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Consolidation Assessment on Fibric Peat Stabilization by using Palm Oil Fuel Ash (POFA)

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Abstract

The study focuses on understanding and improving fibric peat, a problematic soil with high compressibility, void ratio, and moisture content. Engineers face challenges stabilizing this soil, often using cement, which leads to environmental concerns due to high cement usage. This research explores using Palm Oil Fuel Ash (POFA), an unused waste material with cement-like properties, to stabilize fibric peat. Consolidation experiments were performed on peat samples both before and after being treated with POFA (Palm Oil Fuel Ash) to analyze how the settlement under various loads, spanning from 12.5kPa to 400kPa. Results aim to predict how the soil compresses over time when exposed to varying loads. Treated peat (PCP) exhibits a significant reduction in void ratio (e) compared to untreated peat. The $C\alpha/Cc$ ratios for PCP10, PCP15, and PCP20 are 0.025, 0.023, and 0.046, respectively, while untreated peat is 0.056. Lower $C\alpha/Cc$ values indicate reduced compressibility and settlement, indicating stabilization with a mixture of POFA and OPC. The use of POFA could potentially reduce reliance on cement for soil stabilization, offering a more environmentally friendly alternative for improving peat soil performance.

1. Introduction

In Malaysia, the mostly coverage area of peatland found in the states of Johor, Perak, Selangor, Pahang, and Sarawak as shown in Fig. 1 (Hasan et al., 2022). Peat can be found in many kinds of wetlands, such as marshes, swamps, and coastal wetlands. It is an organic material with less than 25% mineral content by weight comprised of partially or completely decayed plant remnants that have accumulated under water-saturated conditions (Huat et al., 2009). It has a spongy texture, organic odour, and is brown to black in color (Huat, Kazemian, Prasad, et al., 2011). There are several types of peat including fibric, coarse hemic, hemic, fine hemic, and sapric, based on its macroscopic, microscopic, and chemical characteristics (Kopp, 2019). Fibric peats are low of decomposition level, thus the plant structure can easily be recognized with fiber content (more than 67%). In the field of geotechnical engineering, peat is acknowledged as a material with high porosity, low shear strength, and high compressibility. (Rahgozar & Saberian, 2016) and (Sing et al., 2008).

Peat soil settles slowly due to its high-water content, making it unsuitable for construction foundations. However, using peat for construction purposes requires stabilization due to its problematic geotechnical properties, making it necessary for supporting structures or infrastructure in construction engineering (Makusa, 2012). Soil stabilization aims to strengthen and increase soil durability against water softening by bonding soil particles or enhancing particle size gradation (Makusa, 2012). This process involves compaction or adding binders like Palm Oil Fuel Ash (POFA) which have pozzolanic properties that can increase soil strength. Palm Oil Fuel Ash (POFA) possesses certain properties that help boost soil strength. Specifically, it contains pozzolanic properties, which means it can enhance the strength of soil when mixed with it. This makes POFA a useful material for improving the stability and durability of soil in various applications.

Oil palm farmers often encounter challenges in transporting palm oil due to difficulties in establishing road networks on weak and highly compressible soils. An effective solution involves using waste materials like Palm Oil Fuel Ash (POFA) and Portland Cement for soil stabilization. Traditional stabilization heavily relies on Portland Cement, but its production causes environmental issues. POFA despite being considered unprofitable waste contains pozzolanic properties that when combined with Portland Cement can strengthen fibric peat, reducing construction costs and minimizing environmental impact compared to solely using Portland Cement.
This approach not only enhances fibric peat stability but also addresses environmental concerns linked to excessive cement usage in soil stabilization processes. The study demonstrated the effectiveness of POFA in enhancing the compressive strength of fibric peat. Aiming to determine the optimal cement and POFA mixture for maximum stability, potentially addressing road construction challenges in oil palm plantations, subsequently improving transportation efficiency, and potentially increasing palm oil production. Thus, fostering regional agricultural growth and urban connections in Johor, Malaysia.

Fig. 1 *Peat Distribution in Malaysia (Hasan et al., 2022)*

2. Literature Review

2.1 Classification of Peat based Von Post Scale

The fiber content of organic soil determined by the dry weight of fibers retained on a 150-micron mesh sieve, indicates the soil's organic makeup which influences its classification using the Von Post scale. Organic content and humification level are considered in classifying peat according to the Malaysian Soil Classification System. The ignition test is commonly used to determine organic content in soils, serving as a quick and cost-effective method alongside ASTM standards for soil classification. The Von Post peat soil characterization framework and qualifying terms and images with depictions are introduced in Table 1 (Huat, 2004). Fibric peat is high in fiber content and is made up of highly decomposed plant material. Fibric peat is defined as having a high content of well decomposed plant fibers, with some recognizable plant structures still visible, according to the United States Department of Agriculture (USDA) (USDA,2014). Fibric peat is composed of the remains of aquatic, semi-aquatic, and shoreline emergent plant growth. It is dark brown to black in color.

Table 1 *Qualifying terms, symbols, and description for peat soil (Huat, 2004)*

Organic	Von Post Scale	Qualifying terms	Symbol	Description and color
Peat			Pt	(75 % organic content)
	H1 - H3	Fibric/fibrous	f	Mostly undecomposed, typically tan to light reddish brown in color.
	H4 - H6	Hemic/moderately decomposed	h	Intermediate in degree of decomposition, organic content and bulk density, dark, reddish brown in color
	H7 - H10	Sapric/amorphous	a	Highly decomposed with the highest organic content and bulk density. Darker in color than fibric or hemic peat

According to past research in Kampung Bahru, Pontian, Johor the type of peat classified as a peat due to the composition of organic matter and fiber within the peat, along with the level of humification observed. The data obtained according to the Von Post humification scale, the peat can be categorized as H4, indicating a low to medium level of decomposition (Gofar, 2006). The data for this previous research has shown in Table 2.

Table 2 *Basic Properties of Peat Soil at Kampung Bahru, Pontion, Johor (Gofar, 2006)*

	Parameters	Results
Index Properties	Von Post Humification of Peat	H4
	Fiber Content	90
	Natural water content (%)	608
	Specific Gravity (Gs)	1.47
	Acidity (pH)	3.24

2.2 Stabilization of Peat Soil

Before construction, soils with low bearing capacity and high settlement should be stabilized. Methods include load transfer to a more stable soil layer or improving in-situ soil properties through ground improvement techniques like soil columns, geosynthetics, or peat soil stabilization (Mohamad et al., 2016). Stabilizing agents like cementitious materials are applied to enhance soils without bulk removal, benefiting contaminated sites and foundation types. Selection and evaluation of engineering properties guide the design mix for improved ground, aiming to meet structural needs. Techniques vary based on soil conditions and moisture content, with options such as dry or wet mixing methods like deep mixing or mass stabilization, contingent on in-situ conditions and binder effectiveness.

The deep mixing method injects wet or dry binders into soft in-situ soils like mud or peat using mechanical devices creating patterns for stabilization. The goal is to stiffen the soil mass like a rigid pile to independently carry the design load while allowing interaction and load distribution with the natural soil. For mass stabilization efficiently treats peat soil in Peninsular Malaysia enhancing performance and reducing settlements using binders like concrete, lime or POFA to minimizing environmental impact by avoiding peat excavation and carbon emissions. Then, stabilization used Oedometer Consolidation and Rowe Cell. Researchers have utilized consolidation tests to observe how peat behaves under pressure and have compiled data on peat compressibility parameters from various global studies. Therefore, the Oedometer Consolidation test can be employed to assess and stabilize peat by gauging its compressibility in response to applied loads. This test allows to determine the extent to which peat settles under applied pressure to make the peat more stable.

2.3 POFA as stabilization of Fibric Peat Soil

Pozzolanic refers to the process of binding particles to create construction material. Pozzolanas, like volcanic ash, pumice, and fly ash, contain alumina, silica, and ferrite (Vakili et al., 2013). When mixed with calcium hydroxide in water, they form compounds with cement-like properties, described by British and American standards. POFA is typically categorized as a Class F agricultural waste and must be used in soil stabilization with a cementing agent like Ordinary Portland Cement. It is a byproduct of palm oil production that acts as a promising pozzolan due to its natural properties. It reacts with calcium hydroxide to form cement-like compounds in the presence of moisture. Collected from a local mill in Kluang, Johor, POFA undergoes drying and sieving to remove incomplete burned material and organic components. With increasing palm oil production, Malaysia generates approximately 10 million tons of POFA annually, posing an environmental challenge if not utilized. Utilizing POFA as a partial substitute for concrete in construction can alleviate this waste issue.

The study showed increased strength with 20% concrete + 10% POFA compared to peat stabilization with concrete only. (Pourakbar et al., n.d.) found that a 15% POFA substitution for cement led to a denser microstructure and improved soil strength. Partially substituting POFA in concrete can enhance strength through concrete hydration, acting as a POFA activator. (Seethapathi, 2022) highlighted POFA's effectiveness as a pozzolan for partially replacing cement in concrete for soil stabilization.

3. Result and Discussion

3.1 Material Properties

Sample preparation involves extracting materials or substances from a larger amount for subsequent analysis, crucial in analytical techniques as some materials cannot be analyzed in situ and certain species or substances can interfere with results. Processes like chemical treatment, filtration, dilution, and extraction are used. This study utilized fibric peat soil that sources from Medan Sari, Johor, POFA from Kluang, Johor, and Portland Cement for sample preparation, creating four different mixtures detailed. The materials underwent a curing process for 7 days, and four samples with high strength from UCS testing were further assessed for peat soil stabilization through consolidation testing over 5 days. The method used in preparing samples and conducting laboratory tests sought to offer understanding about changes in peat soil characteristics before and after stabilization, thereby contributing to a through comprehension of the materials investigated in this study.

This study includes testing procedure, which is moisture content and organic content according to (ASTM, 2020), specific gravity, fiber content (ASTM, 2020), liquid limit, and pH value. This study was conducted using untreated peat. A consolidation test was conducted to stabilize the fibric peat using the various ratios of POFA and Portland Cement. This shows the change of untreated to treated peat after the mixing of POFA and cement material. The test is to determine how the treated peat can improve the soil stabilization. The results in Table 3 demonstrate the change of characteristics and behavior of fibric peat. The combination of POFA and cement resulted in increased strength, decreased compressibility, and improved water resistance as indicated by test results. Evaluations of peat's physical properties aim to grasp and delineate different characteristics linked to its physical makeup. These analyses provide crucial understanding of the soil's composition, structure, and behavior under different circumstances. The primary properties assessment was conducted at the Research Centre for Soft Soils (RECESS) at UTHM.

Table 3 *Physical properties analysis for Medan Sari, Johor*

Laboratory Testing	Result
Moisture Content, %	639.0
Organic Content, %	84.98
pH Value	3.87
Specific Gravity, Gs	1.25
Fiber Content, %	77
Liquid Limit, %	199

3.2 Effect of POFA Replace Partially of OPC on the Deformation Characteristics

To assess Palm Oil Fuel Ash (POFA)'s impact on settlement in peat soil, consolidation tests were performed to analyze the deformation characteristics of the mixtures. Samples from untreated (P) and stabilized (PCP) mixtures were subjected to consolidation tests, utilizing materials obtained from the Unconfined Compressive Strength (UCS) test. The highest achieved value from the (UCS) test was utilized for subsequent consolidation testing to evaluate the influence of Palm Oil Fuel Ash (POFA) in stabilizing peat soil. The results obtained from the consolidation testing were compared between a mixture of peat-cement with POFA and untreated peat.

Fig. 2 illustrates the relationship between void ratio (e) and effective vertical stress (σv') particularly concerning untreated peat. The considerable values of e directly impact the high coefficient of compressibility (Cc), determined by Δe/(Δ log σv'), registering at 7.779 and 0.853 respectively. Wong et al. (2012) attribute these elevated e and Cc values to the presence of plant materials within the peat.

Utilizing the Casagrande graphical construction method based on the void ratio (e) against time curve, the estimated pre-consolidation pressure (σc') for Medan Sari peat was around 25 kPa. This σc' value closely aligns with findings in the study by (Talib et al., 2015) for fibric peat, which reported a value of approximately 25.5 kPa, showing a similarity in these results.

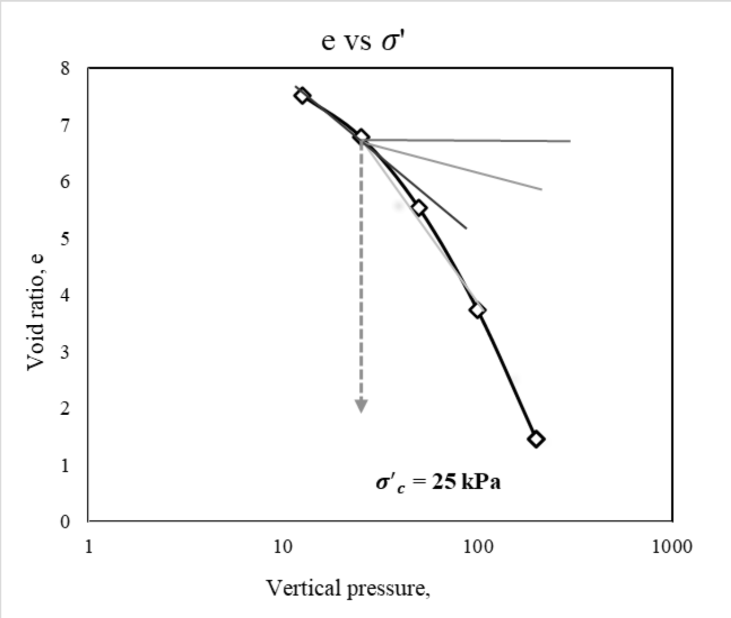

Fig. 2 *The relationship between void ratio, (e) versus effective vertical stress, (σv') for untreated peat*

Table 4 *Result of analysis for untreated peat*

Pressure, *P* (kPa)	Void ratio, *e*	C_c	C_α	$C_c/1+e_o$	$C_\alpha/1+eo$	mv (m^2/kN)	C_v (m^2/s)	*k* (m^2/s)
0.000	7.779	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.500	7.522	0.853	0.020	0.097	0.002	4.749E-02	1.698E-06	7.909E-07
25.000	6.791	2.426	0.100	0.276	0.011	7.164E-02	1.223E-06	8.592E-07
50.000	5.531	4.188	0.415	0.477	0.047	7.041E-02	3.681E-07	2.543E-07
100.000	3.736	5.964	0.537	0.679	0.061	6.374E-02	1.800E-07	1.125E-07
200.000	1.465	7.541	0.185	0.859	0.021	6.305E-02	6.599E-08	4.082E-08

Stabilize fibric peat is the aim to evaluate the effectiveness of this combination in consolidating the fibric peat. The experiment involved conducting consolidation tests to analyze how the addition of POFA affects the consolidation behavior and overall stability of the fibric peat, The consolidation tests carried out in this research affirm the significance of (σc)' in enhancing the compression behavior of treated peat that curing for 7 days with Ordinary Cement Portland (OPC) and POFA. Effective stress emerges as a critical factor responsible for mitigating deformation tendencies in both treated and untreated peat samples. As per (Hebib & Farrell, 2003), alterations observed in the compression curve at higher effective stress levels indicate evident improvements in stabilized peat. This change signifies the efficacy of stabilized peat in reducing settlement tendencies, reflecting its capacity to endure and withstand higher effective stress levels without experiencing excessive deformation.

Fig. 3 exhibits the void ratio, (e), in stabilized peat demonstrating a notable decrease when compared to untreated peat. Void ratios show the decrease in peat stabilization thus so the permeability, (K) Fig. 4. Fig. 5 shows the PCP mixture decreasing of the Coefficient of Volume Compressibility, (mv) for the PCP15. The (mv) was slightly higher at lower pressures but significantly decreased at higher pressure as the compression increased. Consequently, the decrease in (mv) aligns with a reduction in the potential for settlement.

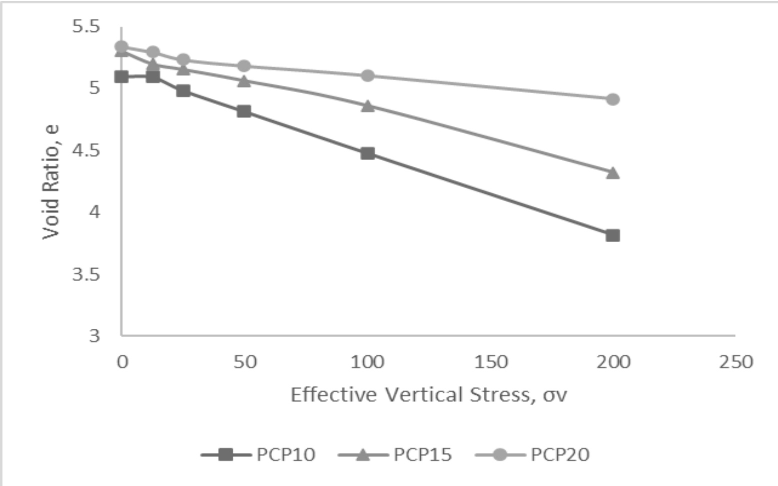

Fig. 3 *The relationship void ratio, (e) versus effective vertical stress, (σv') of treated peat*

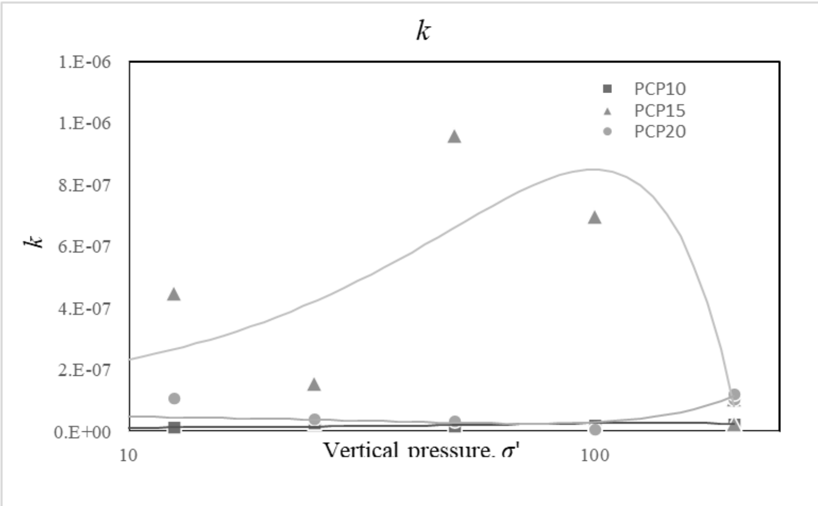

Fig. 4 *The relationship coefficient of permeability, (k) versus effective vertical stress (σv') of treated peat*

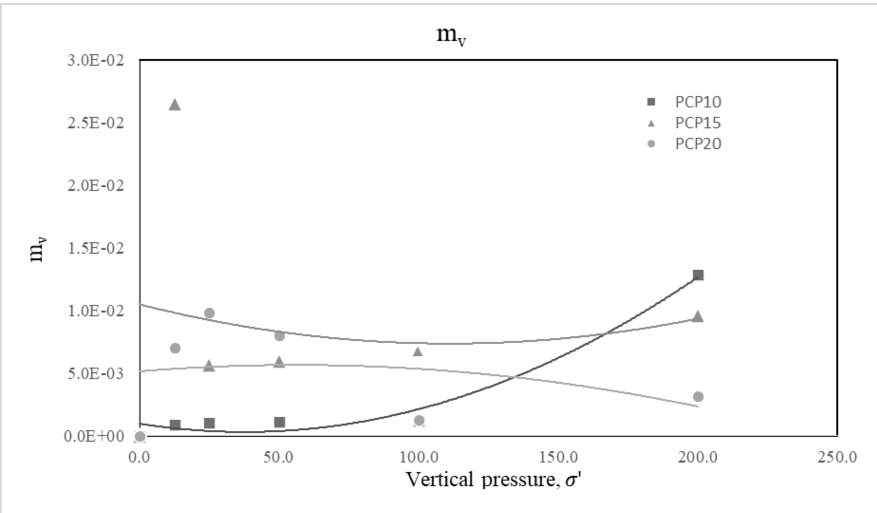

Fig. 5 *The relationship coefficient of volume compressibility, (mv) versus effective vertical stress, (σv')*

The main and secondary compression indices, Cc and Cα, depicted in Fig 6 and Fig 7, respectively, pertain to Medan Sari peat. For this study, it was presumed and applied that the secondary compression begins following 4 hours (240 minutes) of applied loading on the stabilized peat. This assumption was made due to the limitation of the apparatus used in this study, which cannot measure water dissipation during consolidation (Mesri et al., 1997). It is observed that Cc gradually increases with rising σv', while Cα is also anticipated to increase over time. According to (Mesri et al., 1997), when Cα experiences recompression, the values of Cc reach their maximum. Table 5 shown the analysis results for PCP15 since it was the optimum value for UCS and more stabilize than other sample.

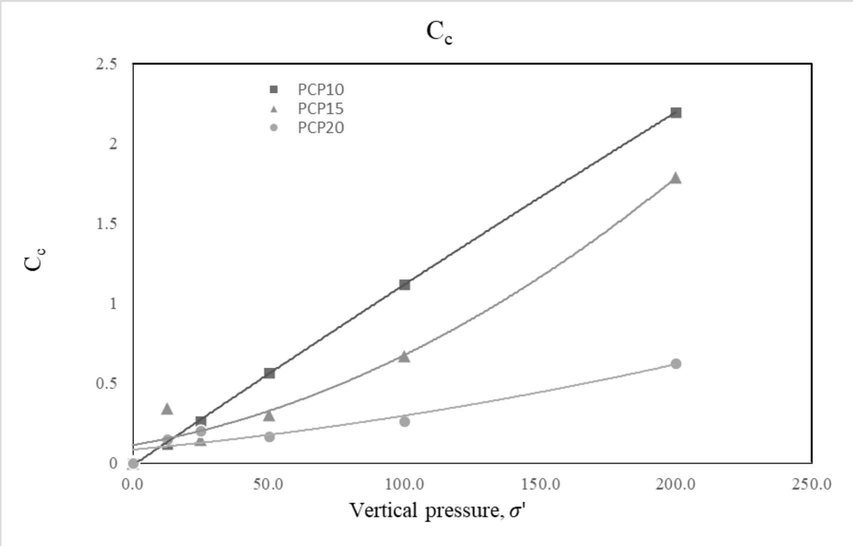

Fig. 6 *The relationship compression index, (Cc) versus effective vertical stress, (σv')*

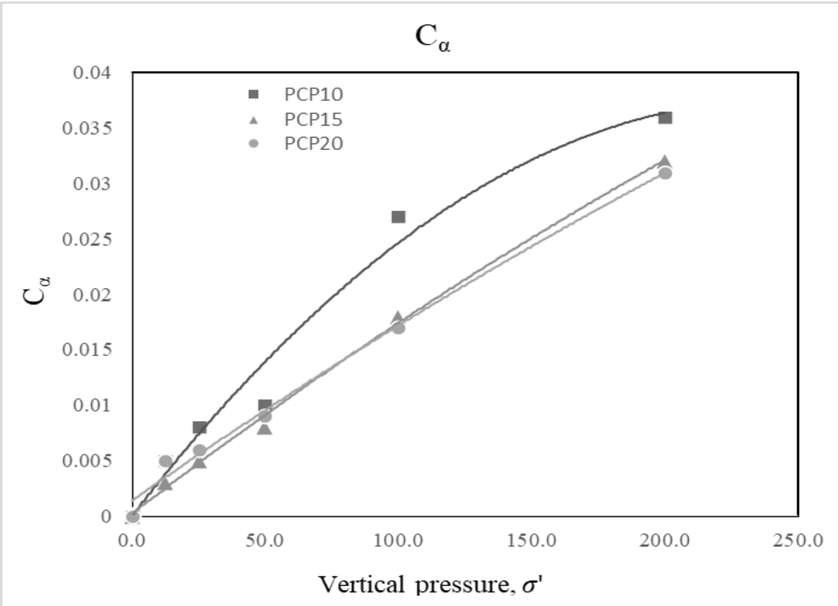

Fig. 7 *The relationship secondary compression index, (Cα) versus effective vertical stress, (σv')*

Table 5 *Result analysis for stabilized peat (PCP15)*

Pressure, *P* (kPa)	Void ratio, *e*	C_c	C_α	$C_c/1+e_o$	$C_\alpha/1+eo$	m_v (m^2/kN)	C_v (m^2/s)	*k* (m^2/s)
0.000	5.301	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.500	5.197	0.344	0.003	0.055	0.000	2.654E-02	1.720E-06	4.477E-07
25.000	5.153	0.147	0.005	0.023	0.001	5.714E-03	2.776E-06	1.556E-07
50.000	5.062	0.302	0.008	0.048	0.001	5.963E-03	1.643E-06	9.609E-08
100.000	4.860	0.673	0.018	0.107	0.003	6.797E-03	1.047E-06	6.984E-08
200.000	4.320	1.792	0.032	0.284	0.005	9.649E-03	1.115E-06	1.055E-07

Fig. 8 depicts the compression index ratio, $Cc/1+e_o$, in relation to the secondary compression ratio, $C\alpha/1+e_o$, observed in both untreated and treated peat. In (Mesri et al., 1997), they utilized a compression ratio range of $Cc/C\alpha=0.06\pm0.01$ for natural peat. In this study at Medan Sari has been observed a value of approximately 0.0560 falling within the specified compression ratio range. The stabilized peat demonstrates a significant enhancement in the Cα/Cc ratio in comparison to untreated peat. A lower Cα/Cc ratio indicates reduced soil compressibility. Consequently, this implies a lesser tendency for creep settlement, suggesting effective stabilization of the peat using an optimal mixture of cement and POFA. The reduction in Compression Index ratio indicates a change in soil behavior from highly compressible in untreated peat to slightly compressible after stabilized. Thus, the engineering characteristics of the soil are observed to transition from peaty or organic soil behavior to that resembling inorganic soils, and ultimately towards granular material, which is considered excellent for foundational purposed shown in Fig. 9.

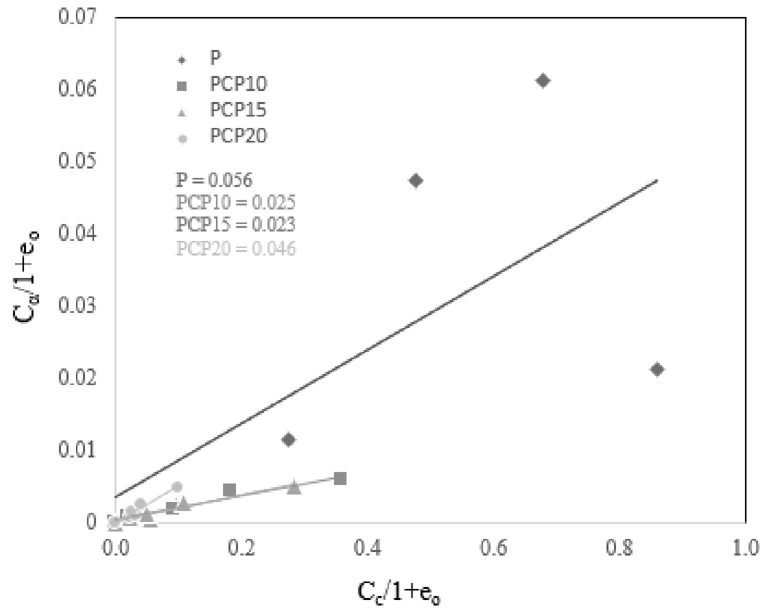

Fig. 8 *The relationship compression index ratio, ($Cc/1+e_o$) versus secondary compression ratio, ($C\alpha/1+e_o$)*

Fig. 9 *Compression index ratio Cα/Cc for untreated and stabilized peat*

4. Conclusion

The study successfully met its objectives in stabilizing peat soil by utilizing Palm Oil Fuel Ash (POFA). Analysis of the peat soil from Medan Sari revealed characteristics of fibric peat, showcasing high moisture content (639%) and organic matter content of 84.98%. Additionally, the soil displayed high acidity (pH 3.87), a liquid limit of 199%, and a specific gravity of 1.25. The incorporation of POFA as a partial replacement for cement yielded promising outcomes, particularly the PCP15 sample, which achieved a maximum strength of 29.68 kPA within 7 days. This approach reduced cement usage by 15% while promoting environmental sustainability by curbing emissions associated with cement production.

Furthermore, the stabilized peat showcased reduced compressibility in comparison to untreated peat, demonstrating improved soil engineering behavior. This shift signifies a transition from highly compressible untreated peat to slightly compressible stabilized peat. These findings suggest the potential viability of stabilized peat for foundational purposes due to its improved engineering characteristics, offering a more stable and less compressible material for construction applications.

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Conflict of Interest

The author affirms with utmost certainty that there are no conflicts of interest related to the publication of this paper. The research and its communication have been carried out with absolute impartiality, guaranteeing transparency, and adhering to the highest ethical standards.

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