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In-Situ Stabilization Analyses of Peaty Clay Soil Layers Using Solid Waste from of Biomass Power Plant

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ABSTRACT

The dominant soil layers in Mempawah District, West Borneo, consist predominantly of peaty clay, a material unsuitable for construction due to its high compressibility, low strength and volume instability. This study explores the use of solid waste derived from the combustion process at Biomass Power Plants as a stabilizing agent for these problematic soil layers, particularly those found along the Kapuas River shoreline. Initial laboratory experiments were conducted to establish field design parameters and the optimal mix composition between peaty clay and solid waste. Comprehensive analyses were performed to anticipate settlement, lateral movement, and pore water pressure. Subsequently, field implementation involved the application of filling and preloading procedures, utilizing clay and sand from the study site's periphery, presenting a weight volume of 1.8 gr/cm^3, as the preload material. Post-implementation monitoring was performed using geotechnical instruments such as settlement plates, inclinometers, and piezometers. Data acquired over a three-month period showed that the average degree of consolidation (U), computed using the Asaoka method, was approximately 66%. Consolidation coefficients were found to be 3.5×10^{-7} m^2/sec in the vertical direction (c_v) and 1.58×10^{-6} m^2/sec in the horizontal direction (c_h) respectively. Lateral movement, as indicated by inclinometer data, remained less than 25.4 mm, confirming the safety of the upper and lower soil layers with a safety factor (SF) exceeding 1.30. Field Cone Penetration Tests (CPT) and laboratory triaxial tests indicated a 30% increase in the shear strength of the stabilized peaty clay from the ground surface. The pore water pressure, as monitored by the piezometer, decreased to hydrostatic pressure levels. These findings, drawn from three months of observational data, suggest that solid waste can be effectively employed as a stabilizing agent for peaty clay layers.

1. INTRODUCTION

The Mempawah District's Biomass Power Plant in West Borneo faces two main challenges: the problematic bearing capacity, settlement, and lateral movement of the peaty clay soil [1], and the management of solid waste material from the combustion furnace process. This research aims to address both these issues by utilizing the solid waste as a stabilization agent for the peaty clay soil layer. In doing so, the research also contributes to environmental protection by reducing the impact of potential pollutants.

Several stabilization methods using organic stabilizers have been proposed [2], but these are often expensive and only suitable for unique circumstances. For instance, conventional stabilizers are ineffective with organic soils like wood, rattan, palm shells, etc., which have a high organic matter content (large than (≥) 2 percent). It is here that alternative organic stabilizers, such as coal fines and latex, have shown promise in modifying the rheological flow properties of bitumen, the main stabilizer material. However, their effectiveness in field implementation remains uncertain [3].

This research explores the use of non-organic material, specifically the residual solid waste from the Biomass Power Plant's combustion process, as a stabilizing agent. The goal is to enhance the properties of the peaty clay soil by mixing it with this non-organic solid waste, thereby reducing pore space, shortening inter-particle distance, and improving soil layer stability through increased shear strength [4].

Preliminary studies were conducted to understand the behavior of peaty clay and the characteristics of solid waste. Soil layer parameters were analyzed to predict the before and after effects of stabilization. The stabilization design was based on a laboratory standard proctor for the compaction method, determining the material composition [5] between peaty clay soil and solid waste, and adding clay and/ or sand material [6] prior to field stabilization. These results will be compared with in-situ measurements from geotechnical instrumentation, such as settlement plates, inclinometers, and piezometers, to determine the degree of consolidation (U), coefficients of consolidation in both horizontal and vertical directions (c_h and c_v), maximum vertical and lateral displacement, and the safety factor (SF) of embankment during the monitoring phase.

The Biomass Power Plant uses raw material from industrial plantation forests, leaving behind residual solid waste that transforms from organic to non-organic material. Typically, this waste is disposed of in the Kapuas River or distributed to the community without pre-processing, potentially leading to water and land pollution and consequent environmental damage [7, 8]. This research proposes to utilize this combustion residue as a stabilizing material for peat soil layers, simultaneously minimizing the environmental impact. The mixture of peaty clay and solid waste is expected to enhance the soil parameter, such as: specific gravity, weight volume, cohesion, internal friction angle, and bearing capacity, while reducing water content. As a result, the solid waste from the combustion process can be optimally utilized, contributing to environmental sustainability.

2. STUDY AREA AND MATERIAL

2.1 Geography location

Recently, Indonesia has been developing Biomass Power Plant [9]. The Biomass Power Plant study area is near the Kapuas River and has an area of 2.0 Ha. Based on geographic informatics system (GPS) data, the location of the study area exists at coordinates 0° 00' 48" North Latitude (NL) and 109° 17' 07" East Longitude (EL), as shown in Figure 1. The location of the Power Plant is very easy to access from Pontianak central city to the west towards the Mempawah and Singkawang cities, respectively. The distance from the City Center of Pontianak is around 76.1 km, or if driving takes more or less 1 hour 47 minutes. The location of the Power Plant is very easy to access from Pontianak central city to the west towards the Mempawah and Singkawang cities, respectively.

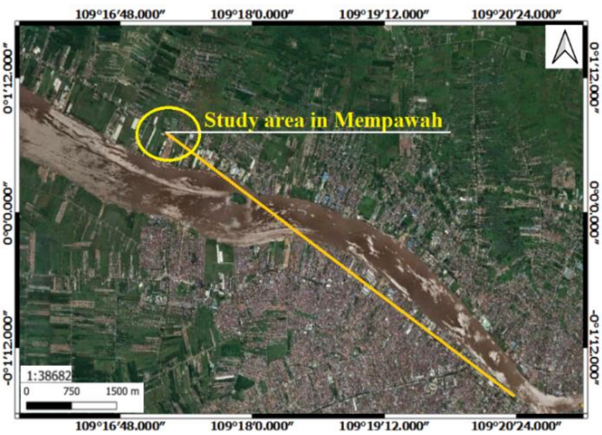


Figure 1. Existing topography situation in the study area (Mempawah Biomass Power Plant area)

2.2 Climate condition

Climatic conditions in the Mempawah area are more influenced by the regional equatorial region. Rainfall varies according to every month measured by the observation of the Siantan rainfall station. The average rainfall in Mempawah Regency in 2012 ranged from 54.7 (in June) to 319.3 (in December) millimeters every year. In 2012, the number of rainy days in Mempawah Regency ranged from 9 to 28 rainy days. The highest number of rainy days occurs in November every year. The Mempawah area has relatively high humidity; data from 2012 – 2018 indicated that the average humidity ranged from 82 to 86 percent. The air temperature was influenced by the elevation area of the mean sea level and distance from the coastal area. Based on data from the 2011 Siantan Climatology station, the average air temperature ranges from 23.1℃ (September) to 27.9℃ (May) every year. Local climatic conditions strongly influence the formation of peaty clay in Mempawah. Mempawah peat soil can be called tropical peat soil. Peat soil is formed through a process of paludification; the term paludification was introduced by several researchers [10]. The climate factor has a great influence on the paludification process. Peat at Mempawah as tropical peat is formed by paludification process. The paludification process can induce the thickening of Mempawah peat due to the accumulation of organic matter in a waterlogged state. Mempawah peat is mixed with other mineral soil, especially clay and sand, and can be classified as shallow peat with a thin thickness [11].

2.3 Soil and geological condition

The Mempawah area is a lowland with a dendritic river pattern. Settlement occurred in the lowland area and was more caused by an organic or peaty clay layer. Generally, the soil characteristic of the Mempawah area is soft to very soft, reaching 35.0 m depth. Based on the USCS classification system, this soil can classify into the group of CH to CH-MH with high plasticity. The high plasticity is indicated by a plasticity index limit value that exceeds 30%, resulting in this type of soil having a high swelling potential [11]. This type of soil is presumably formed from weathering of sedimentary rocks and erosion that often occurs along the Kapuas River. These layers must be stabilized to prevent land subsidence caused by axial and lateral movement, increasing the pore water pressure during the filling works and the high swelling potential. Field implementation begins with the reclamation work on the shore of Kapuas River peaty clay after stabilization with solid waste according to the results of laboratory standard compaction. This implementation is more like reclamation works using bamboo pile walls to separate the wet and dry areas. The average depth of the filling area is around 2.5 to 3.0 m from mean sea level (MSL) (± 0.00 m).

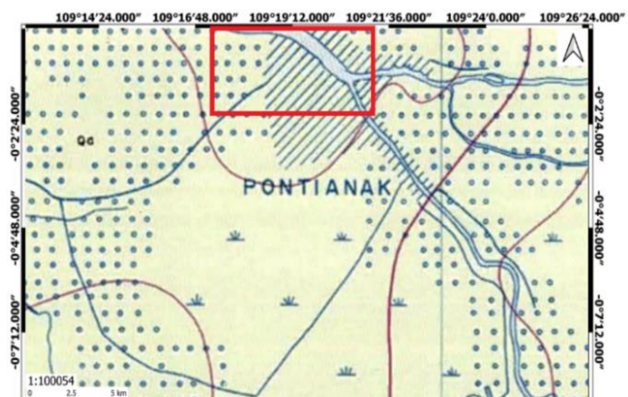


Figure 2. Geological condition of the study area [12]

Then, according to a systematic geological map of Indonesia, Siantan District, Menpawah Regency is located at the biggest Kapuas catchment areas, as shown in Figure 2. There are no faults in the study area. The geological structure of the Power Plant area is a development area of the Mempawah geological structure, Pontianak, and parts of Kubu Raya. The most dominant geological condition in the Mempawah Regency area is organic soil type or clay soil with an organic layer or peat, which states as peaty clay (Q_a). Geologically, the layers of deposits in the study area are an alluvium deposit and swamps (Q_a), consisting of mud, sand, river clay sediment, gravel, and plant debris (composed of material from mud, sand, gravel, and plant matter). Generally, West Borneo was composed of old Triassic rocks (± 204 million years old) in forming sandstone, andesite, and granite layers which were covered at the top by Quaternary sedimentary rocks and alluvium (< 1.6 million years). In addition, the Mempawah Hilir area is the largest river basin. The study area exists in the zone of Mempawah Hilir area. The riverside area comprised alluvium soil fraction, sedimentary rocks, and several places in shaping granite, granodiorite, and dacite rocks from Singkawang, Bengkayang, Sukadana, and Kendawangan beach areas. Metamorphic rocks were intruded by biotite granite exposed in the northern area, while in the southern area were intruded by Early Cretaceous tonalite/granitoid exposed in the surrounding Melawi Regency. The southern part of West Borneo was known as the Sepauk tonalite group, characterized by monzogranite–granodiorite type granitoid. Tonalite magmas were calcareous, and their occurrence was identified as a process of weathered igneous rock. Subsequent intrusions in forming Sukadana granite that occurred in the Late Cretaceous consisted of monzonite granite fraction in some places around the scene of study.

Generally, the rock layer is fairly stable; however, soil layers from the ground surface to the rock layers are dominated by a soft layer, and it can be classified alluvium as the result of weathering of soft rock, which causes instability or landslide; low bearing capacity, in this area, also always occurs differential and over settlements. The other additional material must stabilize these alluvium deposits from topsoil to hard layers; for this case, the research tries out to use the solid waste from the furnace process as stabilizer material.

3. METHODS

3.1 Research flowchart

Some analyses used geotechnical software to predict settlement, lateral movement; dan safety factor (SF) of slope sliding. The result of the prediction analysis would be compared with the actual measurement in the field [13]. Settlement plate; inclinometer; and piezometer would read the actual settlement; lateral movement; and pore water pressure, respectively, occurred at the field. All results would be displayed as graphic images as a real-time data record.

Figure 3. Flow model for peaty clay soil stabilized by solid waste from biomass power plant

The flow of the research method is shown in Figure 3. Besides, the location existed at the flow area of Kapuas River. Research problematic for peaty clay stabilization is not the same as the general characteristic of the peat layer as recognized from several references, where the peat layer exhibits high compressibility, medium to low permeability, low strength, very low bearing capacity, and volume instability. Pre-study has indicated that the peaty clay soil parameter from several field tests (CPT, SPT, and taken a sample for laboratory work) still contains clay and sand fraction like the alluvium sediment around the coast. From the point of view of geological aspects in the previous study, the lowland, like the study area, is dominated by alluvial deposits (peaty clay with a few thin sand layers). The settlement that occurred in the lowland area was more caused by organic or peaty clay layers as it is known that the soil characteristic of the Mempawah area is soft to very soft soil layer with a 35.0 m depth to the hard layer. Field marking is required to indicate the location of the field test and sampling location of the disturbed sample (DS) or undisturbed sample (UDS). Laboratory soil investigation involves physical and mechanical properties using the DS and UDS samples. Physical properties are used to determine grain size material distribution, natural water content (w), specific gravity (G_s), weight volume (wet and dry), and plasticity index (PI). High water content reaching 300% is also one of the problems of stabilizing this soil type, so it is necessary to consider reducing the water content before the stabilization process begins. In laboratory work, all soil samples must be dried before they are used as a sample in the proctor test.

3.2 Stabilization model

The characteristic of peaty clay or clay with organic matter soil is that it contains fiber, has high organic content, and is brown to grey or black [14, 15]. Peaty clay soil has a small specific gravity (G_s), so the weight volume of this soil type is very light. Generally, peaty clay soil has properties such as a strong colloid which can bind water since peaty clay soil can absorb high water. Mempawah peaty clay is clay with organic matter, can store and absorb water less than 300%, and some composition with organic from peat soil, classified as the fibrous soils (coarse and fine fibers), comes from vegetation and fossil deposits; and is often found in swamp areas influenced by the tidal. The bearing capacity of soil type is very low because cohesion (c) and angle of internal friction (ϕ) or strength parameters of soil are also very low. The compression coefficient of this peaty clay soil is higher than soft soil. An important problem and natural behavior of peaty clay is the settlement, lateral movement, and sudden landslide. The utilization of solid waste material is purposed to reduce the natural behavior of settlements and stability aspects due to the loads acting on the ground surface according to the selected method in the consolidation process. The stabilization for the subsoil does not have to reach a depth of 35.0 m in the soft layer; from the stress in soil mass principle [16], the stress of the lower layer will close to zero at a certain depth after reaching the equilibrium condition according to the acting working load. The alteration of shear strength at the upper layers can influence the lower layers.

Solid waste produced by the combustion or carbonation reactor process has a very large amount every day (20 tons /day). In general, the solid waste from the combustion process is wasted into the river and shared or taken by residents or settlements around the power plant area to fill out the yard and or land used by them closing their house. The development of the utilization of biomass power plant waste is one aspect that affects stabilization research. Furthermore, soil stabilization involves using solid waste as a stabilizing agent in weak soils to improve the geotechnical properties of the peaty clay soil, such as compressibility, strength, bearing capacity, permeability, swelling potential, and durability of peaty clay. The development of the utilization of biomass power plant waste is one aspect that affects the stabilization of this research on the peaty clay layers of this research [17-19].

According to Figure 3, laboratory works for a standard proctor test are conducted to determine the composition of peaty clay and solid waste from a biomass power plant in the stabilization process. From the standard proctor test, the optimum moisture content (OMC) and maximum dry density (γ_{dmax}) for each composition implemented can be found. Then, a sample from the mold of the standard proctor test for each composition is used for laboratory triaxial and consolidation tests. All the results of the proctor standard would be used as a measurement base in determining the weight and volume of solid waste for field works during the stabilization process. The high water content of the peaty clay soil sample must be lowered below 100% before the stabilization process.

3.3 Bamboo reinforcement system

The most reasonable method is to use the preloading method. However, by the principle of laboratory consolidation testing, the peaty clay layer must be loaded gradually and at a very low consolidation rate. Thus, to avoid the immediate loading during the transfer load process to the peaty clay layer, it is necessary to install an additional reinforcement system on the peaty clay soil layer. The reinforcement system consists of a mat and a pile of bamboo material. Generally, the bamboo material used for reinforcement is Green Ampel type (Bambusa vulgaris sharader ex. wendland var vitata) and comes from the Tanjung Kasih Sayang area, Kubu Raya Regency. Generally, this bamboo has a diameter of 6 - 8 cm, with a length of between 8 to 15 m, is generally 3-4 years old, and is dark green-red color. Each bamboo stem has a segment length of 30 - 40 cm with a wall thickness of 1-1.50 cm.

Figure 4. The bamboo was used as a mat and pile for preloading the base structure before monitoring the works

As a biological source, the highest fiber distribution is found on the lower outer edge of the stem. Bamboo fiber bundles have a 108-212 μm diameter, and ultimate fibers have a 9.4-9.9 μm diameter, as shown in Figure 4. The tensile test results showed that the Ampel green bamboo fiber bundles had a tensile strength of 114-314 MPa and a modulus of elasticity of 3.2-7.0 GPa. The lower outer edge of the Green Ampel bamboo stem has the highest strength and rigidity [20]. However, when put in the open air, bamboo has weaknesses in terms of durability and preservation. The age of bamboo used in buildings or construction on the ground is relatively short, only 1-5 years. Bamboo will be damaged by weather changes (rainy and dry seasons or hot sun) and insect attacks. For Green Ampel bamboo, bamboo soaked in river water or peaty clay soil water showed more resistance to the weather and insect.

This bamboo material will be used for mats as a base foundation and piles. Access to transportation of bamboo to the full-scale test site using the Landak River and Kapuas River transportation facilities. The reinforcement system is very useful for creating additional floating forces to reduce the effect of immediate load and for the peaty clay layer to consolidate gradually. The contribution of floating stress of bamboo mat and pile is expected to be completed when the stabilized peaty clay soil has reached a degree of consolidation or (U) closing to 100%.

Field implementation was helped by heavy equipment (excavator) and truck for solid waste material transport from the biomass power plant to the site. This bamboo mat will be modeled as a continuous beam. The parameters needed in modeling the bamboo mat and pile are the flexural stiffness (EI) and the axial stiffness (EA), respectively. The inertia moment of the bamboo pile can be calculated as follows:

$$I = \frac{1}{64}\pi(D^4 - d^4) \quad (1)$$

where, D is the outer diameter of bamboo; d is the inner diameter (d equals $D - t$); t is the thickness of bamboo. On the simulation software program, the thickness of the beam (as a bamboo mat) will calculate automatically as an equivalent thickness (d_e):

$$d_e = \sqrt{12\frac{EI}{EA}} \quad (2)$$

The bamboo pile bearing capacity calculation is the same as the bearing capacity for the piling system. All formula for bearing capacity is determined by some references [21]. Bearing capacity can be defined from:

$$Q_u = Q_b + Q_s \quad (3)$$

where, Q_u is the ultimate capacity of the pile, depends entirely on the load-bearing capacity of the underlying material; Q_b is the load carried at the pile point; and Q_s is the skin friction developed at the side of the pile (caused by shearing resistance between the soil and the pile).

Furthermore, when the water content is less than 100% on each layer of peaty clay, the next problem is spreading the solid waste material layer by layer on the bamboo mat until it reaches the designed elevation. The number of bamboo layers in the mat and pile system was determined using geotechnical software (Geostudio and or PLAXIS) simulation and used the parameter of peaty clay after stabilized by solid waste that depended on the maximum dry weight volume (γ_{dmax}) and optimum moisture content (w_{opt} or OMC). And the monitoring system immediately must be conducted after the material spreads at the field to measure over settlement and lateral movement, landslide, or pore water pressure. The monitoring system devices will use the settlement plate, inclinometer, and piezometer during the preloading process on each layer by layer. The position of each instrument must be arranged to cover the results of full-scale measurement at the field. Data reading for each instrument is scheduled every 2 days. A prefabricated horizontal drain (PHD) was only used during implementation at the field to reduce the waterlogging and vertical seepage from the upper ground surface and has no contribution to increasing the settlement rate. Reschedule works must be changed if there are some force majeur conditions due to over settlements, over lateral movement (recorded data from inclinometer), over pore water pressure (recorded data from piezometer), and over height water level from the alteration of tidal.

3.4 Actual measurement using geotechnical instruments

Surface settlement monitoring is generally conducted using the conventional geodesy method with the level machine and leveling pole (Figure 5).

The elevation of the pipe head of the settlement plate is determined based on elevation measurement work, conducting technical leveling from benchmarks to the settlement plate. The settlement is the difference between initial elevation and elevation at different interval times of measurement. Initial elevation data is determined by the first time of settlement plate installation. Data reading is performed to obtain the elevation change based on the average value of the four times observation. The monitoring results from the settlement plate are as follows: vertical movement or settlement data, the height of the preloading embankment, and graphic correlation between vertical movement versus time. Monitoring and evaluation for soil shear strength observation are conducted based on calculating the degree of consolidation.

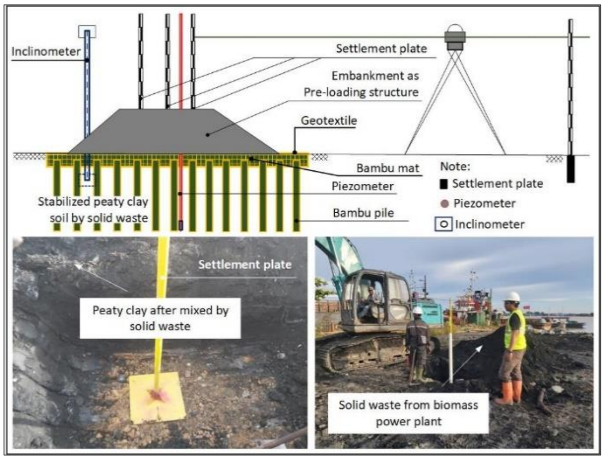


Figure 5. Measurement using the settlement plate device

The consolidation coefficient in vertical (c_v) and horizontal directions (c_h) can be predicted by Terzaghi theory, Asaoka [22], and Finite Element methods [23]. In general, calculation of the coefficient of consolidation (c_v and c_h) in (cm^2/sec) of soft clay (peaty clay soil) can be calculated using:

$$c_v = \frac{T_v H^2}{t} \quad (4)$$

$$c_h = \frac{T_r 4R^2}{t} \quad (5)$$

where, the equation for c_h was adopted by the calculation of the consolidation time of soft soil improved using the PVD. H is the thickness of the consolidated soil layer in (cm) and t (seconds), which is the time required to reach the degree of consolidation (U) (%).

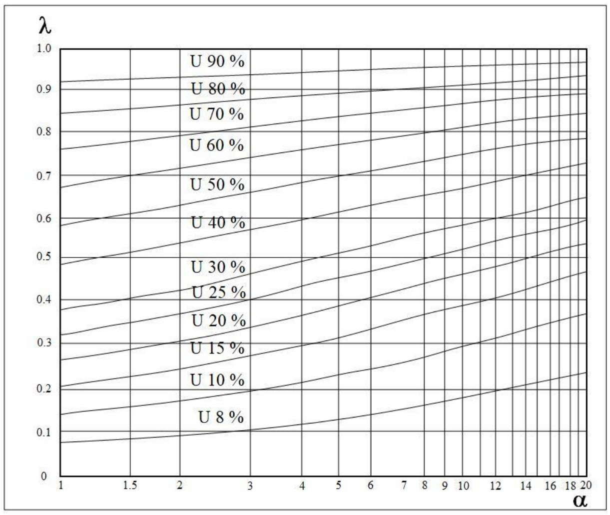


Figure 6. Determination U (%) based parameter α & λ

The average degree of consolidation (U) is measured by comparing the lost pore water pressure with the initial pore water pressure, which is the pore water pressure when applied to a load, or by comparing the settlement at a certain time to the estimated primary settlement that will be occurred. In practice, the degree of consolidation (U (%)) was developed from the Asaoka method for the field observation using the graphic. The degree of consolidation (U)=65.78%. If used, Figure 6 is a comparison value, and the parameter of α the result will obtain U=65.59% with λ=0.648 and α=1.06. The difference in the results obtained is caused by the variance in determining the magnitude of the initial and final settlement.

$$\lambda = \frac{S_{ct}}{S_{\infty}} \tag{6}$$

$$\propto = \frac{\Delta\sigma}{\sigma'_{v0}} \tag{7}$$

where, S_{ct} is the settlement at the time (t); S_{∞} is the magnitude of field consolidation (adopted from the Asaoka prediction method). $\Delta\sigma$ is the surcharge pressure at the time (t). Settlement plate data will determine the stabilized soil condition at intermediate settlement and or final settlement occurred (settlement has not occurred again). However, the data provided by the settlement plate may be invalid due to the installation error or device damage (caused by traffic disturbances at the field).

3.5 Geotechnical data

Peaty clay is classified as soft clay soil with organic matter or peat with soft to very soft characteristics existing between a depth of ± 0.0 to 30.0 m. Primary data produced is data from laboratory testing for peaty clay layers. CPT data identified that the soil was able to classify as clay to silt with high plasticity. As the previous explanation, SPT and borehole data from UDS indicated the soil was clay (CH) to (MH) from the unified soil classification system (USCS). In brief, laboratory data shows that Mempawah peaty clay soil has an organic content higher than 75% at the topsoil; water content (w_c) was higher than 150%; specific gravity (G_s) was less than 2.0 from topsoil to 2.50 m, and close to the value of clay (CH) between 2.60 and 2.73 from 2.50 until 30.0 m; weight volume was less than 2.0 gr/cm^3 and existing between 1.17 to 1.90 gr/cm^3; rate of hemic was influenced by medium ash content and high acidity. Hemic material is partially decomposed (intermediate decomposition) organic material. It often has the look and feel of mature compost. Hemic material has a rubbed fiber content of 17 to 40 percent (by volume) [24].

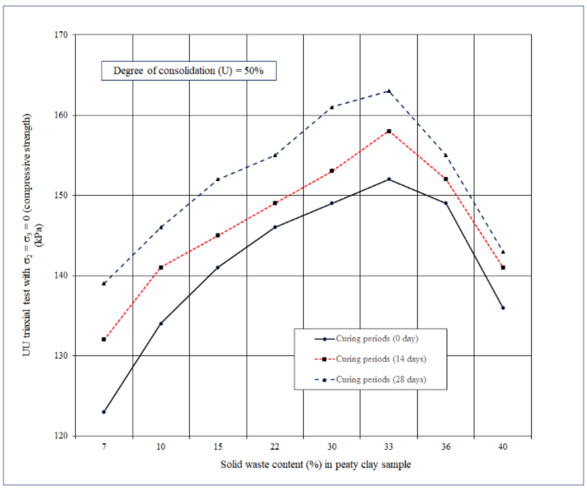
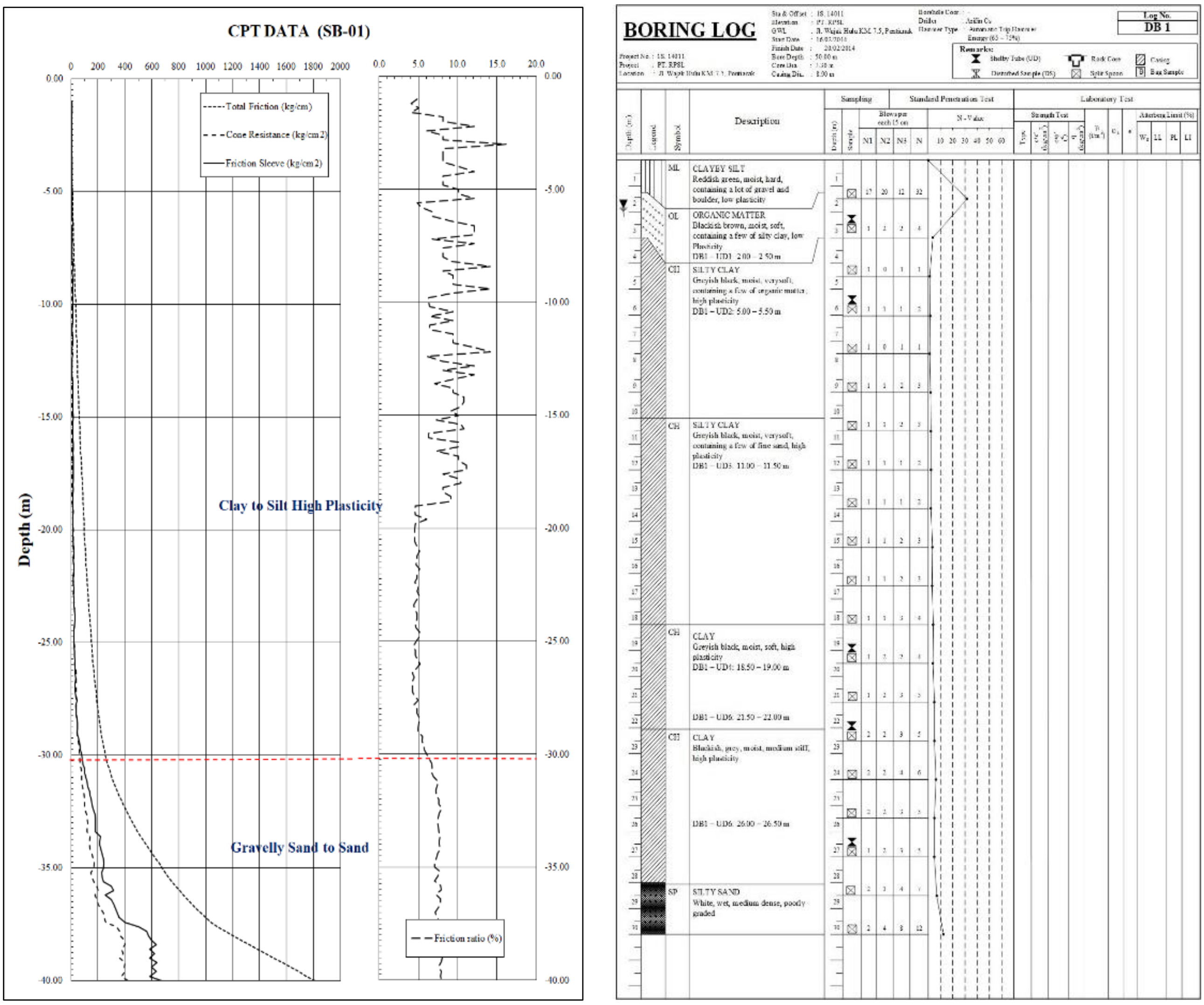


Figure 7. Graphic of standard proctor test for peaty clay soil stabilized by various amounts of solid waste versus compressive strength at 0, 14, and 28 days of curing periods

First of all, stabilization process, the composition of peaty clay and solid waste was tried out at the laboratory compaction test. Generally, the results of the standard compaction test are shown in Figure 7. Soil compaction was conducted to find the optimum moisture content and maximum dry weight using the curing period of 0, 14, and 28 days before all samples were used in the laboratory works. This study used soil samples of peaty clay (clay with organic matter) that passed sieve No. 200 and was oven dry. To get the optimum moisture content (OMC) curve and maximum dry density (γ_{dmax}), from the results of soil properties testing. Laboratory composition test was carried out using the standard proctor for compaction test between peaty clay soil and solid waste from the biomass power plant. The percentage of addition of biomass power plant waste is determined at 7%, 10%, 15%, 22%, 30%, 33%, 36%, and 40% to the weight of peaty clay soil. From all results of the compaction graphic, the sample was taken from compaction molding for UU triaxial testing (where σ_2 and σ_3 = 0, like with conventional unconfined compressive strength test or UCT in determining compressive strength and the results. From the compaction test results with the addition of 33% solid waste obtained, the highest maximum dry density (γ_{dmax}) value was in the 1.57 gr/cm^3 with OMC of 13.9%. Compressive strength of 14 and 28 days was 158 and 163 kPa. Trial-mixing and stabilization process in the field was carried out by using the optimum composition of peaty clay with 33% solid waste and spreading it layer by layer. However, the composition of peaty clay and solid waste depended on the drying process in reducing the natural water content of the soil, especially for the field implementation, was also used the prefabricated horizontal drain (PHD) to drain the surface water at the field. Then, the results of the standard proctor obtained were used to make the mixing between peaty clay and solid waste at the field. The filling process of the mix-design result was conducted by directly dumping it into the predetermined target place, and of course, it will be mixed directly with the natural peaty clay soil at the field.

However, it is very difficult to ensure the soil is mixed (solid waste and peaty clay) after the laboratory standard proctor test with natural peaty clay during the filling process. Thus, random field investigation data consisting of CPT and SPT needed to be performed before preloading structure works to observe the natural soil mixing after the filling process, as shown in Figure 8, respectively. From several observations, the natural soil layers at the bottom layer did not immediately mix with the stabilizing agent (peat clay soil and solid waste). After a few days, the soil layer is getting harder and more stable than before. This observation was conducted when the water surface of Kapuas River was in low tide condition. The next activity is the installation of a bamboo mat and piles at the ground surface to make the preloading structure and some monitoring works after the soil layer is considered stable.

Furthermore, geospatial analysis is used to determine soil parameters based on the CPT and SPT tests [25]. The value of c and ϕ were determined using the correlation from CPT and SPT data. This area has the potential landslide for wedge and rotational landslides moving to the river due to the static or dynamic load caused by the vibration from the biomass power plant. The movement of soil mass on slopes can be occurred due to the interaction of influences between several conditions, including geology, morphology, geological structure, soil-water drying and wetting, and land use to create a slope condition and tends to be a susceptible condition. Solid waste from biomass power plant combustion is expected to retain the peaty clay soil movement in the vertical and horizontal directions. A summary of existing laboratory data is shown in Table 1. Field investigation consists of CPT (6 points) & SPT (2 points), soil observation, and sampling of the disturbed sample (DS) and undisturbed sample (UDS) after the filling process at the predetermined location.



(a) CPT data (b) SPT data-borehole

Figure 8. Field soil data results of CPT and boring Log-SPT

Table 1. Summary of existing laboratory UDS after filling process the mix of peat clay and solid waste

Sample	Physical and Mechanical Properties	DB1–UD1	DB1–UD2	DB1–UD3	DB1–UD4	DB1–UD5	DB1–UD6
Sampling	m	2.00–2.50	5.00–5.50	11.00-11.50	18.50-19.00	21.50-22.00	26.00-26.50
Gradation	Gravel	10.78	0.24	0.00	0.00	0.00	0.00
	Sand	25.12	2.20	4.22	2.80	3.04	2.80
	Silt	56.74	77.31	81.71	87.53	84.08	81.68
	Clay	7.36	20.25	14.07	9.67	12.88	15.52
	Classified No.10 (2.00 mm) %	82.58	99.24	100.00	100.00	100.00	100.00
	Grading No.40 (0.425 mm) %	71.48	98.48	99.32	100.00	100.00	100.00
	Pass No.200 (0.075 mm) %	64.10	97.56	95.78	97.2	96.96	97.20
Liquid Limits	LL %	-	84.90	97.13	74.20	85.30	67.95
Plasticity Index	PI %	-	51.92	41.58	47.07	35.31	43.21
Liquidity Index	LI %	-	0.77	0.73	0.50	0.06	0.46
Classification	Soil Type	**NP**	**CH**	**CH**	**CH**	**CH-MH**	**CH**
Specific Gravity	G_s	1.84	2.64	2.69	2.71	2.69	2.73
Natural State	Water Content (w_n) %	167.42	72.75	56.06	50.73	32.19	44.71
	Wet Density (γ_t) gr/cm^3	1.17	1.56	1.67	1.72	1.90	1.78
	Void ratio (e)	3.21	1.92	1.51	1.38	0.87	1.22
	Degree Saturation (S_r) %	95.93	99.89	100.00	99.66	99.86	99.73
	Compressive Strength (q_u) kg/cm^2	0.05	-	0.07	-	-	0.09

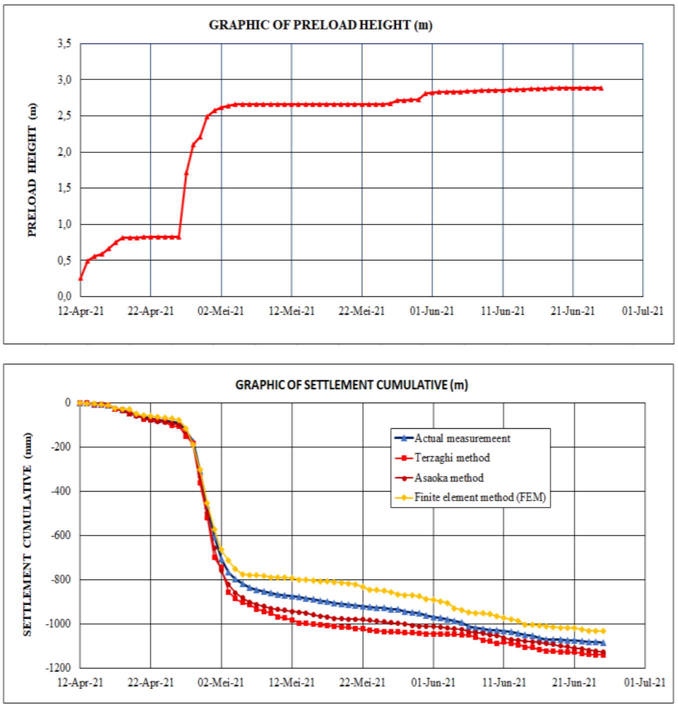
Unconfined Compression Test	Remolded Strength (q_r) kg/cm^2	0.04	-	0.03	-	-	0.06
	Sensitivity ratio (S_t)	1.43	-	2.01		-	1.58
Triaxial Compression Test	Type of Test				**UU**		
	Cohesion (c) kg/cm^2	-	0.05	-	0.08	-	-
	Angle of internal friction (ϕ)º	-	2.47	-	1.15	-	-
Consolidation Test	Yield of consolidation (P_c) kg/cm^2	0.77	1.58	3.00	2.67	2.88	2.50
	Compression Index (C_c)	2.04	1.39	2.34	1.14	0.79	0.77
	Swelling Index (C_s)	0.19	0.06	0.09	0.10	0.04	0.05
Direct Shear Test	Type Test				**Peak**		
	Cohesion (c) kg/cm^2	-	0.04	-	-	0.05	-
	Angle of internal friction (ϕ)º	-	8.72	-	-	800	-
	Type test (remolded)				**Residual**		
	Cohesion (c) kg/cm^2	-	0.03	-	-	0.05	-
	Angle of internal friction (ϕ)º	-	6.58	-	-	6.51	-

Implementation of full-scale test measurements is carried out continuously for approximately 3 (three) months. The measurement stages are adjusted to the stages of filling out peaty clay with solid waste stabilization material from the biomass power plant industry. Measurements are carried out by SNI standards [26] etc. The recorded data is collected for advanced analysis to measure the stability level and increase the shear strength (c and ϕ) parameters at the field.

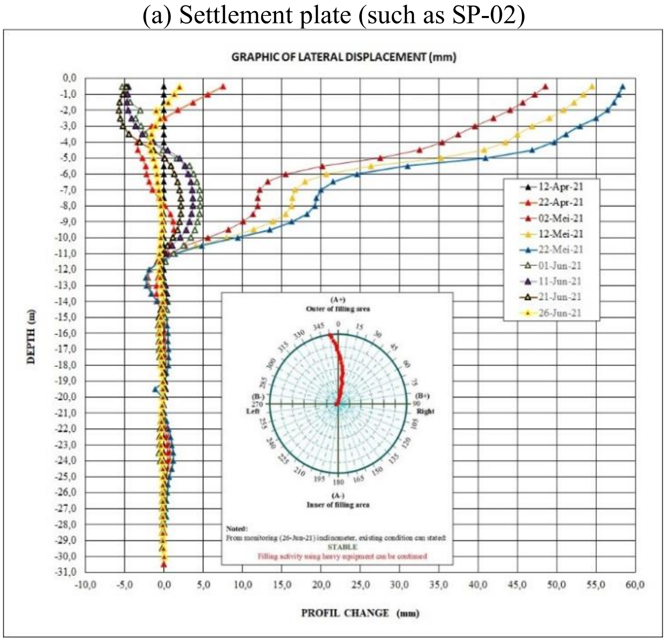
Based on Figure 9(a) settlement plate is a geotechnical instrument that functions to measure settlement occurring during a certain time. This settlement would be a basic measurement of the soil condition stabilized with solid waste in monitoring the intermediate settlement in the under process or final settlement on each stage of the preloading process at the site. The actual degree of consolidation U (%) could be determined using the settlement plate data [27]. In anticipating data invalidity by the settlement plate measurement at the field, the other geotechnical instruments were an inclinometer (Figure 9(b)) and a pneumatic piezometer, respectively, to control the settlement data (Figure 9(c)). This piezometer was used to monitor the pore water pressure in the soil layer. Pore water pressure is very important to measure the soil subsidence during the consolidation process, especially when the soil pore water pressure is large, together with the effective stress of the soil decrease. For this case, the addition of the initial loading during preloading implementation must be temporarily stopped until the pore water pressure becomes stable or constant before reloading.

The initial measurement of the piezometer was carried out every day until the results of the last 3 (three) measurements were constant. The data reading of the piezometer was performed by using a data logger unit. The inclinometer is one of the geotechnical instruments used to detect whether the settlement or soil subsidence occurred to endanger the surrounding soil layer stabilized. The inclinometer also functions to measure and calculate the shear strength of the soil. So that this tool can provide an early warning for soil layers to stabilize, or the soil shear strength can be able to retain all soil layers that would not move or landslide.

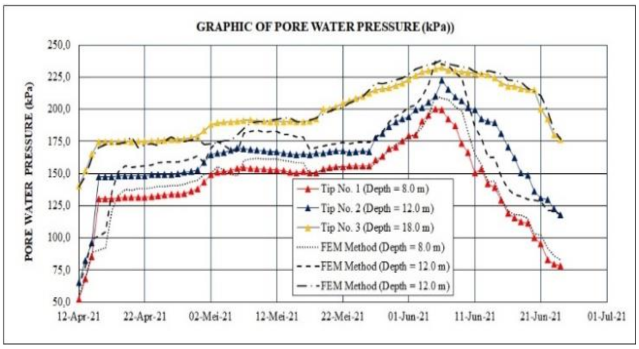
In this case, the addition of the initial load during preloading implementation must be temporarily stopped until the ground surface becomes stable. Reinforcement should be given to support where necessary to slow down movement. Several cases at the field: the settlement (vertical displacement) was still small 6 days after 10 days of the first preloading stage (63 mm); the loading must be postponed for several days to wait for the peaty clay to move gradually according to the prediction line using laboratory consolidation test results; the loading stage sometimes was stopped when the upper ground surface (2.00 m) occurred the crack with 15 mm width.



(a) Settlement plate (such as SP-02)



(b) inclinometer (such as IN-01)



(c) Vibrating wire piezometer (such as VWP-02)

Figure 9. Typical data monitoring result

Installation of the settlement plate, the piezometer, and the inclinometer required experts who really understood the ground contour and how to install it so that the researcher could make sure the three instruments used were of good quality and the data results could be used as the analysis data. Data recorded obtained as shown in Figure 9 during the field observation can be explained as follows: Figure 9(a) shows a settlement plot at the maximum height of soil fills. The fill heights to reach final compression at the study area were around 3.0 m with staging 20 to 30 cm. Lateral displacement was also large the first time when the subjected loading (150 mm) (Figure 9(b)). Lateral displacements were gradually reduced in 4 to 5 days after the first stage. The pore water pressure of the peaty clay layer after the first stage increased in 18 days (100 kPa), and when the next stage (second and third stages) continued to 230 kPa in 24 days (215 kPa) (Figure 9(c)).

4. RESULTS

The calculation of c_v, c_h, and U based on the actual measurement can be elaborated as follows: Figure 9(a) presents the correlation between settlement Si and Si-1 from the observational results. Select calculation time t_0=30 days with initial settlement S_0=704 mm. Predict the final settlement and consolidation degree using the Asaoka method with monitoring cycle Δt=10 days. From observation in the field, there is no difference significantly if the monitoring is performed every 1 day. It can be assumed that the bamboo mat and pile structure contributed to the settlement rate since the bamboo structure system increased the floatation stress during all stagings of the preloading. Every preloading stage was conducted with a thickness of 30 cm/day until 3.0 m final height. The graph in Figure 10 shows that the relationship between S_i and S_{i-1} is y=a.x+b, whereas: a=0.9405 and b=63.68, using the Asaoka method will be obtained: S_∞ = 1070, 25 mm.

The initial vertical coefficient of consolidation (c_v) of peaty clay and solid waste before the preloading process (U=0%) was obtained at 0.0025 cm/sec based on a laboratory consolidation test. This average c_v value was determined until 26.5 m or for all depth layers. This value obtained was without some consideration of the natural mixing process at the field after filling at a predetermined location. As the previous explanation, there is no change value significantly of the previously recorded data during 10 days. And then, the monitoring works have to be performed regularly for the next 10 days for the compilation of recorded data. When the U has reached 65.38% with a duration of 80 days, the c_v value can be calculated and obtained using Eq. (4). For all depths and using correlation in determining T=0.349 [28], the average c_v value results is 3.5×10^{-7} m^2/sec and the value of c_h=1.58×10^{-6} m^2/sec. The Asaoka method gives better results in predicting the settlement compared to the Terzaghi and FEM methods.

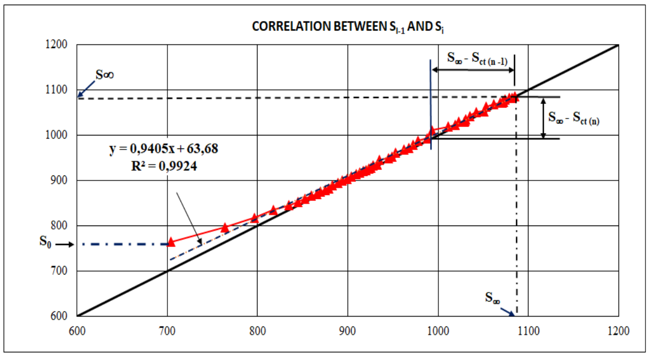


Figure 10. A total settlement using the Asaoka method

Based on geotechnical instrumentation analysis in the field, several results could be explained that all settlement plate points show a degree of consolidation (U) of more than 60%, which means that the soil settlement stabilized under the preloading system was not yet been completed; the measurement of the water level in the piezometer supports the readings from the settlement plate indicating that soil stabilized compression was under consolidation process although the filling works must be stopped when the pore water pressure increases rapidly or unsafe condition; and the inclinometer measurement data where the soil layers could be safe during the consolidation process.

Shear strength values in the form of cohesion data (c) and internal shear angle (ϕ) are plotted on the graph to show the condition before and after stabilization. At the degree of consolidation (U) > 60%, there was an increase in the shear strength parameter after the stabilization process was carried out. CPT (cone penetration test) was carried out on as many as 6 points. CPT test samples are typically shown only for CPT-1, CPT-4, and CPT-6. Based on Figure 11, the cohesion value (c) and internal shear angle (ϕ) increase with the consolidation process of the peat clayey soil layer, and it is easier to compress vertically than lateral stability. In this case, the solid waste from the combustion of the power plant has replaced air and water in the pores of the peaty clay soil during the consolidation process in the field using the preloading method [29]. These existing macro-mechanical results still must be proven by testing or experiments in micro laboratories using SEM (Scanning Electron Microscope) tools [30]. Generally, the shear strength parameter values (c and ϕ) based on CPT field data and triaxial laboratory differ by about 3% to 5%. However, laboratory and field procedures are very different, and very difficult to create a particular correlation. It can be assumed that this difference is also due to the handling of undisturbed samples that are not by the standard requirements of the triaxial laboratory [31]; for example, the sample does not reach a saturated state (S_r=100%) condition.

Based on the results of the correlation of soil types with CPT data using the Robertson chart, five types of soil were obtained, namely: silt clay for zone 3, clayey silt for zone 4, sandy silt for zone 5, silty sand for zone 5, and clean sand for zone 6. The correlation of CPT values with laboratory triaxial data is differentiated based on the cohesive and non-cohesive soil type. Non-cohesive soils in the study area are interpreted as silt sand (silty sand) and sand to gravelly sand. Cohesive soils in the study area are interpreted as peaty clay to silt clay. Some correlation in determining parameter c and ϕ is very dependent on soil classification, especially for cohesive soil. Generally, the advantage of Robertson graphs using normalized parameters is that the soil description is closer to actual conditions. However, when the vertical effective stress in an area has a value range of 50 kPa to 150 kPa, usually the type of soil that will be obtained from parameters that are not normalized will have insignificant differences from those that are normalized. Most calculations in the literature are based on the relationship between q_c (cone resistance) and N-SPT (number of blow-Standard Penetration Tests). The q_c value is considered more consistent than f_s (friction sleeve). Thus, it should be evaluated to find the possible q_c compared with the N trend in the existing area. However, the subsurface conditions in the study area can be accepted; the bore log correlation results show the presence of clay lenses in the sand layers or sand lenses at silty sand or sand to gravelly sand layers like a coastal depositional environment.

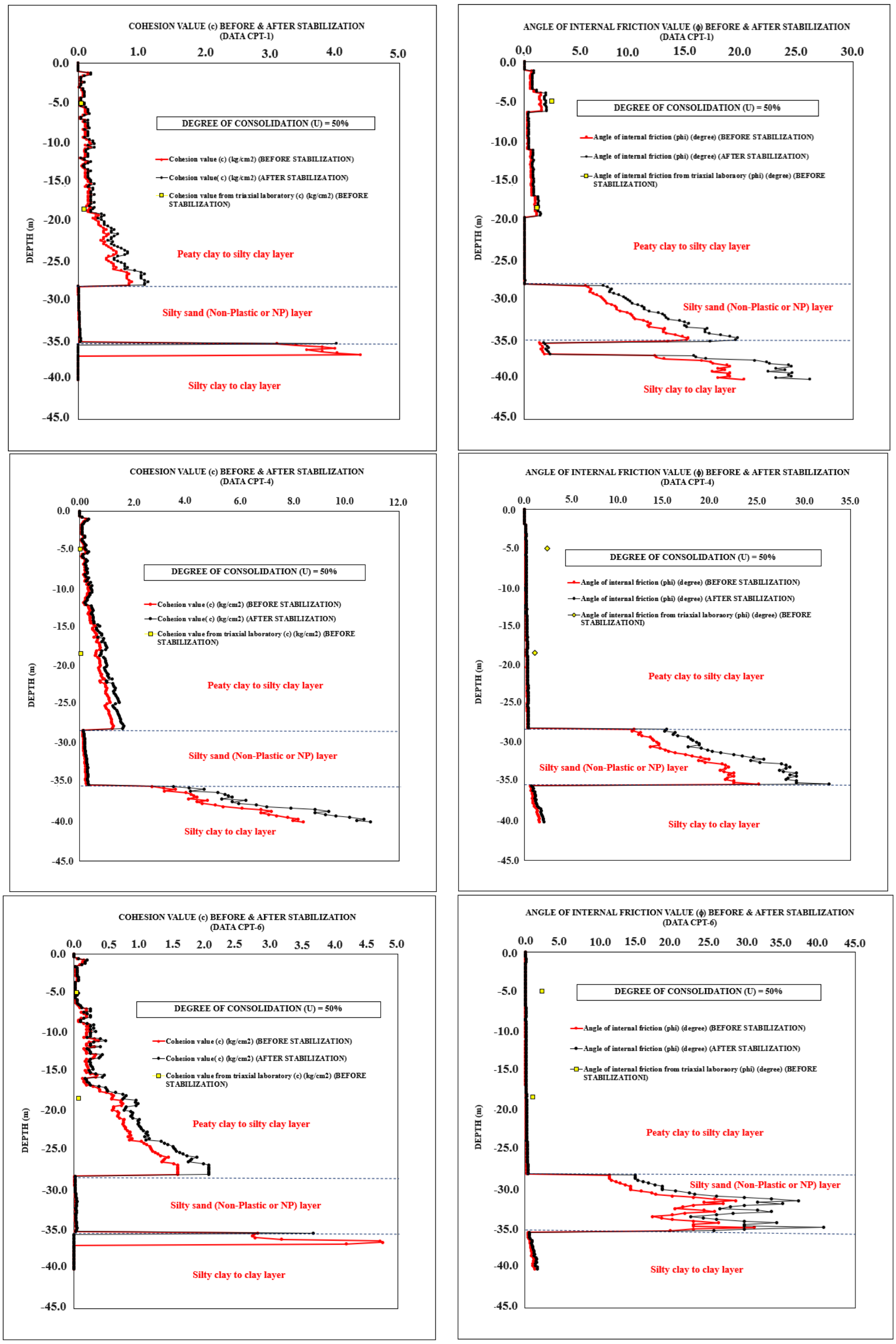


Figure 11. CPT and triaxial laboratory results for samples CPT No. 1, 4, and 6

5. DISCUSSION

Table 1 shows that the soil layer in the Mempawah is inorganic clays of high plasticity, fat clay. This USCS classification is not entirely correct because, from some observation, these soil layers have been mixed with fragments of organic matter coming from the original peat at sub-layers at the study site. Based on the classification made by ASTM, OSRC, and LSG, the Mempawah soil sample can be classified as a mixture of peat and clay or peaty clay soil because it has an organic content and reach more than 75%. Mempawah peat soil is classified as hemic soil with moderate ash content and high acidity. The actual peat soil layer has high water content with low specific gravity (G_s) (less than 2.0) and low weight volume (less than 0.80 gr/cm$^{3)}$. Mixing with clay fraction increased the G_s value and exceeded 2.62 with a weight volume larger than 1.10 gr/cm^3. But, peaty clay layers of Mempawah still have low bearing capacity. The stabilization process with solid waste from the combustion process activity of the Biomass Power Plant mixed with clay and sand could increase the bearing capacity and soil strength and decrease pore water pressure. Generally, solid waste can also be classified as activated charcoal can absorb heavy metals and acidic properties of the soil [32].

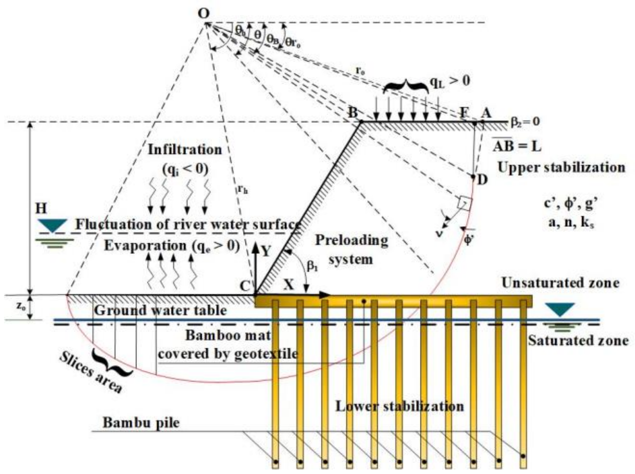
Natural soil is both a complex and variable material, however, because of its universal availability and its low cost of winning. Not uncommonly, however, the soil at any particular locality is unsuited, wholly or partially, to the requirements of the construction engineer. Classically, a basic decision must therefore be made whether to: (i) accept the site material as it is and design it to standards sufficient to meet the restrictions imposed by its existing quality; (ii) remove the site material, and replace it with a superior material; (iii) alter the properties of the existing soil to create a new site material capable of better meeting the requirements of the task in. The third point (iii) is what underlies this research. This research is not only to improve the properties of soil materials as the usual soil stabilization works in the construction project, such as volume stability, increasing shear strength, reducing permeability, and adding resistance to all technical behavior when used as land for construction, but also this research is trying to help the local government to save the environment from all types of waste as a residual of processing technological products that are being developed at this time. The Indonesian government has published some regulations related to non-organic waste, categorized as B3 waste categorized 2 from specific sources (UU No. 3 of 2014; Government Regulation No. 74 of 2001; No. 55 of 2015; No. 101 of 2014; No. P.63 of 2016). Utilization of non-organic wastes, classified as category 2 of B3 waste, can help to prevent the environment from material pollution and conservation of natural resources in the form of peat soil stabilization material.

Problematic marine clays *(peat),* including the peaty clay at the shoreline of the Kapuas River exhibit high compressibility, low strength, and volume instability [33]. Some researchers have all shown that peaty clays' bearing capacity is very low [34]. The problem becomes more difficult to handle if the superficial soils are permeable, as in many parts of the study area [35]. Mass stabilization of peaty clays started in the 1990s in Finland, and ever since, the technique has spread very quickly [36]. The mass stabilization method is performed by mixing a binder or mixture of binders throughout the volume of the treated soil layer [37]. For this study, the binder material can be assumed as a solid waste material near furnace slag stabilization. Specific gravities (G_s) of solid waste as a residual of the combustion process at the biomass power plant are 1.377 and 1.530 for as-prepared/uncompacted and compacted manufactured wastes, respectively; 1.072 and 1.258 for uncompacted and compacted fresh wastes, respectively; and 2.201 for old wastes. The average organic content and degree of decomposition were 77.2% and 0%, respectively, for fresh wastes and 22.8% and 88.3%, respectively, for old wastes. The G_s increased with decreasing particle size, compaction, and increasing waste age. For fresh wastes, reductions in particle size and compaction caused clogged-up intraparticle pores to be exposed and waste particles to be deformed, resulting in specific gravity increases. For old wastes, the high G_s resulted from the loss of biodegradable components that have low $G_{s,}$ as well as potential access to previously occluded pores and deformation of particles due to both degradation processes and applied mechanical stresses [38]. Based on this research results, the G_s of peaty clay and fresh solid waste mixed can be increased by the decreasing particle size and compaction process besides the increasing waste age. Furthermore, the stabilization process using the preloading method can be applied together with the bamboo mat and pile, and later on, it can result in the compounding process perfectly to improve the physical and mechanical properties of stabilized soil.

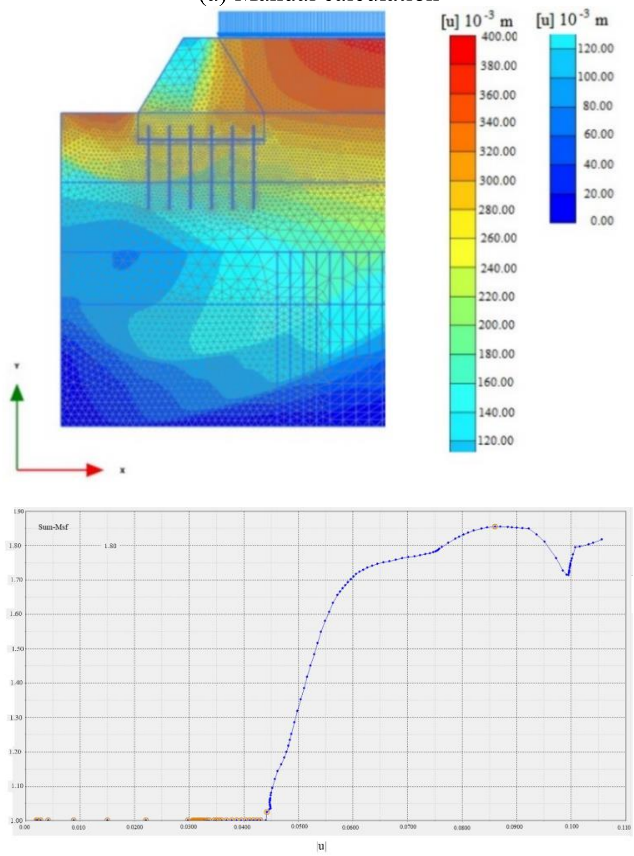
Mass stabilization could also be combined with another material stabilization method, such as sand column stabilization shown in the after-mass stabilization manual [39]. Once mass stabilization is achieved, embankments, buildings, etc., can be founded on it in the same way as on firm natural soil. According to the mass stabilization manual, the benefits of the mass stabilization method may include (i) Rapid ground improvement that can be adapted to varying soil conditions; (ii) Economically efficient, saves material and energy; (iii) No differential settlements; (iv) Soil replacement is not needed, it is not problem with transportation, traffic pollution, or disposal sites. Laboratory tests to establish the most suitable stabilizers, optimize the number of stabilizers and assess strength deformation properties must be carried out before the mass stabilization to assure the safety and quality of the final stabilized product. A new laboratory testing procedure is in place to simulate any field conditions in the laboratory. The binder results in a mix of peaty and solid waste, constitutes can cut half of the total cost of a stabilization project. Careful laboratory tests can ensure savings in selecting the appropriate stabilizer material and its optimal amount. So far, the important thing in the field is to try to stabilize the water content (w_{opt}) and maintain the maximum dry weight volume (γ_{dmax}) close to the results of the laboratory compaction test, especially when spreading and filling works of peaty clay material which has been stabilized with solid waste.

Slope stability analysis was conducted by manual calculation and geotechnical software. The systematical method has culminated in establishing the Swedish Method (or the Ordinary Method) of Slices (Fellenius in 1927). Several subsequent refinements to the method were made: Taylor's stability chart (Taylor in 1937); Bishop's Simplified Method of Slices (Bishop in 1955) ensures the moments are in equilibrium; Janbu extended the circular slip to generalized slip surface (Janbu in 1973); Morgenstern and Price (1965) ensured moments and forces are simultaneously in equilibrium; Spencer's (1967) parallel inter-slice forces; and Sarma's (1973) imposed horizontal earthquake approach. These various methods have resulted in the modern Generalized Method of

Slices (GMS) [40].



(a) Manual calculation



(b) Calculation using geotechnical software

Figure 12. Manual and geotechnical software analysis in determining safety factor (SF)

Cross section model of the Biomass Power Plant on manual calculation was drafted by CAD/CAM Software. In manual calculation, some steps on the ordinary slices method could be described before analyzing slope stability, such as: (i) determination of each weight of soil slice; (ii) determination of the size of the angle from the center of the slice to the center of gravity; (iii) calculation every force and total moment that works on each soil slice according to the position of landslide line. Figure 12(a) can explain the process of calculation. The stability analysis resulted in the safety factor (SF) of slope stability analysis before the stabilization process at the range of 0.921 to 1.122 using manual calculations of the ordinary slice method. However, after the stabilization process, there was an increase in SF between 1.311 and 1.521. These values have already been appropriate with Indonesian regulations for geotechnical engineering; the SF value from slope stability analysis should be larger than 1.20. The manual slope stability analysis will take along some calculations, which should be carried out repeatedly. With the Ordinary Method of Slices, sometimes known as the Fellenius Method or the Swedish Circle Method [41], several simplifying assumptions are made to render the problem determinate. Some difficulties may be experienced with the equation which was used in this prediction analysis. There are two different ways of carrying out slope stability analyses for this case. The first approach is the total stress approach which corresponds to peaty clayey slopes with saturated under short-term loadings with the pore pressure not dissipated. The second approach corresponds to the effective stress approach, which applies to long-term stability analyses in which drained conditions prevail.

For these slopes should be analyzed with the effective stress method, considering the maximum water level under fluctuation of river water surface, including infiltration ($q_i < 0$) and evaporation (q_e) aspects. This is particularly important for the Mempawah area, where intensive rainfall may occur over a long period, and the water table can rise significantly after a rainy season. These aspects will increase the level of complexity and require more simplification engineering judgment in the detail soil parameter when using the manual calculation models. Geoslope and or PLAXIS in 2D analysis can be easier to identify the landslide line of the cross-section. The ordinary slice method was used to determine the safety factor (SF). All parameter soil can be input together with external forces. Some simulations can be obtained faster than manual calculation. Some analysis can be made after some simplification and idealization in the context of the site's intended purpose; a ground model can then be set up. These forces are the soil weight of the slice, the normal and tangential forces acting on the lower boundary of the slice, and the side forces which act on the sides of the slice of the soil layer. Negative values of effective normal force may be created by the large values of cohesion and angle of internal friction when the pore water pressures are stable. But, there is no guarantee that all simplification and idealization can be suitable with field conditions; the pore water can alter every time during the stabilization proses of peaty clay using the stabilizer agent of solid waste [42]. There are many unforeseen in each conventional analysis method in both methods (manual or using the geotechnical software), so the monitoring works play an important role during stabilization. For example, the slope stability calculation method using manual and software (geostudio and or PLAXIS) used the ordinary slice method with a specific gravity of water (γ_{water}) of 10 kN/m^2 and a uniform load value (q_L) of 180 kN/m^2. Stability analysis after the stabilization process during the revetment construction for 5 (five) stages to the final height of 3.0 meters produced SF value between 1.378 and 1.732, but actually, during the stabilization process at the field in every stage, always created some cracks at the upper ground.

Kapuas River water table in the study area can alter at every time and influence soil parameters dynamically [43]. This phenomenon can be avoided by using the protection structure as a shore retaining wall in front of the soil stabilized because it is difficult to detect any change in water level every time. Furthermore, every analysis using all methods may be unforeseen for this phenomenon. Actually, this condition will produce smaller factors of safety than the predicted value which has been performed. Here, the implementation should be realized that all prediction analysis results can change with the actual condition at the field every time.

Stabilization using solid waste from Biomass Power Plant shows that after stabilization could reduce the settlement in the range of 13.50 to 22.5% and retain the consolidation rate until between 34.5 to 45.4%, So the settlement occurred could be slower than before stabilization. It can be identified that the compression index (C_c) before the stabilization of peaty clay soil layers was higher than after stabilization, where a high of (C_c) soil layer was always close to the behavior as normally consolidated and a small of (C_c) lower usually approaching to analytical methods, the completion of primary consolidation could be predicted in a time range from 1.5 to the behavior as overconsolidated soil. Finally, settlement occurred due to the loading will be smaller. Based on several Based on several analytical methods, the completion of primary consolidation could be predicted in a time range from 1.5 to 2.0 months. The plasticity and swelling potential of the peaty clay could be reduced when mixed with solid waste from a combustion process. The plasticity and swelling potential decrease when the solid waste content increases. Several investigations have been conducted by studies [44, 45]. However, increasing the process on shear stress of peaty clay soil was required in further geotechnical investigation chemically.

A landslide that occurred in the field was caused by high pore pressures in the peaty clay layer that resulted from the highly organic nature of the waste plus the addition of recirculation-induced pore pressures before the stabilization process gradually; this observation was almost similar to the study result. Solid waste material could reduce the pore water pressure during the stabilization process. It could be identified that the solid waste from Biomass Power Plant increased the void ratio in the peaty clay before the compaction or consolidation process. Results obtained from the conceptual groundwater analysis at the larger void ratio show that the pore water pressure could decrease slowly with the larger void ratio. From physical observation, the solid waste from the combustion process would stimulate the peaty clay to compact with a larger void ratio in decreasing pore pressure. A comparison between predicted lateral movement and actual measurements in the field was carried out before and after stabilization, respectively. The actual measurements were 17.5 to 34.6% greater than the prediction analysis. Solid waste stabilization contributed to reducing the lateral movement because the soil particle orientation of peaty clay was changed to the horizontal direction and easier to compact since the particle moved closer to one another. When the particle movement horizontally caused by cohesion (c) increased, the shear strength would be inflated as well.

However, of all the advantages of the biomass power plant described above, the peat stabilization research that will be carried out is focused on utilizing waste resulting from the combustion or carbonation reactor processes that have been removed from the reactor to stabilize the peat soil, for the need for road infrastructure development; bridges and or piers. Generally, solid waste from biomass power plants is usually dumped directly into rivers by generator operators into watersheds or dumped on riverbanks without being utilized beforehand; it turns out that solid waste has economic value as a soil stabilizing agent.

Figure 13 shows the finishing stage at the field. The idealized stabilization model implemented in the laboratory can be used as a basis for implementation in the field, but not all work in the laboratory can be carried out in the field according to the research plan. Here, creativity is needed to overcome problems in the field, such as the many aspects that are not visible when carried out in the laboratory. Many findings in the laboratory cannot be applied directly in the field, only as findings without implementation. Solid waste, which was assumed to be a pollutant material previously, can be used as a stabilizer agent for the stabilization works of peaty clay; the stabilization using this material can decrease the potential damage to the environment.

Figure 13. Stabilization of the peaty clay using solid waste from the biomass power plant at the final stage of preloading

From this discussion, several points can be drawn, such as the solid waste can be used as a stabilizing agent for peaty clay soil layers. Solid waste, which was initially a residual material and directly only thrown into rivers or landfills, can be optimally used for preparing the land, which has many technical problems in engineering (low bearing capacity, high compressibility, etc.). This stabilization implementation model is unique because it requires several additional reinforcement systems, namely bamboo mat and pile, to generate the floating forces to reduce the gravitational force when the preloading system is applied. Model analysis can be performed in a simple way manually or using existing geotechnical software.

6. CONCLUSIONS

Generally, peaty clay with stabilization material from solid waste of Biomass power plants shows all filling out areas or embankments in stable condition. All settlement plate points show a degree of consolidation of less than 50%, which means that the soil stabilized by solid waste material under the embankment has not been completed yet (100%). Maximum lateral embankment soil measured after maximum elevation (4.50 m) by inclinometer shows less than 1.0 inch (25.4 mm), so this embankment is also in stable condition. From prediction analysis, it could be known that the SF value is larger than 1.30; the safety factor of the embankment is in a safe condition. However, the measurement of the water level in the piezometer increases in accordance with the vertical displacement of the settlement plate. Along with time, pore water pressure decreases to hydrostatic pressure conditions.

Generally, solid waste resulting from the combustion of a biomass power plant can be used as a stabilizing agent or material. This material can change the physical and mechanical properties of the soil layers at the study site, is ready for use due to its large volume, and is continuously produced by a biomass power plant. The materials contained in this type of waste could gradually stabilize the peaty clay soil layer and change the behavior closing to CH and/or MH soil type, so the compressibility is faster and more stable. The shear strength (c and ϕ) increase naturally with the consolidation time. This increase results in specific gravity (G_s) of up to 10%, and its value is close to the G_s value in conventional clays, which range from 2.64 to 2.65. The measurement of settlement or vertical displacement in the field is 10 to 12% smaller than the analysis results. Cohesion values (c) and angle of internal friction (ϕ) naturally increase up to 10 to 12% when field monitoring with settlement plates produces a degree of consolidation (U) of larger than 50% using the Asaoka method can be more accepted than the practical method.

Stabilization efforts using solid waste need to be encouraged from the combustion process of biomass power plants. Along with current technological developments, stabilization methods have developed rapidly, and stabilization applications in the field are a point of success in this work. This research is already finished in implementation; this research is only limited to the application of macro testing from the laboratory works and implemented in the field with a unique method. Future studies need to be directed to micro research. Thus, more valid information can be obtained regarding the results of the stabilization that has been carried out in the future, especially to determine the classification of fresh or old waste before use for the stabilization works; the model of the particle bonding between peaty clay and solid waste from the combustion process of a biomass power plant; the ability of solid waste in decreasing the particle distance of peaty clay; the process when the solid waste to reduce the pores of peaty clay; including chemical aspects, etc.

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REFERENCES

[1] Otoko, G.R. (2014). A review of the stabilization of problematic soils. International Journal of Engineering and Technology Research, 2(5): 1-6.

[2] Dahale, P.P., Nagarnaik, P.B., Gajbhiye, A.R. (2012). Utilization of solid waste for soil stabilization: A review. Electronic Journal of Geotechnical Engineering, 17: 2443-2461.

[3] Ingles, O.G., Metcalf, J.B. (1972). Soil stabilization principles and practice, Chapter 4-7, 11. Butterworth and Company Publishers Limited, London.

[4] Le, H.V., Pham, B.T., Ho, L.S., Nguyen, M.D. (2017). Analysis of consolidation degree using settlement observation results and Asoka method: A case study of route KM 94+ 340-KM 94+ 440 of Hanoi Haiphong highway construction project. International Journal of Civil Engineering and Technology, 8(11): 91-100.

[5] Salimah, A., Simatupang, S., Christian, R., Hasan, M.F.R., Agung, P.A.M. (2023). Clayshale stabilization using Portland pozzolan cement type II to increase the shear strength of soil. In IOP Conference Series: Earth and Environmental Science, 1218(1): 012034. https://doi.org/10.1088/1755-1315/1218/1/012034

[6] ASTM D698-12. (2007). Standard test methods for laboratory compaction characteristics of soil using standard effort (12,400 ft-lbf/ft3 (600 kN-m/m^3)). Annual Book of ASTM Standards, USA, pp. 1–5. https://www.astm.org/d0698-12r21.html.

[7] Basu, P. (2010). Biomass gasification and pyrolysis: Practical design and theory. Academic Press. https://doi.org/10.1016/C2009-0-20099-7.

[8] Raveendran, K., Ganesh, A. (1996). Heating value of biomass and biomass pyrolysis products. Fuel, 75(15): 1715-1720. https://doi.org/10.1016/S0016-2361(96)00158-5.

[9] Koppejan, J., Van Loo, S. (2012). The Handbook of Biomass Combustion and Co-Firing. Routledge, England.

[10] Lavoie, M., Paré, D., Fenton, N., Taylor, K., Groot, A., Foster, N. (2005). Paludification and forest management in the Northern Clay Section: A literature review. Lake Abitibi Model Forest Technical Report No. 1. 75. https://en.wikipedia.org/wiki/Paludification.

[11] Chen, F.H. (2012). Foundations on Expansive Soils. Elsevier, New York.

[12] Sanyoto, P., Pieters, P.E. (1993). Geological map of the Pontianak / nangataman quadrangle, Kalimantan. Geological Research and Development Centre, Indonesia. https://geologi.esdm.go.id/geomap/pages/preview/peta-geologi-lembar-pontianak-dan-nangataman-kalimantan.

[13] Agung, P.A.M., Hasan, M.F.R., Susilo, A., Ahmad, M.A., Ahmad, M.J.B., Abdurrahman, U.A., Sudjianto, A.T. Suryo, E.A. (2023). Compilation of parameter control for mapping the potential landslide areas. Civil Engineering Journal, 9(4): 974-989. https://doi.org/10.28991/CEJ-2023-09-04-016

[14] Agus, F., Anda, M., Jamil, A. (2016). Lahan Gambut Indonesia: Pembentukan, Karakteristik, dan potensi Mendukung Ketahanan Pangan (Indonesian Peatlands: Formation, Characteristics and Potential to Support Food Security). IAARD Press, Bogor.

[15] Hasan, M.F.R., Utama, I.Z., Razzak, A.F.A., Salimah, A., Agung, P.A.M. (2023). Clayshale stabilization using active natural lime to increase the shear strength of soil. In IOP Conference Series: Earth and Environmental Science, 1173(1): 012025. https://doi.org/10.1088/1755-1315/1173/1/012025

[16] Das, B.M., Sivakugan, N. (2015). Introduction to Geotechnical Engineering. Cengage Learning, United States.

[17] Salimah, A., Hazmi, M., Hasan, M.F.R., Agung, P.A.M. (2022). A comparative study of red brick powder and lime as soft soil stabilizer. F1000Research, 10: 777. https://doi.org/10.12688%2Ff1000research.27835.2

[18] Robertson, P.K. (2016). Cone penetration test (CPT)-based soil behaviour type (SBT) classification system-an update. Canadian Geotechnical Journal, 53(12): 1910-1927. https://doi.org/10.1139/cgj-2016-0044

[19] ASTM D4427-23. (2002). Standard Classification of Peat Samples by Laboratory Testing. Annual Book of ASTM Standards, United States. https://www.astm.org/d4427-23.html

[20] López, C., Shanley, P. (2004). Riches of the Forest: Food,

Spices, Crafts and Resins of Asia. Bogor, Indonesia, Center for International Forestry Research.
[21] Das, B.M., Sivakugan, N. (2018). Principles of Foundation Engineering, Ninth Edition. United States, Cengage learning.
[22] Asaoka, A. (1978). Observational procedure of settlement prediction. Soils and Foundations, 18(4): 87-101. https://doi.org/10.3208/sandf1972.18.4_87
[23] Zdravković, L. (1999). Finite Element Analysis in Geotechnical Engineering: Theory. Chapter 10 and 12. London, Thomas Telford.
[24] Deneele, D. (2016). Scanning Electron Microscope (SEM) investigations in soil microstructure description. 1st IMEKO TC-4 International Workshop on Metrology for Geotechnics Benevento, Italy.
[25] Agung, P.A.M., Hasan, M.F.R., Ahmad, M.A., Martina, N., Saifullizan, M.B. (2022). Prediction of Q_u and R_u Capacities of pile in clayey soil layer using geospatial analysis. GEOMATE Journal, 23(98): 31-38.
[26] SNI-8460. (2017). Persyaratan Perancangan Geoteknik. Badan Standardisasi Nasional, 1-323. https://binamarga.pu.go.id/index.php/nspk/detail/sni-84602017-persyaratan-perancangan-geoteknik.
[27] Lakkoju, V., Kommu, S., Reddy, M.M., Sony, B., Asadi, S.S. (2020). In-situ consolidation analysis by Asaoka and hyperbola methods. International Journal of Scientific & Technology Research, 9(2): 6296-6302.
[28] Holtz, R.D., Kovacs, W.D., Sheahan, T.C. (1981). An Introduction to Geotechnical Engineering. Englewood Cliffs, Prentice-Hall.
[29] Murthy, V.N.S. (2002). Geotechnical Engineering: Principles and Practices of Soil Mechanics and Foundation Engineering. CRC press, United States.
[30] Rahman, N.A., Widhiana, I., Juliastuti, S.R., Setyawan, H. (2015). Synthesis of mesoporous silica with controlled pore structure from bagasse ash as a silica source. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 476: 1-7. https://doi.org/10.1016/j.colsurfa.2015.03.018
[31] ASTM D2850-03. (2017). Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils. Annual Book of ASTM Standards, United States.
[32] Sing, W.L., Hashim, R., Ali, F. (2008). Engineering behaviour of stabilized peat soil. European Journal of Scientific Research, 21(4): 581-591.
[33] Hebib, S., Farrell, E.R. (2003). Some experiences on the stabilization of Irish peats. Canadian Geotechnical Journal, 40(1): 107-120. https://doi.org/10.1139/t02-091
[34] Islam, M.S., Hashim, R. (2008). Use of mackintosh probe test for field investigation in peat soil. In Proceeding of the International Conference, pp. 26-27.
[35] Lahtinen, P., Niutanen, V. (2008). Development of mass stabilisation technique for contaminated sediments. In 5th International SedNet Conference.
[36] Jelisic, N., Leppänen, M. (2000). Mass stabilization of peat in road and railway construction. In ISRM International Symposium.
[37] White, D.J., Harrington, D., Ceylan, H., Rupnow, T. (2005). Fly ash soil stabilization for non-uniform subgrade soils, Volume I: Engineering properties and construction guidelines. Iowa State University.
[38] Yesiller, N., Hanson, J.L., Cox, J.T., Noce, D.E. (2014). Determination of specific gravity of municipal solid waste. Waste management, 34(5): 848-858. https://doi.org/10.1016/j.wasman.2014.02.002
[39] Ampera, B., Aydogmus, T. (2005). Recent experiences with cement and lime-stabilization of local typical poor cohesive soil. In Geotechnik-kolloquium Freiberg, 121-144.
[40] Cheng, Y.M., Lau, C.K. (2008). Slope Stability Analysis and Stabilization: New Methods and Insight. CRC Press, United States.
[41] Zolkepli, M.F., Ishak, M.F., Zaini, M.S.I. (2019). Slope stability analysis using modified Fellenius's and Bishop's method. In IOP Conference Series: Materials Science and Engineering, 527(1): 012004. https://doi.org/10.1088/1757-899X/527/1/012004
[42] Fernandez, G., Hendron, D., Castro, A. (2005). Pore pressure induced slide in municipal solid waste Doña Juana Landfill–Bogota, Colombia. In Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering, Osaka, Japan, pp. 2253-2256. https://doi.org/10.3233/978-1-61499-656-9-2253
[43] Das, B.M., Luo, Z. (2016). Principles of Soil Dynamics. Cengage Learning, United States.
[44] Ortiz, F.G., Campanario, F.J. (2018). Hydrogen production from supercritical water reforming of acetic acid, acetol, 1-butanol and glucose over Ni-based catalyst. The Journal of Supercritical Fluids, 138: 259-270. https://doi.org/10.1016/j.supflu.2018.04.023
[45] Huang, Y., Zhang, Z., Wei, W., Long, Y., Li, G. (2021). Experimental study on characteristics of hydrogen production from exhaust gas-fuel reforming in a catalytic fixed-bed reactor. Fuel, 290: 120068. https://doi.org/10.1016/j.fuel.2020.120068