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Ground Surface Quality Assessment Using P-wave Velocity from 2-D Seismic Refraction Method

Zul Fadhli[1*], Sabrian Tri Anda[2] ,Muhammad Syukri[3,*], Moehammad Ediyan Raza Karmel[4], Alfi Sunny Tutifla[1], Purwandy Hasibuan[5], and Rini Safitri[3]

[1]Geophysics Engineering Department of Engineering Faculty of Syiah Kuala University, 23111, Indonesia
[2]Physics Department, Engineering Faculty, Universitas Samudra, 24416, Indonesia
[3]Physics Department of Mathematics and Science Faculty of Syiah Kuala University, 23111, Indonesia
[4]Mining Engineering Department of Engineering Faculty of Syiah Kuala University, 23111, Indonesia
[5]Civil Engineering Department of Engineering Faculty of Syiah Kuala University, 23111, Indonesia
*Corresponding author: zulfadhli@unsyiah.ac.id

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Abstract – A good strength level of the ground surface is the main concern in an area with rapid housing infrastructure development, such as Baitussalam district-Aceh Besar, Indonesia. A seismic refraction method was applied with three similar profile lines using PASI 16S – 24P equipment and 10 Hz vertical geophones to identify the sub-surface layer. The result was processed using Winsism software and Surfer 8. The results of seismic refraction were deduced and correlated with conventional geotechnical investigation obtained by a previous study. The results of 3 survey lines show that the area has two main layers. The first layer was interpreted as overburden (soil and clayey sand) with a compressional wave velocity (Vp) value of fewer than 1.8 km/s. The second layer produces a high velocity of more than 2 km/s. This second layer is interpreted as highly to moderately weathered rock. The results of seismic refraction surveys of the present study suggest a reasonably good correlation with the standard penetration test (SPT) and rock quality designation (RQD) obtained in the previous investigation. The strength level of the second layer showed N-SPT of 65 and RQD of at least 50%.

Keywords: seismic refraction, compression wave velocity, N-SPT, RQD.

Introduction

As science keeps evolving, especially in the civil and environmental engineering disciplines, the involvement of geophysics as a problem-solving approach has allowed a new subset of geophysics, particularly applied geophysics or geophysical engineering. The term geophysical engineering can be interpreted as the application of geophysical methods to investigate subsurface material to explain subsurface conditions, in which the results would have significant implications for engineering science (Reynolds, 2011).

The involvement of geophysical methods in civil and environmental engineering aims to broaden knowledge and accommodate the rapid development of urban areas in various countries. The traditional method, such as the borehole method, is considered less effective in determining subsurface conditions even though it can accurately describe subsurface conditions (Mohamad *et al.*, 2015). The lack of efficiency is due to longer measurement time, destructive nature, and limited coverage with high application cost (Massarch, 2000).

The application of geophysical methods in civil and environmental engineering varies greatly, from determining the "rippability" of rock and the depth of scour around bridge pilings, providing soil-strength estimates for dams and building foundations to predicting liquefaction zone (Steeples, 2001, Syukri *et al.*, 2020, Soupios *et al.*, 2007, Abidin *et al.*, 2007, Lai, 2018). However, major problems in both engineering disciplines could not be solved and explained solely by geophysical methods. Determining the appropriate geophysical method also enables the researchers to minimize errors during data interpretation. For example, the seismic method is the most suitable geophysical method for engineering or environmental site investigation because the measured parameter in the form of wave velocity is closely related to the density and modulus of elasticity of the material being measured (Chengbo *et al.*, 2016).

The seismic refraction method can accurately describe the subsurface conditions by the speed of acoustic wave propagation. Generally, the waves used are P and S waves generated by a seismic source, i.e., a sledgehammer, weight drop, air gun, etc. (Sabrian *et al.*, 2018). The description of the subsurface model presented by this method is plotted based on the time and distance of the wave travel, where the wave speed can be calculated to distinguish the types of layers below the surface.

The main purpose of this study is to determine the subsurface condition based on the relationship between physical parameters obtained by the seismic refraction method and the quality of the ground surface. The physical parameter, P-wave velocity, obtained by field measurement, was correlated with estimated rock quality designation (RQD) and N-values of standard penetration test (SPT) obtained by the previous study. The correlation will lead to the estimation of soil and rocks for a building foundation of the study area.

Geology of Study area

The research was conducted in an area between 2 fault segments: the Aceh segment and the Seulimuem segment. The Aceh segment is approximately 13 km west of the research area, while the Seulimuem segment is 10 km east. Based on the topography, this area is considered a caldera, surrounded by mountains formed by the subduction of the Eurasian and Indo-Australian plates. Based on the geological map of Banda Aceh, its geological condition is dominated by a coastal area consisting of Alluvium (Qh) formations with sedimentary deposits, including mud, sand, and gravel. In the surrounding area, Lam Teuba volcanic rocks (QTvt) contain andesite, dacite, pumice breccia, tuff, agglomerates, and ash flows. Based on Figure 1, 80% of the Aceh Besar area incorporates alluvium deposits, and the rest is Lamteuba volcanic rock.

Materials and Methods

In geotechnical engineering, the knowledge of the geometry of hard layers (bedrock) is fundamental, especially ones related to a tall building. Bedrock must have good rock layer quality because it will work as a large load-bearing above the surface. Geotechnical engineering declares that bedrock quality according to SPT and RQD value/percentage. RQD and SPT are standards for assessing rock quality and its features. Several studies correlated the RQD and SPT values with the geophysical method. The correlation is carried out to strengthen the results with each other and to minimize the level of misinterpretation of rock layers and types. The most frequently applied geophysical method in the geotechnical field is the seismic refraction method. This method has a good level of correlation in defining rock types and rock quality.

Seismic refraction is one of the geophysical methods to measure the anomaly of wave propagation due to differences in rock density below the surface. The velocities get faster when they pass through a hard layer or high density (Syukri *et al.*. 2020). The Seismic refraction method is based on Huygens principle, Azaz Fermat, and Snell's Law. Snell's Law explains that some waves will be reflected on the surface, and some will propagate below the surface. The seismic refraction method uses mechanical or elastic waves as a source that propagate into the Earth. The arrival time of the first wave is applied in this method since the primary wave has a greater speed than the secondary wave. The lithology, density, porosity, depth, and age of the rock are the factors that determine the velocities of seismic waves. The seismic method is a common application (2D or 3D) in a range of early explorations to study structures on a regional scale, such as rock type, rock layer, and fractured.

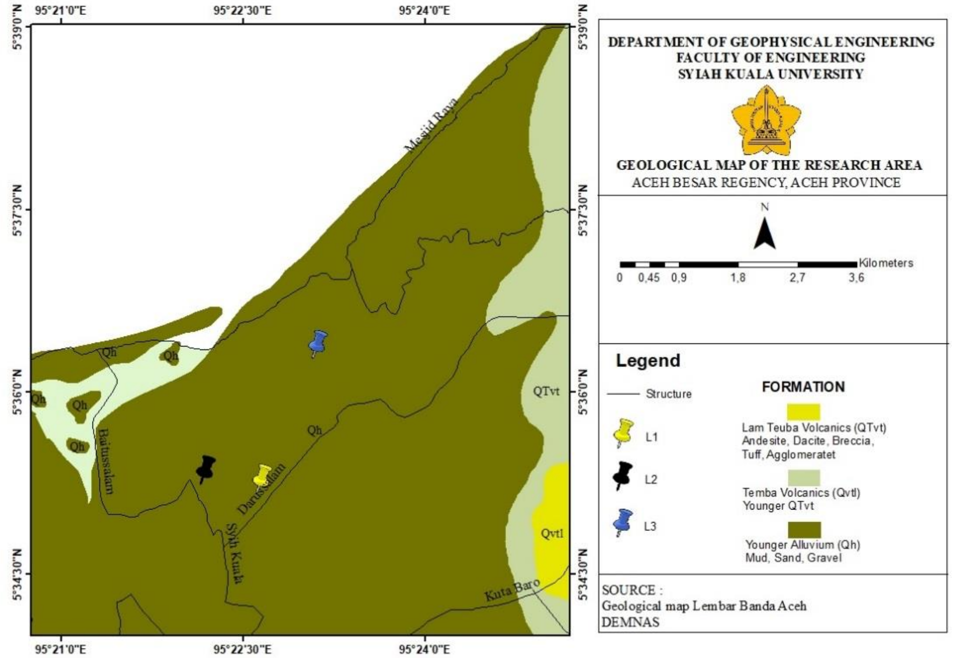

Figure 1. Geological Map of Study Area (Modify from Bennet *et al*., 1983)

The basic principle of the method is recording the travel time of an elastic wave. The type of wave being recorded is a P-Wave or primary wave. This wave is produced by vibration from hitting a steel plate with a hammer (in this study) or gun. This wave is refracted from every layer with different velocities, recorded by a geophone, and then transferred into a seismograph.

Figure 2 illustrates a ray path that travels into two different layers of the Earth and delineates the reflection and refraction. Wave generated from source travel at velocity V_1 in the first medium hit the interface between two different mediums. The wave is refracted at a critical angle θic and propagates parallel to the interface.

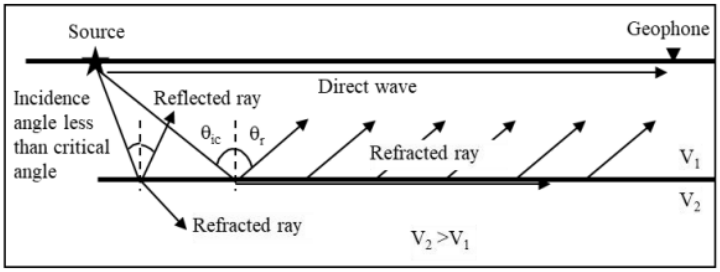

Figure 2. Raypath travel with two layers

The equipment deployed in the field is Seismograph Pasi 16S-24P, 25 Geophones 10Hz including 1 trigger geophone, 5 cables, and other additional items. This study conducted 3 seismic refraction survey lines in the Baitussalam district – Aceh Besar. L1 is located at the paddy field, and L2 is at the road's side. The L1 and L2 were set with a geophone interval of 3 meters, a 100-meter offside shoot point, and the line's length of 69 m. The L3 is located one kilometer from the shoreline with the spacing of geophone is 10 meters with a 10-meter offside shoot point, and the length of the line is 230 m (Figure 3). During the survey, the P wave travel time was considered. First, arrivals to each geophone are marked and extracted from the data.

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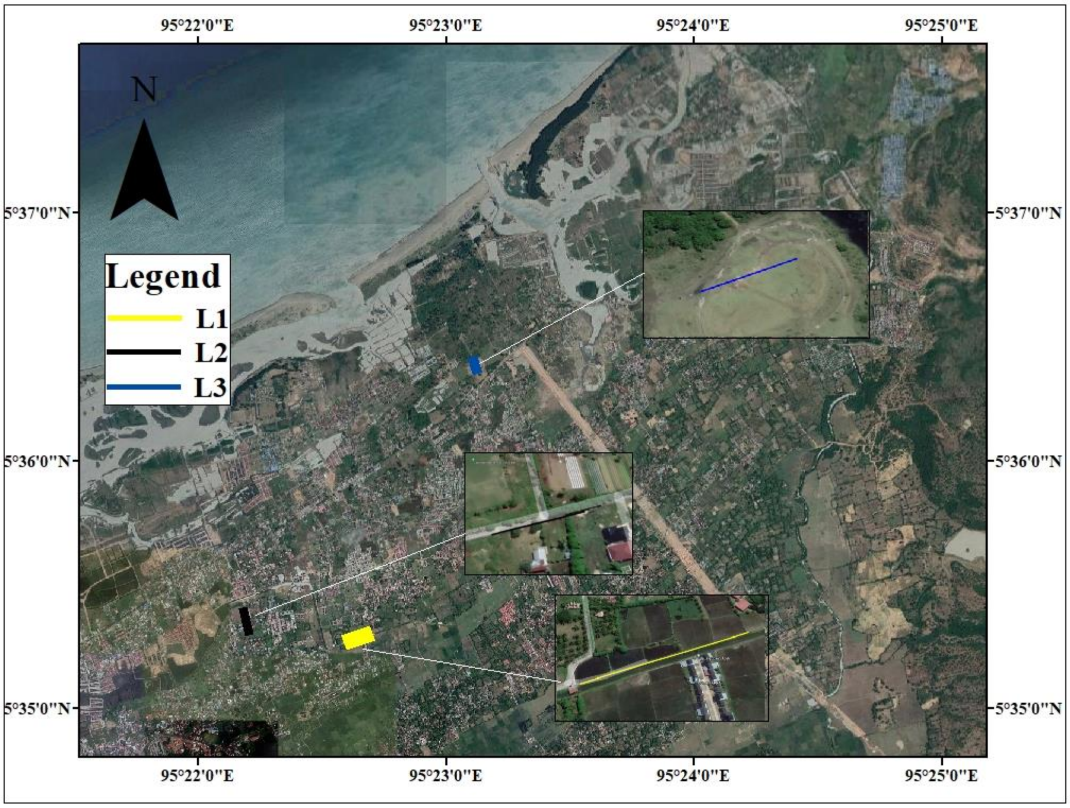

Figure 3. Map of the survey lines

The data were processed using a PC with *Winsism Software* and *Surfer*. A band-pass filter was applied in the first step to eliminate noise and wiggle in traces. The filtering process would enable much easier further steps. Then, the next one was detecting the first break arrival time of the seismic wave. This *first break time picking* step would serve as an input to display the velocity anomaly of underground seismic waves. The picking was conducted at every shot point, then combined to create a travel time curve. This curve was modeled by the inversion technique to obtain the final layers of the sub-surface image.

Results

In this section, the results of field measurements will be described to explain the subsurface conditions based on measurements using the 2D seismic refraction method. Generally, the subsurface layer in the research area is classified into the overburden layer and the bedrock layer. The layers are defined based on the Vp value, which is less than (<) 1.8 km/s for the overburden layer and more than (>) 2 km/s for the bedrock layer. The condition of the overburden layer was also briefly discussed based on the P wave velocity value to segregate the saturated and unsaturated layers. Hereafter, it was found that the depth of the bedrock layers found in each location changed as it became closer to the shoreline. The tendency of the overburden to become thicker towards the shoreline is assumed to be the result of the weathering of rocks by seawater. Furthermore, the Vp value measurement results will also be correlated with the soil or rock layer strength table based on the SPT-N and RQD values obtained from previous research.

Figure 4 shows the results of the L1 measurement line. This line is approximately 3 km from the shoreline. The tomography model is described solely to characterize the bedrock layers. Based on interpretations, the cross-sectional model is generally classified into two layers. The first layer, thought to be an overburden layer, was composed of clayey sand with a P wave velocity value of <1.8 km/s. Furthermore, the first layer, classified as an overburden, was segregated into two types according to the condition of the layer. The layer with a P wave velocity of 0.8-1.2 km/s is suspected to be a saturated clayey sand layer, while the unsaturated clayey sand layer is classified with a P wave velocity of 1.2-1.8 km/s. The second layer is a bedrock layer composed of sandstone

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with a P wave velocity of > 2 km/s. It is also known that the thickness of the overburden layer is 18-22 m, while the bedrock layer is found at a thickness of > 18 m.

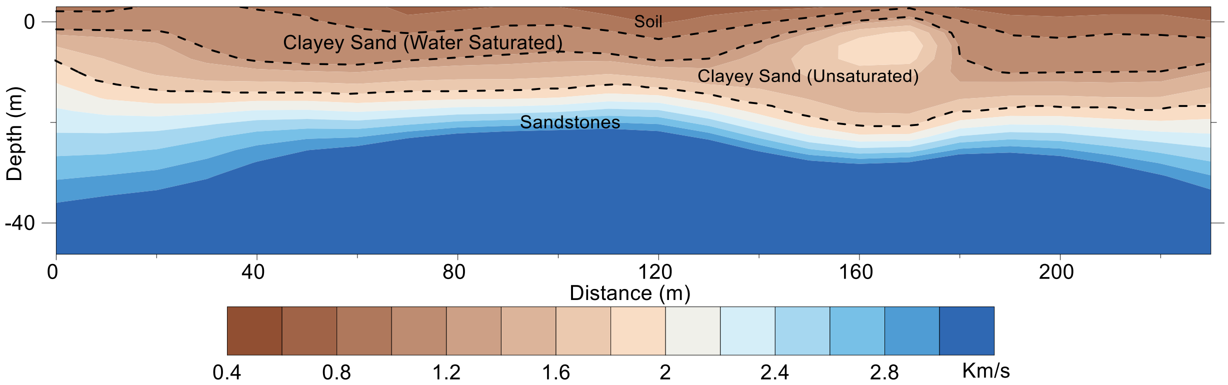

Figure 4. Seismic refraction result of Line 1

The subsurface cross-sectional model for the L2 measurement path is shown in Figure 5. This measurement line is located ± 2.1 km from the shoreline. Based on data processing and interpretation results, the 2D cross-sectional model for L2 is classified into two main layers. The first layer is categorized as overburdened with a thickness of ± 25 m. Mainly, this layer is composed of clayey sand with saturated and unsaturated conditions. The saturated layer of clayey sand is described with P wave velocity value of 0.8-1.2 km/s, while the unsaturated clayey sand is delineated with a velocity value of 1.2-1.8 km/s. The second layer is classified as bedrock or sandstone. The bedrock layer is found undulated at a depth of > 18 m with a Vp of >2 km/s.

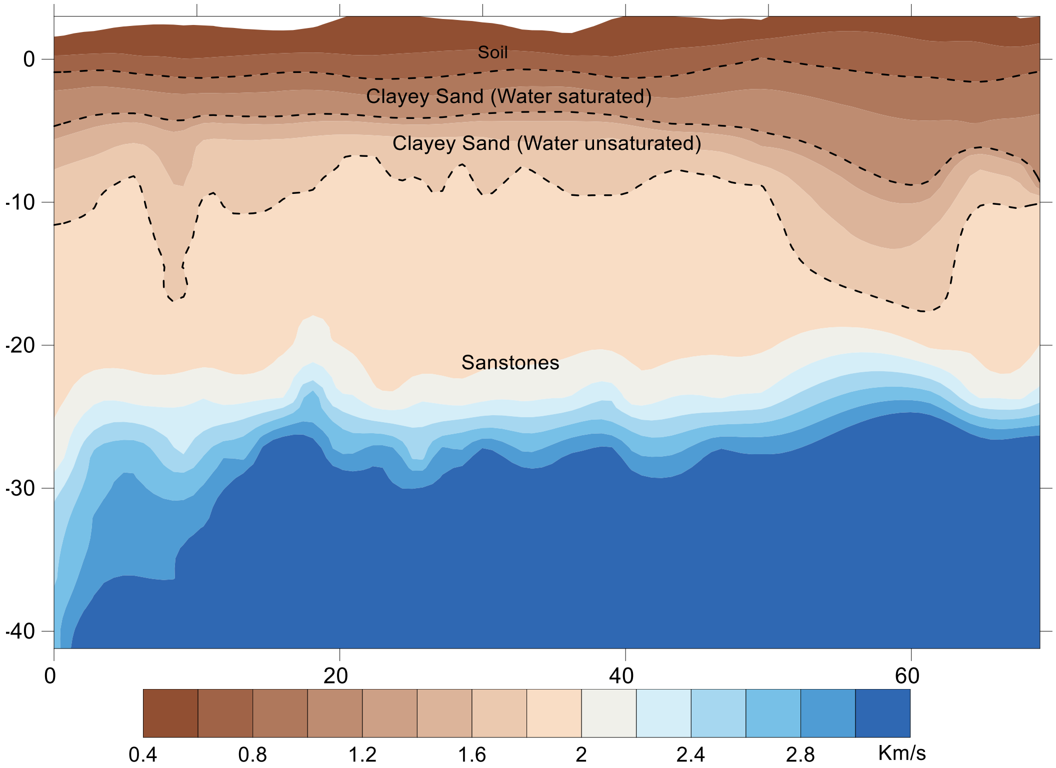

Figure 5. Seismic refraction result of Line 2

Figure 6 shows the results of processed 2D seismic refraction data on line 3 with a penetration depth of up to ±40 m. The subsurface conditions in this measurement area are categorized into two main layers. The first layer is suspected to be an overburden layer with a thickness of ± 22 m. This layer is interpreted as a soil layer composed of topsoil, saturated, and unsaturated clayey sand based on the value of the P wave velocity, which is <0.8, 0.8-1.2, and 1.2-1.8 km/s, respectively. The second layer is considered a bedrock layer based on the vp value > 2 km/s and is classified as a sandstone layer.

Discussion

As the final objective of this research, this section will briefly describe the prediction of soil and rock strength at each location of the research area. The strength of the soil intended to support a building can be explained using several measurement parameters, such as the Cone Penetration Test (CPT) and Standard Penetration Test (SPT) measurements. Meanwhile, explaining a rock's strength level can be done using rock mass classification, and rock mass classification using Rock Quality Designation is a common method to use (Salaamah, A. F. *et al.*, 2018). The parameters mentioned above can be applied as a basis in planning the construction of a building foundation so that further analysis in the form of determining the type of foundation, dimensions, and depth of the foundation can be carried out (Diaparna & Setyono, 2017). However, in reality, the aforementioned parameters use complex methods and require complicated permissions in their application. Therefore, this study will try to estimate soil strength using the correlation between seismic wave velocity values obtained from field measurements using the 2D seismic refraction method with geotechnical parameters obtained from existing correlations made by previous researchers. It is known that seismic wave velocity is closely related to soil and rock properties such as uniaxial compressive strength, modulus elasticity, Schmidt hardness, slake durability index, density, and also porosity (Sharma and Singh, 2008; Yagiz, 2011; Khandelwal, 2013).

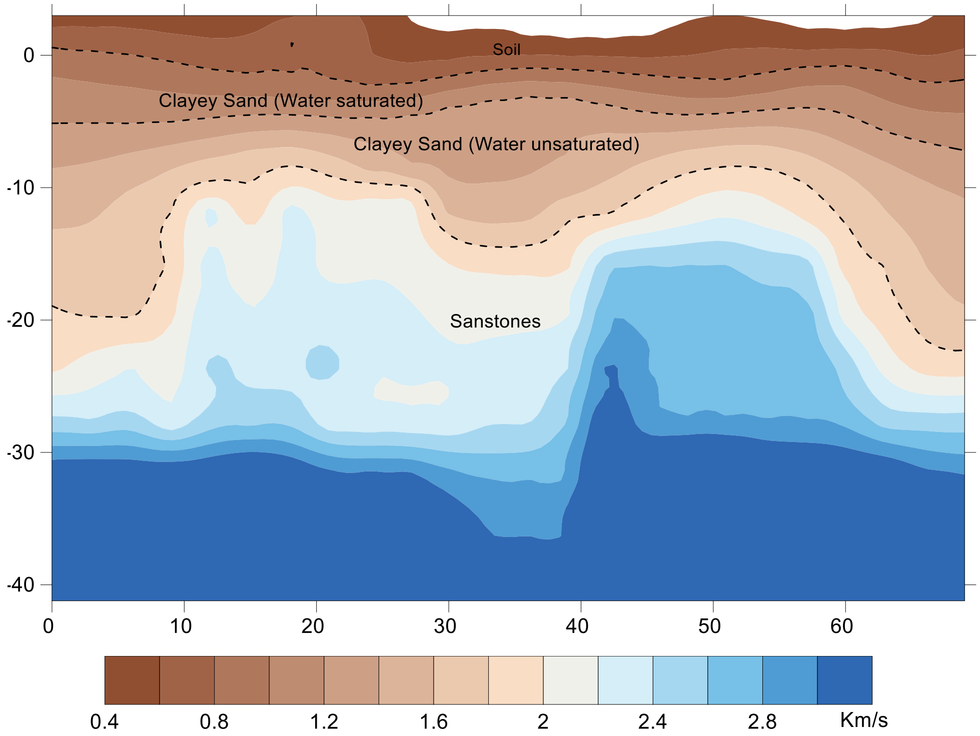

Figure 6. Seismic refraction result of Line 3

Table 1. Correlation of P-wave Velocity with SPT – N and RQD (Bery & Saad, 2012).

P-wave Velocity km/s	N-Value (%)	RQD Value (%)
0.4 – 1.0	<50	-
1.0 – 1.7	50 – 65	<50
1.7 – 2.1	65 – 75	50 – 70
2.1 – 2.7	75 – 85	70 – 85
Over 2.7	>85	>85

Table 1 explains the correlation of P-wave velocity with geotechnical parameters (SPT-N and RQD). Based on the existing correlation, the SPT-N and RQD obtained from the table are correlated with the P-wave seismic velocity gained by field measurement in this research to estimate the level of soil and rock strength. The estimation will be used as a preliminary study to understand the soil and rock strength level for building foundation purposes. In addition, the seismic refraction method is also capable of delineating the saturated layer of the study area since the water content of the subsurface also plays an essential role in geotechnical discipline besides the strength and stress deformation behavior of soil and rock (Ozcep, F. & Ozcep, T., 2011). In general, the results of the interpretation and modeling of the subsurface layer in the study area are classified into two main layers. Based on the correlation results, it was found that the first layer with a P-wave velocity value of <1.8 km/s was identified as having an average SPT-N value of 65% with an RQD value of <50%. Meanwhile, the second layer with a P-wave velocity value > 2 km/s for each study area was identified as having an SPT-N value of 75 – 85% with an RQD value of 70 – 85%.

Conclusion

The Seismic refraction data Show contrast velocity in each measurement line by depth. According to Vp values, the study area is classified into two layers (Overburden and Bedrock). The first layer was interpreted as soil and clayey sand with a velocity value of < 1.8 km/s and the second layer as sandstones with a velocity value of> 2 km/s. Based on the correlation of Vp value and Geotechnical parameters (SPT and RQD), the second layer has a higher strength level than the first layer. The first layer still has an N-Vlue of < 50% and an RQD of <50%, which is still saturated by water. The second layer with Vp value is > 2 km/s, SPT-N value is 65%, and RQD < 50%. The second layer is a good bedrock layer used for the foundation of infrastructure. The results also show that the bedrock layer goes more profound as it gets closer to the coastal area.

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