Compressive Failure of Rattan Reinforced Soil Mixture

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Abstract. Natural fibrous materials such as coir, jute and kenaf have been used as reinforcement to increase the compressive strength of soft soil. This study introduces a new natural fibrous material namely rattan as the reinforcement for soft soil. The main objective is to determine the compressive failure of soft soil reinforced with rattan. Unconfined Compression Test was conducted according to BS1377-7:1990 standard testing procedures. The first series of testing was conducted on inclusion of different content of rattan strip (0 %, 0.5 %, 1.0 %, 1.5 % and 2.0 %) in soft soil. The second testing series is conducted on inclusion of different length of rattan strip (2 cm, 3 cm, 4 cm, 5 cm and 6 cm) in soft soil. The samples are all prepared at optimum moisture content (27 %) and maximum dry density (1.435 Mg/cm³). Mix performances were obtained where inclusion of rattan can be either beneficial or detrimental depending on the content and the length of the rattan. Rattan fiber of 0.5 % and length of 4 cm seems to be the optimum value in achieving higher compressive strength. Generally, the reinforced soil using rattan strip shows more plastic and ductile behavior.

Keywords: Rattan, Unconfined compression strength, Failure mechanism, Soft Soil.

1. Introduction
Construction of infrastructures on soft and weak soil area is a great challenge for civil engineers because of the susceptibility of the soil to differential settlement, poor shear strength, and high compressibility. Hence, the soil requires modification or reinforcement to enhance its physical properties and behavioral state for construction and land development purposes.

Nowadays, different improvement techniques have been implemented to treat the soft soil such as chemical stabilization with lime or fly ash, stone column, and fiber inclusion with either nature or synthetic fiber. [1] stated that unlike natural fibers like wool, cotton and silk, current synthetic fibers are petroleum-based products and are mostly not biodegradable. While natural fibers can be recycled and biodegrade, mixed fibers that contain natural and synthetic fibers are difficult or costly to recycle. The major weakness of synthetic fiber is that they severely pollute the environment, clogging sewers and filling landfill [2]. Synthetic polymers are a significant challenge on land because they are often disposed of in landfills where they will remain for centuries into the future slowly leaking toxins into soil as time passes [3].

[4] studies emphasize that the use of random discrete flexible fibers mimics the behavior of plant roots and gives the possibility of improving the strength and the stability of near-surface soil layers.
The statement clearly shows that the main idea in which soil reinforcement techniques are usually adapted from natural observation on how the plant roots provide strength and stabilized the soil structure. Fiber reinforcement increased the physical properties of the soil. With the presence of fiber reinforcement in the soil, the compressibility of the soil is decreasing and the maximum dry density of the soil is increasing as there less space for the water to absorb into the soil structure thus increasing the shear strength and angle of friction of the soil. According to [5], laboratory tests measured an increase in the ability of the reinforcement soil to resist shear strength, an increase in the post-peak strength response and increase in modulus of the soil.

As for this paper, the reinforcement materials that are used for the soil reinforcement materials are rattan fiber. Rattan fiber is a new material to be introduced as soil reinforcement material. The use of other natural such as jute, coir, bagasse, sisal and kenaf as the additive for the soil reinforcement studies also showing outstanding results. Like the other natural fiber, rattan fiber also has its own physical properties that can enhance the compression strength and stabilization of the soil structure. The effectiveness of rattan fiber as soil reinforcement material is yet to be revealed through this study.

A study conducted by [6] obtained that tensile strength of a single rattan fiber is in the range of 400-600MPa. Rattan also a cost-effective material and can be obtained locally in a large quantity. This can reduce the construction cost when rattan fiber is used in the construction industries. Compare to synthetic fiber and chemical admixtures, rattan fiber as natural fiber have more benefits in many terms. Even though rattan fiber is not as strong as steel fiber, however rattan fiber has the potential to enhance the strength and stability of soft soil when the fiber is included in the problematic soil.

Studies on the tensile and flexural behaviour of concrete reinforced by rattan cane have been conducted by a number of researchers [7]-[11]. They have proved that rattan can increase the tensile and flexural strength of the reinforced concrete structure. The results showed that even tensile strength of rattan cane is lower compared to steel, but it has adequately improved the strength of reinforced concrete.

As soft soil is lower in strength and stability, it is proposed that soil reinforcement using rattan fiber could be adopted and implemented in construction on soft soil area. Therefore, this study is conducted to investigate the effectiveness of rattan fiber as soil reinforcement materials. The compressive strength and the failure modes are the focus of this study.

2. Methodology

2.1. Sample Preparation

The soil used in this study was silty soil collected at coastal area in Balik Pulau, Pulau Pinang, taken from 1.5 m below ground level (Fig. 1). The physical properties of the soil are shown in Table 1. The entire testing program was conducted according to BS1377-7:1990 standard laboratories testing procedures.

![Fig. 1 Location of soil sample collected](image)
Soil properties

| Soil properties | Values  |
|----------------|---------|
| Natural bulk density (Mg/m³) | 1.19    |
| Natural moisture content, Wc (%) | 66.87   |
| Specific gravity, Gs        | 2.33    |
| Plastic limit, PL (%)       | 36.57   |
| Liquid Limit, LL (%)        | 65.58   |
| Plasticity index, PI (%)    | 29      |
| Optimum moisture content (%)| 27      |
| Maximum dry density (Mg/m³) | 1.435   |
| Sand (%)                    | 10.78   |
| Silt (%)                    | 83.25   |
| Clay (%)                    | 5.81    |
| Soil classification         | SILT of High Plasticity (MH) |

Rattan was collected locally from Sarawak. The rattan was in the form of waste product from rattan handicraft making. The rattan waste collected was in different diameter and length as shown in Fig. 2. It was then screened into dimension approximately of 2.4mm width and 0.3mm thickness.

2.2. Testing Program

Unconfined compression test (UCT) test was selected to give compressive strength of the soil-rattan mixture. The first series of testing were conducted to determine the influence of rattan strip content (0%, 0.5%, 1.0%, 1.5%, and 2.0%, based on dry density of soil) on the unconfined compression strength. The length of rattan strip is kept constant at 2cm for every sample of different rattan strip content. The second series of experimental testing were conducted to determine the influence of the length of rattan strip on unconfined compression strength of reinforced soil. The length of rattan strip varies from 2 cm to 6 cm while the ratio of rattan strip content is kept constant at 1.0% for all soil samples in the second series. The fibers are randomly mixed in the soil samples to form a homogeneous mixture of soil-fiber. All soil samples were prepared at the optimum moisture content (27%) and maximum dry density (1.435 Mg/m³). After mixing, the soil mixtures were tested immediately to prevent loss of moisture.
3. Results and Discussion

3.1. Effect of Rattan Content
The unreinforced sample has an unconfined compressive strength, $q_u$ of 27 kN/m$^2$ while the unconfined compressive strengths of different rattan contents are shown in Fig. 4. The maximum strength of $q_u = 29$ kN/m$^2$ was obtained with result of 0.5% rattan content. Further inclusion beyond 0.5% gave detrimental effect to the unconfined compressive strength, this is probably due to increasing overlapping surface of rattan strip which has lower friction between interface compared to soil-rattan interface. Hence, the 0.5% rattan can be regarded as the optimum inclusion content even though the improvement on the compressive strength is marginal.

It was observed that the modulus of the soil mixture reduced with the increase of rattan content. The secant modulus for the unreinforced sample is about 2500 kN/m$^2$ and this reduced to as low as 900 kN/m$^2$. The decrease in modulus implies higher compressibility. In general, higher amount of rattan content increase the ductility of the soil mixture.

![Stress-Strain Curve](image)
3.2. Effect of Rattan Strip Length

The effect of rattan strip on unconfined compression strength is observed from the stress-strain curve as shown in Fig. 5. Generally, all strip lengths give positive improvement in terms of compressive strength except at the length of 2cm which shows detrimental effect. The 4 cm strip length seems to give the highest compressive strength ($q_{cu} = 35$ kN/m$^2$) with 17% improvement compared to unreinforced soil and can be regarded as the optimum length in improving the unconfined compressive strength. Besides, the secant modulus at this strip length is the highest. Little improvement observed in longer fiber maybe attributed to fiber overlapping and possibility of entangled with each other.

![Stress-Strain Curve for Inclusion of Rattan Strip of Different Strip Length](image)

Fig. 5 Stress-Strain Curve for Inclusion of Rattan Strip of Different Strip Length

![Fracture mode of rattan reinforced soil mixture](image)

(a) (b)

Fig. 6 Fracture mode of rattan reinforced soil mixture (a) unreinforced (b) Reinforced with 4 cm rattan strip

Figure 6 shows the failure modes for reinforced and unreinforced specimen. Bulging and crushing failure are observed in unreinforced specimen while for soil mixture with rattan inclusion, the failure mode is tended to be shearing and slippage along the rattan fibers. The slippage between two strips should be avoided in order to obtain higher compressive strength and modulus.
4. Conclusion
In this study, the compressive failure of rattan inclusion in soft soil was investigated. The unconfined compression strength test shows the inclusion of rattan strip at different content and length gave different performance. The maximum unconfined compression strength was achieved with the inclusion of rattan strip at 0.5% rattan content and 4 cm strip. More ductile behavior was observed for soil mixed with rattan strip. The lowest unconfined was obtained from 2 cm strip. Failure mode in rattan reinforced soil mixture is dominantly shearing mode and local failure along the rattan slip. Generally, rattan inclusion can give beneficial effect to the compressive behavior. However, more testing is required to justify this finding. Besides, mixing process required careful handling to ensure less overlapping happened between 2 rattan fiber slips.

References
[1] Penn State. 2017. Tiny fibers create unseen plastic pollution. ScienceDaily. Retrieved January 30, 2020 from www.sciencedaily.com/releases/2019/02/190217115852.htm
[2] Pandit, V.M., Dikkar, H.S., Patil, J.K, Rajput, K.G., Chavan, P.S., & Deore, Y.S. 2016. Effect of Plastic Strip on Compaction Characteristic of Soil. International Journal of Modern Trends in Engineering and Research 3(4): 572-576.
[3] King, Justin. 2020. Environmental Problems Caused by Synthetic Polymers" sciencing.com, https://sciencing.com/environmental-problems-caused-by-synthetic-polymers-12732046.html. 31 January 2020.
[4] Baruah, H. 2007. Effect of Glass Fibers on Red Soil. International Conference on Technologies Sustainability – Engineering, Information Technology Management and the Environment: 508-514.
[5] Girija, K.M. 2013. Behaviour of Randomly Distributed Fiber-Reinforced Soil. International Journal of Research in Engineering and Technology: 456-458.
[6] Liu, X., Yang, S., Shang, L., & Ma, J. 2015. Properties of Rattan Cane and Its Comprehensive Utilization Technology. International Seminar on Rattan Sustainable Management and Utilization in South-East Asia. Retrieved fromhttps://www.slideshare.net/inbar_sm/properties-of-rattan-cane-and-its-comprehensive-utilization-technology
[7] Mahzuz, H.M.A., Ahmed, M., Uddin, M.K., Hossain, M.M., & Saquib, N. (2013). Determination of Tensile Stress and Bond Stress with Concrete of a Rattan (Calamus Guruba). Scholars Journal of Engineering and Technology, 1(1), 39-43.
[8] Adewuyi, A.P., Otukoya, A.A., Olaniyi, O.A., & Olafusi, O.S. (2015). Comparative Studies of Steel, Bamboo and Rattan as Reinforcing Bars in Concrete: Tensile and Flexural Characteristics. Open Journal of Civil Engineering, 5, 228-238.
[9] Olawale, A.J., & Wasiu, A.S. (2013). Structural Characteristic of Bamboo and Rattan Cane Reinforced Concrete Struts. Physical Review & Research International, 3(4), 602-611.
[10] Obilade, I.O., & Olutoge, F.A. (2014) Flexural Characteristic of Rattan Cane Reinforced Concrete Beams. The International Journal of Engineering and Sciences, 3(6), 38-42.
[11] Das, P., Basa, B., Digal, S., & Jana, C. (2016). Cane Reinforced Cement Concrete: An Experimental Approach on Flexural Strength Characteristic in Comparison with Steel RCC. International Journal of Civil Engineering and Technology, 7(4), 463-473.

Acknowledgment
The authors would like to thank Universiti Teknologi MARA, Cawangan Pulau Pinang of supplying the research materials and providing research facilities for the current research.