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Durability of Lime Treated Soil Reinforced by Natural Fiber under Bending Force

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***Abstract*—**Earth structures constructed of marine clay soils have tendency to crack. In order to improve the flexural strength and brittleness, a technique of mixing short fibers is introduced to the soil lime mixture. Coir fiber was used in this study as reinforcing elements. An experimental investigation consisting primarily of flexural tensile tests was conducted to examine the influence of coir fibers on the flexural behaviour of the reinforced soils. The test results that the coir fibers were effective in improving the flexural strength and Young's modulus of all soils examined and ductility after peak strength for reinforced marine clay soil treated by lime. 5% lime treated soil and 1% coir fiber reinforced soil specimens' demonstrated good strength and durability when submerged in water and retained 45% of their air-cured strengths.

***Keywords*—**Flexural strength, Durabilty, Lime, Coir Fibers, Bending force, Ductility.

I. Introduction

MALAYSIA being a peninsular country has large area under coastal regions. The soil which is found in the coastal regions is generally called as marine clay. Marine clay is an uncommon type of clay and normally exists in soft consistency. Due to the increasing infrastructure activities along the coastal lines, it has become a necessity to utilize this area after suitable methods of improvement in the ground. Many earth structures such as clay barriers, earth-filled dams, highway and railway embankments, are constructed of fine grain soils such as marine clay soils, which have a tendency to crack, primarily as a result of bending of soil layers due to differential settlements. A severe damage such as shrinkage cracks of the land based structure due to uneven moistures distribution in marine clay soil effects on the change of soil strength also cannot be avoided.

In recent years, fibers have been added and mixed with soils to improve the strength and mechanical behavior of soils [4], [8]-[10], [13]. They found that with an inclusion of discrete polypropylene fibers, the tensile strength of clays tend to increase and induce more ductile failures. Generally, the high tensile strength and extendibility of the added fibers help to effectively reduce the compressibility and brittleness of the host soil, which is generally superior to traditional soil improvement approaches such as using cement and/or lime [1], [3], [5], [7], [11], [15].

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The objective of this paper is to determine the flexural behavior of randomly distributed coir fiber (15mm long) reinforced marine clay soil treated by lime. A series of three-point bending tests were carried out on soil samples with different percentages of fiber and lime inclusion. By conducting scanning microscopy tests (SEM), the microstructure and the behavior of interfaces between fiber surface and soil were investigated. Furthermore, the durability of lime treated marine clay reinforced by coir fiber was investigated.

II. Materials and Methods

A. Materials

The primary materials used in this study include soil, lime as chemical additives and coir fiber. The basic properties of soil such as grain size, specific gravity, and Atterberg limits (liquid limit and plastic limit) were determined according to classification tests of the British Standard (BS1377-2). The soil can be classified as inorganic clay with high plasticity (CH). Klang marine clay was extracted from the depth between 5 and 8 m. Fig. 1 shows the particle size distribution curve of soft marine clay and Table I provides the properties of the soil. In addition, lime was used as an active additive. The chemical composition of lime used in this study is given in Table II.

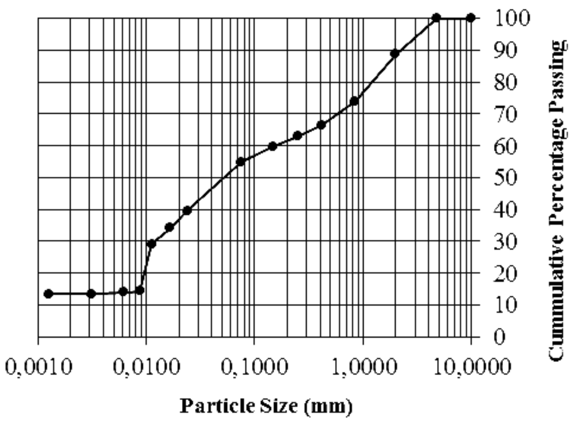

Fig. 1 Particle size distribution

Coir fibers used in this investigation were obtained from a factory in Batu Pahat, South of Malaysia. The chemical and physical properties of coir fiber are shown in Table III. The coir fibers with length 15mm and diameter within 0.2 to 0.3mm were used in this study.

TABLE I
BASIC PROPERTIES OF KLANG SOFT MARINE CLAY

Basic Properties	Value
Natural Moisture Content (%)	74
Unit Weight (kN/m^3)	12.6
Plastic Limit (%)	42
Liquid Limit (%)	95
Undrained shear strength (kPa)	15.6
Predominant clay minerals	Montmorillonite Kaolinite, illite, Halloysite

TABLE II
THE CHEMICAL ANALYSIS OF LIME

Chemical Composition	Typical Analysis (%)
$Ca(OH)_2$	92
$CaCO_3$	1.5
MgO	0.4
SiO_2	1.4
Al_2O_3	0.3
Fe_2O_3	0.2
SO_3	0.5

TABLE III
THE CHEMICAL AND PHYSICAL ANALYSIS OF COIR FIBER

Basic Properties	Values
Chemical Analysis	
Lignin (%)	45.84
Cellulose (%)	43.44
Water Soluble (%)	05. 25
Ash (%)	02.22
Physical Analysis	
Length(cm)	13- 15
Density (g/cm^3)	1.40
Breaking Elongation (%)	30
Diameter (mm)	0.2 – 0.3
Tensile Strength (MPa)	60-90

TABLE IV
THE DETAILS OF DIFFERENT FIBER CONTENT AND LIME CONTENT

Notation	Coir fiber content (%)	Lime content (%)
S	0	0
SL	0	5
SL+0.5%F	0.5	5
SL+1.0%F	1	5
SL+1.5%F	1.5	5
SL+2.0%F	2	5

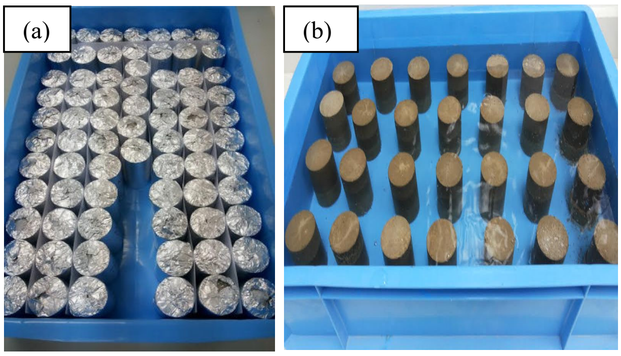

Fig. 2 (a) Flexural test specimens (b) Immersed specimens before durability testing

Two series of the soil mixtures, with and without additives were thoroughly mixed with various moisture contents to prepare the specimens for flexural and durability tests. The soft marine clay and coir fibres were initially mixed thoroughly with the water being added and then the moist mixture was mixed with lime.

Different percentages of coir fibres (15 mm long) were used in this study. We used 15 mm long of coir fibers which were maximum improvement for strength and stiffness response of coir fibre reinforced soil [1]. To lessen the influence of the coir fiber variation, 25 samples were adopted with variation of diameters from 0.1mm to 0.3mm. The aspect ratio (L/D) with the difference less than 10% through the mean and standard deviation less than 10 was used as proposed material [2]. Table IV gives the details of different fibre and lime content and the notation used for them in this paper.

The static compaction pressure was adjusted in order to reach the same dry density as a standard Proctor for optimum water contents. Compaction was carried out using a hydraulic pressure at a fixed displacement rate of 1 mm/min and a downward static compaction pressure of 1700 kPa. This pressure was used to prepare all samples. A five-layered compaction was adopted to keep the uniformity of specimens. The specimens were divided to two series for flexural and durability tests The specimens for flexural tests were wrapped with thin plastic film, aluminium foil and were stored in the curing box at room temperature (25±1°C) for 7, 21, and 90 days before tested (Fig. 2 (a)). For durability tests, the specimens were air-cured for 21 days. The specimens were then immersed in water for 7 days according to the BSI 1990b before tested (Fig. 2 (b)).

B. Experimental Work

The experimental work consisted of the characterization of the soils (the results of which are presented in Table I) and the evaluation of the effect of various percentage of fibers on moisture content-dry density relationship, flexural strength and durability.

The three point bending test (flexural) was conducted on soil specimens to evaluate the effect of the inclusion of randomly oriented discrete coir fibers reinforced limed soil on the flexural strength. The ASTM D1635 was used as reference in order to determine a testing procedure. Circular specimens with 100 mm length and 50 mm diameter were vertically loaded at the middle on two simple supports until failure occurs. The specimen was placed on two supports having a 60 mm span length between the supports. The flexural specimens were tested in triplicates (the average value was adopted as the test value) after 7, 21, and 90 days.

The flexural strength for circular section of the outer layer of the specimen was calculated as based on (1) [2]:

$$\sigma_f = \frac{PL}{\pi r^3} \qquad (1)$$

where P is the maximal applied load; L is the distance between the supports and r is the radius of the specimen. Then, the young's modulus of the specimen was calculated according to

(2) [2]:

$$E = \frac{PL}{12\pi r^4 y} \quad (2)$$

where, y is the deflection at the centre of the specimen from the neutral axis.

Durability tests were carried out using three point bending test. The retained strength was calculated according to (3):

$$Ri = 100\frac{Pi}{Pc} \quad (3)$$

where, Ri is the retained strength or the resistance to loss in strength, Pi is the flexural strength of immersed specimen (MPa), and Pc is flexural strength of unimmersed specimen (MPa) cured in air for the same duration.

III. Results and Discussion

Dry density-moisture content of lime treated marine clay soil at various percentage of coir fibers are shown in Fig. 3. The MDD has reduced and OMC have increased for lime treated soil reinforced with coir fiber. This was due to the disintegration of soil particles with the addition of the coir fibers.

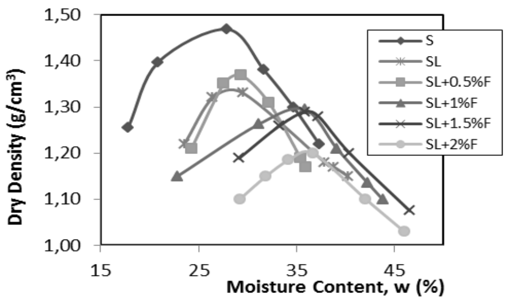

Fig. 3 Maximum dry density- optimum moisture content

The flexural responses of S, SL and SL+F are shown in Fig. 4. The load is found to increase linearly with the increasing deflection from the beginning up to the peak load. The trend of pre peak response is found similar at 7 days curing time. The presence of coir fiber reinforced limed soil has been attested. As it is observed, adding 1% fiber leads to give the highest bending load and the large deflection. The presence of fiber improved ductility of the reinforced marine soil. The fiber bridging effect helps to control rate of energy release. Thus, SL+F remain its ability to carry load after the peak (residual load). Adding more than 1% fiber leads to reduce load deflection; however, the ductility of specimens is almost similar to each other. On the contrary, SL samples experienced a more sudden rupture although SL had a more brittle behavior which may correspond to the brittle behavior of the hardened lime at all curing ages. The failure mode was more ductile in S which may be well explained by cohesive nature of marine clay soil. However, in the case of all the fiber-reinforced marine clay specimens, there was some residual strength, as opposed to the lime treated soil only, which was brittle.

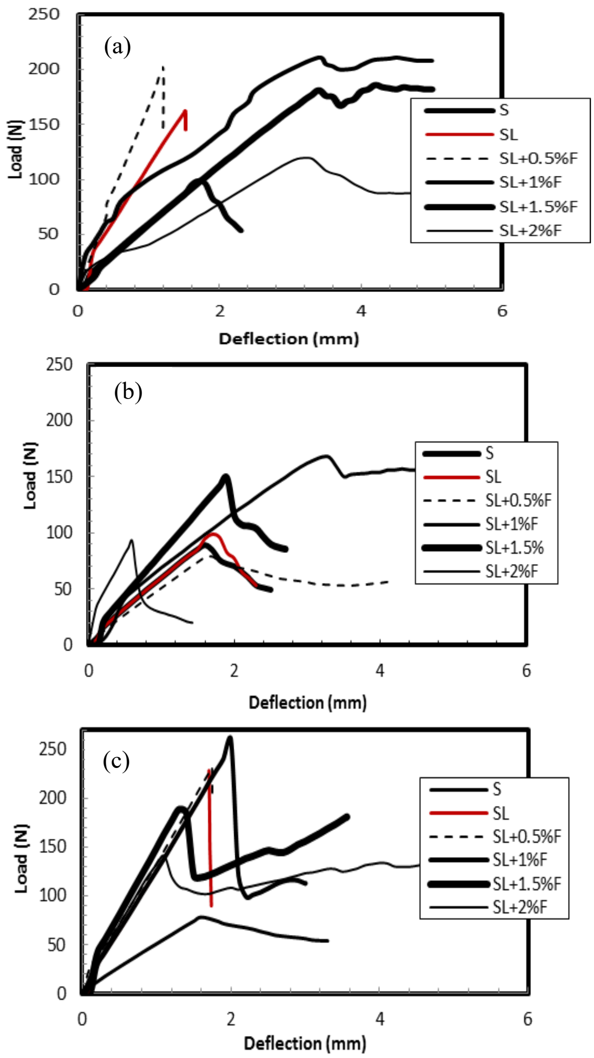

Fig. 4 Load-deflection plots for fiber-reinforced marine clay soil and lime inclusion (a) 7 days, (b) 21 days, and (c) 90 days

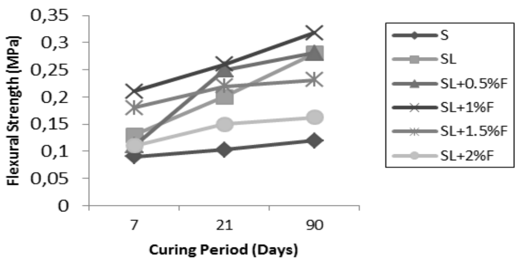

Fig. 5 Flexural strength development of fiber-reinforced marine clay soil and lime inclusion

Flexural strengths with respect to cure duration for untreated and treated fiber reinforced marine clay soil specimens are presented in Fig. 5. There was general increase in flexural strength with an increase in cure duration. Generally, coir fiber reinforced specimens treated with lime gave better strength compared to lime treated specimens only, thereby highlighting the benefits of the combination of coir fiber and chemical additive. Due to the incomplete reactions between lime and soil, the strength variation trend of 7-day and 21- day cured specimens with lime content is lower than those of specimens after curing 90 days. The interfacial friction and bonding between the contact area of the soil particles and the fibers may aid in the load transfer and contributed to an increase in tensile resistance of fiber reinforced soil. The few cases where they gave less strength was most likely due to the fact that inclusion of fibers results in the formation of surfaces of weakness at the fiber-soil interface, leading to a reduction in flexural strength.

The highest values for flexural strength and young's modulus were obtained in SL+1%F samples. The maximum values of flexural strength of samples at 7, 14, and 28-day curing were 0.21, 0.26, and 0.32 MPa, respectively. It was revealed that inclusion of 1 percent of coir fibers reinforced soil resulted in sufficient bonds in the interaction zone between limed soil and fibers permitting load to transfer through shear when samples were loaded. When the specimens were subjected under a load, the interaction between soil particles and the fiber provided the linkage effect in the soil-fibre mixtures. However, the addition of too many fibers could reduce the effectiveness of these improvements in strength, in as much as the fibres adhering to each other form lumps and could not contact fully with soil particles [10].

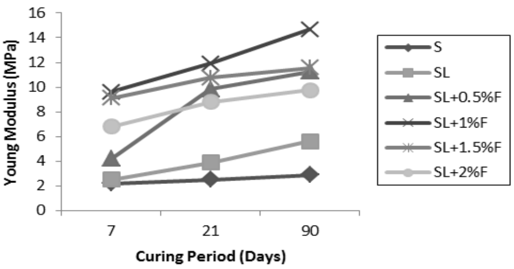

Fig. 6 Young's modulus development of fiber-reinforced marine clay soil and lime inclusion

The maximum values of Young's modulus of samples at 7, 14, and 21-day curing were 9.1, 12, and 15 MPa repectively (Fig. 6). Young's modulus data obtained from three point bending tests may represent the behaviour of the earth platform under surface load.

The inclusion of discrete randomly oriented fibers in the soil improved the load deflection behaviour of the soils. There were improvements in both the failure mode and the flexural strength of reinforced specimens. The improvements are important practical significance in the pile supported earth platform. The inclusion of randomly oriented fibers ensures that instead of catastrophic brittle failure, a structure is still able bear load, sometimes increasing load after the first crack. The improved flexural strength and ductility of fiber reinforced limed soil has led to its use in fissure repairs in the earth platform as load transfer base layer.

Immersion-type durability tests were conducted on selected specimens. Treated and untreated fiber –reinforced marine clay soil remained intact in water 7 days. Fig. 7 shows the results of the retained strength after immersion type tests for coir fiber reinforced limed marine clay specimens. There was generally a large reduction (55 to 80%) in strength as a result of the 7-day immersion in water. The maximum 28-day strength retentions for coir fiber reinforced limed soil were 45% for SL+1%F followed by SL+0.5%F was 27%. This durability test represents a severe damage such as shrinkage cracks of the land based structure due to uneven moistures distribution in marine clay soil. This can be enhanced by making provisions for the drainage of water/runoff from the earth platform as the land based structure. This total immersion-type durability test is designed for soils treated with chemical additives/hydraulic binders.

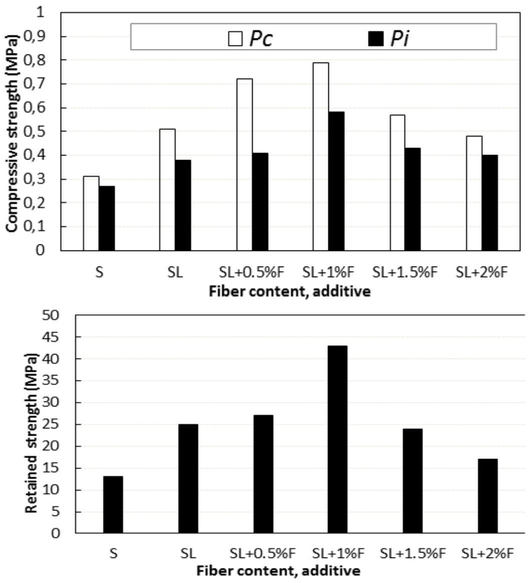

Fig. 7 Durability test fiber-reinforced marine clay soil and lime inclusion (a) retained strength after 7-day immersion in water (b) resistance to loss in strength

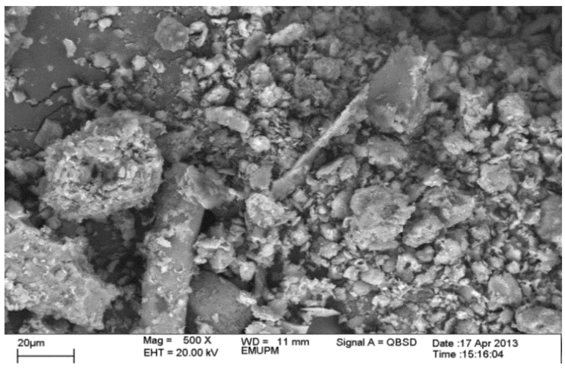

Fig. 8 SEM image of fiber reinforced limed soil

From Fig. 8, it can be seen that the fiber surface is attached by many clay minerals which make the contribution to bond strength and friction between the fiber and soil matrix. Consequently, the stretching resistance between clay particles and strength behaviour was improved. Several researches pointed out that the fiber sliding resistance was strongly dependent on the fiber surface roughness [6], [12], [14]. As the fibers were mixed or samples were compacted, the hard particles (such as sands) of mixtures impacted and abraded the fiber surface, causing plastic deformation and even removal of part of the surface layer. Furthermore, the hydration of the lime binds soil together and makes the matrix compact, and causing an increase in normal stress around the fiber body and the effective contact area. As a result, the static friction coefficient between fiber and composite matrix is increased.

III. Conclusions

The effect of randomly oriented discrete coir fiber inclusions on the properties of marine clay treated with lime was evaluated in this paper. Based on the laboratory tests and analyses presented in this paper, the following conclusions were reached.

- The inclusion of randomly oriented discrete coir fibers in the soils did not lead to a significant change in the moisture-density relationship of the soils examined.
- The inclusion of the fibers led to significant improvements in the flexural load-carrying capacity of the soils.
- There was an increasing of deflection after first crack due to fiber inclusion compared to the brittle, catastrophic failure of the unreinforced specimens or lime treated marine clay only.
- The inclusion of the fibers led to an increase in the flexural strength and young's modulus of the specimens. The maximum value of coir fiber reinforced limed soil to be at SL+1%F.
- The inclusion of randomly oriented discrete coir fibes in the test soils led to practical improvements in their tensile properties. There were increases in maximum load sustained (in some cases). These improvements in tensile properties will translate into earth platform as land based structures and retains its ductile behaviour. However, brittle behaviour would put the shear mechanisms that operate the load transfer at risk in the earth platform.
- SL+1%F specimens had greater resistance to the effects of moisture. The SL+1%F flexural strength specimens retained 45% of their respective strength after 28 days of curing (including 7 days of soaking).
- Issues of moisture susceptibility due to uneven moisture distribution of treated and reinforced marine clay can be ameliorated by making adequate provisions for the drainage of water/runoff from the earth platform as land based structures.

Acknowledgment

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