

INVESTIGATION ON THE ENGINEERING PROPERTIES OF PEAT SOIL STABILISED USING LIME STABILISATION AND ALKALINE ACTIVATION

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Lee Foo Wei^{1*}, Yip Chun Chieh²

^{1,2}Department of Civil Engineering, Lee Kong Chian Faculty of Engineering and Science,
Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, Cheras,
43000, Kajang, Selangor, Malaysia

*Corresponding author: ah_foo3@hotmail.com

ABSTRACT

Peat soil is typically classified as a problematic soil due to its expansive behaviour that possesses geotechnical drawbacks. Thus, the condition of peat soil must be improved prior to any construction works. Stabilisation of peat soil can be done via chemical stabilisation and alkaline activation while incorporating industrial by-products or wastes as additive. This study aims to investigate the effect of press mud as an additive in lime-stabilised and alkaline activator-stabilised peat soils. Press mud is a by-product of sugarcane juice filtering. The lime adopted is at 3% and 5.5% while the alkaline activator is used in cold and warm condition. A total of 5 percentages of press mud have been employed, namely 0%, 0.25%, 0.5%, 1% and 2%. The investigations revealed that regardless of the percentage of lime adopted, the optimum moisture content increases while the maximum dry density decreases when the percentage of press mud incorporated is increased. However, when the lime content is increased, the optimum moisture content increases significantly. The UCS of lime-stabilised peat soil sample achieved the greatest strength improvement when the lime and press mud is used at 5.5% and 0.25%, respectively. In contrast, the unconfined compressive strength (UCS) of 3% lime-stabilised peat soil samples with or without press mud shows comparable 28-day strength. On the other hand, the UCS of peat soil stabilised with alkaline activator shows significant improvement, while addition of press mud further improves the strength. Nonetheless, using warm alkaline activator improves the early strength development but cold alkaline activator results in higher 28-day UCS.

Keywords: Alkaline Activation, Lime Stabilisation, Peat Soil, Press Mud, Unconfined Compressive Strength

1.0 INTRODUCTION

Peat soil is a non-homogeneous or heterogeneous soil that is formed when organic matter such as plant remnants, foliage, leaves, and trunks putrefies (Ismail *et al.*, 2021). Peat soil can be found wherever in the world, except the arctic and arid areas, and it makes up around 5-8% of the planet's surface area (Mesri and Ajlouni, 2007). Untreated peat soil is usually high in moisture content, which is attributed to the high organic content of peat soil that increases the space between the peat soil particles and allows more water to be absorbed (Hauashdh *et al.*, 2020). Thus, peat soil usually has poor volume stability in the presence of water (James, 2020).

Peat soil typically possesses the following characteristics, namely high natural moisture content, high compressibility and water-holding capacity, low specific gravity, low bearing capacity, and medium-to-low permeability (Talif *et al.*, 2021). These characteristics are usually undesired in construction as they will increase the difficulty and complexity of works done on the peat land. The consequences are usually detrimental. For instance, in the worst scenario, a structure may collapse (Kolay and Taib, 2018). Considering the harmful risk, working on such soil is usually avoided. However, construction on peat land area has become or will become a necessity due to rapid industrialisation

and population growth. To minimise the deleterious effect of peat soil, several soil improvement methods are employed, for instance, chemical stabilisation, alkali activation, soil replacement, prewetting, surcharge loading and usage of geosynthetics (Cristelo *et al.*, 2011; James and Pandian, 2016).

Besides stabilising problematic soils or peat soil using lime or cement as stabilisers, a combination of stabilisers with industrial by-products or wastes as additives in soil stabilisation technique has been explored (Dahale *et al.*, 2012), attributed to the solid waste management concerns developed from the huge number of industrial by-products or wastes that have been generated annually. Fly ash, phosphogypsum, rice husk ash, ceramic waste, silica fume, and paper sludge are some of the industrial by-products or wastes that have been employed in soil stabilisation (Choobbasti *et al.*, 2010; James and Pandian, 2016). Recently, the effect of press mud on lime-stabilised peat soil has been investigated. Press mud is the industrial waste of the sugar manufacturing industry. It is the leftover from the sugarcane juice filtration process. The sugarcane juice undergoes the clarification process to separate the juice and mud. The clear juice is sent for manufacturing and the mud sink in the bottom is collected and sent for filtration to filter out the suspended materials (Chittaranjan *et al.*, 2021).

In Malaysia, peat soil land represents 2.7 million hectares and this value is about 8 % of the total area of Malaysia (Rahman *et al.*, 2016). Thus, it is an unavoidable situation where the construction of peat land area is required, especially when the land becomes limited and higher in cost. Therefore, before construction, these soils should be stabilised and improved to ensure smooth and safe progress. In this work, locally available peat soil has been stabilised via lime stabilisation and alkali activation combined with the press mud. The optimum moisture content and maximum dry density of lime-stabilised peat soil incorporating press mud are investigated while the unconfined strength test (UCS) of the lime-stabilised and alkali activator-stabilised peat soil admixed with press mud is examined.

This study introduces an innovative approach to peat soil stabilisation by employing press mud, a by-product of the sugar industry, in combination with lime or an alkaline activator. While plenty of studies have explored soil stabilisation using either lime or alkaline activators, our research uniquely investigates the effects of integrating press mud into these methods. Unlike previous studies where stabilised soils often undergo additional chemical or physical treatments, we maintain the natural composition of our soil and press mud to preserve their inherent properties. We hope that this novel method could open new possibilities in the effective utilisation of organic waste materials like press mud for soil stabilisation.

2.0 MATERIALS AND METHOD

2.1 Materials

An essential natural resource, peat soil, was painstakingly collected from the scenic area of Sekinchan in Selangor, Malaysia. This area, renowned for its verdant vistas and distinct biological variety, offered the ideal setting for our soil collecting mission. With extreme care and precision, the peat soil known for its high organic matter content and remarkable water retention qualities was harvested with the least amount of disturbance to its fragile ecology. It is noted that this perfect peat soil was used exactly as it was, without being processed further to retain its natural qualities for our research.

Concurrently, in an attempt to utilise all available organic resources, press mud, a lucrative by-product of the sugar industry—was procured from Penang, a bustling city. This rich, dark residue was carefully harvested to preserve its purity and integrity. It is a by-product of processing sugar cane. As with the peat soil, the press mud was added to our study without being subjected to any chemical or physical treatments, so its natural composition and high nutritional content were preserved. These raw, organic materials served as the basis for our investigation,

Table 1: Stabilisers and Press Mud

Stabilisers	Press mud (%)				
	0	0.25	0.5	1	2
3 % Lime	0	0.25	0.5	1	2
5 % Lime	0	0.25	0.5	1	2
Cold alkaline activator (Room temperature)	0	0.25	0.5	1	2
Warm alkaline activator (50 °C)	0	0.25	0.5	1	2

which was an honest and pure examination of their natural qualities and possible uses.

2.2 Hydrated Lime

The alkaline activator is a mixture comprised of a 12.5M sodium hydroxide (NaOH) solution and sodium silicate (Na₂SiO₃) solution at a ratio of 1:2, by mass. Information regarding the chemicals. The alkali activator was stored in an oven at 50°C to serve as a warm alkali activator whereas for cold alkaline activator, it was cooled down to room temperature.

2.3 Mix Proportion

Table 1 presents the mixed proportion of stabilisers admixed with press mud to examine the engineering properties of the stabilised peat soil samples. Stabilisers adopted in this work were lime and alkaline activators; the former was added in two different percentages while the latter was employed at two different temperatures. A total of 4 types of stabilisers, i.e., 3 % lime, 5 % lime, cold alkaline activator and warm alkaline activator, were employed and admixed with various percentages of press mud, namely 0 %, 0.25%, 5%, 1% and 2%.

2.4 Testing Methods

Due to the heterogeneity of the peat soil samples, a minimum of three samples were tested with each percentage of stabilisers and the average result is reported.

2.4.1 Standard Proctor Test

The standard proctor test was carried out by the ASM D 698 to identify the optimum moisture content and the maximum dry density of the soil using the following equations.

$$w = \frac{M_w + M_d}{M_w} \times 100 \tag{1}$$

where

W = Natural moisture content, %

M_w = Soil sample mass in wet condition, kg

M_d = Soil sample mass in dry condition, kg

$$\rho_m = \frac{M_{cs}}{v} \tag{2}$$

where

ρ_m = Soil sample moist density, kg/m³

M_{cs} = Moist compacted soil mass, kg

v = Mould volume, m³

$$\rho_d = \frac{\rho_m}{1 + \frac{w}{100}} \tag{3}$$

where

ρ_d = Compacted soil dry density, kg/m³

ρ_m = Soil sample moist density, kg/m³

w = Moisture content, %

2.4.2 Unconfined Compressive Strength

The UCS test was conducted in accordance with the ASTM D 2166 to examine the effect of press mud on the lime-stabilised and alkaline activator-stabilised peat soil samples. To determine the UCS, the sample was loaded between the upper and lower plates and in the UCS test's centre of the loading machine. The upper plate was adjusted to the height that was able to contact

the peat soil sample and the deformation was set to zero. The test then began with a steady axial strain of between 0.5 and 2.0% per minute and the load and deformation readings were collected. The test was stopped when a decrease in load values happened or achieved 20% of the axial strain. The load and deformation values were recorded for calculations. The following equations were employed to determine the UCS of the samples.

$$e = \frac{\Delta L}{L_0} \quad (4)$$

where

e = Axial strain

ΔL = Change in soil sample length, m

L_0 = Initial soil sample length, m

$$A = \frac{A_0}{(1 - e)} \quad (5)$$

where

A = Average soil sample cross-sectional area, m²

A_0 = Initial average soil sample cross-sectional area, m²

e = Axial strain

$$\sigma_u = \frac{P}{A} \quad (6)$$

where

σ_u = Unconfined compressive strength, kN/m²

P = Applied axial load at failure, kN

A = Average soil sample cross-sectional area, m²

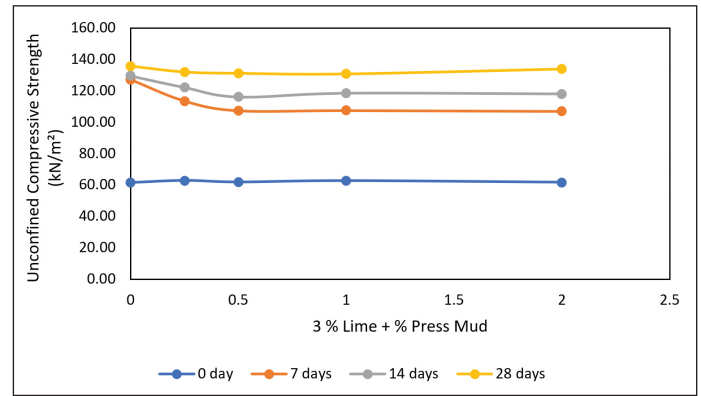


Figure 1(a): UCS of Lime-Stabilised Peat Soil with Different Percentages of Press Mud: 3% Lime

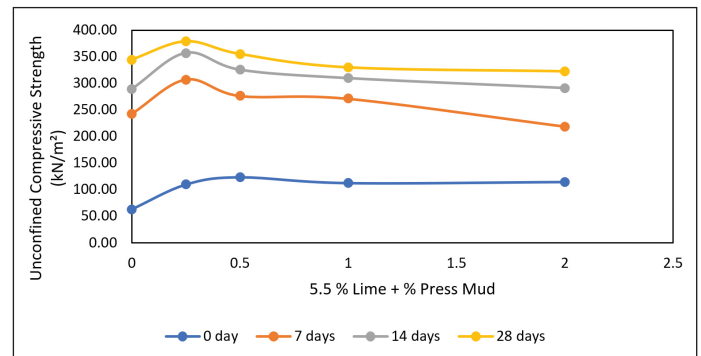


Figure 1(b): UCS of Lime-Stabilised Peat Soil with Different Percentages of Press Mud: 5.5% Lime

3.0 RESULTS AND DISCUSSION

3.1 Standard Proctor Test

Table 2 shows the results of the standard proctor test carried out on the lime stabilised-peat soil samples stabilised with 3% or 5.5% lime and admixed with various percentages of press mud, namely 0%, 0.25%, 0.5%, 1.0% and 2.0%. It is observed that regardless of the percentage of lime adopted, when the percentage of press mud incorporated is increased, the optimum moisture content increases while the maximum dry density decreases. A similar trend has been observed (Saini *et al.*, 2022). This is possibly due to the nature of press mud that possesses good water-holding capacity. On the other hand, it is also noticed that when the lime content is increased, the optimum moisture content increases significantly.

3.2 Unconfined Compressive Strength

3.2.1 Lime-Stabilised Peat Soil with Press Mud as an Additive

The UCS of 3 % or 5.5 % lime-stabilised peat soil samples with different percentages of press mud are illustrated in Figure 1.

Generally, the UCS of lime-stabilised peat soil samples admixed with press mud increases with the curing period, indicating the pozzolanic reaction induced by the lime with the peat soil itself, and with the press mud. It can be seen from Figure 1(a) that when the content of press mud is increased, the UCS of 3% lime-stabilised peat soil samples were reduced significantly at an early age, especially at day 7. Nevertheless, the UCS of 3% lime-stabilised peat soil samples with or without the addition of press mud become comparable at day 28. The 28-day UCS of 3% lime-stabilised peat soil samples with 0%, 0.25%, 0.5%, 1% and 2% of press mud were 135.65 kN/m², 131.95 kN/m², 131.12 kN/m², 130.72 kN/m² and 130.80 kN/m², respectively. This indicates that the reaction between lime and the press mud happens at a slower rate, attributed to lower lime content.

On the other hand, incorporating press mud into 5.5% lime-stabilised peat soil samples showed significant strength improvement compared to the 3% lime-stabilised peat soil samples, implying 5.5% lime is sufficient to enhance the engineering properties of the peat soil samples. Among all the 5.5% lime-stabilised peat soil samples, the addition of 0.25% of press mud significantly improved the UCS of the peat soil

Table 2: Optimum Moisture Content and Maximum Dry Density of Lime-Stabilised Peat Soil

	3% lime + X % press mud					5.5 % lime + X % press mud				
	0	0.25	0.5	1	2	0	0.25	0.5	1	2
Optimum moisture content (%)	27.29	27.84	27.98	30.10	32.39	55.30	55.70	55.73	56.94	63.44
Maximum dry density (Mg/m ³)	0.59	0.57	0.56	0.49	0.42	0.67	0.67	0.66	0.66	0.65

samples, in which the highest 28-day UCS was achieved (378.92 kN/m²). Further increment of press mud content does not show increment but decreases the UCS of 5.5% lime-stabilised peat soil samples, at all ages. Nonetheless, the UCS are still higher compared to the pure 5.5% lime-stabilized peat soil sample except when the press mud content is beyond 1%; The 28-day UCS of 5.5% lime-stabilised peat soil samples with 0%, 0.25%, 0.5%, 1% and 2% of press mud were 344.56 kN/m², 378.92 kN/m², 355.15 kN/m², 329.85 kN/m² and 322.38 kN/m², respectively. This could be attributed to the presence of higher P₂O₅ that has known to influence the strength development. On top of that, the increment of press mud content also increased the organic content in the mixture due to high fibre content, which could be another potential factor in such observed trend (James, 2020; James and Pandian, 2016).

3.2.2 Alkaline Activator-Stabilised Peat Soil with Press Mud as an Additive

Figure 2 presents the UCS of alkali activator-stabilised peat soil samples admixed with different percentages of press mud, namely 0%, 0.25%, 0.5%, 1% and 2%. It is observed that the UCS of alkaline activator-stabilised peat soil samples is significantly enhanced regardless of the temperature of the alkaline activator. On top of that, the UCS of alkaline activator-stabilised peat soil samples gradually increase as the curing period increases, indicating the ongoing reaction between the alkaline activator with the peat soil and also the press mud. In addition, the UCS of alkaline activator-stabilised peat soil samples is found to increase with the press mud content, at all ages. The highest 28-day UCS is achieved when 2% of press mud is adopted into the alkaline activator stabilised peat soil, which is 423.85 kN/m²

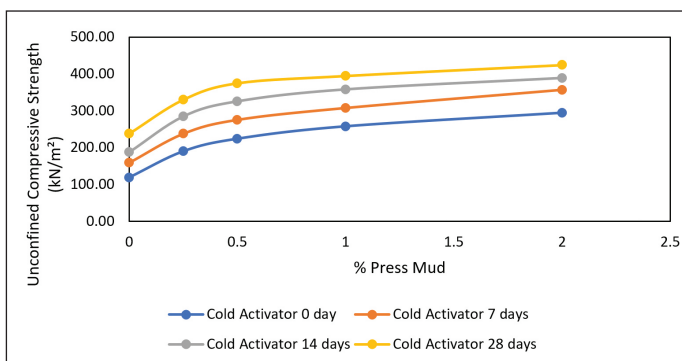


Figure 2(a): UCS of Alkaline Activator-Stabilised Peat Soil with Different Percentages of Press Mud: Cold Alkaline Activator

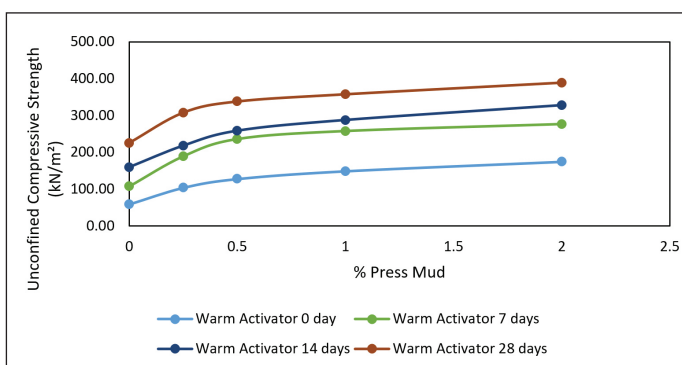


Figure 2(b): UCS of Alkaline Activator-Stabilised Peat Soil with Different Percentages of Press Mud: Warm Alkaline Activator

using a cold alkaline activator and 388.94 kN/m² using a warm alkaline activator. Although both alkaline activators successfully enhanced the UCS of the treated peat soils, the cold alkaline activator showed a much better soil stabilisation potential.

On the other hand, it is observed that the UCS improvement by percentage using warm alkaline activator decreases from time to time and has the least improvement at the 28-day curing period. Additionally, the peat soil samples stabilised with a cold alkaline activator showed smaller strength improvement compared to the peat soil samples stabilised using a warm alkaline activator at day 0 and day 7. This is possibly due to the increase in temperature helps in accelerating the chemical reaction thus improving the strength gain in the early stage. However, in the longer curing period, the peat soil structure will deteriorate (Cristelo *et al.*, 2011). Thus, this implies that increases in the temperature of alkaline activators can improve the strength development of peat soil at an early stage.

4.0 CONCLUSION

The study investigated the impact of press mud on peat soil stabilisation with lime or an alkaline activator. It was found that as press mud content increased, the optimum moisture content of lime-stabilised peat soil increased, but the maximum dry density decreased. Increasing lime content correspondingly led to an increase in optimum moisture content. A strength reduction was noted at the early stage in 3% lime-stabilised peat soil with added press mud, but this strength became comparable by day 28. For 5.5% lime stabilised peat soil, strength improved when press mud was less than 1%.

In terms of alkaline activation, peat soil's strength increased significantly irrespective of press mud addition when compared to lime stabilisation. However, the Unconfined Compressive Strength of warm alkaline activator-stabilised peat soil decreased over time, suggesting activation temperature can improve early strength gain of treated peat soil, but long-term enhancement was better with a cold alkaline activator.

Conclusively, this study demonstrated the potential of press mud as an effective additive in peat soil stabilisation. More research can further optimise these interactive effects for enhanced soil stabilisation.

5.0 ACKNOWLEDGEMENT

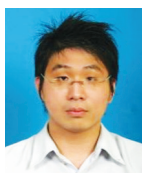
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PROFILES



LEE FOO WEI earned his Ph.D. in 2017, specialising in non-destructive testing, construction waste materials development, and soil stabilisation. With a keen focus on advancing these critical areas, Lee's research contributions have played a pivotal role in enhancing the safety, sustainability, and efficiency of the construction industry. His innovative work in non-destructive testing methods, sustainable materials development, and soil stabilisation techniques has left a lasting impact, establishing him as a respected authority and a driving force in the field of civil engineering and construction.

Email address: ah-foo3@hotmail.com



YIP CHUN CHIEH is a lecturer at Universiti Tunku Abdul Rahman since 2016 and a Professional Engineer. He graduated with a degree in Bachelor of Civil Engineering with Honours from Swinburne, master's degree in Civil-Structural with Best Research Student Award from UTM and PhD in Civil from UTM. He has more than 10 years of industrial experience in civil construction and steel structural design as his primary field of interest. He is a Professional Engineer and Professional Technologist to teach Civil Engineering students in steel and advanced steel structural courses. He is engaged under the Lee Kong Chian Faculty of Engineering & Science (LKC FES), Universiti Tunku Abdul Rahman (UTAR). His primary field of research is Civil Structure & Seismic resistance.

Email address: yipcc@utar.edu.my