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Geological Approach for Land Subsidence Analysis in Peatlands in the Awareness Area of Pekanbaru, Riau, Indonesia

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Abstract

This study area is administratively located in Parit Indah District, Bukit Raya District, Pekanbaru City, Riau Province. Geographically, the research area is located at coordinates 0° 28' 30.92" N 101° 28' 9.45" E N 0° 27' 25.63" - 101° 29' 47.30" E. The aim of this study was to find out the effect of peat soil types on subsidence. The data collection method in this study was carried out using sieve analysis, water content analysis, specific gravity, subsidence analysis, and soil testing in the laboratory. The effect of peat soil on subsidence has a significant effect between the type of peat and subsidence, the higher the maturity level of the peat, the lower the level of subsidence on peat soil. Based on the study's results, the soil consolidation test with a depth of 75cm-3m had a soil settlement value of 0.467. It is recommended to do this to reduce the impact of subsidence in the land area such as the research area so that it does not have too much impact on the construction which is carried out by hardening the location using the vertical wick drain method, as well as for building foundations it can be done using chicken claw foundation.

Keywords: Geological Mapping, Characteristics, Peat Soil, Subsidence, Consolidation Test

1. Introduction

The area of Indonesian peatlands is estimated to range from 17-21 million hectares (Soil Research Institute, 2011), and Riau is one of the provinces in Indonesia located on the island of Sumatra which has an area of approximately 8.7 million hectares, of which 3.9 million hectares is peat land.

Fibrous peat soils have poor physical and technical properties, namely high-water content and void ratio, low specific gravity and carrying capacity, and large and uneven compression. Peatlands that are dry and no longer store water which then causes subsidence or subsidence *(Anbalagan, 1992; He et al.,* 2022; Kausarian *et al.,* 2020, 2021). There are two types of subsidence, namely endogenic subsidence and exogenic subsidence. Endogenic subsidence is caused by natural forces from within the earth such as plate movements, folding and faulting of the earth's surface and earthquakes. Exogenic subsidence is caused by human activities such as underground mining, excess groundwater extraction, oil and gas drilling activities and changes in soil composition (Dikshit et al., 2020; El Jazouli *et al.,* 2019; Izumi *et al.,* 2019; Lubis, Anurogo, *et al.,* 2017).

The construction of a housing complex which carried out in the research area is the basis for research to be able to calculate the impact of peatland subsidence and solutions to inhibit peatland subsidence (Basharat *et al.,* 2021; CERRI *et al.,* 2017; Kausarian *et al.,* 2018).

2. Study Area

Administratively the research area is located in a conscious housing area in the awareness area of Tangkerang Labuai Village, Marpoyan Damai District, Pekanbaru City, Riau Province.

Stratigraphically, the study area is composed of rocks which are surface deposits, namely Old Surface Deposits (Qp) (Clarke *et al.,* 1982; Heidrick & Aulia, 1993; Kausarian *et al.,* 2023; Koesoemadinata & Matasak, 1981; Lubis, Anggraini, *et al.,* 2017).

3. Methodology

3.1 Research Object

To carry out all the research methodology, we summarize all the research steps as

1. Sampling by hand auger method.
2. Sieve analysis, is an analysis of filtering a soil sample through a set of sieve.
3. Liquid Limit is a certain water content where the behavior changes from plastic to liquid. Plastic limit is defined as the water content in a position between plastic and semi-solid.
4. The relationship between the Atterberg Limit and Soil Properties is useful for estimating the properties and knowing the type of soil The water content in the soil is the ratio between the weight of the water contained in the soil and the weight of the soil grains, and is expressed in percent.
5. Specific gravity is the ratio between the weight of soil and the weight of water using the same volume.
6. Consolidation Analysis

3.2 Sieve Analysis

The use of Sieve Analysis is to find out the physical properties of the soil to be tested. While the purpose of Sieve Analysis is to find out a soil to be tested, whether it is poorly graded, uniformly graded or well graded, as well as to determine grain size (Deng *et al.,* 2017; Ruiz-Martínez *et al.,* 2016; Ubani et al., 2018).

The results of the sieve analysis are generally depicted on semi-logarithmic paper, which is known as the grain size distribution curve. The parameters of the grain size distribution curve include;

1. The effective size is the diameter in the grain size distribution curve corresponding to the finer 10% (passes the sieve),

2. The uniformity coefficient is a coefficient that shows the uniform properties of the soil.

If : Cu = D60/D10.

The value of Cu and Cz = 1, then the soil grains are the same size. Cu value > 5, the soil grains are increasingly non-uniform. Cu value < 3, then the soil grains are more uniform.

3. The Coefficient of Gradation is a coefficient that shows the distribution of grain size variations

If: Cz < 5 graded well, if value Cz> 5 graded badly.

$$Cz = \frac{(D30)^2}{D60 \ x \ D10}$$

4. Sorting Cooeficient

So = √D75/D25

If : So < 2.5, then the sorting is good. So 2.5 – 4, then the sorting is moderate. So > 4, then the sorting is bad.

3.3 Moister Content (Content of Water in Soil)

The water content in the soil is the amount of water in the pore space between the soil grains which is dried using an oven. This analysis is carried out to determine the amount of water in the soil expressed as a percent – the age of dry soil mass. The following is the formula for calculating the water content in the soil.

Weight of Water = W2 – W3
Dry Soil Weight = W3 – W1
Moisture Content (%) = (W2 – W3 / W3 – W1) x 100%
Note: W1 is the weight of the container. W2 is wet soil sample + container. W3 is dry soil sample + container.

Table 1. Calculation Table of Moisture Content

Number of Treatment			Per.01	Per.02	Per.03
Wet Ground Mass + Cup	m_2	gr			
Dry Ground Mass + Cup	m_3	gr			
Cup Mass	m_1	gr			
Water Mass	$m_2 - m_3$	gr			
Dry Ground Mass	$m_3 - m_1$	gr			
F. Water content in the ground $\frac{m2 - m3}{m3 - m1}$ x 100%		%			

If: The water content in the soil is 20% - 100%, then the soil is normal. The water content in the soil is > 100%, then the soil is saturated with water. The water content in the soil is <20%, then the soil is dry.

3.4 Consolidation Test

The consolidation test is used to determine the compression properties of a soil sample, namely the nature of the change in contents and the process of water escaping from the soil due to axial pressure acting on the soil.

4. Result and Discussion

4.1 Hand Auger

In the drilling that has been carried out in the study area (Fig. 1), there is 1 log out of 10 drilled holes, this is because all types of peat in all drill holes in the study area are the same physically, namely:

Figure 1. The sampling process using the hand auger method

4.1.1 Bore Hole 06

In Bore Hole 06 with coordinates N 00°27'12.74" E 101°28'49.85" with a depth of 3 meters, 2 types of lithology were found, namely clay (soil stockpile) and peat. This lithology is found at different depths.

4.2 Sieve Analysis

In the study area, the soil types in this study area were dominated by fibrous soils or peat soils, so that sieve analysis was used to determine the grain size distribution of the soil.

The following is the result of sieve analysis in the laboratory from the drill hole 6 sample:

4.2.1 Bore Hole 06 (Depth: 75 cm-3 cm)

Dealing with the data in Fig. 2 and Table 2, it can be seen that the smaller size of the filter hole, the less sample is filtered. For example, with a sieve size of 4.75, 81.38% of the sample was filtered out, which is the largest filter hole size and the number of samples that pass through the filter is also the largest. On a 2.00 mm sieve hole size, the less the sample passes the sieve, which is as much as 59.64%. At the smallest sieve size of 0.075 mm, the least filtered sample is 15.08 mm. Figure 4 can be seen that the sieve analysis graph shows that the sample contains fine sand to medium gravel material.

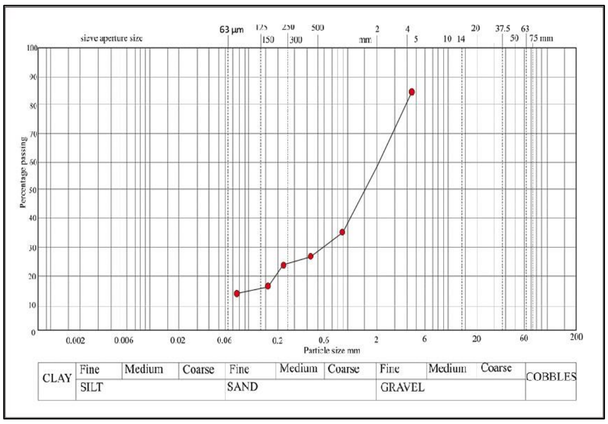

Figure 2. Graph of bore hole 06 sieve analysis

Table 2. Data from Bore Hole Sieve Analysis Results 06 Depth 0.75 – 3 m

Sieve Size		Individual	Cumulative	Percent	Percent
Inch	Mm	Retained (Gram)	Retained (Gram)	Retained (%)	Passing (%)
# 4	4.75	14.75	14.75	18.62	81.38
# 10	2.00	17.23	31.98	40.36	59.64
# 20	0.850	19.42	51.40	64.87	35.13
# 40	0.425	5.94	57.34	72.37	27.63
# 60	0.250	2.94	60.28	76.08	23.92
# 140	0.106	5.85	66.13	83.47	16.53
# 200	0.075	1.15	67.28	84.92	15.08

After obtaining the above data, it is then plotted onto a sieve analysis diagram to find out the grain distribution of the Bore Hole 06 sample with a depth of 75cm – 3m, and the following calculations are also obtained:

a. *Sorting Coefficient* (So)

$So = \sqrt{(d75/d25)}$

$So = \sqrt{(6mm/0{,}5mm)}$

So = 3,4mm

Dealing with the results of Fig. 2, it can be concluded that in bore hole 06 with a depth of 75cm – 3 m, the grain size distribution of fine sand is obtained. However, the data cannot be determined for the Cu and Cz calculation values because the value of $D10$ is not known. Because the sample has stopped on the 200 sieve with a larger presentation than 10%, but Cu and Cz can still be known through the curve graph of the sieve analysis results above where the sample curve is in the type of fine sand to medium gravel, with sand in the size of 0.7mm – 2mm and graval from 2mm – 9mm, which means that the sample in the study area is non-uniform and well graded, and from the calculation results obtained So = 3.4, which means moderate sorting.

4.3 Water Content in Soil

The water content in the soil in the study area is very influential on the consistency of the soil, and the suitability of the soil for cultivation in the study area. Because the amount of peat water in the study area has a big effect on the soil derivatives that will occur. The following are the results of the analysis of soil water content from the bore hole samples in Table 3.

Table 3. Data from Analysis of Water Content in Soil

Data	Unit	Mass
Cup Weight+wet ground	gr	48,03
Cup Size+dry ground	gr	18.54
Cup Weight	gr	8,5
Water weight	gr	29.49
Berat dry ground	gr	10,04
Water content	%	293,73

Regarding to the soil water content test experiments in this study, the experimental results were obtained as follows:

$$W = \frac{M2-M1}{M3-M1} x100$$

$$W = \frac{48{,}03\ \text{gram} - 18{,}54\ \text{gram}}{18.54\ \text{gram} - 8.5\ \text{gram}} x100$$

$$W = \frac{29{,}49\ \text{gram}}{10{,}04\ \text{gram}} x100$$

W = 293,73

W = Moisture Content

$m1$ = Weight of Cup

$m2$ = Weight of Cup + Wet Soil

$m3$ = Large Cup + Dry Soil

Based on the data that has been analyzed above, the percentage of water content in peat soil at a depth of 0.75-3 meters is 293.37%, which means that the type of peat soil in this study area is water saturated. The water content in the soil in the study area is influenced by the organic content in the soil. Dry soil has a low organic content while water-saturated soil has a high organic content. Evidenced by the discovery of many roots and stems of plants (Fig. 3).

Fig. 3. An example of an organic content in the soil in the study area

4.4 Test of Atterberg Limit

The Atterberg Limit test is divided into two tests, namely:

4.4.1 Liquid Limit Test

The following is an analysis of the results of the liquid limit test in the laboratory, namely: Liquid Limit Test Bore Hole 01 Depth 75cm-3m. The following is a Table 4, the results of the liquid limit test for soil samples and a graph of the relationship between the number of knocks and the liquid limit for soil samples at a depth of 75 cm to 3 meters.

Table 4. Results of the Liquid Limit Test for Soil Samples at a Depth of 75 cm – 3 m

Water Limit Test (Soil Type: Sand)		
Cup Number		1 2 3 4
Cup Weight	Gram	
Cup Weight + Wet ground	Gram	
Cup Weight + Dry ground	Gram	Non-Plastic
Weight of Wet ground	Gram	
Weight of Dry ground	Gram	
Water weight	Gram	
Water content (LL)	%	
Number of Hit		

Soil samples at a depth of 0.75 – 3 m cannot be tested for liquid limit values because the type of soil at this depth is sandy soil, where sand is semi-solid and dense or because the liquid limit is the boundary between a semi-liquid and semi-plastic state, so the type of soil that is The only liquid limit test that can be tested is clay soil, silt soil, or sandy soil containing a mixture of clay, in other words, soil that has a mixture of plastic materials, so that soil samples at a depth of 0.75 to 3 meters cannot be tested.

4.4.2 Plastic Limit

The plastic limit is defined as the water content in the soil between the plastic and semi-solid phases. If the water content in the soil decreases, the soil becomes harder and has the ability to withstand deformation. The plastic limit test is intended to determine the amount of water content in the soil sample when the soil changes from the plastic phase to the semi-solid phase or vice versa.

The following is the result of the plasticity limit test for soil samples at a depth of 75cm – 3m which has a sandy soil type (Table 5).

Table 5. Results of the Plastic Limit Test for Soil Samples at a depth of 75 cm – 3m

Plastic Limit Test (Soil Type: Sand)					
Cup Number		**1**	**2**	**3**	**4**
Cup Weight	Gram				
Cup Weight + Wet ground	Gram	Non-Plastic			
Cup Weight + Dry ground	Gram				
Weight Wet ground	Gram				
Weight Dry ground	Gram				
Water weight	Gram				
Water content (LL)	%				
Average Plastic Limit (PL)	%				

Soil samples at a depth of 0.75 – 3 meters cannot be tested for plastic limit values because the type of soil at this depth is sand, where sand is semi-solid and dense or because the plastic limit is the boundary between a plastic and semi-solid state, so the only soil type can be tested the liquid limit is clay soil, silt soil, or sandy soil containing a mixture of clay, in other words the soil at a depth of 0.75 – 3 meters has almost no plasticity.

4.5 Spesific Gravity Tests

Specific gravity or specific gravity is the ratio between the grain weight of the soil and the grain volume at a certain temperature. The soil referred to here is the grain weight of the soil itself without water or air (without pores). While the volume of soil referred to in this case is the volume of soil without containing pores. Following are the results of the specific gravity analysis on drill hole 06 in the study area (Tabel 6).

Table 6. Data from the Specific Grafity Analysis

Data	Unit	Mass
Pignimeter	gr	162.0
Sand Weight	gr	102.3
Pigno weight + water	gr	659.4
Cup Weight + water + dry ground	gr	692.9
Weight of dry ground	gr	33.5
	gr	68.8
Spesific gravity	gr	1.487

In the table above, the W2 value or sand weight is 102.3gr and the dry weight or W6 is 68.8gr. Following are the results of specific calculations from the soil samples in the study area:

$GS = \frac{W2}{W6}$

$GS = \frac{102,3}{68,8}$

GS = 1,487

Description:

W1 = Pignimeter
W2 = Sand Weight
W3 = Piqno Weight + Water
W4 = Cup Weight + Water + Dry Resistant
W5 = Weight of Dry Soil

The results of calculating specific gravity analysis data in the study area, a specific gravity of 1,487 grams was obtained, which means that in the study area the type of soil is peat soil/organic soil because the distance ranges from 1.25-1.80. The research area is included in the low specific gravity where it will be easier to decrease.

4.6 Consolidation Test

Consolidation is divided into two, namely direct consolidation and gradual consolidation. In this analysis, gradual consolidation is used. The following are the results of the study area consolidation analysis:

4.6.1 Consolidation Coefficient (CV)

The consolidation coefficient states the speed of the consolidation process of a soil and this analysis is used to determine the velocity of water flow in the vertical direction in the soil. The following results of calculating the CV value can be seen from the table below (Table 7).

Table 7. Data from Consolidated Coefficient Analysis Results

Pkpa	Cv
50.00	0.16667
100.00	0.36259
200.00	0.48006
400.00	0.37581

In the table above, we can see that at a minimum pressure of 50.00 Kpa, there is a decrease in speed of 0.16667. When the pressure is increased to 100.00 Kpa, the decreasing speed also experiences a greater change, namely 0.36359. At a pressure of 200.00 Kpa, the greatest decreasing speed is 0.48006. However, at the maximum pressure of 400.00 Kpa, the decrease speed is 0.37581 which is smaller than the pressure of 200.00. For more details, see the CV chart below (Fig. 4).

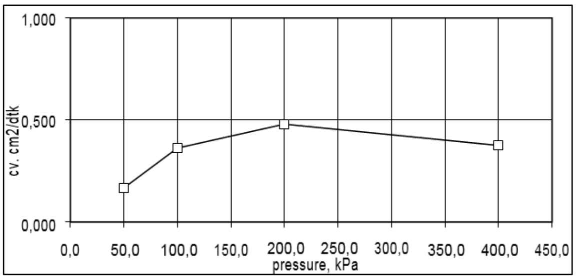

Figure 4. Data Graph of Consolidated Coefficient Analysis Results

From the results of the consolidation coefficient (CV) above, we can see that peat has a relatively high increase in CV. This is because peat soil has high permeability properties, so it is easily penetrated by water. Due to the nature of high permeability when pressure is applied, water will flow out of the soil quickly so that the soil subsidence that occurs is also greater and the faster it reaches a stable layer of soil when it has run out of compressed pore water. The land will continue to decrease until it is in a stable position.

4.6.2 Compression Coefficien (CC)

Compression Coefficien or compression index is used to calculate the amount of settlement that occurs in the study area, as a result of consolidation can be determined from the curve that shows the relationship between pore and pressure. More details can be seen in Table 8 of the compression index calculation results in the study area.

Table 8. Compression Coefficien Analysis Result Data

Pkpa	Void ratio
50.00	4.130
100.00	3.942
200.00	3.797
400.00	3.700

From the table above, the relationship between void ratio and effective pressure shows that the void ratio decreases in proportion to the increase in the applied pressure. This decrease indicates a reduction in the number of existing soil pores, thereby reducing the size of the void ratio. It can be seen in the table above that at a pressure of 50.00 it produces a void ratio of 4.130 Kpa, the greater the pressure, the smaller the void ratio. For example, the maximum pressure of 400.00 Kpa produces the smallest void ratio, namely 3,700. the additional load only occurred three times because the consolidation test sample had reached its maximum settlement so that it was unable to accept any additional load. This is due to the very high water content of the peat soil consolidation test sample.

From the table above we can calculate:

$CC = \frac{e1-e2}{\log p2-\log p1}$

$CC = \frac{4.130-3.700}{\log 400-\log 50}$

$CC = \frac{0.43}{0.91}$

CC = 0,472

Description:
CC = Compression Coefficient
e1 = Largest CC value
e2 = Smallest CC value
W4 = Cup Weight + Water + Dry Resistant
W5 = Weight of Dry Soil
For more details, see the picture below (Fig. 5);

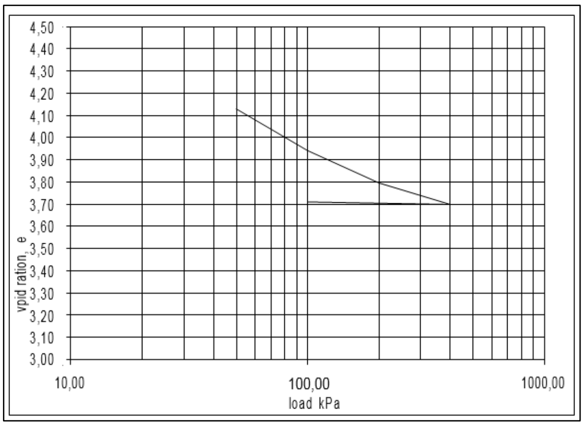

Figure 5. Graph of Compression Coefficien Analysis Results

From the graph above, we can see that the greater the pressure, the smaller the pores in the soil. This is caused by the release of pore water contained in the soil due to pressure. Based on the analysis that has been carried out starting from sieve analysis, soil water content analysis, soil consolidation tests in the study area have grain distribution ranging from sand to gravel with uniform soil grains. poorly graded (soil having uneven grain sizes from large to small grain sizes) and uniform sorting or sorting of grains (medium sorting). Furthermore, having a water content in the soil is dominated by water-saturated soil with a moisture content of > 100%. The water content in the soil in the study area is influenced by the organic content in the soil which is quite high. The following are the general results from the research area in the conscious residential area, awareness walk, beautiful ditch, namely (Table 9):

Table 9. Data Analysis Results

NO	Analysis	Result
1.	*Sieve Analysis*	Size of sand grain until gravel
2.	Uniformity	Good
3.	Gradation	Bad
4.	Sortation	Medium
5.	Water content in the soil	Water Saturated Soil
6.	*Atterberg Limit*	-
7.	*Gs*	1,487
8.	Consolidation	0,476

After carrying out all of the above analysis, the conscious area has decreased, this decline continues depending on the weight of the load and the water content in the soil until the soil is compressed. This primary decline will slowly damage the building infrastructure above it, such as bumpy ground or cracks in the house, as shown below (Fig. 6 and 7):

Figure 6. One of the Documentations in the Research Area House

Figure 7. One of the documentation of building damage due to land subsidence

On the soil in the research area is not too good for building construction. But there are several ways that can be done to reduce the impact of subsidence on land areas such as research areas so that they don't have too much of an impact on the development being carried out. There are several efforts that can be made before building construction on peat soil for the peat soil road paving process itself. It will go through several stages. The first thing to do is to repair the existing peat area. The repair process can be done by digging or peeling. Then the part excavated will be filled with soil or sand in better condition. The excavated peat soil will be compacted by applying a load on the surface, either with soil or sand, for a certain period of time. In order for the soil compaction process to take place more quickly, you can use a vertical sand drain which must be installed at a certain distance. Then another way can be by using synthetic materials where the installation is vertical. This method is known as vertical wick drain.

In the vertical wick drain method itself can also be done by adding a vacuum pump (Fig. 8). The goal is for the soil to solidify faster. Later the water and air in each layer of soil will come out.

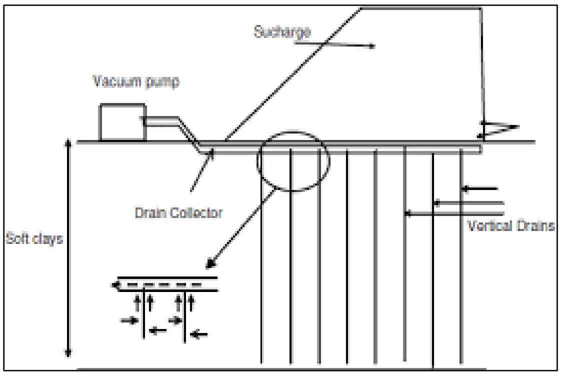

Figure 8. Example of Vertical Wick Drain Modeling

However, if the peatland area is not too large like the research area, then the method can be done by using a chicken claw foundation. After the foundation has been installed, the top layer can be loaded with soil or sand for compaction. Then later the peat road paving construction can be built on the top surface. Besides that, there is also a way that costs quite affordable, namely by using dolken or known as bamboo. In addition, you can use geo-textile which has a light weight but has great traction when receiving loads on it and the price is also not expensive.

For the type of pavement on peat soil itself, the most recommended is to use a flexible construction pavement. On peat soils, this type of pavement is more suitable because it is lighter. If you use a rigid pavement then the results are actually not good. Stiff pavement on peat soil pavement will cause the pavement to crack. This is because rigid pavements tend to be heavier in nature. Before peat soil is processed, it is necessary to carry out a stabilization process. For peatlands, this process takes longer because they have to use conventional methods. The term is also known as pre-loading. The soft and organic nature of peat makes it more difficult to move than normal soil. Many say that peat land is unfavorable land to use for the development process. That is what then makes the pavement process more complicated.

5. Conclusions

Dealing with the results of the analysis and calculation of land subsidence in conscious housing, the Pekanbaru awareness road which was carried out on drill 6, it can be concluded that:

1. Regarding to the results of the sieve analysis, it can be concluded that the grain size distribution in the study area was fine sand to medium gravel in size, which means that the grain in the study area is not uniform and has good grades.
2. Based on the results of calculating the water content in the data that has been analyzed, the percentage of water content in peat soil at a depth of 0.75-3 meters was 293.37%, which means that the type of peat soil in this study area is water saturated and not very good for the construction of roads and buildings.
3. Based on the calculation of specific gravity analysis data in the study area, it was found that the specific gravity was 1,487 gr, which means that in peat/organic soil areas. and research is included in a low specific gravity where it will be easier to decrease.
4. From the results of land subsidence using the consolidation test, it can be concluded that the coefficient of consolidation (CV) of peat had a relatively high increase in CV. This is because peat soil has high permeability properties. And experienced a decrease of 0.476. The settlement continues continuously depending on the weight of the load and the water content in the soil until the soil is compressed.

Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, or proof reading the article, etc.).

Acknowledgement can be write in this paper or not. Using 9 pt font, 6 pt after headings.

References

Anbalagan, R. (1992). Landslide hazard evaluation and zonation mapping in mountainous terrain. Engineering Geology, 32(4), 269–277. https://doi.org/10.1016/0013-7952(92)90053-2

Basharat, M., Riaz, M. T., Jan, M. Q., Xu, C., & Riaz, S. (2021). A review of landslides related to the 2005 Kashmir Earthquake: Implication and future challenges. Natural Hazards, 108(1), 1–30. https://doi.org/10.1007/s11069-021-04688-8

CERRI, R. I., REIS, F. A. G. V., GRAMANI, M. F., GIORDANO, L. C., & ZAINE, J. E. (2017). Landslides Zonation Hazard: Relation between geological structures and landslides occurrence in hilly tropical regions of Brazil. Anais Da Academia Brasileira de Ciências, 89(4), 2609–2623. https://doi.org/10.1590/0001-3765201720170224

Clarke, M. C. G., Kartawa, W., Djunuddin, A., Suganda, E., & Bagdja, M. (1982). Geological Map of the Pekanbaru Quadrangle, Sumatera. Harahap Bhakti H., Syaiful B., Baharuddin, Suwarna N., Panggabean H., Simanjuntak TO (2003), Stratigraphic Lexicon of Indonesia,(Special).

Deng, Y., Cai, C., Xia, D., Ding, S., Chen, J., & Wang, T. (2017). Soil Atterberg limits of different weathering profiles of the collapsing gullies in the hilly granitic region of southern China. Solid Earth, 8(2), 499–513. https://doi.org/10.5194/se-8-499-2017

Dikshit, A., Sarkar, R., Pradhan, B., Acharya, S., & Alamri, A. M. (2020). Spatial Landslide Risk Assessment at Phuentsholing, Bhutan. Geosciences, 10(4), 131. https://doi.org/10.3390/geosciences10040131

El Jazouli, A., Barakat, A., & Khellouk, R. (2019). GIS-multicriteria evaluation using AHP for landslide susceptibility mapping in Oum Er Rbia high basin (Morocco). Geoenvironmental Disasters, 6(1), 3. https://doi.org/10.1186/s40677-019-0119-7

He, K., Li, J., Li, B., Zhao, Z., Zhao, C., Gao, Y., & Liu, Z. (2022). The Pingdi landslide in Shuicheng, Guizhou, China: Instability process and initiation mechanism. Bulletin of Engineering Geology and the Environment, 81(4), 131. https://doi.org/10.1007/s10064-022-02596-0

Heidrick, T. L., & Aulia, K. (1993). A structural and tectonic model of the coastal plains block, Central Sumatra Basin, Indonesia.

Izumi, Y., Widodo, J., Kausarian, H., Demirci, S., Takahashi, A., Razi, P., Nasucha, M., Yang, H., & Tetuko S. S., J. (2019). Potential of soil moisture retrieval for tropical peatlands in Indonesia using ALOS-2 L-band full-polarimetric SAR data. International Journal of Remote Sensing, 40(15), 5938–5956. https://doi.org/10.1080/01431161.2019.1584927

Kausarian, H., Redyafry, Lady, Josaphat Tetuko Sri Sumantyo, Suryadi, A., & Muhammad Zainuddin Lubis. (2023). Structural Analysis of the Central Sumatra Basin Using Geological Mapping and Landsat 8 Oli/Tirs C2 L1 Data. Evergreen, 10(2), 792–804. https://doi.org/10.5109/6792830

Kausarian, H., Sri Sumantyo, J. T., Putra, D. B. eka, Suryadi, A., & Gevisioner, G. (2018). Image processing of alos palsar satellite data, small unmanned aerial vehicle (UAV), and field measurement of land deformation. International Journal of Advances in Intelligent Informatics, 4(2), 132. https://doi.org/10.26555/ijain.v4i2.221

Kausarian, H., Suryadi, A., Susilo, Batara, & Sumantyo, J. T. S. (2021). Flood Problem in Pekanbaru City Analysis Using GIS Approach. Journal of Physics: Conference Series, 1783(1), 012090. https://doi.org/10.1088/1742-6596/1783/1/012090

Kausarian, H., Trionaldi, E., Khalif Arrahman, T., Bagus eka putra, D., & Batara. (2020). Settlement and Capacity Analysis of Land Support Development on Flyover in Large City; Pekanbaru, Indonesia. Journal of Geoscience, Engineering, Environment, and Technology, 5(2), 103–111. https://doi.org/10.25299/jgeet.2020.5.2.5048

Koesoemadinata, R. P., & Matasak, T. (1981). Stratigraphy and Sedimentation: Ombilin Basin, Central Sumatra (West Sumatra Province).

Lubis, M. Z., Anggraini, K., Kausarian, H., & Pujiyati, S. (2017). Review: Marine Seismic And Side-Scan Sonar Investigations For Seabed Identification With Sonar System. Journal of Geoscience, Engineering, Environment, and Technology, 2(2), 166. https://doi.org/10.24273/jgeet.2017.2.2.253

Lubis, M. Z., Anurogo, W., Kausarian, H., Surya, G., & Choanji, T. (2017). Sea Surface Temperature and Wind Velocity in Batam Waters Its Relation to Indian Ocean Dipole (IOD). Journal of Geoscience, Engineering, Environment, and Technology, 2(4), 255. https://doi.org/10.24273/jgeet.2017.2.4.778

Ruiz-Martínez, G., Rivillas-Ospina, G. D., Mariño-Tapia, I., & Posada-Vanegas, G. (2016). SANDY: A Matlab tool to estimate the sediment size distribution from a sieve analysis. Computers & Geosciences, 92, 104–116. https://doi.org/10.1016/j.cageo.2016.04.010

Ubani, C. E., Ani, G. O., & Womiloju, T. T. (2018). Permeability Estimation Model from Grain Size Sieve Analysis: Data of Onshore Central Niger Delta. European Journal of Engineering Research and Science, 3(12), 119–125. https://doi.org/10.24018/ejers.2018.3.12.503