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THE BEARING CAPACITY OF PEAT SOIL WITH BAMBOO REINFORCEMENT

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ABSTRACT: Peat soil is a type of soil that has low bearing capacity and high settlement, which has an unfavorable effect on construction. Peat soils require a reinforcement system of micropile-reinforced slabs. One alternative material that can be used as a micropile is bamboo. This study aims to determine the impact of bamboo micropiles on increasing bearing capacity, modulus of subgrade reaction, and reducing settlement. This research was conducted by testing a physical model on peat soil reinforced with bamboo micropiles and concrete micropiles as a comparison. The lengths of the piles used were 10 cm, 20 cm, 30 cm, and 40 cm, respectively, which were installed on a 30 cm x 30 cm slab. The plate load test is conducted on the slab to obtain the bearing capacity. The results showed that micropiles could increase bearing capacity and reduce settlement. The bearing capacity of slabs with bamboo micropiles was close to that of concrete micropiles, or about 0.92 times the bearing capacity of concrete micropiles. The primary difference between the two materials was the rougher surface of the concrete micropile, which provided higher shaft friction than the bamboo micropile. The subgrade reaction's initial and secant moduli were 170 and 50 times the bearing capacity, respectively. Settlement reduction due to pile installation was relatively high at the initial loading and constant at higher loads.

Keywords: Peat soil, Bearing capacity, Slab, Bamboo, Micropile

1. INTRODUCTION

Peat soil is classified as soil that has a low bearing capacity. The construction is unsafe when placed directly on the peat soil because this soil generally has low shear strength, high settlement, high compressibility, and low bearing capacity [1]. The peat improvement is needed to increase performance in carrying construction loads. The improvement of bearing capacity is conducted through soil stabilization [2].

The improvement of peat soil can be done by using a reinforcement system. Several previous studies have shown much relation to peat improvement, such as a combination of fiber and cement by Ghanbari et al. [1], a combination of gravel piles and cement fly ash by Umravia & Solanki [3], and bamboo pile mattresses as reinforced embankments [4]. Geotextile reinforcement on top of the rail track's subgrade, sub-ballast, and ballast can minimize settlement. The result contradicts when they are used without geotextile [5]. When loaded, the peat soil reinforced with basalt fiber showed ductile performance [1]. Reinforcement such as geotextile increases the shear strength of subgrades in road construction [6].

Generally, this reinforcement system has a good effect on increasing bearing capacity and reducing settlement, but finding alternative materials to reduce construction costs is necessary. Bamboo material can be used as a micropile material on peat soils. The results of research using this material on peat soils show good performance in holding loads. Bamboo has a high tensile strength and can reach 370 MPa [7]. Bamboo as reinforcement can be in the form of woven grids that are installed horizontally or in the form of piles that are driven vertically.

Reinforcing using the bamboo grid increases the bearing capacity of peat soil [8]. Using a bamboo grid can reduce the settlement of peat soils by up to 68% for a three-layer bamboo grid [9]. The number of layers of bamboo grids that have good potential for reducing peat soil compression is 2-3 layers [10]. Bamboo grids in the horizontal direction must be combined with piles in the vertical order. Bamboo grid reinforcement combined with concrete piles has a good performance in holding the embankment load during the consolidation of peat soil [11]. Concrete piles stabilize the embankment on peat soil during loading; this system becomes more rigid when monoliths are installed with concrete slabs [12].

The bamboo micropile material must be compared with concrete micropile to determine how far the bearing capacity can be achieved. Bamboo piles can reduce settlements by up to 48%, depending on the pile spacing [13]. Mini piles require closer spacing than long piles to perform well in increasing soil bearing capacity [14]. The bearing capacity of a pile consists of shaft friction and end bearing capacity for each type of soil [15].

Pile stiffness over the long term can affect the bearing capacity of piles. The bearing capacity is getting smaller, and the strain increases over time [16]. Meanwhile, according to Amornfa and Sanguanduan [17], pile dimensions and soil modulus influence pile stiffness. Bearing capacity correlates with the pile dimension's parameters and spacing [18].

Bearing capacity needs to be analyzed to find its relationship with the value of the modulus of subgrade reaction to find a correlation when the plate bearing test is not conducted. This study aims to determine the subgrade reaction's bearing capacity and modulus in peat soil slabs with bamboo and concrete micropiles.

2. RESEARCH SIGNIFICANCE

This research was conducted through experimental tests in the laboratory. The soil used in this research is peat soil from Riau, Indonesia. A concrete slab with an area of 30 cm x 30 cm and a thickness of 2 cm was used. The slab is reinforced with a micropile of bamboo and concrete with a diameter (d) of 2 cm and a length (L) of 10 cm, 20 cm, 30 cm, and 40 cm (Fig. 1). The combination of a micropile with a slab as a shallow foundation provides a higher bearing capacity than a slab without a micropile or just a pile foundation [19].

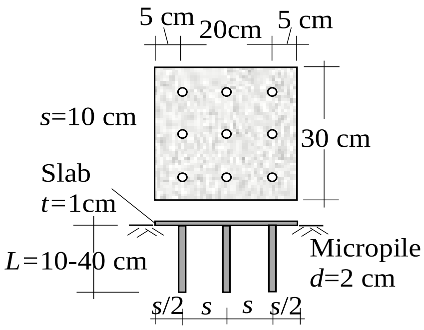


Fig. 1 Model dimensions and micropile configurations

The soil is compacted in a test box measuring 120 cm x 90 cm x 90 cm. The thickness of the peat soil layer is H_1 of 50 cm, and the rest is filled with a solid layer of H_2 of 40 cm. The test boxes used in this study are the same size as the test tanks used in this study [11]. The micropile is driven by nine piles in a layer of peat soil, with a spacing of 10 cm between the piles.

The test variations consist of slabs without micropile (S), slabs with bamboo micropile (S+MP-B), and slabs with concrete micropile (S+MP-C). The slab with micropile consists of bamboo with a length of L of 10 cm (S+MP(B-10)), L of 20 cm (S+MP(B-20)), L of 30 cm (S+MP(B-30)), and L of 40 cm (S+MP(B-40)). The slab with micro-pile consists of piles with lengths L of 10 cm (S+MP(C-10)), L of 20 cm (S+MP(C-20)), L of 30 cm (S+MP(C-30)), and L of 40 cm (S+MP(C-40)).

The plate load tests were conducted on slabs with and without micropiles, as shown in Fig. 2. The load is applied gradually until significant settlement occurs. The plate load test results show the relationship between pressure (q) and settlement (δ). The pile capacity is obtained from the load-settlement relationship [20]. The bearing capacity of peat soil is obtained to determine the ultimate bearing capacity (q_u). The modulus of the subgrade reaction (k) is determined by comparing pressure and settlement. In addition to the results of the plate load test, the ultimate bearing capacity value can be determined based on the value of the modulus of subgrade reaction from methods [21,22], Eq. 1 for k, Eq. 2 for k_{secant}, and Eq. 3 for $k_{initial}$ respectively.

$$k = 40\ q_u \quad (1)$$
$$k_{secant} = 49\ q_u \quad (2)$$
$$k_{initial} = 175\ q_u \quad (3)$$

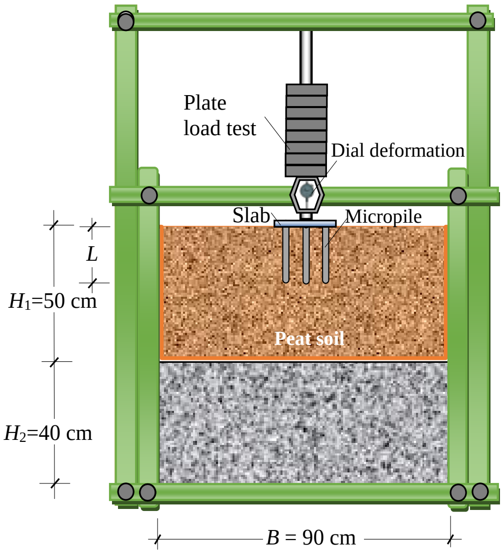


Fig. 2 Plate load test

3. RESULTS AND DISCUSSIONS

The research results are presented as plate load test results, which consist of the relationship between load and settlement of the plate with bamboo and concrete micropiles. Then it presents the bearing capacity analysis results, the modulus of subgrade reaction, and the correlation of these two parameters.

3.1 The Results of the Plate Load Test

The results of the plate load test on the slab with bamboo micropiles are shown in Fig. 3, while the slab with concrete micropiles is demonstrated in Fig. 4. Both results show the effect of pile length on settlement reduction. The change in settlement for pressure < 1.6 kPa tends to be relatively smaller, while for pressure > 1.6 kPa, it shows a change in settlement that is somewhat higher as the load increases. The micropile minimized settlement and increased the slab's ability to withstand loads.

A comparison between the bamboo micropiles and the concrete micropiles can be seen in Fig. 5. The test results show that the decrease in the concrete micropile-reinforced slab is smaller than the bamboo micropile-reinforced slab. As it is known, the pile capacity is obtained from the end bearing and shaft friction. The end bearings can be assumed to be the same because the pile end area and soil conditions are the same. However, the friction between the pile and the ground affects the shaft friction along the pile. Bamboo and concrete differ because the concrete's surface is rougher than bamboo's. This can cause the shaft friction in concrete to be higher, which impacts reducing settlement compared to bamboo. Bamboo material can be an option because the cost factor is more economical than concrete material.

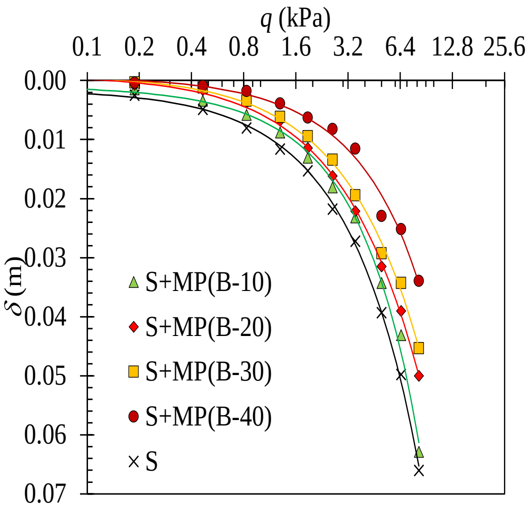


Fig. 3 The result test of the slab with bamboo micropiles

The reduction in settlement due to micropile reinforcement in slabs is shown in the ratios δ_o/δ and δ_o in Fig. 6. The value of δ_o is the settlement of the slab and δ is the settlement of the slab with micropiles. The reduction in settlement is high at the start of loading but looks constant at higher loads. Settlement reduction for slabs with bamboo micropiles was constant when slab settlement was > 0.015 m, whereas for slabs with concrete, micropiles were constant when slab settlement was > 0.02 m. Both settlements show a ratio of δ_o/δ about 1-2 for higher loads, but for smaller loads a ratio of $\delta_o/\delta > 2$ for smaller loads. It can be seen that the effect of pile length on settlement reduction is getting higher.

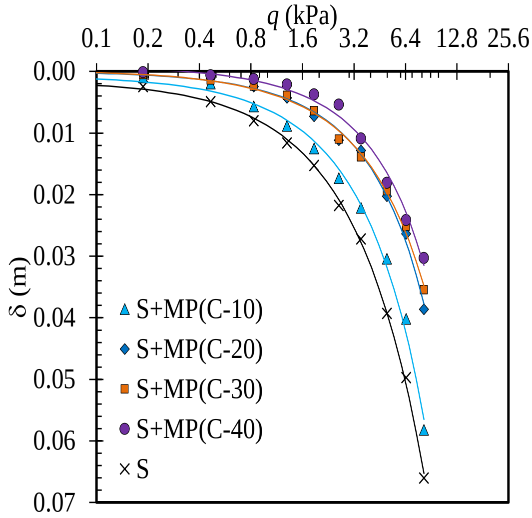


Fig. 4 The result test of the slab with concrete micropiles

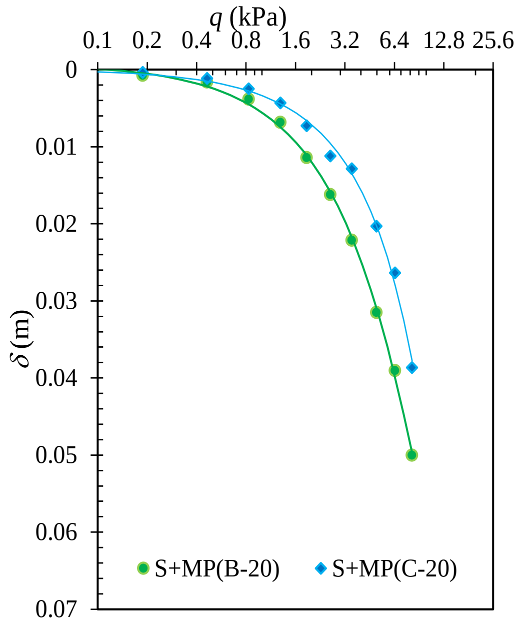
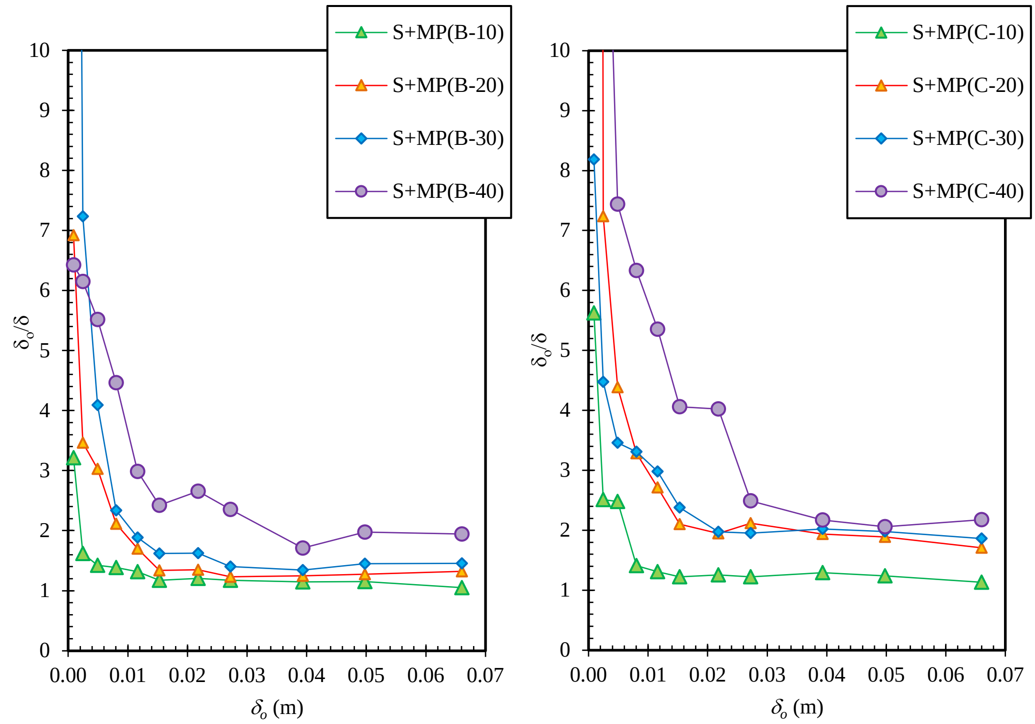


Fig. 5 Comparison between the bamboo micropile and concrete micropile

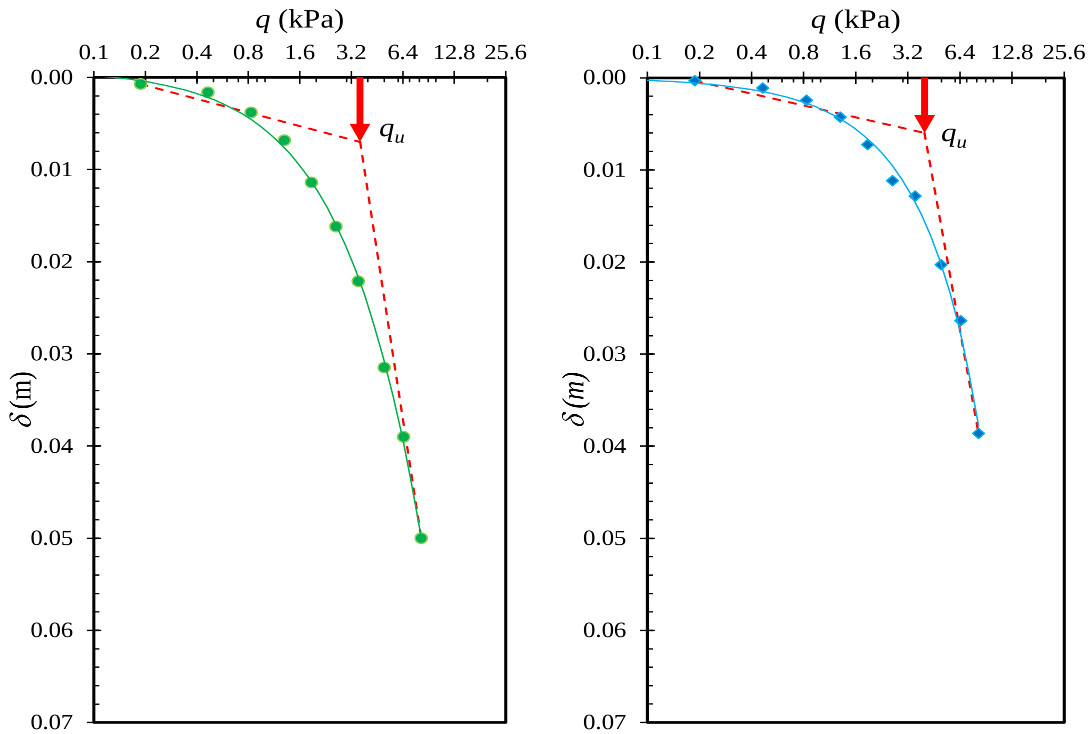
3.2 Bearing Capacity and Modulus of Subgrade Reaction

The bearing capacity of slabs with bamboo micropiles and concrete micropiles was obtained by using the relationship between load and settlement, as shown in Fig. 7. Using Fig. 7, the ultimate bearing capacity was determined employing the double tangent method, such as the method carried out by Umravia and Solanki [3]



(a) (b)

Fig. 6 The relationship between δ_o and δ_o/δ of the slab with: (a) Bamboo micropile; (b) Concrete micropile



(a) (b)

Fig. 7 The bearing capacity (q_u) of the slab with: (a) Bamboo micropile; (b) Concrete micropile

Based on the bearing capacity (q_u) analysis for each pile as done in Fig. 7, the bearing capacity was obtained for all types of tests as in Fig. 8. The value of q_u increased with the length of the pile used. A comparison of bearing capacity between slabs with concrete and bamboo micropiles showed that the q_u value of concrete micropiles is higher than that of bamboo micropiles; this is related to the friction of concrete micropiles, which contributes to increasing shaft friction. The bearing capacity of bamboo micropiles was around 0.92 times higher than that of concrete micropiles.

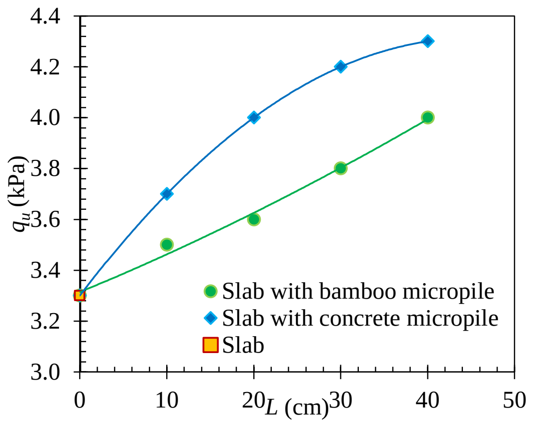


Fig. 8 The relationship between L and q_u

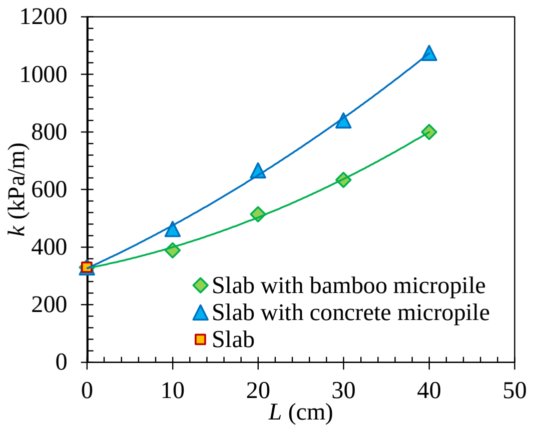


Fig. 9 The relationship between L and k

Based on the pressure with settlement relationship (δ) for each micropile, as shown in Fig. 7, the modulus of subgrade reaction (k) was obtained and is shown in full in Fig. 9. The results of this study show that the k value for slabs without piles is 330 kPa/m. This value is higher for wider slab due to the influence of the slab's weight [23]. Pile contributes to increasing the value of k; as shown in Fig. 9. There is an increase in the modulus of subgrade reaction for the longer pile for both the concrete micropile and the bamboo micropile. The value of the modulus of subgrade reaction on concrete micropiles was higher than the modulus of subgrade reaction on bamboo micropiles; this was followed by an increase in bearing capacity.

3.3 Relationship between Bearing Capacity and Modulus of Subgrade Reaction

The modulus of the subgrade reaction on a slab consists of the initial modulus of the subgrade reaction and the secant modulus of the subgrade reaction. The initial modulus of subgrade reaction is obtained from a comparison of bearing capacity (q_u) with settlement. Meanwhile, the secant modulus of subgrade reaction was obtained from the comparison between the final pressure and final settlement in each test. The relationship between q_u and k values can be seen in Fig. 10. There is a linear relationship for both the k_{initial} and the k_{secant}. The modulus of the subgrade reaction is higher for higher bearing capacity.

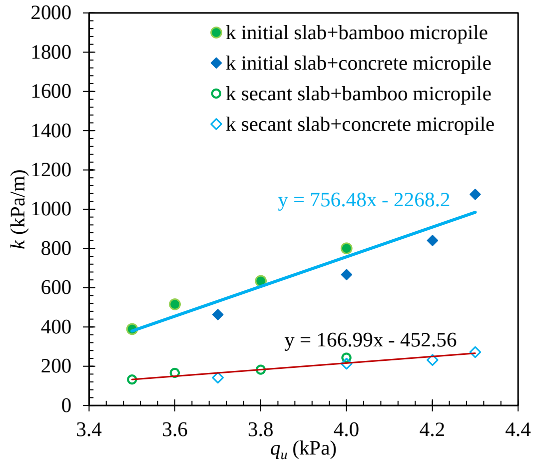


Fig. 10 The relationship between q and k

The average comparison between the value of the modulus of the subgrade reaction and the bearing capacity is 170, so it can be said that the k_{initial} is 170 q_u. The relationship between q_u and k_{initial} obtained in this study is almost the same as that of Waruwu and Pardosi [22], with k_{initial} being 179 q_u (Eq. 3). The comparison of the two is shown in Fig. 11. This correlation can be considered in estimating the bearing capacity value based on the modulus of subgrade reaction, and vice versa.

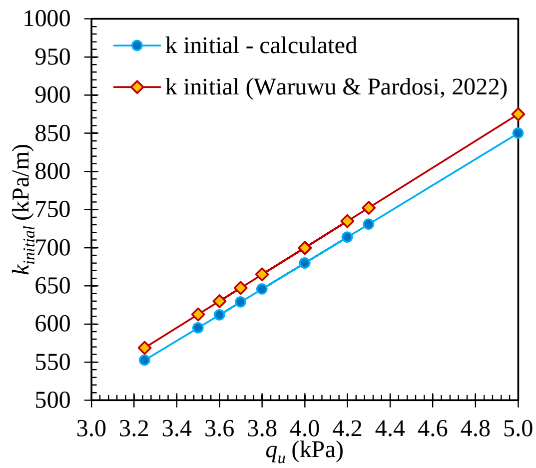


Fig. 11 The relationship between q_u and k_{initial}

In this study, the relationship between bearing capacity and k_{secant} obtained a linear relationship with an average ratio of 50, or k_{secant} is 50 q_u. This correlation is not much different from Bowles [21], with k being 40 q_u (Eq. 1) and Waruwu and Pardosi [22] with k_{secant} being 49 q_u (Eq. 2). The full results of the analysis and comparison of the three are shown in Fig. 12. The results of this study are close to those of Waruwu and Pardosi [22]. This could be because the soil studied was peat soil, while Bowles [21] is a common soil type.

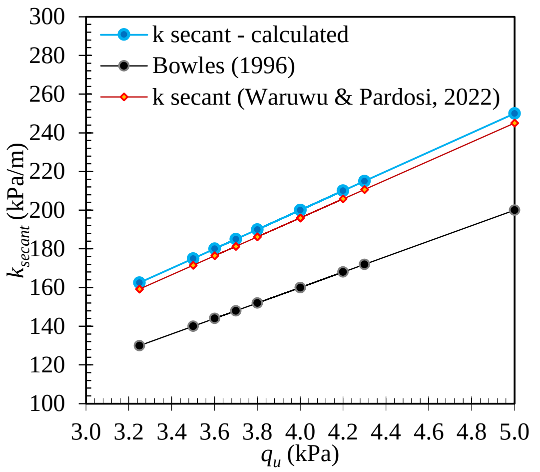


Fig. 12 The relationship between q_u and k_{secant}

4. CONCLUSION

The conclusions of this study are:

1. The micropiles installed for reinforced slabs contribute to increasing bearing capacity, modulus of subgrade reaction, and settlement reduction. Longer piles showed better performance due to increased shaft friction in the micropile.
2. The bamboo micropiles showed performance that was almost the same as the concrete micropiles; the difference was obtained from the surface of the concrete, which was rougher than bamboo so the shaft friction of concrete micropiles was higher. However, bamboo was more economical than concrete, so this material could be considered a slab reinforcement on peat soil. The bearing capacity of bamboo micropiles was around 0.92 times that of concrete micropiles.
3. The settlement ratio of the slab without micropiles and slab with micropiles (δ_o/δ) was high at the start of loading because the piles contribute to holding the load, but at higher loads the reinforcement system was found to have a constant effect on the ratio δ_o/δ.
4. This study found a relationship between the modulus of the subgrade reaction and bearing capacity; each initial modulus of the subgrade reaction was 170 times the bearing capacity, and the secant modulus of the subgrade reaction was 50 times the bearing capacity.
5. Bearing capacity could be estimated from the value of the modulus of subgrade reaction based on the existing correlation, and vice versa. In contrast, the modulus of the subgrade reaction could be determined from the value of the bearing capacity.

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