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Identification of Subsurface Structures in South Bengkulu Manna City Based on The MASW Method

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Abstract

South Bengkulu is one of the regencies in Bengkulu Province which is in an area of active tectonic plate activity, namely the India-Australia and Eurasian plates so it is prone to earthquakes. The City of Manna continues to carry out developments so that it requires various information for urban and regional planning, especially information on subsurface rock structures. This study aims to determine the structure of rock layers based on shear wave velocity (Vs), Poisson ratio, shear modulus and Young's modulus in Manna City. This research was conducted using the Multichannel Analysis of Surface Wave (MASW) method at 12 measurement stations. The tool used is the PASI 16S24-P seismograph. Data processing to produce a 1D model is WinMASW 5.0 Professional Software and to display 3-D data Voxler software is used based on the value of Vs. Then do the calculation to get the value of Vs_{30}*. From the results of the* V_{s30} *value in the study area, it shows that the Manna City area consists of 4 rock types including soft soil (SE), stiff soil (SD), very dense soil and soft rock (SC) and rock (SB) rock types. The highest layering value of shear wave velocity (Vs) is at the fourth point with a value of Vs 386-1263 m/s, Poisson ratio 0.40-0.35, shear modulus 298-3652 MPa and Young's modulus 804-9430 MPa at a depth of 4.4 -30 meters. While the smallest value is at the sixth location point with a value of Vs 180-474 m/s, Poisson ratio 0.40-0.30 shear modulus 60-461 MPa, and Young's modulus 168-1.243 MPa at a depth of 2.6-30 meters.*

Introduction

Bengkulu Province is one of the areas of active tectonic activity which is influenced by the confluence of the India-Australia plate and the Eurasian plate which collide with each other so that these conditions result in the vulnerability to direct and sudden release of energy in the form of wave propagation or earthquakes [1]. Based on historical records, Bengkulu Province has been shaken by major earthquakes several times, such as in 1833, 1871, 1914, 1933, 1938, 1979, 2000, and 2007 [2].

Administratively, the research area is situated northwest of Manna City, South Bengkulu Regency, one of the regencies in Bengkulu Province. Manna City is a sub-district as well as the capital of South Bengkulu Regency where this area is an area that continues to experience development in terms of infrastructure development in the form of offices, housing, roads and public facilities. City of Manna is an area that is in the subduction zone, besides that this area is also close to the Manna segment of the fault where the northern Manna segment is relatively close to the Musi segment and the south to the Kumering segment with a length of 85 km and experiencing a slip rate of 13.5 mm/ yr. The maximum potential for earthquake strength in this segment reaches M=7.3 SR [3].

Factors that affect damage caused by earthquakes in an area do not only depend on the distance from the area to the epicenter, the magnitude of the earthquake and the quality of the building, but also depend on the geological conditions or subsurface conditions in the area [4]. According to history, on June 4 2000 Bengkulu Province was shaken by a tectonic earthquake with a magnitude of 7.3 SM centered on Enggano Island which was felt quite large in Seluma Regency and South Bengkulu Regency with a scale VI-VII MMI and on 12 September 2007 it happened again large earthquake with a magnitude of 7.9 SM [5]. Thus, information about the subsurface structure in this area is very important so that areas that have hard and soft soil types can be identified. Soft soil can cause very high vibrations due to large amplification so that when there is vibration the building above it will be damaged during an earthquake, and vice versa, hard soil is not too affected by vibrations due to earthquakes because the denser the medium the ground, the resulting vibration is also smaller because of the small amplification so that the buildings on it remain firm during an earthquake.

One of the parameters that can be used to identify the hardness and softness of the soil medium is the shear wave velocity because these waves generally dominate the amplification of ground motion during an earthquake [6]. In addition to the *Vs* value parameter, other parameters such as shear modulus, Young's modulus and Poisson ratio can also be used. Therefore, this research was conducted to identify subsurface structures in the Northwest of Manna City, South Bengkulu by interpreting *Vs* values, shear modulus, Poisson ratio and Young's modulus.

A large Young's modulus will be followed by a lower deformation when a force is applied since the Young's modulus is a measure of a material's hardness. To put it another way, the harder the material or the smaller the resulting strain, the greater the Young's modulus value [4]. Shear stress and shear strain are compared using the shear modulus. According to [7] research, the Poisson ratio is crucial for understanding the elastic deformation of rocks under static or dynamic stress. This is because knowledge of the Poisson ratio's various aspects can be helpful for the design of rock structure.

The seismic technique known as MASW (Multhichannel Analysis of Surface Wave) is one of the geophysical techniques that can be used to locate subsurface structures. Because the rock layer modelling used to construct the stratigraphy can produce a minimum misfit value, this technique is very useful for viewing subsurface rock stratigraphy in detail. The parameters used in this method to determine the characteristics of the subsurface structure are the value of *Vs*, shear modulus, Young's modulus and Poisson's ratio, where rock hardness will always be directly proportional to the shear wave velocity *(Vs)*, shear modulus, Young's modulus, but different the case with the Poisson ratio value, the harder the rock, the smaller the Poisson ratio value.

The Northwest Area of Manna City will have potential in the future as a development location in infrastructure development in the form of office buildings, settlements, roads and public facilities. Therefore, it is necessary to have information about the subsurface rock structure so that locations with soft soil types and hard soil types can be identified, but because there is no information about this, this research is important to identify subsurface rock structures as an effort for disaster mitigation as well as as a study for the government on regional and urban planning in the City of Manna, South Bengkulu Regency.

Regional Geology

South Bengkulu Regency is located at latitude 4^{o} – 5^{o} south latitude and longitude 102^{o} – 103^{o} east longitude. South Bengkulu Regency is bordered to the north by Seluma Regency, to the east by South Sumatra, to the south by Kaur Regency, and to the west by the Indian Ocean. Alluvial soil types are present in Manna, which is a city with an elevation of 0-20 meters above sea level [8].

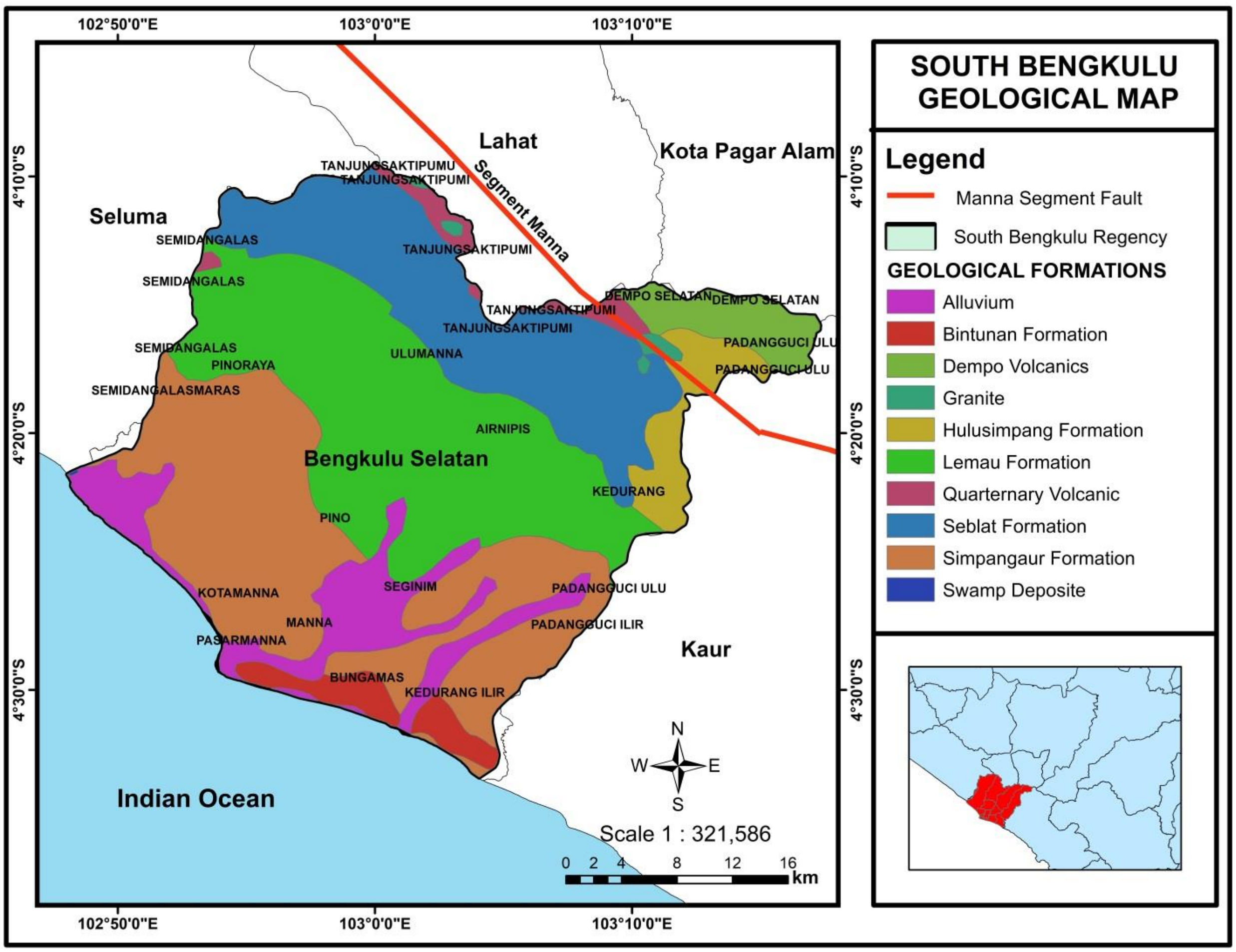


Figure 1. Geology Map of South Bengkulu Region

Tectonically, South Bengkulu is located in the Bengkulu Basin which is a forward arc basin with active tectonic conditions, located between two regional structures, namely the Sumatran fault in the northeast and the Mentawai fault in the southwest. Geologically, South Bengkulu consists of several types of rock formations as shown in Figure 1 where based on statigraphy from old to young the rock arrangements are the Hulusimpang Formation, Seblat Formation, Lemau Formation, Bintunan Formation, Simpangaur Formation and Alluvium Formation [8].

Theory and Calculation

Disaster Mitigation

Mitigation is the process of taking various preventive measures to minimize the impact on humans from the damage caused by natural disasters. This process includes assets, infrastructure and the environment, as well as preparedness and long-term risk mitigation measures [3]

According to Law Number 24 of 2007, which deals with disaster management, there are a number of steps that can be taken to lessen the danger of a disaster through physical improvement, increased awareness, and the development of disaster risk management skills. One of the mitigation efforts that aims to reduce the impact of earthquake victims and losses is to study vulnerability by knowing the characteristics of the area to the possibility of a disaster occurring.

Earthquakes

Earthquakes are underground vibrations that originate deep within the earth and then reach the surface through cracks and strong movement of the faults. Earthquakes are caused by the dynamics of the earth (tectonics), volcanic activity. According to the elastic rebound theory, the cause of earthquakes is the sudden release of elastic-strain. This elastic strain energy collides due to movement between plates in the earth's crust. This causes a huge release of energy that causes earthquakes. This process also causes the particles to vibrate in all directions which are known as seismic waves. Earthquakes that often cause losses and victims are tectonic earthquakes [9].

Seismic Wave

Elastic waves that travel beneath the earth's surface are called seismic waves. The wave media consists of several rock layers with different physical properties between each layer. The propagation of seismic waves will depend on the elastic properties of the rock [10]. There are two different types of seismic waves : body waves and surface waves. P waves and S waves are the two waves that make up body waves, which are waves that occur inside the earth [11]. Free waves, which have variuos elastic qualities, cause surface waves, which propagate as a result. There are two different forms of these waves; Rayleigh waves and Love waves. P waves are waves where the particle motion is parallel to the direction of the wave propagation [12].

$$V_P = \sqrt{\frac{\lambda+2\mu}{\rho}} \quad (1)$$

With, λ is the lame constant, ρ is the density and is the shear modulus.

Shear waves, often known as S waves, are waves in which the direction of the particles motion is opposite the direction in which the wave is propagating [12].

$$V_s = \sqrt{\frac{\mu}{\rho}} \quad (2)$$

where μ is the shear modulus and ρ is the density.

Shear Modulus

Shear stress to strain ratio is used to define the shear modulus.

$$G = \rho\, Vs^2 \tag{3}$$

Where ρ is the density and Vs is the S-wave velocity value. The shear modulus is important in distinguishing the quality of sandstone because the shear modulus is not affected by fluids [13].

Young's Modulus

The proportional factor between normal stress and normal strain is known as Young's modulus.

$$E = \frac{\rho Vs^2(4-3k^2)}{(1-k^2)} \tag{4}$$

Elasticity is a gauge of a material's stiffness. The amount of deformation brought on by force will decrease as the material's modulus of elasticity increases. Thus, the higher the modulus value, the lower the stress or the stiffer it is [10].

Poisson Ratio

Poisson ratio is a measure of the amount of pressure exerted on an object in the form of transverse contraction and longitudinal stress due to pressure or compression.

$$\sigma = \chi = \frac{\left(\frac{Vp}{Vs}\right)^2 - 2}{2\left[\left(\frac{Vp}{Vs}\right)^2 - 1\right]} \tag{5}$$

With σ being the Poisson ratio, Vp is the velocity of the P wave and Vs is the velocity of the S wave [7].

Multichannel Analysis of Surface Wave (MASW) Method

The MASW method is a geophysical technique that examines conditions below the surface using surface waves. By using this technique, the Rayleigh surface wave velocity can be used to compute the shear wave velocity *(Vs)*. Rayleigh surface waves can be easily detected by seismic survey equipment using vertical geophones. 2/3 of the seismic energy generated is Rayleigh waves, so seismic waves absorb most of the seismic energy [6].

The MASW method is very popular for identifying seismic zones and is classified based on the class of the soil site, which refers to the average shear wave velocity down to a depth of 30 meters (V_{s30}). Table 1 shows the classification of soil site classes for the V_{s30} value based on SNI 1726 of 2019 [14].

Table 1. Classification of land site classes by SNI 1726 : 2019 [14]

Rock Type	Rock Type Profile	V_{s30}
(SA)	Hard Rock	On 1.500 m/s
(SB)	Rock	750 until 1.500 m/s
(SC)	Very dense soil and soft rock	350 until 750 m/s
(SD)	Stiff soil	175 until 350 m/s
(SE)	Soft soil	Under 175 m/s

Methodology

The MASW approach, which bases subsurface structure identification on shear wave velocity, was employed in this investigation. This study was carried out at Manna City, South Bengkulu Regency, in the northwest. Figure 2 shows a map of the research location, where the adjusted research location based on the South Bengkulu geological sheet map shows that in the study area almost all of the research location points are in the Simpangaur rock formation and only one point is in the Alluvium rock formation.

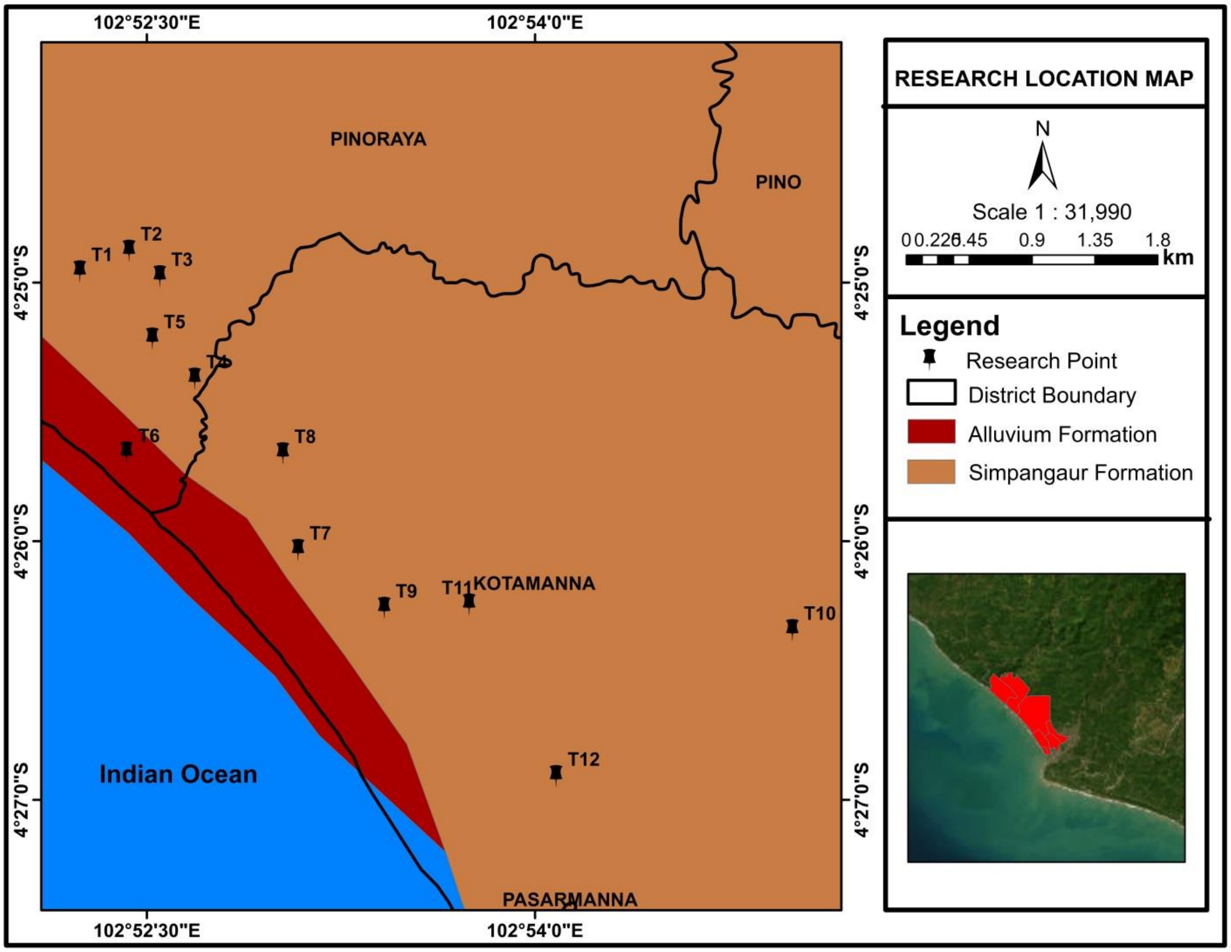


Figure 2. Map of research location

The tool used in this research is the PASI 162-24P seismograph which is a set of seismic tools. The number of measurement location points is 12 points. The wave data acquisition phase uses 24 geophones and uses a sledgehammer weighing 5 kg as a source. The total distance on the track is 52 m with a distance between geophones of 2 m and 4 m offside. The value of the shear wave velocity *(Vs)* was obtained after processing using the WinMASW 5.0 Professional software by changing the recorded data obtained from the geophone from the time domain to the frequency domain. The first step in data processing is selecting data, in this case Rayleigh waves, and removing any noise that was captured during the data collecting process. After that the dispersion curve is obtained and then proceed with picking or selecting good data to get minimal misfit. After that, an inversion analysis was performed to obtain a one-dimensional (1-D) profile. The results obtained from the inversion are in the form of Vs values, shear modulus and Poisson ratio and for Young's modulus values are generated by performing manual calculations. The dispersion curve inversion process is carried out using the Rayleigh wave propagation problem solution in layered media. Then the results of this 1-D profile will be interpolated to obtain a three-dimensional (3-D) model and after obtaining the 3-D model, data analysis is carried out and ends with conclusions. It can be seen from Figure 3 that the following is a data processing flowchart.

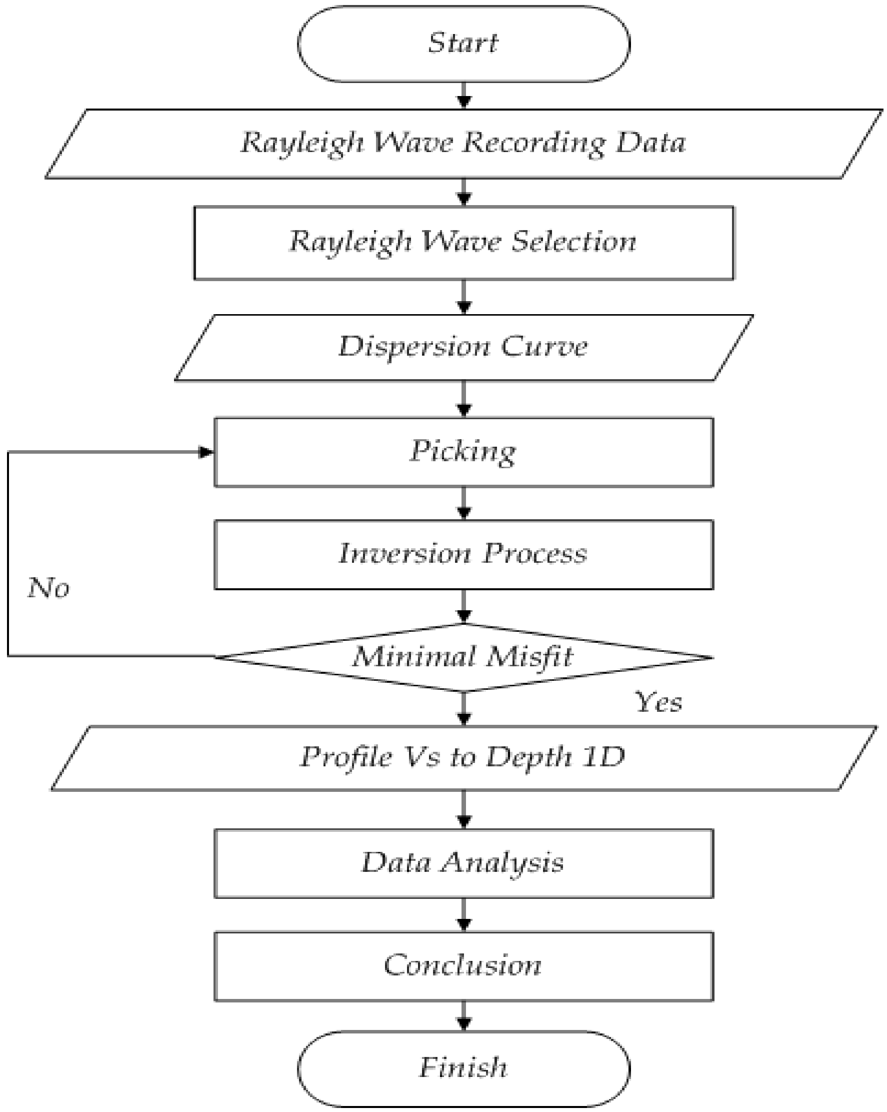


Figure 3. Data processing flowchart

Result and Discussion

This research was conducted at 12 measurement point locations. The data used is the result of data collection directly in the field using the PASI 16S24 P seismograph with a frequency of 4.5 Hz using the MASW seismic method. The length of the path affects the penetration depth, that is, if the distance between the geophones and the distance from the first geophone to the vibration source is long, deep penetration is produced and vice versa if the geophone distance is short, shallow penetration is obtained [6]. At each research point, data measurement needs to be repeated 3-10 times to get the best results so you can know the consistency of the results of the data measurements. The sampling time and recording time used to measure each research location were 125 µs and 1024 ms. The *Vs* values, Poisson ratio, shear modulus and Young's modulus at 12 data collection points related to soil types based on SNI 1726 of 2019 [14] are shown in Table 2 to Table 13.

Table 2. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 1

Layer	Depth (m)	*Vs* (m/s)	Poisson *ratio*	Shear Modulus (MPa)	Young's Modulus (MPa)	Type of Soil
1	0-3,6	261	0,40	133	371	Medium Soil
2	3,6-6	338	0,35	225	607	Medium Soil
3	6-7,9	328	0,35	211	569	Medium Soil
4	7,9-13,2	443	0,35	399	1.075	Solid Soil, Soft Rock
5	13,2-30	626	0,35	830	2.242	Solid Soil, Soft Rock

Table 3. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 2

Layer	Depth (m)	*Vs* (m/s)	Poisson *ratio*	Shear Modulus (MPa)	Young's Modulus (MPa)	Type of Soil
1	0-3,1	168	0,40	52	145	Soft Soil
2	3,1-8	183	0,35	61	164	Medium Soil
3	8-12,2	272	0,35	142	383	Medium Soil
4	12,2-24,2	280	0,35	151	406	Medium Soil
5	24,2-30	689	0,35	1.045	2.814	Solid Soil, Soft Rock

Table 4. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 3

Layer	Depth (m)	*Vs* (m/s)	Poisson *ratio*	Shear Modulus (MPa)	Young's Modulus (MPa)	Type of Soil
1	0-5,9	271	0,40	144	401	Medium Soil
2	5,9-10,1	370	0,35	273	735	Solid Soil, Soft Rock
3	10,1-14,9	573	0,35	688	1.861	Solid Soil, Soft Rock
4	14,9-21,4	512	0,35	542	1.464	Solid Soil, Soft Rock
5	21,4-30	887	0,35	1.733	4.672	Solid Soil, Soft Rock

Table 5. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 4

Layer	Depth (m)	*Vs* (m/s)	Poisson *ratio*	Shear Modulus (MPa)	Young's Modulus (MPa)	Type of Soil
1	0-4,4	419	0,40	362	1.012	Solid Soil, Soft Rock
2	4,4-10,1	386	0,35	298	804	Solid Soil, Soft Rock
3	10,1-12,5	568	0,35	676	1.820	Solid Soil, Soft Rock
4	12,5-17,3	720	0,35	1.116	3.008	Solid Soil, Soft Rock
5	17,3-30	1.263	0,35	3.652	9.430	Rock

Table 6. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 5

Layer	**Depth (m)**	***Vs* (m/s)**	**Poisson *ratio***	**Shear Modulus (MPa)**	**Young's Modulus (MPa)**	**Type of Soil**
1	0-5,2	180	0,40	60	168	Medium Soil
2	5,2-13,2	221	0,35	91	246	Medium Soil
3	13,2-16,7	262	0,35	131	353	Medium Soil
4	16,7-22,4	384	0,35	295	796	Solid Soil, Soft Rock
5	22,4-30	648	0,35	893	2.414	Solid Soil, Soft Rock

Table 7. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 6

Layer	**Depth (m)**	***Vs* (m/s)**	**Poisson ratio**	**Shear Modulus (MPa)**	**Young's Modulus (MPa)**	**Type of Soil**
1	0-2,6	180	0,40	60	168	Medium Soil
2	2,6-7,2	193	0,35	68	184	Medium Soil
3	7,2-11,8	214	0,35	85	229	Medium Soil
4	11,8-23	290	0,35	162	438	Medium Soil
5	23-30	474	0,35	461	1.243	Solid Soil, Soft Rock

Table 8. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 7

Layer	**Depth (m)**	***Vs* (m/s)**	**Poisson *ratio***	**Shear Modulus (MPa)**	**Young's Modulus (MPa)**	**Type of Soil**
1	0-0,9	127	0,40	29	79	Soft Soil
2	0,9-3,9	151	0,35	40	108	Soft Soil
3	3,9-6,4	185	0,35	62	168	Soft Soil
4	6,4-9,1	212	0,35	83	225	Soft Soil
5	9,1-30	617	0,35	805	2.168	Solid Soil, Soft Rock

Table 9. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 8

Layer	**Depth (m)**	***Vs* (m/s)**	**Poisson *ratio***	**Shear Modulus (MPa)**	**Young's Modulus (MPa)**	**Type of Soil**
1	0-1,6	176	0,40	57	160	Soft Soil
2	1,6-3,7	223	0,35	93	251	Medium Soil
3	3,7-6	305	0,35	181	487	Medium Soil
4	6-6,9	278	0,35	148	400	Medium Soil
5	6,9-30	522	0,35	565	1.522	Solid Soil, Soft Rock

Table 10. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 9

Layer	Depth (m)	*Vs* (m/s)	Poisson *ratio*	Shear Modulus (MPa)	Young's Modulus (MPa)	Type of Soil
1	0-2,7	167	0,40	51	143	Soft Soil
2	2,7-7,3	170	0,35	52	140	Soft Soil
3	7,3-12	217	0,35	88	236	Medium Soil
4	12-22,1	285	0,35	157	423	Medium Soil
5	22,1-30	488	0,35	490	1.324	Solid Soil, Soft Rock

Table 11. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 10

Layer	Depth (m)	*Vs* (m/s)	Poisson *ratio*	Shear Modulus (MPa)	Young's Modulus (MPa)	Type of Soil
1	0-5,9	164	0,40	49	137	Soft Soil
2	5,9-10,8	208	0,35	80	216	Medium Soil
3	10,8-19,2	241	0,35	110	296	Medium Soil
4	19,2-26,8	278	0,35	148	400	Medium Soil
5	26,8-30	549	0,35	629	1.700	Solid Soil, Soft Rock

Table 12. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 11

Layer	Depth (m)	*Vs* (m/s)	Poisson *ratio*	Shear Modulus (MPa)	Young's Modulus (MPa)	Type of Soil
1	0-2,0	175	0,40	57	157	Soft Soil
2	2,0-5,8	167	0,35	50	135	Soft Soil
3	5,8-10,4	204	0,35	77	207	Medium Soil
4	10,4-23,4	285	0,35	157	423	Medium Soil
5	23,4-30	531	0,35	586	1.583	Solid Soil, Soft Rock

Table 13. Value of Vs, Poisson ratio, shear modulus and Young's modulus at location 12

Layer	Depth (m)	*Vs* (m/s)	Poisson *ratio*	Shear Modulus (MPa)	Young's Modulus (MPa)	Type of Soil
1	0-1,9	199	0,40	74	208	Medium Soil
2	1,9-3,5	290	0,35	162	438	Medium Soil
3	3,5-6,7	324	0,35	206	555	Medium Soil
4	6,7-8,3	278	0,35	148	400	Medium Soil
5	8,3-30	522	0,35	565	1.522	Solid Soil, Soft Rock

The resulting value on the 1-D *Vs* profile for 12 measurement points can show 5 layers with different *Vs* values in each layer. According to [15], shear wave velocity values for various types of material show that measurements for the sixth location have a value of *Vs* 180-474 m/s with a depth of 2.6-30 meters and at the ninth location with a value of *Vs* 167-488 m/s with a depth of 2.7-30 meters including soft mud and dry sand materials. At the third location with a value of *Vs* 271-887 m/s at a depth of 5.9-30 meters and the fourth location with a value of *Vs* 419-1263 m/s at a depth of 4.4-30 meters including the type of material soft mud, dry sand, clay and wet sand. At the first location with a value of *Vs* 261-626 m/s with a depth of 3.6-30 meters, the second location with a value of *Vs* 168-698 m/s with a depth of 3.1-30 meters the fifth location with a value of *Vs* 180-648 m/s s at a depth of 5.2-30 meters, the seventh location with a value of *Vs* 127-617 m/s at a depth of 0.9-30 meters, the eighth location with a value of *Vs* 176-522 m/s at a depth of 1.6-30 meters, the tenth location with a value of *Vs* 164-549 m/s at a depth of 5.9-30 meters, the eleventh location with a value of *Vs* 199-522 m/s at a depth of 1.9-30 meters and the twelfth location with a value of *Vs* 175-531 m/s s at a depth of 2-30 meters including types of soft silt material, dry sand and clay. The Poisson ratio value can be calculated after obtaining the *Vp* and *Vs* values. For Poisson ratio values at points 1-12 research locations the results are the same for each layer with a range of 0.40-0.30, based on the Poisson ratio value for soil type according to [16] the type of material is saturated clay and silt .

From the estimation of rock layers based on shear modulus values according to [12] that for shear modulus values at the first location point the results are 133-830 MPa at a depth of 3.6-30 meters, at the second location with a value of 52-1045 MPa at a depth 3.1-30 meters, in the third location with a value of 144-1733 MPa at a depth of 5.9-30 meters, in the fourth location with a value of 362-3652 MPa at a depth of 4.4-30 meters, in the fifth location with a value of 60- 893 MPa at a depth of 5.2-30 meters, at the sixth location with a value of 60-461 MPa at a depth of 2.6-30 meters, at the seventh location with a value of 29-805 MPa at a depth of 0.9-30 meters, at the eighth location with a value of 57-565 MPa at a depth of 1.6-30 meters, at the ninth location with a value of 51-490 MPa at a depth of 2.7-30 meters, at the tenth location 49-629 MPa at a depth of 5.9-30 meters, at at the eleventh location with a value of 57-586 MPa at a depth of 2-30 meters, at the twelfth location 74-565 MPa at a depth of 1.9-30 meters, including the same type of material, namely clay material.

The Young's modulus value obtained from the research results refers to [17] regarding the assumption of soil type on the Young's modulus value. the second location with a value of 145-2.814 (MPa) at a depth of 3.1-30 meters, in the fifth location with a value of 168-2.414 (MPa) at a depth of 5.2-30 meters, in the seventh location with a value of 79-2.168 (MPa) at a depth of 0.9-30 meters including soft clay materials, sand, gravel and silt. At the sixth location with a value of 168-1.243 (MPa) at a depth of 2.6-35 meters, at the eighth location with a value of 160-1.522 (MPa) at a depth of 1.6-30 meters, the ninth location with a value of 143-1.324 (MPa) at a depth of 2.7-30 meters, at the tenth location with a value of 137-1,700 (MPa) at a depth of 5.9-30 meters, at the eleventh location with a value of 158-1,583 (MPa) at a depth of 2-30 meters at the twelfth location with values 208-1522 (MPa) at depths of 1.9-30 meters include very soft clay materials. Whereas for the third location with a value of 401-4,672 (MPa) at a depth of 5.9-30 meters and the fourth location with a value of 804-9,430 (MPa) at a depth of 4.4-30 meters, it includes medium clay and silty sand materials.

Value of shear modulus and Young's modulus depends on the value of *Vs* and density, the greater the value of *Vs* and density produced, the greater the value of shear modulus and Young's modulus obtained and vice versa. If a layer has softer soil conditions, the value of *Vs* tends to be relatively small compared to layers with denser soil conditions. So that if an earthquake occurs it will be easy for wave vibrations caused by earthquakes to tend to increase on soft soil compared to solid soil [18]. For the value of *Vs*, shear modulus and Young's modulus in SE and SD rock types, they are susceptible to the impact of earthquakes that are felt at the time of the earthquake because the soil type is relatively soft. In rock type areas SB and SC can reduce the occurrence of damage to buildings during earthquake wave vibrations because they have a high density because the higher the density value, the denser and harder the rock layers.

From the geological conditions of the study area, it is known that there is one point in the Alluvium formation area with SD rock types and 11 points in the Simpangaur formation area with SD to SC rock types, so that almost all of the research locations are in the Simpangaur formation area. However, if viewed from the distribution of the average shear wave velocity values up to a depth of 30 meters, it can be seen in Table 14 that the characteristics of the rock-forming materials of the two formations are dominated by the Alluvium formation. This is because basically the geological conditions of the South Bengkulu region are almost entirely covered by surface deposits of alluvium and sandstone, while the Simpangaur formation with bedrock, clay and conglomerate is generally in a transitional shallow marine environment [5].

The value of V_{s30} in the study area is shown in Table 14. It can be seen from Table 14 that the value of V_{s30} in the Northwest area of Manna City ranges from 236-650 m/s, which according to the class classification of land sites based on SNI 1726: 2019, the Northwest area of Manna City is classified as into SD and SC site classes. The SD site class is an area of moderate soil and the SC site class is an area of hard, very dense soil and soft rock.

Table 14. Distribution of V_{s30} values in the Manna City area

Research point	Longitude (°)	Latitude (°)	V_{s30} (m/s)	*Vs* layer (m/s)
1	102,870689	-4,415949	464	199-522
2	102,873863	-4,414618	267	168-698
3	102,875839	-4,416259	470	271-887
4	102,878088	-4,42286	650	419-1263
5	102,875358	-4,420277	245	180-648
6	102,873701	-4,427627	266	180-474
7	102,884744	-4,433901	346	127-617
8	102,883767	-4,427673	409	176-522
9	102,890291	-4,437633	258	167-488
10	102,916572	-4,43907	236	164-549
11	102,895752	-4,437417	260	175-531
12	102,901363	-4,448475	415	199-522

Figure 4 displays the distribution of V_{s30} values in the research area. The relationship between soil type classification and risk due to earthquakes can be determined based on the shear wave velocity, namely V_{s30}≤350 m/s has a large risk, V_{s30} 350-750 m/s has a high risk. moderate and V_{s30}≥750 m/s has a small risk [14]. Thus, from Figure 4 it can be seen that for the study of regional and urban planning in the future development of Manna City, based on the distribution of V_{s30} values, the Northwest area of Manna City is categorized as a good location for development, because it can be seen from map of the distribution of V_{s30} marked in green, yellow and brown where these locations have values of V_{s30} above 350 m/s so it is assumed that most of the Northwest area of Manna City has a moderate risk of the impact of an earthquake. However, because the Vs value of the layers varies, so if you want to carry out construction, you need to pay attention to the condition of the soil layers, such as building foundations and soil compaction which functions to increase the thickness of the soil layer. When viewed from the *Vs* value of each soil layer, the values range from 127-1263 m/s, so that these values indicate that the types of material in the Northwest area of Manna City are soft clay, dry sand, loam, wet sand and clay. Based on the geological conditions of the research location, in general these materials are the constituents of the Simpangaur and Alluvium rock formations.

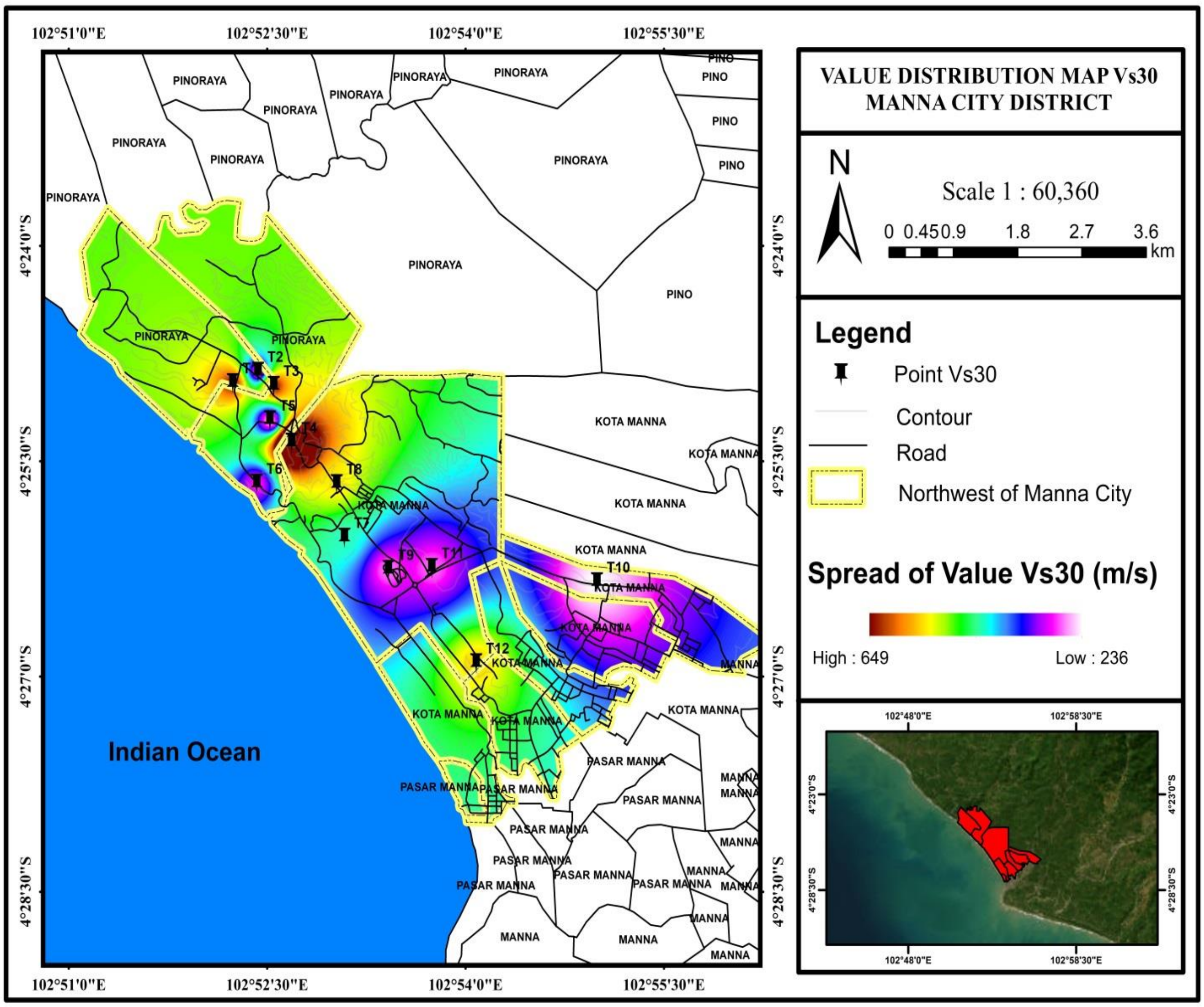


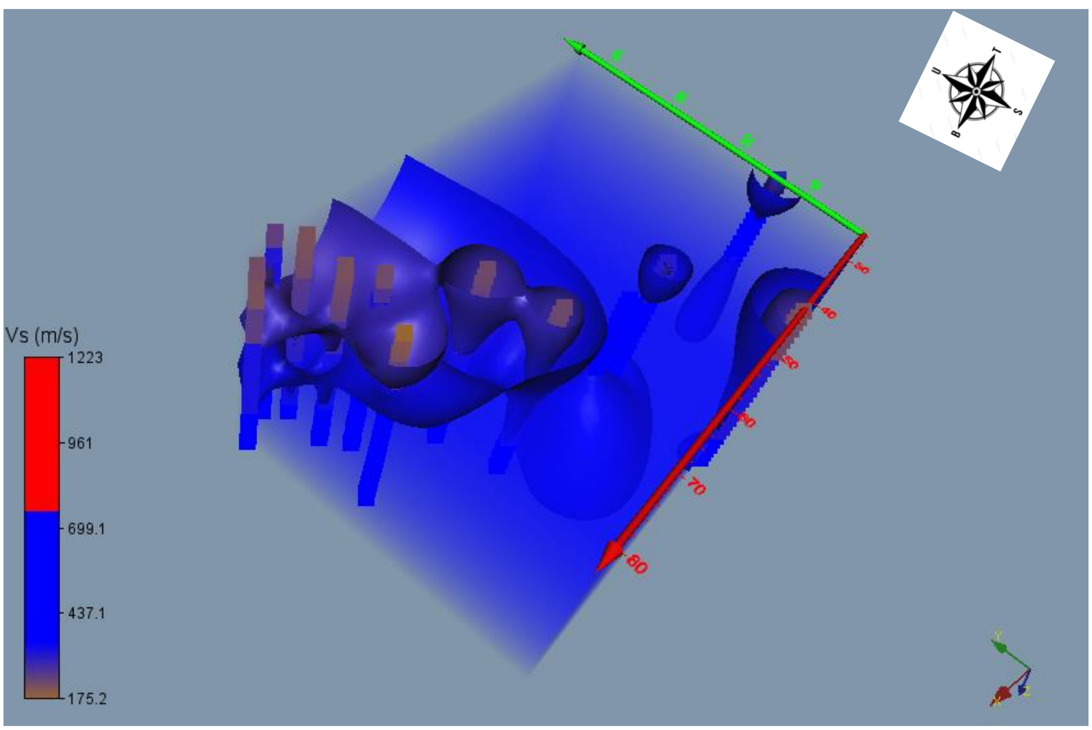
Figure 4. Distribution map of V_{s30} in the northwestern area of Manna City

The research data that was used to derive the *Vs* values had a minimal misfit value that was near to 0, falling between -10,7427 and -1,2282. This lowest misfit value is affected by the outcomes of the observed Rayleigh surface waves as well as the data selection procedure that was used during data processing in the WinMASW 5.0 Professional program. Table 15 below shows the minimum misfit value derived from the data processing results for each research location point:

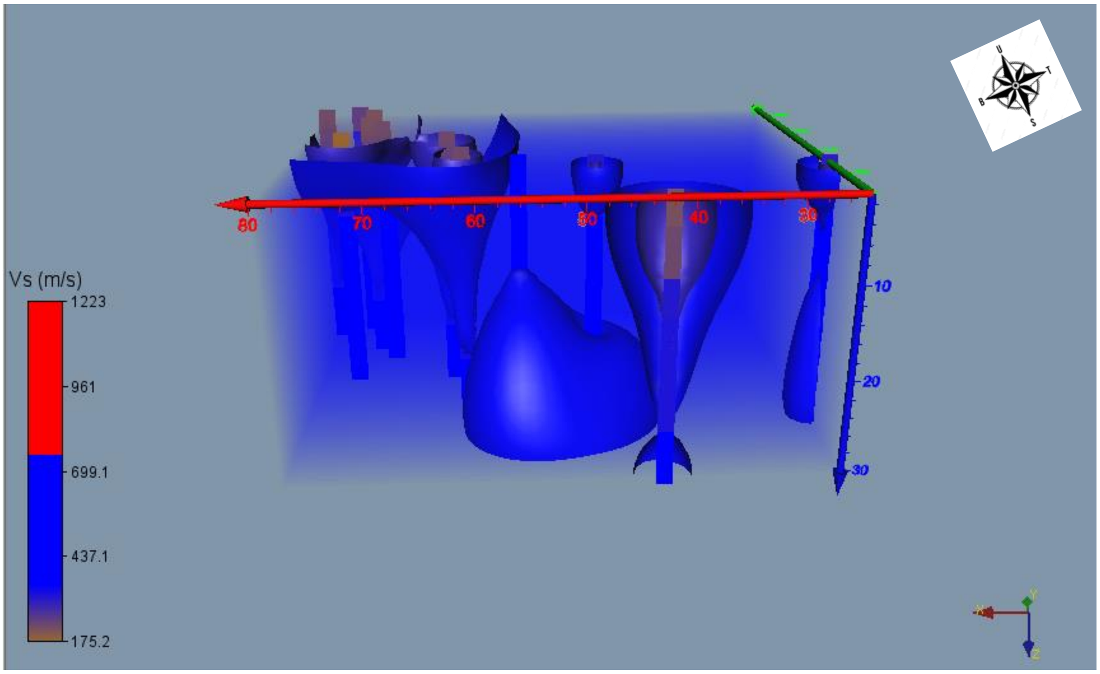
Table 15. Value of minimum misfit

Research point	Value of V_{s30} (m/s)	Minimum Misfit
Location 1	464	-2,2076
Location 2	267	-3,5188
Location 3	470	-5,3457
Location 4	650	-10,7427
Location 5	245	-3,3721
Location 6	266	-1,2282
Location 7	346	-1,6672
Location 8	409	-3,6830
Location 9	258	-1,8032
Location 10	236	-2,9624
Location 11	260	-1,6821
Location 12	415	-2,3069

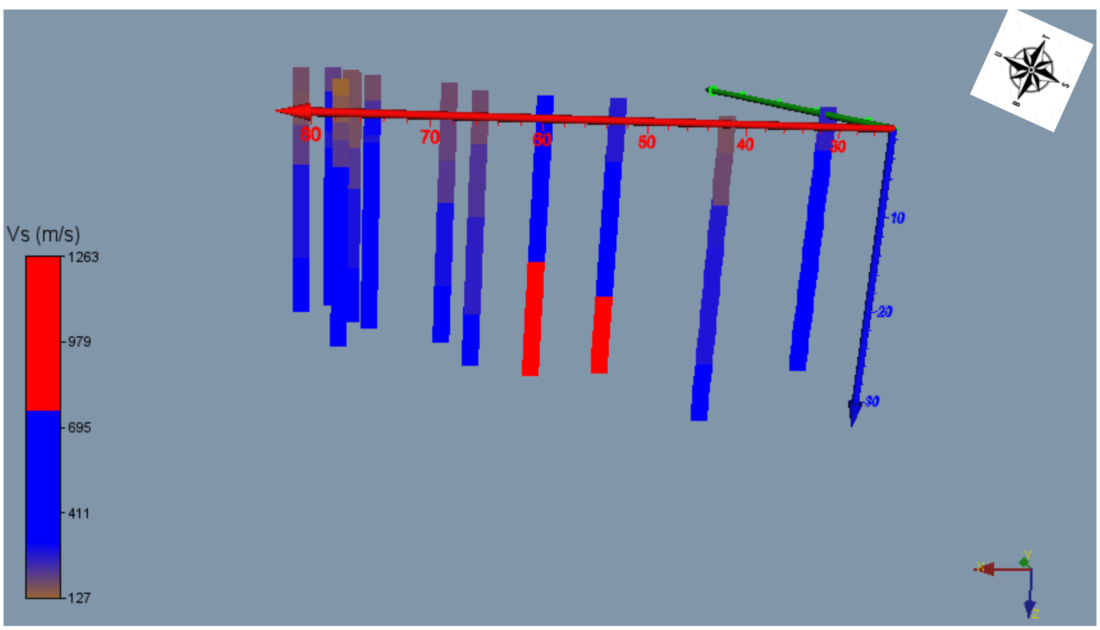
The results of modeling using winMASW 5.0 Professional software in the form of a 1-D *Vs* value profile for each layer are then modeled in a 3-D view using Voxler software as shown in Figure 5. With the X axis, Y denotes coordinate variables (longitude and latitude) and Z denotes variables depth.



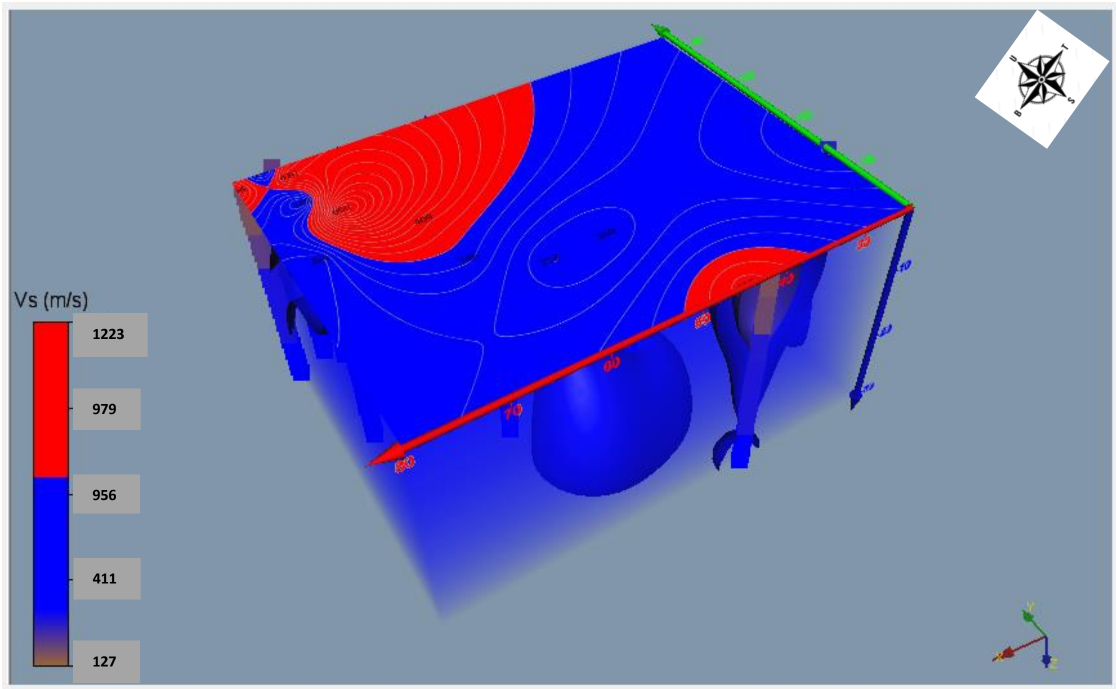
(a)


Vs (m/s)
1223
961
699.1
437.1
175.2
80
70
60
50
40
30
10
20
30

(b)


Vs (m/s)
1263
979
695
411
127
80
70
60
50
40
30
10
20
30

(c)



(d)

Figure 5. 3-D view using a voxler based on the *Vs* layering values of 12 measurement data, (a) top view (b) side view, (c) view per point of data measurement location (d) The red area is an area with a hard soil type compared to the blue soil type; this is influenced by the fact that the rock layering structure is areas in red are typically composed of dense soil types or soft rocks. The image of the Vs_{30} distribution placed above the image of the *Vs* value of the layers in 3-D cross-section shows this.

Conclusion

After obtaining the results from data processing and conducting research in the Northwest area of Manna City, South Bengkulu Regency, it can be concluded that the subsurface structure in the Northwest area of Manna City consists of rock types of soft soil (SE), stiff soil (SD), very dense soil. and soft rock (SC) dan rock (SB). The largest value is located at the fourth point with a value of Vs 386 m/s-1263 m/s, Poisson ratio 0.40-0.35, shear modulus 298-3652 MPa and Young's modulus 804-9430 MPa where the subsurface structure consists of from hard soil, very dense and soft rock to rock, while the smallest value is at the sixth point with a value of Vs 180 m/s-474 m/s, Poisson ratio 0.40-0.30, shear modulus 60-461 MPa and Young's modulus 168-1.243 MPa where the subsurface structure consists of medium to hard soil, very dense and soft rock. So from the results of this study it can be seen based on the values of *Vs*, V_{s30}, Poisson ratio, shear modulus and Young's modulus, that the Northwest area of Manna City is categorized as a good location for the development of infrastructure development and public facilities for Manna City in the future.

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