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Effect of Bamboo Fibers in Hydrated Lime - Treated Residual Soil on Permeability Characteristic

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Abstract

Residual soil describes soil that forms naturally in its current location as a result of bedrock weathering and decomposition. Usually, it can be located above the parent rock where it first formed. Their variation of soil properties composition porosity, particle size, texture and strength have huge implications towards the level of permeability. However, most of the studies within the field of residual soil that only focused on strength and durability improvement and information on permeability of the residual soil is not yet provided sufficiently. Most of the research were focused on permeability testing method. Therefore, the purpose of this research is to obtain the optimum result in soil permeability on the various usage of hydrated lime and bamboo fiber by using falling head permeability testing method. The mix proportions of hydrated lime and bamboo fiber are also prepared into five groups with treated sample each, 5% of Hydrated Lime for all mix design, and 0%, 0.5%, 1%, 2% bamboo fiber for each mix design respectively. There is a total of 51 samples for permeability testing. In this study, bamboo fiber will be prepared with different length, which are 5mm, 10mm, and 20mm respectively in the permeability test apparatus to determine the level of permeability of the soil. In this study, it was found that the permeability of hydrated lime -treated soil using 1% BF was at 0.05 mm/s and 0.03 mm/s using 10 mm and 20 mm length of BF respectively.

Keywords:
Permeability, Bamboo fiber, Hydrated lime, Residual soil

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INTRODUCTION

Generally, soil is a crucial material for construction of buildings, foundations and many more similar engineering projects. In Malaysia's tropical region, most of the land is covered with granitic residual soil (GRS) amounting to 75% of total land area [1]. GRS is very indistinctive in terms of soil properties, strength and permeability. Laterite soil which is a another name of residual soil are highly weathered reddish tropical soils that have concentrated oxides of iron and aluminum with kaolinite, the predominant clay mineral [2].

In Malaysia particularly in Klang Valley, major construction of many engineering project has been shifted to hilly sides due to the limited area for development. Since climate change has been drastically under hostile changes overtime with unfavorable pattern of rainfall intensity, that leads to multiples occurrence of landslides due to slope erosion in the region [3], [4]. The exposed topsoil profile, which is commonly subjected to extreme deformation and variable volume change, as the high vacancy ratio of the soil would cause failure or damage to the structural foundation [5]. As GRS have a high void ratio and high strength characteristic in a dry environment, they also break down easily in water and can result in collapse and other geological calamities [6].

Generally, weak soil without improvement and stabilization effort could yield disastrous consequences to buildings or structures. Therefore, it is a common to stabilize the soil with conventional binder and chemical additions such cement, lime, bitumen, and fly ash to achieve targeted strength to suit a design purposes [7]. Both conventional and non-traditional agents can always be used to accomplish this with variable results. Traditional or conventional chemical stabilization agents, which are often calcium-based, include lime, cement, bitumen, and fly ash were used for these purposes. According to a prior study, traditional stabilization of residual soil by adding chemical additives can enhance the residual soil's strength properties within the curing period [5]. However, the used of traditional binder such as ordinary Portland cement (OPC) and other chemical substituents might be too conservative given that there are other viable options that are more environment-friendly to reduce carbon footprint effort.

As an adoption of more environmental conscious and sustainable development approach, the employment of natural fibers is getting more attention and has attracted researchers throughout the world to push their potential use in geotechnical and construction industries [8], [9]. In addition, natural fiber could further improve mechanical properties of treated soil using traditional binder of pozzolanic materials such as hydrated lime [10]. In previous research, researchers determined the performance and effectiveness of different proportions from 0% to 5% of quick and hydrated lime when applied separately to the soil of tropical and sub-tropical regions. Hydrated lime enhanced the strength by increasing the curing time but needed additional admixture [7].

Natural fiber such as bamboo fibers has unique characteristics that can bring advantages for civil engineering works. Bamboo fiber is the natural renewable source that can be extracted from various species of bamboo [11]. The cost-effective factor has always being signified to make sure the new material and improvement method has the same or higher performance compared to the conventional method. Because they are inexpensive, readily available locally, and ecologically acceptable, the utilization of waste materials and natural fiber helps to enhance soil properties [12].

On strength characterization of stabilized soil, studies also have shown that an increase in bamboo fiber content enhances shear strength, reduce settlement, and increase resistance to erosion [13]. The length and orientation of bamboo fibers also play a crucial role, with longer fibers exhibiting better load carrying capacity and bridging larger gaps [14]. Bamboo fiber with high cellulose structure also has a property of high water-absorption rate as its natural property of the material that could significantly influence the soil's shear strength parameters [8]. In addition to being a green fiber, it also possesses anti-bacterial and UV protection qualities. This makes bamboo a distinctive textile material that is utilized for high-performance requirements of composite material due to its tensile strength, stability, and durability characteristics [15], [5]. Without put a limitation to hydrated lime only, other pozzolanic binder such as gypsum could also be combined with bamboo fiber as binding agent in the mixture for a cost-effective and environmentally friendly choice. However, if fiber length is not designed properly, it can affect the shear behavior of the soil which in consequent affect its in-situ application [16], [17], [10].

Other than strength parameters, hydraulic conductivity is one of important parameters that measure the ability of water to flow through a soil. It should be considered when designing roads to provide good drainage for the structural stability and longer service life. Some study aimed to prove that employing pozzolanic materials such as fly ash, rice husk ash and bottom ash would increase the hydraulic conductivity characteristics of treated while also decreasing the disposal costs of this industrial by-products [18], [19], [20].

In other study, natural fiber such as coir fiber combined with bottom ash had improved the shearing resistance of the residual soil and increased the soil’s permeability by facilitating additional flow paths through its porous particles [20]. Based on the previous literatures, the reduced permeability was not sufficiently addressed during the compaction to qualify the untreated soils for specific construction purpose, thus requiring additional form of stabilization to enhance the permeability characteristics [21]. In general practice, natural fibers have been found their way in application of reinforcing soils for geotechnical construction by using mechanical reinforcement when combined with binding agents such as lime, bottom and fly ash, and other similar pozzolanic materials. Unfortunately, less attention has been taken to the hydraulic properties of soil treated with natural fiber. Moreover, the hydraulic properties are the key parameters when conducting transient seepage analysis in reinforced slope stability calculation [22].

In some application of pozzolanic binder such as bottom ash in soil treatment, the optimum strength can be produced but results show that the permeability tests had resulted in a considerable decline in hydraulic conductivity with the addition of coal ashes to the typical aggregates. Thus, proper drainage must be carefully applied to these blended embankment materials so as to avoid substantial ingress of water [23]. However, in other research showed that a percentage combination of bamboo fiber with organic soil could improve the mechanical properties for the application of embankments and subgrades [24].

MATERIAL AND METHOD

Material

The main component for this research is granitic residual soil, which is often found in many parts of Malaysia along with natural bamboo fiber as additional binder. Due to naturally lateritic or partially lateritic soil, residual soil in Malaysia is often reddish-brown in color. Malaysian residual soils are usually unsaturated, with the exception of the initial days of rain, because of the deep-water table and strong evaporative effects in hot weather [1].

In this research, the binding agent that has been used to stabilize the granitic residual soil was ordinary hydrated lime (calcium hydroxide- $Ca(OH)_2$) with additional substance of bamboo fiber. The mix design is referred from previous studies which also used natural fiber as soil binders. Bamboo fiber of Gigantochloa scortechinii (*buluh semantan)* species was used as additional binder with varying length from 5 to 20 mm of various proportion between 0 to 2% respectively.

Regardless of age and culm height, the high cellulose content of this species indicates its good potential as a raw material in many industrial applications. It holds significant potential for sustainable and eco-friendly applications in the construction, furniture, and renewable energy industries [25].

Figure 1. Raw Uncut Bamboo Fiber of Gigantochloa Scortechinii Species

Methods

Preliminary, the soil samples optimum moisture content (OMC) was acquired based on optimum design mix of 5% hydrated lime composition with varying length of fiber between 5 to 20 mm. The samples were then cured for 7 and 28 days before tested under permeability test. Falling head test was conducted in favor to its initial characteristic of the soil identified based upon its indistinctive properties in term of clay, silt, sand and gravel fractions under previously conducted sieve analysis test. This permeability test was performed according to the ASTM D5084 standard test and procedure.

The calculation of coefficient of permeability (k) was following the Darcy's Law as follows:

$$k = 2.3026 \frac{aL}{At} log_{10} \frac{h_1}{h_2}$$

$\boldsymbol{k}$ = Coefficient of permeability, m/s
$\boldsymbol{A}$ = Cross-sectional area, mm^2
a = Tube Cross-sectional area, mm^2
$\boldsymbol{t}$ = time taken, s
$\boldsymbol{h_1}$ = Initial head, mm
$\boldsymbol{h_2}$ = Final head, mm

Bamboo fiber is the material that has been used in this research as additives. Bamboo fiber also can be got at the market with economical price. The sizes (length) of the bamboo fiber used in this research are 0.5cm, 1cm and 2cm. The percentage of bamboo fiber that will be used in this experiment are 0%, 0.5%, 1%, and 2% respectively.

Figure 1. Falling Head Permeability Test

RESULTS AND DISCUSSION

Results and Discussion in this chapter mainly focused on the effect of BF length specifically for 10 mm fibers and 28 days of curing. It represents the optimum performances of hydraulic conductivity throughout various BF proportions used in the study. The discussion is primarily on the effect of BF length and proportion, and how hydraulic conductivity of hydrated lime-treated sample was affected by the curing periods.

Effect of BF Length and Proportion

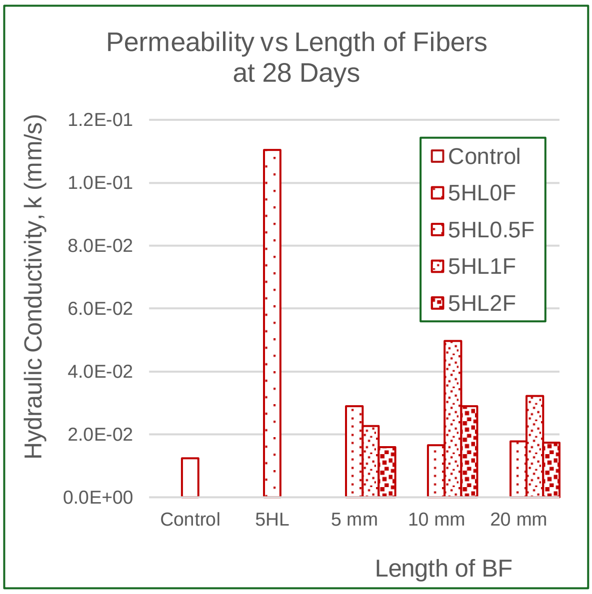

Figure 2. Permeability vs BF Length for Various BF Proportions

Figure 2 shows the permeability of treated samples using various lengths and proportions of BF. The graph indicates that adding some amount of BF ranging from 5 mm to 20 mm had decreased the permeability of the treated soil. However, the permeability in the soil had gradually increased to 0.029 and 0.05 mm/s when treated using 1 and 2 % BF respectively, as the length of fibers was increased from 5 mm to 10 mm. In contrast, the permeability had decreased when 20 mm length of BF was used particularly for 2 % BF content. It indicates that the use of longer BF lengths of greater than 10 mm would reduce the performance of soil hydraulic conductivity as higher proportion of BF greater than 2 % is used in the mixtures.

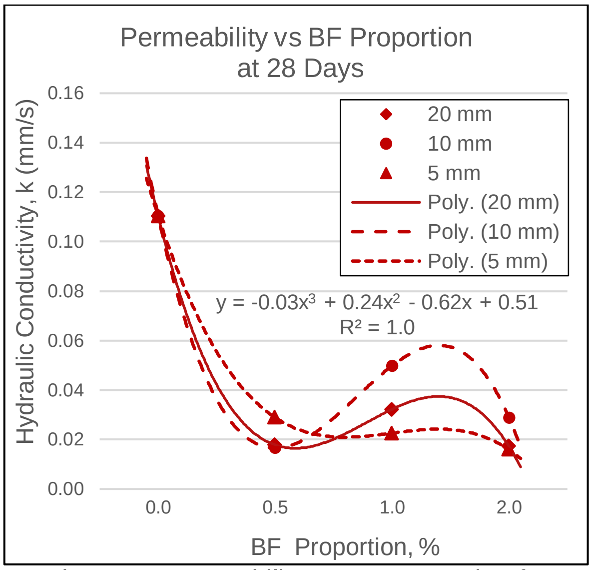

Figure 3. Permeability vs BF Proportion for Various BF Lengths

Figure 3 above illustrates the permeability of soil at 28 days curing period when treated using various BF proportions from 0 to 2 %. The graph shows the polynomials threads that represent the hydraulic conductivity behavior in soils. Ideally, it follows the 3rd order of polynomial equation for all length of BF conducted in this study. It is assumed to be true when hydrated lime-treated soil is introduced with BF binder from 0 to 2 % in the design mix.

It also shows that the optimum hydraulic conductivity of soil had been achieved by using 10 mm length of fiber as previously depicted in Figure 2 when hydrated lime-treated soil was added with additional BF binder of 1%. The graph shows 3rd order polynomial equation of permeability with R^2 value equal to 1. According to previous research, optimal amount of BF in soil improvement for last decade mainly within 1 to 4% range [24].

Effect of BF Proportion and Curing Period

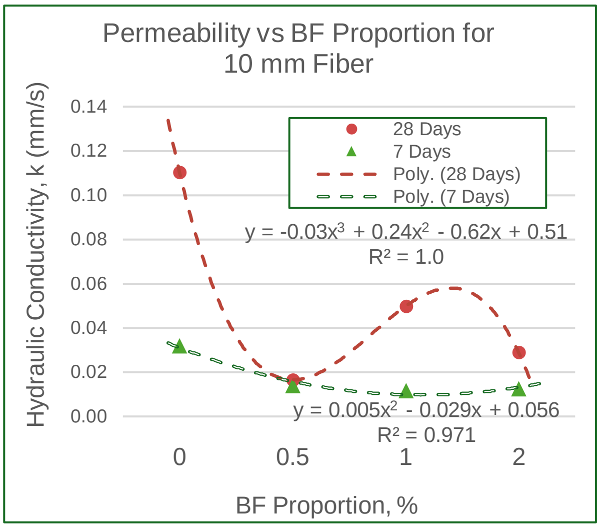

Figure 4. Permeability vs BF Proportion at 7 and 28 Days of Curing Period

Graph of permeability versus BF proportion is shown in Figure 4 with respect to different curing periods of 7 and 28 days to replicate both short term and longer curing period of 28 days. The figure exhibits both curing time that replicates polynomial threads with exceptional values of R^2. It shows that soil treated along with 10 mm length of BF using 1% proportion attains greater values of hydraulic conductivity at 28 days of curing period, compared to that of 7 days sample before slightly reduces to 0.032 mm/s. It is also noticeable that under short term curing period of 7 days, the improvement of permeability seems to be very limited. It is due to the fact that any addition of BF proportion beyond 2% can be practically unrealistic given that the physical properties of the fiber that is very light in nature.

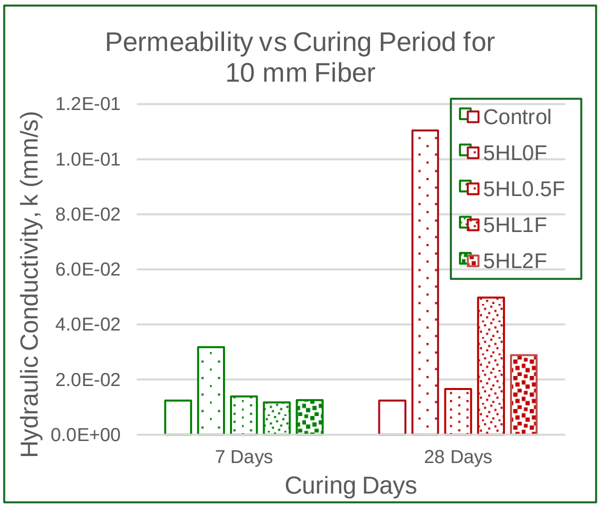

Figure 5. Permeability vs Curing Periods at Various BF Proportions

On the other hand, the results in Figure 5 shows the permeability value versus curing periods for various BF proportions. The graph depicts the improvement of permeability which is largely dominated by 1% BF content after 28 days of curing. The result also shows that permeability decreases as BF is added in the mixtures as compared to HL-only treated sample. However, small depreciation of permeability would be deemed acceptable to facilitate greater strength of treated soil. It is especially true when the hydrated lime – treated soil was added with 1% BF binder. According to other research, microstructure pores size increased in expansive soil suggesting that the flocculation and agglomeration occurred due to cation exchange in the soil treatment after 7 days of curing period [26].

CONCLUSION

In conclusion this research purpose was to study the effect of permeability on hydrated lime-stabilized granitic residual soil with the various mix proportions of BF under 7 days and 28 days of curing period. Based on the results, some findings could be drawn as follows.

From the investigation, the addition of BF generally could affect the strength properties of treated granitic residual soil. It was found that the improvement of permeability can be exhibited after 28 days of curing period.

However, the reduction of permeability can also be noticed if compared to treated soil with HL only. Most importantly, this study had proven that increasing percentage of BF in the mixtures had improved the permeability. Similarly, increasing the length of BF also resulted in improvement of permeability particularly when added with 1% BF binder of 10 mm length.

In this study, it was found that optimum proportion of BF is 1% when 10 mm and 20 mm length of BF is used respectively. Whereas optimum length of fiber found to be 10 mm to achieve 0.05 mm/s permeability. Additionally, it can be concluded that the improvement of hydraulic conductivity of treated sample can be achieved through enhanced interlocking and packing, that is facilitated by additional flow paths channeled through BF's porous particles.

In other words, interconnected pore spaces with bamboo microfiber structure can promote directional water movement and subsequently increase permeability. The addition of HL in the mixtures substantially improved the permeability in the long run at least up to 28 days as per depicted in this study.

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