Distribution analysis of brittleness index, modulus young, modulus bulk, and Poisson’s ratio using the integration of refraction seismic method and MASW case study of Fasilkom UI's new building

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Abstract. This research was conducted by validating the results of the SPT data collection that had been previously taken using geophysical methods in the engineering and environmental fields. This study can help to determine the subsurface lithology used to find the right building foundation. This research conducting to determine the distribution of the Brittleness value and the rock mechanic parameter values below the surface of the cross-section of the refractive seismic data processing in the field of the case study of Fasilkom UI's new building in January 2020. Analysis of the distribution of Brittleness values and rock mechanics was carried out based on the calculation of Vp and Vs values obtained from processing the results of data acquisition and supporting data in the form of data (Soil Penetration Test) SPT. The 2D cross-section of rock mechanic parameters are Poisson's Ratio has results ranging from -1 to 0.5, bulk modulus has resulted in the range 0 to 5.4, and modulus young has resulted in the range 0 to 9.5. The distribution of Brittleness values below the surface of the first and second layers is dominated by the brittle layer, the third layer is the distribution of the brittle and ductile layers, the fourth and fifth layers are dominated by ductile layers.

Keywords: Brittleness index, rock mechanics, seismic refraction, Vp and Vs

1. Introduction
Infrastructure development in Indonesia is increasing in a more advanced direction. This is a challenge for the Indonesian government. A strong building requires a strong foundation. Efforts to improve the quality of the success rate of building an infrastructure need to be done. One of the efforts made based on geophysical science is knowing the shallow subsurface structure to determine the value of the rock brittleness index which can be used as consideration for building buildings. The seismic refraction method and MASW in geophysics are reliable methods for determining subsurface structures [1]. This method is carried out in three stages, namely data acquisition, data processing, and interpretation. By utilizing sound waves, refractive seismic and MASW methods can determine the condition of subsurface structures. However, in the interpretation stage, it is still necessary to integrate SPT data and further analysis to determine the value sought. The brittleness value is used in oil and gas exploration to determine the mechanical properties of rocks in locations where oil and gas are present. To get the Brittleness value, many formulas can be used, one of which is the formula from Rickman [2].
Rickman looks for the brittleness value using the dynamic young modulus and the dynamic Poisson ratio from the log sonic results [2]. This research was conducted to determine the brittleness value of the dynamic Poisson ratio and dynamic young modulus obtained from the seismic refraction method and the MASW method for near-surface geotechnical purposes. This research was first conducted using the brittleness index formula from Rickman [2]. This study aims to predict the value of modulus young, bulk modulus, and Poisson's ratio in the study area; determine the relationship between Poisson's ratio and modulus young in the calculation of the brittleness index; predict the correlation of the value of the brittleness distribution with the SPT results in the study area; determine the distribution of the brittleness value to depth; predict the cross-sectional comparison of Vp on the GRM and Plusminus methods.

The research site is in the new FASILKOM UI building located in Depok, West Java, as can be seen in figure 1. The geology of the research area is a sediment environment. The surface of the research area is at the red point covered by alluvium caused by landslides. This can be seen from the area in the east which is covered by alluvium and has an active, winding river. The alluvium is a river deposit in the past.

2. Experimental

This research method uses seismic refraction data and MASW. In this study, there were SPT data that had been acquired first and were used to validate the results of this study. Processing data processing seismic refraction data and MASW data. First, the acquisition of seismic refraction data and MASW data in the research field uses a survey design as shown in figure 2.

The length of the research field is 67.5 meters with 24 geophones installed. Both the refractive seismic data processing and MASW. In seismic data processing, refractive using the GRM and Plusminus methods is done just fine with which method is better and will produce a Vp value. The refractive seismic data processing stage includes picking the first break, traveling time travel, and inversion of Vp modelling is shows in figure 3.

MASW data processing includes reconstruction of the disperse curve with the velocity phase plot and the inversion process to obtain the shear wave velocity (Vs) is shows in figure 4.

![Figure 1. Geology map of research area](image-url)
The Vp and Vs data processing methods that have been obtained previously to find the value of rock mechanic parameters: the Poisson ratio, young modulus, and bulk modulus using the Mavko et al. [3]. Fourth, Poisson ratio and modulus data processing to obtain the fragility value uses the Rickman formula [2].

![Figure 2. Survey design seismic refraction (a) and (b) MASW.](image)

![Figure 3. (a) Picking the first break and (b) traveling time travel.](image)

![Figure 4. (a) Reconstruction of the disperse curve and (b) inversion process.](image)
3. Results and discussion

Figure 5a shows that the seismic wave velocity value is 200 m/s to 1750 m/s. Figure 4a shows that the seismic wave velocity value is 200 m/s to 650 m/s. Changes in velocity values contained in each layer indicate differences in lithology below the surface.

From table 1 and correlated with the existing SPT data, it can be concluded that in the first layer, the Vp section of the GRM method is a layer of soil [4]. The second layer is a layer of sand (loose compactness) and the third layer is a layer of clay with a small layer of sand (lose compactness). The results of the 2D Vp section are slightly different from Vs where the Vp section cannot detect the sand layer between the two clays, this is due to the very slight velocity difference [5]. From table 1 and correlated with existing SPT data, it can be concluded that in the first layer, the Vp section of the PlusMinus method is a layer of soil. The second layer is a layer of sand (loose compactness).

![Figure 5.](image)

**Figure 5.** (a) Vp GRM methods and (b) Vp PlusMinus methods.

Axis x is distance and axis y is depth.

| Materials natural soil and rock | Primary velocity, Vp (m/s) |
|--------------------------------|----------------------------|
| Weathered surface material     | 240–610                    |
| Gravel or dry sand             | 460–915                    |
| Soil                           | 100–500                    |
| Sand (dry,loose)              | 200–2000                   |
| Sand (saturated)              | 1220–1830                  |
| Shale                         | 2000–3500                  |
| Caly (saturated)              | 915–2750                   |
| Water1                         | 1430–1665                  |
| Sea Water1                     | 1460–1525                  |
| Sandstone                      | 1830–3960                  |
| Limestone                      | 2134–6100                  |
| Granite                        | 4574–5800                  |
| Metamorphic rock               | 3050–7000                  |
The data from the research results are in the form of distance and wave propagation speed, then the processing is carried out using the MASW method in the easyMASW application so that a 2D cross-section of the value of the wave velocity $Vs$ under the surface of the new building of Fasilkom Universitas Indonesia is obtained. The results of the MASW method analysis are displayed using the surfer application.

According to the soil and rock classification based on table 2 (ASCE 2010 [6]), $Vs$ in figure 6 can be concluded that the first layer and the third layer are soft soil, the second layer is medium soil, the fourth layer is medium to hard soil and the fifth layer is hard soil to little rock.

Figure 7 shows the data result from $Vp$ and $Vs$ calculation using the Mavko et al. formula [3]. The bigger the bulk modulus value, the smaller the elastic strain that occurs or the stiffer the volume change experienced by each object when it is stretched differs from one another depending on the elasticity of the material. The bigger the Poisson's Ratio value, the more rigid the rock is (not rigid), conversely the smaller the Poisson's Ratio value, the stiffer the rock is. The amount of Poisson's Ratio experienced by each object when given pressure/pull is different from one another depending on the material. The bigger the modulus young value, the smaller the elastic strain that occurs or the stiffer.

The amount of length increases experienced by each object when it stretches is different from one another depending on the elasticity of the material.

Based on table 3 the modulus young values in this study ranged from 0.0 to 4.5. The greater the value of the modulus young, the smaller the elastic strain that occurs or the stiffer. The amount of length increases experienced by each object when it is stretched is different from one another depending on the elasticity of the material.

### Table 2. Soil and rock classification based on ASCE 2010 [6].

| Site classification | $Vs$ (m/det) |
|---------------------|--------------|
| SA (Hard rock)      | $> 1500$     |
| SB (Rock)           | 750–1500     |
| SC (Hard soil)      | 350–750      |
| SD (Medium soil)    | 175–350      |
| SE (Soft soil)      | $< 175$      |

Figure 6. Vs MASW Methods( Axis x is distance and axis y is depth).
Based on table 4 the bulk modulus values in this study ranged from 0.0 to 5.4. Bulk modulus is a measure of the volumetric elasticity of a material, so that the higher the soil bulk modulus value, the less change in shape will occur when given a force.

The greater the Poisson's Ratio value, the more rigid the rock is (not rigid), on the contrary, the smaller the Poisson's Ratio value, the stiffer the rock is. The amount of Poisson's Ratio experienced by each object when given pressure / pull is different from one another depending on the material.

Based on table 5 at a depth of 0 to 5 meters the layer has a Poisson ratio value of 0.2. If it is equated with the result, the 0-5 meters layer is soft - medium stiff clay. At a depth of 5–13 meters, the layer has a Poisson ratio value of minus -0.5 to -0.05, it is not included in the classification of the Poisson ratio value, this is because there is no increase in the value of Vp, while the value of Vs increases so there is an error during the calculation, there is no increase in the value of Vp due to speed between layers is not too contrast. At a depth of 13 meters to 16 meters, the layer has a Poisson ratio value of 0.05 to 0.4.
Table 3. Modulus Young value vs depth

| Layer | Depth     | Modulus young value |
|-------|-----------|---------------------|
| 1     | 0–6 meter | 0.085–0.115         |
| 2     | 6–10 meter| 0.085–0.12          |
| 3     | 10–12 meter| 0.095–0.1          |
| 4     | 12–16 meter| 0.2–1             |
| 5     | 16–24 meter| 0.5–3.5           |
| 6     | 24–30 meter| 2.0–4.5          |

Table 4. Modulus bulk value vs depth

| Layer | Depth     | Modulus bulk value |
|-------|-----------|--------------------|
| 1     | 0–15 meter| 0.01–0.6          |
| 2     | 15–20 meter| 1.2–1.8        |
| 3     | 20–30 meter| 2.8–5.4         |

Table 5. Poisson’s ratio value vs depth

| Layer | Depth     | Poisson’s ratio value |
|-------|-----------|-----------------------|
| 1     | 0–6 meter | 0.05–0.2             |
| 2     | 6–10 meter| -1–0.05              |
| 3     | 10–12 meter| 0.05–0.2          |
| 4     | 12–16 meter| 0.05–0.4          |
| 5     | 16–24 meter| 0.05–0.43        |
| 6     | 24–30 meter| 0.1–0.45         |

If it is equated with the results, the 13 to 16-meter layer is a medium for stiff clay. At a depth of 16–30 meters, the layer has a Poisson ratio value of 0.22 to 0.49. If it is equated with the results, such as the 16 to 30-meter layers are sand loose compactness to hard stiff clay.

Based on the table 6 and the correlation results of the brittleness index value with the results as can be concluded, in the first layer 0 m to 5.5 m and the second 10 to 12 meters is dominated by the brittle layer which has a value above 35 where the layer is soft clay. A brittle zone where when pressure is applied the layer will immediately destroy without any deformation. It can be said that at that depth the soil is still loose and easily destroyed (figure 8). The third layer 12 to 16 meters there is a spread of brittle and ductile layers where the layer is silty clay there is a zone that has a high Poisson ratio value. The fourth layer and the fifth 16 to 24 meters is dominated by a ductile layer in which the layer is sand loose compactness. And based on the correlation results of the brittleness index value with the results as can be concluded, in the first layer 0 m to 5.5 m and the second 10 to 12 meters is dominated by the brittle layer which has a value above 35 where the layer is soft clay. A brittle zone where when pressure is applied the layer will immediately destroy without any deformation. It can be said that at that depth the soil is still loose and easily destroyed, the third layer 12 to 16 meters there is a spread of brittle and ductile layers where the layer is silty clay there is a zone that has a high Poisson ratio value, the fourth layer and the fifth 16 to 24 meters is dominated by a ductile layer in which the layer is sand loose compactness and silty clay hard consistency. The ductile zone in this study has a Poisson's ratio value of more than 0.3.
Table 6. Britteness index and soil type

| Layer | Depth       | Brittleness index | Brittle/ductile | Soil type                                      |
|-------|-------------|-------------------|-----------------|------------------------------------------------|
| 1     | 0–5.5 meter | 40–70             | Brittle         | soft clay                                      |
| 2     | 6–10 meter  | 100–250           | Not detected    | -                                              |
| 3     | 10–12 meter | 40–70             | Brittle         | soft clay                                      |
| 4     | 12–16 meter | 10–70             | Brittle-ductile | silty clay                                     |
| 5     | 16–24 meter | 0.05–0.43         | Ductile         | sand loose compactness and silty clay hard consistency |
| 6     | 24–30 meter | 0.1–0.45          | Ductile         | sand loose compactness and silty clay hard consistency |

Figure 8. Britteness index chart (left) and SPT data (right) for (a) 0–5.5 m depth, (b) 5.75–10 m depth, (c) 12–10 m depth, (d) 12–16 m depth, (e) 16–24 m depth, and (f) 24–30 m depth.
Figure 8 (continued). Britteness index chart (left) and SPT data (right) for (a) 0–5.5 m depth, (b) 5.75–10 m depth, (c) 12–10 m depth, (d) 12–16 m depth, (e) 16–24 m depth, and (f) 24–30 m depth.
Figure 8 (continued). Britteness index chart (left) and SPT data (right) for (a) 0–5.5 m depth, (b) 5.75–10 m depth, (c) 12–10 m depth, (d) 12–16 m depth, (e) 16–24 m depth, and (f) 24–30 m depth.

4. Conclusion
Cross-sectional results of the GRM method produces 3 subsurface layers while the PlusMinus method produces 2 subsurface layers. In the first layer, the GRM and PlusMinus methods produce relatively the same Vp velocity ranging from 200 m/s with a depth of 0-6 meters. Rock mechanical parameters, namely Poisson's Ratio, have a value range of -1 to 0.5 where the range -1 to -0.005 is a Poisson's Ratio error value at a depth of 5.75 meters to 10 meters. The bulk modulus values in this study ranged from 0.0 to 5.4. Young's modulus values in this study ranged from 0.0 to 5. From the brittleness chart analysis, it can be concluded that the greater the Poisson's Ratio value and the smaller the modulus young value, the more ductile the rock will be, conversely the greater the value of modulus young and the smaller the Poisson's Ratio value, then in the soil layer with a depth of 0m to 5.5m, the value distribution of the brittleness index is included in the brittle category. at a depth of 5.75 to 10 meters an error occurs because the Poisson's Ratio value in that area has an error. At a depth of 10 to 12 meters, the distribution of the brittleness index value is included in the brittle category, at a depth of 12 to 30 meters, there is a brittle and ductile distribution. Soil layers that have ductile properties have a Poisson's Ratio value above 0.32. The distribution of the brittleness index in subsurface rocks can be estimated through seismic refraction and MASW methods. However, to validate the correctness of this value, it is necessary to drill wells to run sonic logs at several points of the acquisition area.

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