Vs$_{30}$ Mapping and Site Classification in Surakarta City Based on Multichannel Analysis of Surface Waves Method

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Abstract. The Multichannel Analysis of Surface Waves (MASW) method is one of the non-invasive methods that can be used to determine the shear wave velocity. The shear wave velocity can be obtained from the inversion of dispersion curve of the Rayleigh wave. The surveys have been done at 10 sites in Surakarta city. Active MASW measurements are performed by using the P.A.S.I. Seismograph Mod. 16S24-P. Geophone used as many as 24 channels with threshold frequency is 4.5 Hz of the vertical component and 8 lbs hammer as an active source. Each spread is given once shot point at 5 to 10 meters from the near geophone. The measurement data as a time domain is transformed to frequency domain. The average shear wave velocity up to 30 meters depth is referred as $V_{S_{30}}$. The results show that the distribution $V_{S_{30}}$ of Surakarta between 250 – 450 m/s. Based on the National Earthquake Hazard Reduction Program (NEHRP) classification, these values are classified as C and D class. The highest $V_{S_{30}}$ values at the southwest part (Laweyan site) is 435.7 m/s and the northern part (Banjarsari site) is 411.7 m/s classified as site class C. Meanwhile, the lowest $V_{S_{30}}$ values at the northwest and southeast part (Serengan and Pasar Kliwon sites) classified as D class.

1. Introduction

Surakarta is located in Central Java Indonesia, almost never occured earthquakes disaster. It does not guarantee that Surakarta is safety from earthquake because Surakarta is located between Mount Lawu and Mount Merapi. In addition, there are three faults around Surakarta (Opak fault, Lasem fault, and Kendeng fault) with the distance less than 500 km (impact radius from an earthquake), so Surakarta has high risk potential for seismic disaster. The geology of Surakarta based on Geological Map of Surakarta - Giritontro consists of alluvium, older alluvium, and Merapi’s volcanic rocks [1,2,3,4]. The amplification of ground motion controlled by local geological conditions. In many cases, younger and softer soils has stronger amplify ground motion than older and more consolidated soils [5]. The alluvial area have a low shear wave velocity distribution [6].

In seismic exploration, surface waves are regarded as noise in any required seismic event [7]. Rayleigh wave is one of types of the surface waves that have high signal to noise ratio (S/N) when seismic waves was generated. Rayleigh wave have a retrograde motion and consist of several frequency interval, each of which has its own waves velocity. This phenomenon called dispersion and can be used as a fundamental measuring of shear wave velocity [8,9]. Early 1980 Nazarian introduced a measurement method by a pair receivers to determine the shear wave velocity ($V_s$), this method is called Spectral Analysis of Surface Waves (SASW). The weakness of the SASW method is difficulty in distinguishing signal and noise because it only use a pair of receiver. The multi receiver used to overcome SASW method so obtained data with the quality of the signal that more clearly, this method is known as Multichannel Analysis of Surface Waves (MASW) [7]. The Multichannel Analysis of Surface Waves
method is one of the non-invasive methods that can be used to determine the shear velocity profile [10]. The data acquisition of MASW is easy because the surface wave have high S/N than body wave [11,12].

Shear wave velocity mapping is most important for microzonation studies and earthquake geotechnical investigation [11,13]. The average velocity of shear waves up to 30 meters ($V_{S30}$) is an important parameter in classifying sites for recent buildings and indicator of amplification sites response (considerable influence on the ground motions) [14,15]. The United States Geological Survey (USGS) also provides global $V_{S30}$ map, it has given more information about site conditions [16]. Therefore it is necessary to analysis a research of $V_{S30}$ map in Surakarta city.

2. Methods
The data were collected at 10 locations in Surakarta. The acquisition of data has been performed using the P.A.S.I. Seismograph Mod. 16S24-P with 24 geophones of vertical component (threshold frequency 4.5 Hz). The geophones spacing is 4 meters in a straight line and source offset is 5 to 10 meters (dependent environment noise). The source is generated by striking hammer (8 lbs) to base – plate (metal). Every sites generated waves at one point of the source with 5 times stacking.

![Geological Map of Surakarta](image)

**Figure 1.** Geological map of Surakarta and locations of MASW measurements in Surakarta (modified from Surono, *et al*. [1]).

$\bar{V}_s$ is the average shear wave velocity (upper 30 meters defined $V_{S30}$), $h_i$ is a layer thickness (0 to 30 meters) and $V_i$ is the shear waves velocity of n layers. $\bar{V}_s$ is calculated in the equation :

$$\bar{V}_s = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} V_i}$$

(1)
Based on the $V_{s30}$ values, the site can be defined by The National Earthquake Hazard Reduction Program (NEHRP) classification shown in Table 1 [17]. Furthermore, spatial mapping using Krigging interpolation technique to get $V_{s30}$ map.

Table 1. Site classification by NEHRP [17].

| Soils Classification | Soils Profile | $V_{s30}$ (m/s) |
|----------------------|---------------|-----------------|
| A                    | Hard Rock     | $V_{s30} > 1500$|
| B                    | Rock          | $760 < V_{s30} < 1500$|
| C                    | Soft Rock and Very Dense Soils | $360 < V_{s30} < 760$|
| D                    | Stiff Soils   | $180 < V_{s30} < 360$|
| E                    | Soft Soils    | $V_{s30} < 180$|

3. Result and Discussion
The analysis result of dispersion curve at each site shown in Figure 4. The difference of dispersion curves is indicated the differences in the subsurface. The inversion of dispersion curves to get the 1D shear wave velocity profile. The $V_{s30}$ calculated by Equation, values of each site shown in Table 2.
Figure 4. Dispersion curves.
Table 2. Data of result $V_{S30}$ and sites classification based on NEHRP.

| Location code | Easting (m)  | Northing (m) | $V_{S30}$ (m/s) | Site Class |
|---------------|--------------|--------------|-----------------|------------|
| A1            | 478774       | 9164182      | 326.4           | D          |
| A2            | 476346       | 9162757      | 435.7           | C          |
| A4            | 475780       | 9165057      | 264.8           | D          |
| B1            | 482546       | 9166292      | 386.2           | C          |
| B2            | 479024       | 9166376      | 292.9           | D          |
| B3            | 480050       | 9166212      | 411.7           | C          |
| B4            | 485264       | 9165108      | 329.3           | D          |
| C2            | 482458       | 9162811      | 275.7           | D          |
| C4            | 481524       | 9160582      | 257.4           | D          |
| C5            | 479078       | 9161850      | 307.2           | D          |

Figure 5. 1D shear waves velocity profile.
The 2D shear wave velocity mapping for 10 points measurement MASW shown in Figure 5. The interval $V_{S30}$ of Surakarta city is 250 m/s – 450 m/s. From this figure show that the highest of $V_{S30}$ is the directions of southwest part at site A2 (Laweyan site) has 435.7 m/s and the northeast part at site B3 (Banjarsari site) and B1 (Jebres site) have 411.7 m/s and 386.2 m/s and the both of them categorized as C class site. The lowest of the west part at site A4 (Laweyan site of north part) has 264.8 m/s and the south part at site C4 (Pasar Kliwon site) has 257.4 m/s s and the both of them categorized as D class site. The high $V_{S30}$ means that the site has thin sediment and low factor amplification, the low $V_{S30}$ means that the site has thick sediment and high factor amplification. The distribution of site classification shown in Figure 6. Generally, sites with class D have amplification factor more strongly than class C.

![Figure 6. $V_{S30}$ map of Surakarta based on MASW measurement.](image)

![Figure 7. Site Classification map of Surakarta by NEHRP classification.](image)
4. Conclusions

This result shows that Surakarta can be devided as two classes based on shear wave velocity by NEHRP. The highest $V_{s30}$ values at the southwest part (Laweyan site) is 435.7 m/s and the northern part (Banjarsari site) is 411.7 m/s classified as site class C. Meanwhile, the lowest $V_{s30}$ values at the northwest and southeast part (Serangan and Pasar Kliwon sites) classified as D class. The low $V_{s30}$ values indicates that those locations a has higher amplification factor and the high $V_{s30}$ values indicates that those locations a has lower amplification factor. Based on this research we have recommendation for government or related institution, every building construction must consider site classes to reduce earthquake hazard.

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