Analysis of shear wave velocity on rocks using microtremor refraction method (ReMi) in Watatu Village, South of Banawa, Donggala Regency

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Abstract. The analysis of shear wave velocity on rocks in Watatu, South of Banawa, Donggala Regency using Microtremor Refraction Method (ReMi) has been conducted. The purpose of this research is to analyze the propagation velocity of shear wave on rocks layers up to 30 m in depth and to know the type of rock layer profiles in the study location. The method used was Microtremor Refraction using Surface Wave Analysis Wizard software and WaveEq software. The results showed that the rocks of trajectory 1 and trajectory 3 were classified into type E soft soil type with the respective including Vs30 values of 127.8 m/s for trajectory 1 and 98.9 m/s for trajectory 3. Then for trajectory 2 and trajectory 4 are classified into D type rocks i.e medium soil types with Vs30 values respectively on Track 2 of 235.1 m/s and for Lane 4 of 196.9 m/s.

1. Introduction

Watatu Village is the capital of South Banawa District of Donggala Regency which will grow rapidly in future. Currently, the existence of buildings that have been established is one of the efforts to improve economics of indicators and offices. The rapid development was observed in Watatu Village starting from the development of offices, schools and also the development of health facilities and infrastructures. In fact, the earthquake often occur in this area. So, it fully need good construction planning in order to avoid damage of these infrastructure facilities.

The damages caused by the given energy of disaster is produced by the plate movement. This caution needs to be considered for development planning in future, i.e earthquake-resistant building. The process is strongly influenced by the rock layer condition and the location where the building being built. As it is known that the vibrations caused by the earthquake tend to enlarge in layers of soft rock compared to hard rock layers or solid.

Nurrahmi et al in their research in Kelurahan Talise said that only layers of rock to a depth of 30 m only determine the magnification of earthquake waves [1]. The value of shear wave velocity up to 30 meters depth (Vs30) is used to determine the geotechnical parameters in the infrastructure development. Some important parameter can be obtained using this method, such as classification and type of rock types beneath the surface. As expressed by [2], Vs30 values can also be used in determining the earthquake resistant standard. Muzli et al has also conducted the research on Vs30 measurements using the Multichannel Analysis of Surface Wave (MASW) method [3]. Vs30 values provide ground surface classification information up to 30 meters depth. They found that the city center of Yogyakarta has a relatively high risk of wave amplification with Vs30 value ranging from 115-175 m/s.
One of the geophysical methods that can detect wave velocities up to 30 m depth (Vs30) is the microtremor refraction method. This method records the propagation of shear waves that propagate beneath the surface using sensor to detect natural wave sources. In addition, this method is more effective and can cover large area. As a result, the measurements time can be short with a good results [4]. These properties is the reason using the microtremor refraction seismic method (ReMi) in order to know the layers of subsurface rock type in Watatu Village.

Based on the Geological Maps Review of the Sheet of Palu, it found that the study site and its surroundings is composed of the Alluvium Formation and the Coastal Deposition, the lithology of Molasa Celebes Formation (Sarasin and Sarasin), Tinombo Formation lithology, and the lithology of intrusion rock formations) [5]. The Alluvium Formation lithology cover gravel, mud sand and limestone coral. The lithology of the Molasa Celebes Formation (Sarasin and Sarasin) is consist of conglomerate, sandstone, mudstone, limestone-coral and napal (especially limestone). The lithology of the Tinombo Formation are shale, sandstone, conglomerate, volcanic rock, limestone and chisel, referred to as filit, slate and quartzite, close to intrusions (mainly volcanic rocks). The intrusion rock formations are granite, granodiorite. The geological condition of the research location can be seen on the geological map of the study area shown in figure 1.

![Figure 1. Geological map of the study area](image)

The seismic wave is a wave that travels through the earth. This wave propagation depends on the elasticity of the rock. There are seismic waves that propagate through the earth's interior called body wave and some are propagating through the surface of the earth called surface wave [6]. The speed of seismic wave propagation is determined by the characteristics of the layer in which the wave is propagating. The speed of the seismic waves is influenced by the stiffness and coating density as the medium of wave propagation. Differences in the characteristics of the layers in which the waves propagate may indicate the presence of seismic wave velocity variations in different directions. The difference of wave velocity toward direction can be caused by several factors, namely mineral
composition, fracture, pores and rock mineral crystallography [7]. In Table 1 we can see the values of the primary wave velocity (P) and the shear wave (S).

**Table 1. Velocity from primary wave and Shear wave some material [8].**

| No | Material            | Velocity (km/sec) |
|----|---------------------|-------------------|
|    |                     | P Wave | S Wave       |
| 1  | Steel               | 6.10   | 3.50         |
| 2  | Concrete            | 3.60   | 2.00         |
| 3  | Granit              | 4.50-6.50 | 3.50-3.80 |
|    | Basalt              | 5.00-7.00 | 3.60-3.70 |
| 4  | Sand (no saturation)| 0.20-1.00 | 0.08-0.40  |
| 5  | Sand (saturation)   | 0.80-2.00 | 0.32-8.80  |
| 6  | clay                | 1.00-2.50 | 0.40-1.00  |
| 7  | Alluvium            | 1.50-2.50 | 0.12-3.60  |

In a solid medium, shear waves are capable of traveling at speeds between 3-4 km/sec. As it travels below the surface, the shear waves provide a shear strain on the material it passes [9], while the secondary wave velocity can be written into equation 1.

\[ V_s = \frac{\mu}{\sqrt{\rho}} \]  \tag{1}

Vs30 is a detectable shear wave velocity at a depth of up to 30 m from the surface. According to [2], this Vs30 value can be used in the determination of earthquake resistant building standards. Generally, the shear wave velocity up to 30 m from the surface is called Vs30. Vs30 value is used to determine rock classification based on vibration strength of earthquake due to local effect and used for purposes in earthquake resistant building design. Vs30 is the most important and most used data in geophysical engineering to determine the characteristics of the subsurface to a depth of 30 meters.

According to Wangsadinata only layers of rock to a depth of 30 m only determine the magnification of earthquake waves [10]. Vs30 value can be determined by using equation 2

\[ V_{s30} = \frac{\sum_{i=1}^{m} t_i}{\sum_{i=1}^{m} t_i / V_{di}} \] \tag{2}

Knowledge of the characteristics or properties of rocks is needed to analyze the dynamic nature of the rock, so that rock stiffness and rock shear strength can be known, by measuring the shear wave velocity to a depth of 30 m. Classification of rock types based on mean shear wave velocity up to 30 m depth (Vs30) can be seen in table 2.
2. Methods
The study was conducted in Watatu Village, South Banawa District, Donggala District. The study sites are located at 119° 34' 45" - 119° 35' 15" BT and 0° 52' 30" - 0° 52' 46" LS based on Satellite Imagery Map (2017). The research position is at an altitude of 14 meters to 26 meters above sea level.

The tools and materials used in this research that are Seismic Geometric ES-3000, Global Positioning System (GPS), Software of Surface wave analysis wizard and software waveEq, geological map and map of satellite imagery 2017.

| Type Rock | Rock Profile          | Vs30        |
|-----------|-----------------------|-------------|
| A         | Hard Rock             | > 1.500 m/s |
| B         | Rock                  | 760-1.500 m/s |
| C         | Very Dense Soil and Soft Rock | 360-760 m/s |
| D         | Stiff Soil            | 180-360 m/s |
| E         | Soft Soil             | <180 m/s    |

Source: [11]

The measurement point determine based on the environmental conditions at the research location. The measurement point were made on 4 trajectories on the locations where large buildings will be constructed. Data obtained from field measurements are time and distance which is processed by using Surface wave is analyzed using wizard software and waveEq software. The results of wizard software are frequency and wave phase. While the Surface waveEq software result depth and later wave velocity of this cross-sectional model will be calculated using equation 2 to obtain Vs30 value, rock type and profile type.

3. Result and Discussion
The recorded data in the time domain is converted to the frequency domain by using the Fourier transform to generate dispersion curves. Dispersion waves occur as the wave propagation process has different speeds what passing through the material under surface. Result of dispersion curve shows that the phase velocity increases linearly with frequency.

The dispersion curve was further inverted using the WaveEq software to obtain the profile of shear wave velocity in the subsurface by analysing the velocity to determine the rock type and classification based on the shear wave velocity value. The accuracy level can be seen on Root Mean Square Error (RMSE). The Error value obtained was 7%, where if smaller error value indicates that the obtained result is free of noise.

From the result of shear wave velocity profile (figure 2) the total thickness and the depth that can be obtained for each layer to a depth of 30 m. By this profile the type of each layer can also be determine.
Figure 2. Shear wave velocity model at Line-1

In figure 3 the results of shear wave velocity profile can be obtained thickness and depth which can produce shear wave velocity up to 30 m in depth.

Figure 3. Shear wave velocity model at trajectory 2
Figure 4. Shear wave velocity model at trajectory 3

From figure 4 produces thickness and depth to be obtained value of shear wave velocity up to the depth of 30 m. At this speed profile can also determine the layer obtained.

Figure 5. Shear Velocity model at trajectory 4

From the result of shear wave velocity profile in Figure 5 can be explained that it yields the total thickness and the depth obtained for each layer is up to a depth of 30 m. This profile can also determine the type of layer obtained.

From each trajectory it is obtained the model of shear wave velocity and different layer thickness, where 5 and 3 layers are obtained in trajectory 1 – 3 and trajectory 4, respectively. The value of shear
wave velocity at the depth of each trajectory can be seen in Table 1. For the result Vs30 value can be seen in Table 3.

Table 3. Result shear velocity versus depth in the trajectory 1 to trajectory 4

| Trajectory | Layer | d (m)   | h (m) | Vs (m/s) | Vs30 (m/s) |
|------------|-------|---------|-------|----------|------------|
| 1          | 1     | 0.0 - 1.9 | 1.9   | 100      |
|            | 2     | 1.9 - 5.5 | 3.6   | 109      |
|            | 3     | 5.5 - 9.7 | 4.2   | 120      |
|            | 4     | 9.7 - 26.2 | 16.5  | 135      |
|            | 5     | 26.2 - 30 | 3.8   | 148      | 127.8      |
| 2          | 1     | 0.0 - 1.9 | 1.9   | 120      |
|            | 2     | 1.9 - 4.2 | 2.3   | 200      |
|            | 3     | 4.2 - 9.8 | 5.6   | 250      |
|            | 4     | 9.8 - 26.1 | 16.3  | 290      |
|            | 5     | 26.1 - 30 | 3.9   | 180      | 235.1      |
| 3          | 1     | 0.0 - 1.9 | 1.9   | 55       |
|            | 2     | 1.9 - 5.7 | 3.8   | 178      |
|            | 3     | 5.7 - 9.8 | 4.1   | 65       |
|            | 4     | 9.8 - 26.1 | 16.3  | 112      |
|            | 5     | 26.1 - 30 | 3.9   | 99       | 98.8       |
| 4          | 1     | 0.0 - 1.9 | 1.9   | 149      |
|            | 2     | 1.9 - 5.5 | 3.6   | 190      |
|            | 3     | 5.5 – 30  | 24.5  | 203      | 196.9      |

The results of data processing obtained can be interpreted the relation between subsurface rock layers, shear wave velocity and depth. For trajectory 1, the value of shear wave velocity Vs30 is 127.8 m/s. This value indicates that the rocks in the trajectory are classified into type E (soft soil). In the table 3, it can be seen that the shear wave velocity has different values as well as different depth and thickness. The greater the depth, the greater the phase velocity of the wave. The smallest phase wave velocity of 100 m/s is near the surface at a depth of 0 – 1.9 m. For the largest wave phase velocity is at a depth of 26.2 - 30 m. this indicates that the greater the depth resulted the harder rocks eventhough in the same type of rock.

After the interpretation process for trajectory 1 it is found that the first layer to the fifth layer is grouped as unsaturated sand layer involved in Molasa Celebes formation although it has different values of shear wave velocity. Therefore, in trajectory 1 it can be built a large building using geotechnical engineering by compacting soft soil layers mixing with limestone rocks [8].

For trajectory 2 a Vs30 value obtained is 235.1 m/s, so that the rocks on the trajectory are classified into type D, i.e medium type of soil. From figure 3, it can be seen the different value of the shear wave velocity, the layer depth, and the layer thickness. In table 3, it can be seen that the greater the depth, the
greater the value of wave phase velocity. The largest phase velocity of Vs (i.e 290 m/s) lies in the third layer with a depth of 9.8 - 26.1 m. In the other hand the smallest phase velocity value of 180 m/s indicates softer layer than its upper layer which lies in a depth of 26.1 - 30 m. It can be seen that the greater the obtained depth, the harder the rocks in this trajectory, however, they are still classified as same type of rock. Based on this interpretation results, all the layer is an unsaturated sand layer with Molasa Celebes formation although it has a value of different velocities.

In trajectory 3, the obtained value of shear wave velocity is 98.8 m/s. This Vs30 value is very low, so that it can be classified into type E which includes soft soil type. It also result in the various values of wave velocity, depth and thickness. The largest wave velocity value of 178 m/s is in second layer with depth of 1.9 – 5.7 m, where if value of depth is bigger than phase velocity value will be bigger. Then the smallest phase velocity value 55 m/s is near surface depth of 0 – 1.9 m. Although they have different values, the type of rock in this trajectory is grouped in the same rock type. It can be seen that the value of Vs varies where the first is soft layer, the second layer has hard rock, for the third layer and the fifth layer is softer and the fourth layer consist of hard rock. Therefore in trajectory-3 cannot be built a large building due to the low value of Vs30.

For trajectory 4 the obtained value of Vs30 is 196.8 m/s, grouped into type D with type of medium land. From Figure 5 it can be explained that the respective values of wave phase velocity, depth and thickness are various, whereby the greater the depth obtained, the greater the wave phase velocity. The smallest wave phase velocity of 149 m/s is near the surface with a depth of 0 - 1.9 m. The largest phase velocity of 203 m, is at a depth of 5.5 - 30 m. It shows that the greater the depth obtained, the harder rock, but still includes the same type of rock. The interpretation results obtained the first layer until the third layer can be interpreted as a layer of sand is not saturated with Molasa Celebes Formation, if seen from the Vs30 value on this trajectory can be erected buildings for the benefit of infrastructure by using geotechnical engineering.

Based on Satellite Image Map of trajectory 1 and trajectory 3 are located near basin of Watu River. Therefore, the soil type in both tracks is soft soil type, while trajectory-2 and trajectory-4 have a distance of 100 m from the river so these are classified into medium type of soil.

Based on the shear wave velocity value of the four trajectories, it can be seen that, although the study area conducted in the same area, it has a varying soil type. This result are indicated by the difference in the obtained shear wave velocity. The greater the shear wave velocity, the more compact the constituent material. From both types of this rock can be said that build the infrastructure in that area should respect to the condition of the surrounded area. For the rocks of E type, the infrastructure facilities can be built using engineering techniques to harden the rocks as a building base. Hardening of rocks can be done by compacting soft soil layers and can also be mixed with limestone rocks.

All the trajectories obtained lithology lining in Watu Village consists of unsaturated sand. This is consistent with the Geological Map of the Palu Sheet [5] that the rock formation in the Watatu area comprises the Molasa Celebes Formation (Sarasin and Sarasin) consisting of conglomerates, sandstone, mudstone, limestone-coral and napal which are all hardened weak (especially limestone) found in the study site.

4. Conclusion
Based on the interpretation and the results of data processing on the analysis of shear wave velocity in Watatu Village, can be concluded that it shear wave velocity up to 30 m in depth for 4 trajectories obtained by subsurface that can be grouped as unsaturated sand. For the value of shear wave velocity up to 30 m in depth at track 1 which is in the location plan of palm oil mill and trajectory-3 can be classified into E type rock which is soft soil type, then for Track 2 at location of SMAN 1 Bansel and trajectory-4 is located at the location of the Watatu Square with type D or medium type of soil.

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