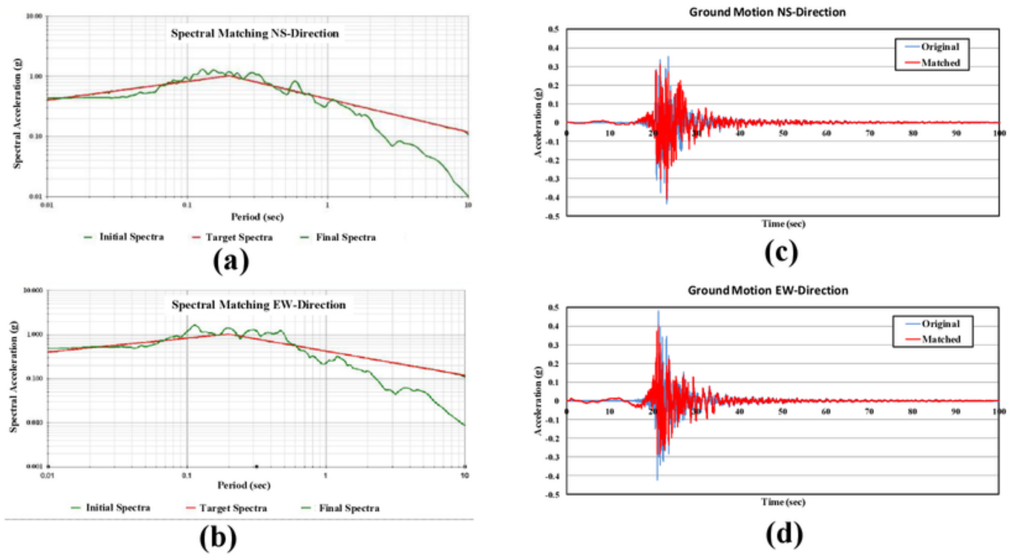

Figure 3. Spectral Matching for (a) NS and (b) EW directions, Original and Matched ground motion for (c) NS and (d) EW directions.

3. Results and Discussions

The development of surface ground motion and spectral acceleration was conducted using two different models of soil profile. Two matched ground motions at the bedrock elevation were used for SPA. The matched spectral acceleration was calculated at the bedrock elevation for both directions of ground motions. A comparative analysis was also performed by comparing the peak ground acceleration (PGA) profiles at each soil layers developed using the two soil models. Figure 5 shows two different spectral accelerations calculated at the surface elevation. The spectral acceleration calculated using Model-A is slightly greater compared to the second model (Model-B). The PGA profiles calculated using two different models also indicated the same results for both models. The PGA profiles calculated using Model 1 are greater than Model-B. The surface PGA difference calculated using both models are 0.1g.

The development of surface ground motion or acceleration time history is also performed using the same two models. Figure 6 shows the surface ground motion calculated using the two models. The ground motion calculated using Model-A is slightly greater compared to the same ground motion calculated using Model-B. Both NS and EW directions calculated using Model-A ere slightly greater than those of Model-B.

The development of surface spectral acceleration and surface ground motion can be simplified by reducing the maximum depth of soil boring investigation (Model B), the time requirement and expenditure, compared to the same requirements developed using Model-A. Based on the PGA profiles, it seems that the second model (Model-B) can be used as a substitute model for developing the surface ground motion.

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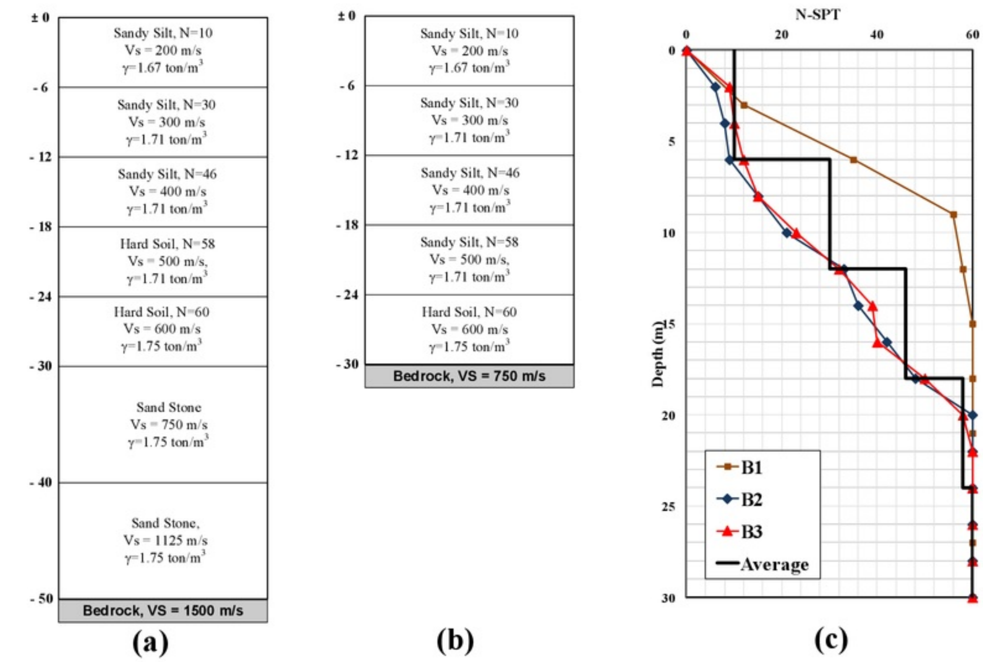


Figure 4. (a) Soil profile model 50 metre, (b) soil profile model 30 metre and (c) N-SPT profile collected from boring no. B1, B2 and B3 and N-SPT 30 metre.

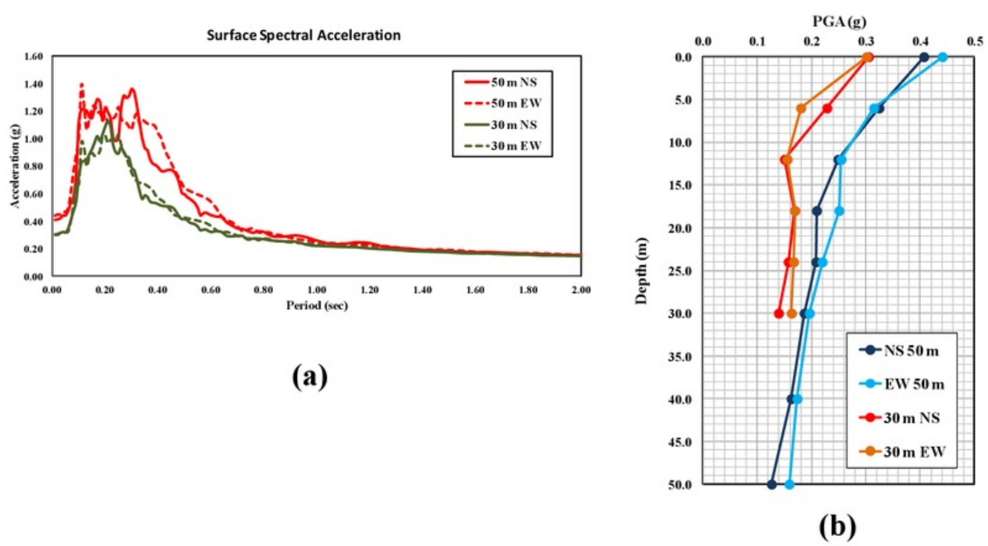
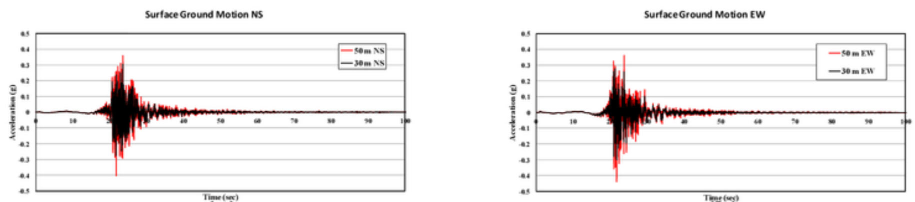


Figure 5. (a) NS and EW direction surface spectral acceleration for Model-A and Model-B and (b) PGA profile for Model-A and Model-B (b).



(a) **(b)**

Figure 6. (a) NS direction surface ground motion for Model-A and Model-B and (b) EW direction surface ground motion for Model-A and Model-B (b)

4. Conclusions

The development of surface ground motion and surface spectral acceleration was performed at the study area based on the shear wave propagation analysis (SPA). The development of surface spectral acceleration and surface ground motion is important for seismic resistance design and evaluation of buildings and other structures. The surface ground motion and spectral accelerations are developed using two different models (50 metre and 30 metre soil model). Three soil boring investigations and 16 points microtremor investigation are performed at the study area. A good correlation between N-SPT and Vs data are observed in the study area for soil data between 0 through 30 metre soil layer.

The surface ground motion and surface spectral accelerations are developed using two direction ground motions (NS and EW). The surface ground motion and surface spectral accelerations are also developed using two models, and the difference of surface PGA calculated using two models is approximately 0.1g. The surface ground motion and surface spectral accelerations calculated using 50 metre soil model is slightly greater compared to the 30 metre soil model. The 30 metre model can be used as a substitute model for developing surface ground motion and spectral acceleration.

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