Analysis of peat soil testing errors based on its characteristics and appropriate recommendation of peat soil testing

Annisa Khoerani[1], *Dewi* Amalia[2*], and *Stephanus* Alexsander[3]

[1]Graduate Program of Civil Engineering, Politeknik Negeri Bandung, Jl. Gegerkalong Hilir, Ciwaruga, Indonesia
[2]Department of Civil Engineering, Politeknik Negeri Bandung, Jl. Gegerkalong Hilir, Ciwaruga, Indonesia
[3]Department of Civil Engineering, Universitas Palangka Raya, Jl. Yos Sudarso, Palangka Raya, Indonesia

Abstract. Peat soils are organic soils formed from decomposed plant parts that spread throughout the world, reaching 423 million hectares. It is well known that peat soils have adverse characteristics for infrastructure development due to their low shear strength and durability. Therefore, a lot of research has been done regarding the improvement of peat soils so that infrastructure development in dominant peat soil locations. However, in conducting the research, many tests were found to be inappropriate based on the characteristics of peat soils, causing doubts about the results of the research. In this paper, a literature study conducted based on books, journals, papers, or previous research to determine the characteristics of peat soils and the types of tests that are suitable for these characteristics. Based on the discussion, the physical properties of peat soil can be tested for ash content, fibre content, organic content, and acidity, while the Atterberg limits cannot be tested. In addition, for testing the mechanical properties of peat soil, the tests that can be carried out are the direct shear test, Rowe cell, and CBR test with notes.

1 Introduction

Peat soil or commonly referred to as organic soil is a soil formed from decomposed plant parts accumulated over thousands of years in waterlogged soil conditions [1]. The total area of peat soil in the world is around 400 million hectares or about 3% of the total land area in the world [2–6]. Xu, et all, 2018 conducted peatland data collection using meta-analysis and the result was that the area of peatland in the world reached 423 million hectares or equivalent to 2.84% of the total area of the world [7]. The world's peatlands are distributed in North America with 43.54%, followed by Asia with 28.08%, and Europe with 24.02% [8]. In Southeast Asia, Indonesia ranks first as the country with the most peatlands area. The area of peatland in Indonesia is 13.43 million hectares spread across four major islands, namely Sumatra, Kalimantan, Papua, and Sulawesi [9].

Infrastructure development can increase sustainable economic growth and equity [10]. The increase in infrastructure development can cause land availability from time to time to be depleted. The lack of land availability makes development on peat soil unavoidable, especially in areas with dominant peat soil. Infrastructure development on peat soil has a high risk because it has a small shear value and high-water content [11]. In addition, peat soils also contain a lot of organic matter and minerals, have a low pH value (acid), high sensitivity value [12], water content value >100% [13], small weight or volume weight, large pore number [14], and low bearing capacity [15]. The risk of infrastructure development on peat soils can be reduced by improving the soil physically, mechanically, or chemically [14, 16]. Therefore, from time-to-time research related to peat soil improvement is carried out to find the best type of improvement that is environmentally friendly.

Unfortunately, the testing done in peat soil research is often done in the wrong way. This is due to researchers' lack of understanding of the characteristics of the peat soil itself. Peat soil with a moisture content of <100% (dry) can cause the soil to become like sand and lose its ability to absorb water [13], indicating that peat soil cannot be tested for Atterberg Limit [17] as was done in Venuja, Mathiluxsan, and Nasvi 2017 [18], or Hamzah, Yusof, and Rahimi 2019 [19]. In addition, dry peat soil no longer has strength or durability and cannot absorb water [13], so peat soil is not suitable for compaction testing as conducted by Roesyanto and Vini, 2019 [20]; Afianda, 2022 [21], Venuja, Mathiluxsan, and Nasvi, 2017 [18]; or Hamzah, Yusof, and Rahimi, 2019 [19].

In this research, an analysis of peat soil characteristics is conducted to determine the appropriate tests that can be carried out for future peat soil research. The research method will be carried out by means of a literature study through sources such as books, journals, papers, and previous research.

*Corresponding author: dewi.amalia@polban.ac.id

https://doi.org/10.1051/e3sconf/202342904018

2 Literature review

2.1 Definition of peat soil

Peat soil, also known as organic soil, is soil formed from the remains of dead plants or trees that have undergone decomposition or decay for thousands of years. Peat soils contain very high levels of organic matter derived from fossilized plants. Peat soils can form because of an imbalance in the accumulation of organic material decomposition, where the speed of deposition exceeds the speed of plant decomposition, which is influenced by certain regions. Influences include low soil biological activity, environmental conditions that are too acidic, or the presence of standing water that creates anaerobic conditions. This is why peat soils are found in poorly drained basins or back swamp areas.

2.2 Types of peat soil

There are various kinds of peat soils in the world, each of which has different characteristics in terms of strength, layer thickness, or soil constituents. Based on the constituent elements, peat soils can be divided into two: fibrous peat and amorphous granular peat [22].

2.2.1 Fibrous peat

Fibrous peat is peat soil that has a fibre content of more than 20%. This type of peat soil is usually found in tropical areas such as Indonesia, where the fibre content reaches 50%. The main constituent material of this peat soil is woody plant or tree biomass that has a high cellulose and lignin content so that the fibres in the peat soil are larger and can still be seen. The fibrous peat is shown in Fig. 1.

2.2.2 Amorphous granular peat

Amorphous granular peat is a peat soil that has a fibre content below 20%. This type of peat soil has similar behaviour or characteristics to clay. This type of peat soil is commonly found in subtropical areas where the main constituent materials are grasses, low bushes, or aquatic plants that have low levels of lignin and cellulose so that the fibres in the soil are smaller. This peat soil also has a faster regeneration time than fibrous peat soil. The amorphous granular peat is shown in Fig. 2.

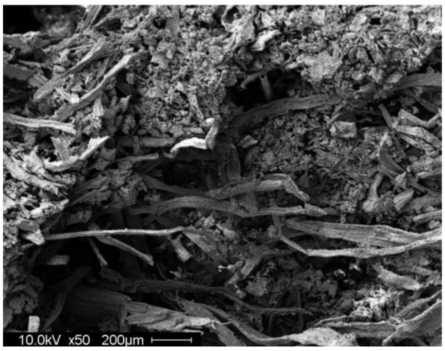

Fig. 1. SEM magnified fibrous peat x200 magnification [22].

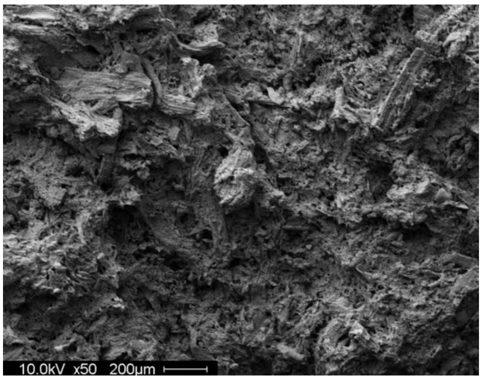

Fig. 2. SEM Magnified Amorphous Granular Peat x200 magnification [22].

Based on the thickness of the soil layer, peat can be divided into four categories: shallow, medium, deep, and very deep peat (Fig. 3) [23].

1. Shallow peat soil; peat thickness between 0.5m - 1m.
2. Medium peat soil; peat thickness between 1 m - 2m.
3. Deep peat soils; peat thickness between 2 m - 3 m.
4. Very deep peat soil; peat thickness of more than 3 m.

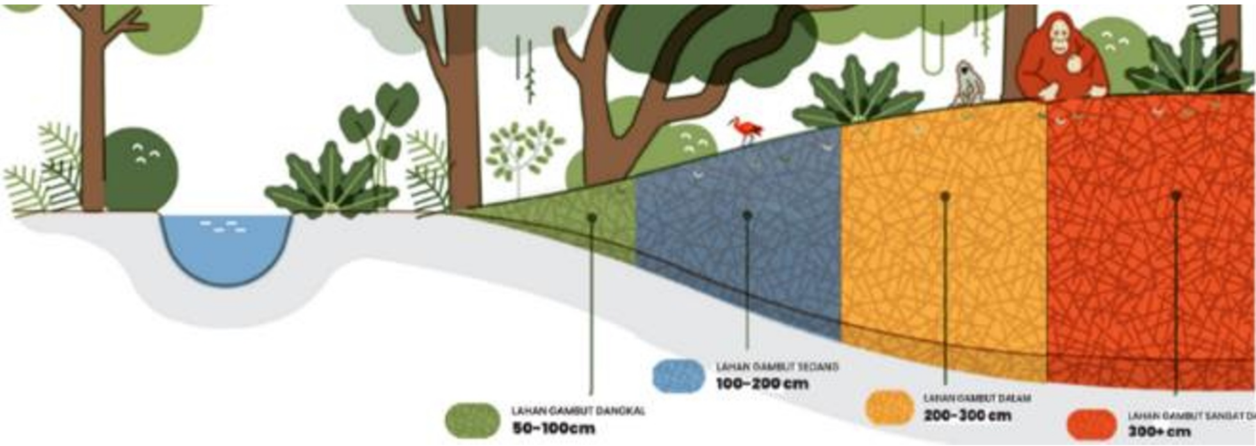

Fig. 3. Classification of peat soil based on layer tickness.

2.2.3 Peat maturity

Peat maturity is the degree of weathering of organic matter, which is the main element in the formation of peat soil. The maturity of the peat affects the fertility of the peat soil and the availability of nutrients; therefore, the level of maturity affects the productivity of the peat soil. Peat on the surface (top layer) is generally relatively more mature than the layer below it because the rate of decomposition is faster. However, in deeper layers of soil, mature peat is often found, proving that the peat soil was once at the surface.

2.2.4 Water content

Peat soil has a higher ability to absorb and store water than other types of soil. This ability is due to the dominant organic matter content. The water contained in peat soil can reach 300-3000% of its dry weight, while the lowest peat soil water content value ranges from 100-1300%. The maturity of the peat determines the average moisture content of the peat when it is in a flooded (natural) condition. In mature peat with micro and meso-processes, gravity will not be able to drain the water stored in the peat soil.

2.2.5 Bulk density

The bulk density of peat soils is very low, <0.1 g/cm3, which is found in raw (fibric) peat, coastal peat soils and river channels, <0.2 g/cm3 because it is influenced by other mineral materials. Soils with a low weight content have a high porosity value which causes the absorption and distribution of water to be higher. In addition, a low weight content causes the soil to have a low bearing capacity.

2.2.6 Bearing capacity

The load-bearing capacity of peat soils is very low, as evidenced by the condition of plants or trees that are not upright. The load-bearing capacity of peat soils is influenced by the maturity of the peat because, in general, mature peat becomes denser. In addition, this condition is also caused by the low weight content of the peat which is very high. Therefore, to increase the load-bearing capacity of peat soils, drainage is usually carried out.

2.2.7 Irreversible drying

Peat soils with a moisture content of <100% by weight generally experience irreversible drying; in which case the peat becomes flammable and easily washed away. Peat soils that experience irreversible drying will look like sand, so they are also known as pseudo sand. Irreversible drying also causes peat that was originally hydrophilic (water-absorbing) to become hydrophobic (water-repelling) so that the peat soil has a decreased ability to absorb water.

2.2.8 Soil acidity

Tropical peat soils have a low pH value of around pH 3 to 5, which caused by the drainage and hydrolysis of organic acids. The thicker the peat soil, the lower the acidity level, for example, deep peat soils have a pH of 3.3 while peat soils on the edge near the river have a pH of around 4.3. In addition, the maturity of the peat also affects the acidity level. Raw peat soil will be more acidic when compared to mature peat soil, this is because mature peat soil has more ash content, so it has more base sources.

2.3 Peat Soil improvement

In the implementation of infrastructure development, soils that have low bearing capacity and unfavourable characteristics need special treatment, one of which is peat soil. The special treatment that can be carried out is soil improvement in the form of soil stabilization. Soil stabilization is an action taken to change the original properties of the soil to be adapted to the needs of infrastructure development. Soil stabilization is a soil engineering method that aims to improve or maintain the properties of the soil to meet the required technical requirements. Based on the implementation process, soil stabilization can be grouped into three types [25], namely:

1. Chemical stabilization is the addition of certain chemicals to the soil material to produce chemical reactions to create new materials that have better technical properties.
2. Physical stabilization is soil stabilization by imposing energy from dynamic loads or static loads on the soil layer so that new decomposition occurs in the soil mass to improve the soil layer as desired.
3. Mechanical stabilization is soil stabilization by adding insert material into the soil layer to improve the technical characteristics in the soil mass to get the desired results. Mechanical soil stabilization is also often referred to as soil reinforcement.

In addition to the three types of soil stabilization that have been mentioned, there is one more type of stabilization, namely biological stabilization. Biological stabilization is soil improvement by mixing soil materials and microorganisms so that biological and/or chemical reactions occur to improve the properties of the soil [26].

2.4 Various peat soil test

Peat soil testing is carried out to determine the characteristics of the soil. The soil characteristics obtained through soil testing are index properties and engineering properties. Index properties are soil characteristics that show the type and condition of the soil, while engineering properties are soil characteristics that show the strength, compression, tendency to expand, or permeability of the soil. In its implementation, soil testing can be divided into two, namely field testing and laboratory testing. The types of tests that are usually carried out for peat soils are as follows.

2.4.1 Field testing

Field soil testing is testing that is carried out directly at the location. Field testing can include:
a) Hand Drilling for soil sampling
b) Vane Shear Test
c) Field CBR
d) Dynamic Cone Penetrometer (DCP)

2.4.2 Laboratory testing

Laboratory soil testing is a test conducted in a laboratory to obtain soil values or characteristics that cannot be known from field testing. Soil samples tested in the laboratory can be undisturbed samples (UDS) or disturbed samples (DS).

1. Soil Physical Properties Testing (Index Properties)
   a) Moisture Content and Weight
   b) Specific gravity examination
   c) Examination of Organic and Fibre Content
   d) Examination of Ash Content
   e) Pore Number Testing
   f) Atterberg Limits Testing
2. Testing of Soil Mechanical Properties (Engineering Properties)
   a) Direct Shear Test
   b) Consolidation Test
   c) Soil Compaction
   d) CBR Test (California Bearing Test)

Of the various types of peat soil tests that are commonly carried out, not all of these tests meet the characteristics of peat soil, so it must be ensured that the test to be carried out is in accordance with the type and characteristics of the peat soil. This is done to obtain data that is valid and in accordance with the condition of the soil to be tested.

3 Methods

This research was conducted using a qualitative method. In this method, research and understanding is conducted based on the characteristics of peat soil to conclude the appropriate type of soil test to determine the characteristics and properties of peat soil, both original peat soil and the results of stabilization. The data needed for this research will be collected through a literature study of books, journals, papers, or previous research related to peat soil and its testing.

4 Results and discussion

Peat soil is a type of soil that is unique and different from other types of soil. This difference is due to the high content of organic matter in peat soils, which causes differences in characteristics with soils containing mineral materials. Peat soil in Indonesia, which is tropical peat, has large fibres because it comes from woody plants or trees.

The high risk of constructing infrastructure on peat soils has made researchers try to minimize the risk. One common method is soil stabilization, which can increase the strength of the soil. In the implementation of soil stabilization, it is necessary to conduct laboratory tests that can show the quality of the stabilization performed. Laboratory testing of peat soil is different from other soils. This is because the peat soil has a very high fibre and mineral content. Therefore, not all soil tests can be performed on peat soil. This research will discuss the types of tests that can be conducted on peat soil based on its characteristics.

Peat soils with a high moisture content and a lot of fibre still have a bearing capacity value even though the value is very small. Therefore, field CBR testing, or vane shear testing can be conducted on peat soils. In addition, hand borings can be carried out to take undisturbed samples so that the peat soil can be tested in the laboratory. It should be noted that the sampling of peat soil and other cohesive soils is very different, because peat soil contains a lot of organic fibres and high-water content.

Peat soil that has been taken from the field can then be tested in the laboratory to obtain the physical and mechanical properties of the peat soil taken. The soil tests that can be carried out for peat soils will differ from those for cohesive soils.

4.1 Index properties of peat soil

Evaluating the index properties of soil usually involves testing the moisture content and content weight, specific gravity, organic content and soil fibre, ash content, pore number, and testing the Atterberg limits. However, in peat soils not all of those tests can be performed. It should be noted that the characteristics of peat soil in dry conditions or a moisture content of <100% have entered into a reverse dry condition which causes the peat soil to lose its microorganisms and nutrients so that the peat soil has difficulty in absorbing water as before.

One of the soil properties index tests that cannot be performed on peat soils is the Atterberg limit. Atterberg limit testing is a test intended to determine the liquid and plastic limits of a soil. The results of the Atterberg limits test can be used to classify soils and can be correlated with various other soil parameters. Peat soil is a soil that contains a lot of organic matter and a high fibre content with little mineral matter. Peat soils in Indonesia have a fibre content of >20% because they are formed from woody plants. In the Atterberg Limit test, the soil tested is soil that passes the No.40 sieve. The use of wet methods to obtain peat soil passing the No.40 sieve allows the fibres of the peat soil not to be carried away and leaves few soil grains to be tested. Dry preparation can at least bring the peat fibres to the test, but in this condition the peat soil will turn into sand and lose its ability to absorb water because the microorganisms have died, and the peat soil has lost its nutrients.

In addition, in plastic limit testing based on ASTM D4318-00 [27] to determine the PL value, the soil must be able to be rolled up to a thickness of 3.2mm diameter. Peat soil cannot be rolled up to the specified thickness, so the peat soil is classified as a non-plastic soil, although the remoulded peat soil has a high level of plasticity. The shrinkage limit test in O'Kelly [17] revealed that the shrinkage limit of a peat sample gives an indication of changes in the level of humification. Damage caused by the preparation of the peat soil for Atterberg limit testing can result in smaller values [28], therefore the peat soil testing carried out will not give a definitive picture of the liquid limit of the peat soil to be studied. Therefore, it can be concluded that the Atterberg limit test on peat soil, although it can be carried out, will not provide a mechanical picture of the condition of the original peat soil.

Based on what has been explained, it can be concluded that to determine the physical properties of peat soil, the tests that should be carried out are testing the moisture content and content weight, specific gravity, organic content and soil fibre, ash content, and pore number.

4.2 Engineering properties of peat soil

In testing the mechanical properties of peat soils, it cannot be tested using triaxial tests or unconfined compression tests. Testing the mechanical properties of peat soil to determine its cohesion value and internal shear angle can only be done using direct shear testing. Direct shear testing has a flattened sample shape that facilitates the formation of test samples, in contrast to triaxial testing or free compressive strength testing. A picture of the shear strength test equipment is shown in Fig. 4 below.

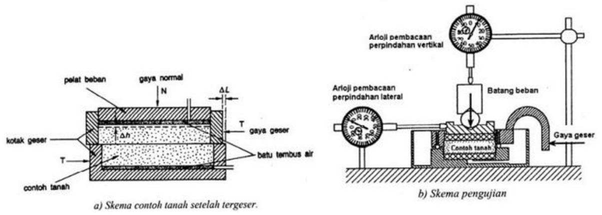

Fig. 4. Direct shear testing equipment.

In addition to direct shear testing, consolidation testing can also be carried out on peat soils to determine the amount of compression of the peat soil. The consolidation test used in peat soils is the Rowe Cell test, which allows back pressure to be applied and the pore water pressure of the tested soil sample to be measured [29].

The next test is the California Bearing Ratio (CBR) test to obtain the value of soil strength based on the comparison between the penetration load of a type of material and the standard load at a predetermined depth and penetration speed [30]. In SNI 1744:2012 concerning Laboratory CBR Test Methods, the manufacture of test objects is carried out based on the maximum dry density value in accordance with the density test carried out in SNI 1743:2008 concerning How to Test Weight Density for Soil [31]. In SNI 1743:2008, the soil samples to be used for density testing must be air-dried or oven dried. For peat soils, this condition will damage the characteristics of the original peat soil because a reverse dry condition occurs which causes the peat soil to lose its ability to absorb water. This condition will result in damaged soil and will not produce accurate test values in accordance with the soil condition. However, Pradana [32] states that peat soil can be dried at a maximum temperature of 105°C for 16 hours and will not cause the organic material in the peat soil to become charred and oxidized. This statement needs to be reviewed to determine its validity and its correlation to the characteristics of peat soil.

5 Conclusions

Based on the discussion, it can be concluded that not all types of soil tests can be carried out on peat soil because peat soil has different characteristics. The characteristic that distinguishes peat soil from other soils is the presence of plant fibres that dominate peat soil. The Atterberg Limit cannot be carried out on peat soil because the characteristics of peat soil tend to resemble sand when it loses its water content. In addition, for testing the physical properties of soil, there is a test for fibre content, ash content, organic content, and acidity, which is characteristic of peat soil. To determine the engineering value of peat soils, peat soils are more suitable for direct shear testing, Rowe cell as a consolidation test, and CBR testing, provided that the preparation of test specimens must be very careful so as not to change the characteristics of the peat soil which will affect the test results.

References

1. Food and Agriculture Organization, Peatlands mapping and monitoring – recommendations and technical overview, Rome (2020) https://doi.org/10.4060/ca8200en
2. M. Silvius, H. Joosten, S. Opdam, Weatland, 3–17, (2007)
3. B. Topcuoğlu, M. Turan, InTech., 1–8 (2018) DOI: 10.5772/intechopen.79418
4. J.R. Melton, E. Chan, K. Millard, M. Fortier, R.S. Winton, J.M. Martín-López, H. Cadillo-Quiroz, D. Kidd, L.V. Verchot, Geosci. Model Dev. **15**, 4709–4738 (2022) https://doi.org/10.5194/gmd-15-4709-2022
5. H. Joosten, M.L. Tapio-Biström, S. Tol, Peatlands – guidance for climate changes mitigation through conservation, rehabilitation and sustainable use 2nd ed (the Food and Agriculture Organization of the United Nations and Wetlands International, 2012)
6. F. Parish, A.A. Sirin, D. Charman, H. Joosten, T.Y. Minaeva, M. Silvius, Assessment on peatlands, biodiversity and climate change. (Wetlands International, 2008)
7. J. Xu, P.J. Morris, J. Liu, J. Holden, CATENA **160**, 134–140 (2018) https://doi.org/10.1016/j.catena.2017.09.010
8. L. Zigang, L. Xintu, The global distribution of peat (EOLSS) https://www.eolss.net/sample-chapters/c08/E3-04-06-04.pdf
9. M. Anda, S. Ritung, E. Suryani, Sukarman, M. Hikmat, E. Yatno, A. Mulyani, R.E. Subandiono,

Suratman, Husnain, Geoderma **402**, 115235 (2021) https://doi.org/10.1016/j.geoderma.2021.115235

10. Regional Infrastructure Development Agency (Sep 9), PUPR Ministry Encourages Infrastructure Development for Economic Growth and Equality, *PU-net* (2022) https://bpiw.pu.go.id/article/detail/kementerian-pupr-dorong-pembangunan-infrastruktur-untuk-pertumbuhan-dan-pemerataan-ekonomi
11. L.J. Hua, S. Mohd, S.A.A. Tajudin, S.N.A. Mohamad, I. Bakar, M.I.M. Masirin, A. Zainorabidin, A.A-W. Mahmood, MATEC Web of Conferences **47**, 03014 (2016) https://doi.org/10.1051/matecconf/20164703014
12. X. Wang, X. Cao, H. Xu, S. Zhang, Y. Gao, Z. Deng, J. Li, E3S Web Conf. **272**, 02019 (2021) https://doi.org/10.1051/e3sconf/202127202019
13. A. Dariah, E. Maftuah, Maswar, Panduan Pengelolaan Berkelanjutan Lahan Gambut Terdegradasi **6**(2), 16–29 (2013)
14. F. Syarif, G.M. Davino, M.F. Ardianto, Jurnal Saintis **20**(1), 47–52 (2020) https://doi.org/10.25299/saintis.2020.vol20(01).4809
15. S.A. Nugroho, Dinamika Teknik Sipil **12**(2), 151–156 (2012) http://hdl.handle.net/11617/2018
16. Yulianto, *Behavior of fibrous peat soil problems and solutions*, in Civil and Infrastructure Engineering National Conference – I, 30 Oct, Universitas Jember (2017)
17. B.C. O'Kelly, Environmental Geotechnics **3**(6), 359–363 (2016) https://doi.org/10.1680/envgeo.15.00003
18. S. Venuja, S. Mathiluxsan, M.C.M. Nasvi, ENGINEER **50**(2), 21-27 (2017) http://doi.org/10.4038/engineer.v50i2.7249
19. N. Hamzah, N.A.M. Yusof, M.I.H.M. Rahimi, MATEC Web Conf. **258**, 01014 (2019) https://doi.org/10.1051/matecconf/201925801014
20. Roesyanto, V.R.E. Putri, IOP Conf. Ser.: Mater. Sci. Eng. **801**, 012014 (2020) DOI 10.1088/1757-899X/801/1/012014
21. N. Afianda, Thesis, Universitas Islam Riau (2022) http://repository.uir.ac.id/id/eprint/15118
22. E.M.B. de Guzman, M.C. Alfaro, Journal of Materials in Civil Engineering **30**(7), 1–12 (2018) https://doi.org/10.1061/(ASCE)MT.1943-5533.0002325
23. F. Agus, I.G.M. Subiksa, Lahan gambut: potensi untuk pertanian dan aspek lingkungan (Balai Penelitian Tanah, 2008)
24. M.A. Ma'ruf, F.E. Yulianto, *Fibrous peat soil: solutions and problems in environmentally friendly infrastructure development*, in Proceedings of the 2016 Geotechnical National Seminar, 1 Oct, PS S1 Teknik Sipil Unlam, Banjarmasin (2016) http://dx.doi.org/10.20527/infotek.v0i0.3125.g2675
25. D. Panguriseng, Dasar-dasar teknik perbaikan tanah (Pustaka AQ, 2017)
26. E. Rismantojo, N.N. Ningsih, Jurnal Teknik Sipil **28**(3), 269–280 (2021) https://doi.org/10.5614/jts.2021.28.3.4
27. ASTM International, Standard test methods for liquid limit, plastic limit, and plasticity index of soils (ASTM D4318-00)
28. B.C. O'Kelly, P.J. Vardanega, S.K. Haigh, G.E. Barnes, Géotechnique **70**(7), 647–651 (2020) https://doi.org/10.1680/jgeot.17.R.039
29. D. Lahabu, A. Faisal, V. Bacthiar, JeLAST **8**(2), 1-8 (2021) http://dx.doi.org/10.26418/jelast.v8i2.48365
30. National Standardization Agency, Laboratory CBR test method (SNI 1744:2012)
31. National Standardization Agency, How to test the weight density for soil (SNI 1743:2008)
32. Y.A. Pradana, Thesis, Universitas Indonesia (2009) http://lib.ui.ac.id/opac/ui/detail.jsp?id=20248386&lokasi=lokal