Shear Wave Velocity ($V_s$) at Reactor Building, Experimental Power Reactor Indonesia

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Abstract. Experimental Power Reactor (RDE) is a Gen IV Reactor type with Hydrogen Gas Cooler. Despite this type of reactor has high safety performance, earthquake hazard should be demonstrated. Detail Engineering Design Activity on RDE has been conducted in the past 3 years. In the end of this phase, preliminary parameter design such as shear wave velocity ($V_s$) should be defined. This parameter correlates with subsurface condition which has high uncertainty. This study is conducted in order to estimate values of $V_s$. Generally, the data collection is carried out through geotechnical investigation but this method cost more time and resources. In the recent decades, another method has been widely introduced which is geophysical passive source Microtremor Array Measurement (MAM) with Spatial Auto Correlation (SPAC) method. This method can be used to estimate values of $V_s$ and can be used as preliminary reference to define the position of borehole before construction phase getting started. The result shows, the location of reactor building is estimated to have 5 soil layers with varying $V_s$ value. The $V_s$ value of the first soil layer is about 152 m/s started from the surface to 8 m depth. The second soil layer has 169 m/s $V_s$ value started from 8 m to 20 m depth. The third soil layer, started from 20 m to 36 m depth, has 384 m/s $V_s$ value. The next layer as the fourth layer of soil, started from 36 m to 70 m depth with a value of $V_s$ around 526 m/s. The last soil layer with a depth 70 m to 100 m, has $V_s$ value of 667 m/s. Based on these $V_s$ value estimation from surface to 30 m depth, the average value of the shear wave velocity ($V_{s,30}$) is m/s. Thus, reactor building is located in the site class SD with medium soil categories according to SNI 1726-2012. The foundation design and excavation planning phase, this information is needed.

Keyword: RDE, shear wave velocity, SPAC

1. Introduction

The Serpong PUSPIPTEK area in South Tangerang, Banten Province is planned as the location of the Experimental Power Reactor (RDE). RDE is a Gen IV Reactor type with Hydrogen Gas Cooler. The site permits of this reactor are granted from the Regulatory Body (BAPETEN) in January 2017. The site evaluation phase was conducted for two years by considering several aspects including seismic, volcanic, geotechnical and foundation, meteorological, hydrological, human-induced events, dispersion and distribution of population aspects [1].

Despite RDE has high safety performance, earthquake hazard should be demonstrated. Considering the site is located on the high seismicity area, which is strongly influenced by the Cimandiri fault, so it
needs an in-depth study of the site's acceptance of all external hazards, especially seismic aspects. In order to assess seismic hazards, the local site effects should be addressed.

Detail engineering design activity on RDE has been conducted in the past three years. At the end of this phase, preliminary parameter design, such as shear wave velocity ($V_s$) should be defined. This parameter correlated with the subsurface condition, which has high uncertainty. $V_s$ is an important parameter in calculating the amplification of the site caused by an earthquake. This earthquake generates seismic waves that pass through the ground so-called ground shaking. Two significant factors affect the level of ground shaking, which are the softness of the surface lithology and the thickness of surface sediment [2], [3].

Estimated values of $V_s$ can be obtained from analysis of geotechnical or geophysical data. There are several methods in order to get these data. For geotechnical data can be obtained by performing geotechnical surveys which considered as direct methods such as geotechnical core drilling. However, this direct method will require a lot of time and money.

Besides the direct method described above, $V_s$ can also be obtained from the geophysical survey. This survey is considered as indirect methods where consume less time and money. As indirect methods, it used two kinds of sources, which are active and passive sources. The active source such as Multi channel Analysis of Surface Wave (MASW), crosshole and downhole seismic testing while the passive source referred as Microtremor Measurements (MM) and Microtremor Array Measurement (MAM). These two kinds of measurements are widely used [4].

The fundamental resonance frequencies of the sites were obtained from the MM using Horizontal to Vertical Spectral Ratios (HVSR) method. This method records the ambient noise and estimates the ratio of the vertical component Fourier spectrum to the horizontal component. Regions that have low to moderate seismic activities recommended utilizing this method [5]. While the phase velocities of the Rayleigh waves were estimated from the MAM using the spatial autocorrelation (SPAC) method where calculates the dispersion curves [6]. The present study is carried out by using MAM. This study aims at calculating the value of $V_s$ as an important parameter in understanding site characteristics [7]. SNI 1726-2012 regulates the site class where the value is determined based on the average value of the shear wave velocity for a depth of 30 m ($V_{s,30}$) [8].

2. Geological Setting

This RDE site is located on the Sunda Mainland, between the Eurasian plate with a southeastward movement of 0.4 cm/year and the Indo-Australian Ocean plate with a northward movement of 7 cm/year [7]. These two plates, together with the Pacific plate, interact by producing one of the most complex active tectonic zones on earth. This is indicated by the presence of volcanic activity and earthquake that is relatively high enough. Seismic records say that there have been several major earthquake events with magnitudes above 7 (M> 7). An example is an earthquake with a magnitude of 9.1 that occurred in the Indian Ocean on 26 December 2004[1], [7], [9].

The kinematic scenario or the real velocity of the plate vector provides information on the relative motion of the Sunda Land and its surroundings shown in Figure 1. Geologically, material in the area study is a young volcanic product from Mount Gede Salak. The underlying stratum of this location is the Serpong Formation ($T_{ps}$), the Bojongmanik Formation ($T_{mh}$), the Genteng Formation ($T_{pg}$), Alluvial ($Q_s$), Alluvial Fan ($Q_{av}$) and Young Mountain Rocks ($Q_{v1}$) as can be seen in Figure 2.
Figure 1. Map of Sundanese and Surrounding Kinematic Scenarios [1]

Figure 2. Regional Geological Map Nearby Area Study [9]

The detail information of each formation is explained as follows, the Serpong Formation (T_{pp}) is composed of coarse tuff interruptions with rock conglomerates, bright white, open, good sorting, dominant matrices, 2-5 cm rock fragments, rough tuff matrices, alternating with coarse tuffs, gradual contact, having direction and slope of the N 130 E bedding layer/7.

The Bojongmanik Formation (T_{mb}) is composed of sandstone, claystone and limestone intervals. Limestone, white gray, bright, very hard, crystalline, alternating with sandstone limestone, there are sandstone inserts, dark gray, carbon, medium to coarse sand, have a thickness of about 20 cm, have a direction and slope layer N 35° E/20 and in some places, there is a thin layer of carbon or lignite. The Genteng Formation (T_{pg}) is dominated by volcanic rocks, and their weathering is very distinctly red to brownish red and shows horizontal bedding as a result of the repetition of volcanic material deposited on land or litoral areas. This formation is composed of tuffs, dark browns, smooth tuffs, rough and lapilli tuffs, horizontal layered, between coarse and fine ones, scoria and pumice, medium-high weathering.

Alluvial (Q_{a}) is founded along the Cisadane River and surrounding streams with piles of material such as clay, silt, sand, gravel, crust, and lumps. Alluvial fan (Q_{av3}) is a material from the deposition of volcanic material that previously existed and deposited (rework) flowing from south to north following the sloping topography. Alluvial fans are composed of conglomerates, tuffs, and sandstones.

Young mountain rocks (Q_{v1}) are composed of volcanic breccias, black-gray, dominant matrix, components of the crust, lumps, monomict, consisting of basalt, poor sorting, medium porosity and tuff, yellowish-reddish, smooth, medium hardness.
3. Methods
The methodology in this study is divided into three stages, which are data acquisition, analysis, and interpretation. The data collection phase is carried out through a geophysical investigation using a passive source, namely the measurement of MAM by the SPAC method. Furthermore, the value of Vs can be predicted at the analysis stage. These results will be compared with similar parameters from the results of previous studies conducted, namely geotechnical and geophysical investigations. Geotechnical investigation is carried out with 100m deep geotechnical drilling, which recorded as a bore log with a detailed description of each layer of soil. Geophysical investigations consist of investigations with active and passive sources. Active source investigation consists of cross hole and down hole seismic testing. From these two tests, parameter values of Vs are predicted. Whereas passive source investigations which is MM. MM is able to calculate the predominant frequencies that correlate directly with the value of Vs.

The final stage is the interpretation stage, which interprets and correlate all the data as so get the final parameter value of Vs. Figure 3 illustrates the flow chart for the shear wave estimation in this study.

3.1. A. SPAC Method
Microtremor is a very small and continuous ground vibration from various sources of vibration in the form of artificial disturbances and natural resources. Artificial disturbances in the form of human activities, industrial machinery and so on, while natural resources can be in the form of wind and sea waves. This ground vibration has an amplitude displacement of 0.1-1 microns and an amplitude velocity of 0.001-0.01 cm/s [10]. The recorded data generated from ambient noise can provide a picture of the ground spectral response of the area study [11]. In hard rocks, the motion of particles in the horizontal component (H) and vertical component (V) approaches the same value, whereas in soft rocks the horizontal component experiences reinforcement.

![Figure 3. The Flow Chart for The Shear Wave Estimation in This Study](image-url)
Mathematically, the basic frequency of a location can be calculated through the comparison of H with V of the natural vibrational spectrum, where \( \omega \) is the angular frequency, S is the secondary wave, NS is the north-south direction and EW is the east-west direction as written in equation 1[12].

The SPAC method utilizes a circular array configuration. Microtremor measurement data from each of these sensors are still in the form of time domain, so it needs to be transformed into the frequency domain [13], [14], [15]. The correlation between time domain and frequency domain are calculated for each pair of the sensor. The harmonic waves of frequency of microtremors by the velocity waveform and which are observed simultaneously at the center of the array and at the point of the array, the SPAC function can be determined as follows [16]:

\[
\emptyset(r, \theta, \omega) = \bar{u}(0,0,\omega,t).u(r,\theta,\omega,t)
\]  
(1)

where \( u(t) \) is the average velocity of the waveform in the time domain. The SPAC coefficient is defined as the average of autocorrelation function in all direction over the circular array, which calculated as follows [16]:

\[
\rho(r, \omega) = \frac{1}{2\pi \times \emptyset(0,\omega)} \int_{0}^{2\pi} \emptyset(r, \theta, \omega) d\theta
\]  
(2)

where \( \omega \) is the SPAC function at the center, of the circular array. The equation number 2 can be expressed as [16]:

\[
\rho(r, \omega) = J_0 \left( \frac{\omega \times r}{c(\omega)} \right)
\]  
(3)
where \( J_0(x) \) is the zero-order Bessel function of the first kind and \( c_\omega \) is the phase velocity at frequency \( \omega \). The SPAC coefficient \( r_{\omega} \) is calculated by using the Fourier Transform of the observed microtremors, which is in the frequency domain [16]:

\[
\rho(r, \omega) = \frac{1}{2\pi} \int_0^{2\pi} \frac{Re[S_{cx}(\omega, r, \theta)]}{\sqrt{S_c(\omega)} \times S_x(\omega, r, \theta)} d\theta
\]

where \( S_c(\omega) \) is the power spectral densities of microtremors at site and \( S_x(\omega, r, \theta) \) is the power spectral densities of microtremors at site, while \( S_{cx}(\omega, r, \theta) \) is the cross-spectrum between ground motions at site C and site X.

4. Result And Discussion

4.1. Microtremor Array Measurement (SPAC method)

Geologically, the reactor area and its surroundings are in the Serpong Formation (Tpss), Bojongmanik Formation (Tmb) and Alluvial Deposition Formation (Qav). The Serpong Formation consists of sedimentary rocks that have been deposited by volcanic deposits deposited in a swampy river environment, in the form of tuffs and sandstone conglomerates, while the Bojongmanik Formation where DH11 is located, which consists of sedimentary rocks deposited in the lagoon-marine environment in the form of sandstones, claystone and a little limestone, which is relatively harder than sedimentary rocks resulting from volcanic deposits [17],[18].

Physically, the presence of tuff material and rock fragments in the Serpong Formation will cause rocks with lower acoustic impedance than sedimentary rocks in the Bojongmanik Formation, so that they will have relatively lower Vs values as well.

Phase velocity can be estimated by looking at the pattern of SPAC coefficient values or coherence in the plot of the phase velocity values at each frequency. The pattern of SPAC coefficient values in the study area is shown in the dispersion curve graph, as can be seen in Figure 5 (a). Based on the results of the dispersion curve, the phase velocity values for each frequency can be generated. In the study area, phase velocity values were obtained in the frequency range of 1.56 hz to 6.25 hz. Phase velocity values are found in the range 188 m/s to 427 m/s. The value of phase velocity is relatively decreased with respect to the magnitude of the frequency value because in general, the increasing depth of rock will be denser and harder. The denser the rock will increase the value of the phase velocity [19].

![Figure 5. (a) Dispersion Curve (b) Model of Shear Waves Velocity Profile (V_s) DH-11](image-url)
The shear wave velocity can be modeled from the dispersion curves that have been obtained. The value of the phase velocity at each frequency can be inverted into the value of the shear wave velocity at each depth. Figure 5 (b) illustrates the shear wave velocity profile model in DH11. The stratigraphic column at this measurement point is modeled as five layers of soil with $V_s$ values varying from 190 m/s to 667 m/s. The first layer can be found at a depth of 8 m, which has value of $V_s \leq 175$ m/s. The second layer is started from a depth of 8 m to 20 m while the third layer is started from a depth of 20 m to 36 m. These two layers are considered as very solid soil layer which have value of 350 m/s $\leq V_s \leq 750$ m/s.

The last two layers which are the fourth and fifth layer, it has value of $V_s \geq 600$ m/s. From this analysis, the engineering bedrock with $V_s \geq 760$ m/s cannot be found yet to a depth of 100 m. The analysis founds that the average value of the shear wave velocity for a depth of 30 m ($V_s \_{30}$) is 286.6 m/s. According to the Indonesian National Standard (SNI) 1726-2012 in site classification, DH11 as the location of the reactor, is located in the site class SD with medium soil categories. This site has features in term of value of 175 m/s $\leq V_s \leq 350$ m/s and 15 $\leq N_{SPT}$ value $\leq 50$.

4.2. Verification value of shear wave velocity

The value of $V_s$ from MAM analysis results are then correlated with the predominant frequency from MM. Then after that, it compares with the value of $V_s$ from the crosshole, downhole testing and geotechnical drill that already done.

As site area measurement, a total of 15 microtremor measuring points were conducted at the site with intervals ranging from 100-300 m using the OYO brand McSEIS-MT NEO type seismometer. The results of the HVSR method show that the predominant frequency values vary from 3.06 Hz to 23.27 Hz. The plot of the predominant frequency value distribution shows the highest predominant frequency value is at the southern part of the site, while the lowest predominant frequency value is at the western part of the site as can be seen in Figure 6.

The description of the soil at the southern part of the site is a tertiary rock zone composed of hard rock. From the geological point of view, this area belongs to Bojongmanik Formation ($T_{mb}$), which is composed of intertwined sandstone, claystone and limestone. On the other hand, at the western part of the site with the lowest predominant frequency value, is accounted as the Alluvial Fan ($Q_{av}$) which is a deposited material from volcanic material composed by conglomerates, tuffs and sandstone. This means that this area has a thicker sedimentary layer compared to other areas. According to SNI 1726-2012 for the soil classification, the western part of the site is classified as soil types III, meaning that the soil is an alluvial rock formed from delta, mud or other very soft sedimentation [9].

Figure 6. Distribution of predominant frequencies at the RDE Site

The predominant frequency does not only depend on the sediment thickness but also controlled by the value of $V_s$ [20]. As we can see at Figure 6, the predominant frequency of DH11 is found at value of 8.75Hz. Based on the soil classification from analysis microtremor, this soil is considered as Type 2
which has diluvium rock with a thickness of 5 m and consists of sand-gravel, sand hard clay and loam. The sediments are predicted to be 5 up to 10 m. This condition correlates with the result of MAM which is founded the value of $V_s$ relatively low compare to the area with no sediments with higher predominant frequency value.

Borehole data was collected in the previous survey by conducting soil investigation and geophysics surveys. Soil investigation through geotechnical core drilling is conducted using the rinse method which is generally well known for its use in soils and rocks. The purpose of the geotechnical core drilling is to determine the condition of the subsurface soil layer. This information is very important in order to perform geotechnical hazard analysis. DH11 is a geotechnical core drilling point as the center of the reactor building with 100m of depth. The position and result of DH11 core drilling that stored in the core box can be seen in Figure 7 (a) and (b). As the drilling process kept up, SPT testing and sampling were taken using the undisturbed method. The results of the geotechnical core drill are a description of the core drill that will be used in making the stratigraphy. Then it recorded into the borehole log as shown in Figure 7 (c).

Figure 7. Soil Investigation at Reactor Building (a) Map of Geotechnical Core Drilling (b) Core box of DH11 (c) Borehole log of DH11

Geophysics surveys in term of crosshole and downhole seismic testing is conducted in order to estimate the value of shear wave velocity. Figure 8 shows the comparison of shear wave velocity from the field measurements which are MAM, crosshole and downhole seismic testing.

Figure 8 illustrates the shear wave velocity profile from various testing methods at each soil layer. The soil stratigraphic column in DH11 is divided into five layers of soil. In general, the mean value of $V_s$ at each soil layer from the MAM results appears to have the same pattern compared to the value of $V_s$ from the crosshole and downhole testing.
The MAM result shows that the first layer only up to 8 m depth while the second layer is founded at depth of 8 m to 20 m. These two layers, from the surface to 20 m of depth, is interpreted as a soft sediment layer that consists of loose sediment. Because of the limitation of MAM especially for the shallow zone, the crosshole data is mostly used for the first two layers of $V_s$ interpretation. In the third layer, from 20 m to 37 m of depth, the MAM result and crosshole data are quite similar with $V_s$ value of 384 m/s. This layer was interpreted consists of soft rocks that have relatively low $V_s$. In the fourth and fifth layer, the crosshole data is rather unstable with many $V_s$ lense. Therefore, the MAM results show that these layers have relatively stable $V_s$. For the last two layers, the interpreted $V_s$ layers have value of 526 m/s and 667 m/s respectively. The value was obtained from the crosshole data normalization with the MAM data. As for the fifth layer, the MAM results are in accordance with the downhole data, thus considered to give a better interpretation. Therefore, the MAM $V_s$ result was chosen for this layer. This interpretation also implies that the MAM gives better results in the depth zone analysis.

MAM is not only able to be used as a preliminary reference in order to define the value of $V_s$ of reactor building which on the foundation design and excavation planning phase, but also this information is needed to choose the position of borehole before construction phase getting started.

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