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The combination of bamboo grid and concrete pile as soil reinforcement under the embankment

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Abstract. Material availability and economic price make bamboo a viable option for soil reinforcement. Grids made of split bamboo rods require reinforcement with concrete piles, which are known to have a good bearing capacity under the embankment. The combination of these materials allows reducing the settlement and deflection of the bamboo grid as a subgrade on peat. However, research is needed to get the distance and length of a pile that can provide significant performance in supporting the embankment load. In this research, the pile system with diameters of 2 cm was driven into the peat layer to a certain length and distance. The piles have a length of 15 cm and 25 cm in peat soil layers. The piles were connected monolithically with a bamboo grid using a wire. The pile's distance was 5–20 cm. The peat soil was compacted layer by layer with a total thickness of 50 cm close to the field density. The embankment load was applied in three stages over one day with pressure of 3.02 kPa at each stage. The reinforcement proved to reduce the settlement and the deflection of the bamboo grid. The results showed that the combination of grid bamboo with concrete piles can be used for reinforcement purposes on peat soils on the following conditions: if L/H = 0.3, the ratio $s/d \le 2.5$; if L/H = 0.5, the ratio s/d ≤ 7.5.

1. Introduction

Peat soil has high water content, low specific gravity, low density, and low bearing capacity. Fibrous peat has low ash content, and very high compression. Improvement on peat soils is commonly performed using cement columns, cement, other pozzolanic materials, and preloading method [1–5]. The applying embankment on the peat layer can reduce the compression [6]. The embankment load can lead to lower high and uniform layer of peat. The reinforcement contributes in increasing the stability of the embankment, while strengthening and peat soil shear strength will withstand lateral forces that work [6].

The concrete slab can be used as a reinforcement to the peat to generate uniform settlement under embankment [7]. In addition to a concrete slab, other materials that can be used as soil reinforcement is bamboo. The bamboo is a renewable material and is spread around the world including the Asia-Pacific region, American region as well as African region [8]. The settlement due to embankment load can be reduced with the installation of bamboo grids on the layer of peat [9]. Bamboo grids in the peat soil settlement are able to reduce, increase the modulus of subgrade, and shear modulus. Reinforcement bamboo grids on top of two layers are quite effective in increasing the bearing capacity and reducing the settlement [10]. The use of bamboo grid is effective if the number of layers on top is of two layers, so that it is necessary to consider to use a bamboo grid [11]. Reinforcement bamboo grid is difficult to implement if the peat layer is thick, because it requires the dismantling of the land prior to the installation of the bamboo grids. For that, it needs a combination of mini piles from concrete to increase the stiffness of soil confinement system and inter pile. The reinforcement by sheet pile combined with the nailing is effective

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method to reduce the lateral and vertical displacements of clay soil under embankment [12]. The same thing is obtained as a reinforcement for concrete slab on peat soil. The settlement pattern of the concrete slab under embankment on peat soil is similar to that of punching shear [7]. The use of mini piles under the reinforced soil abutments can meet the required bearing capacity value and reducing the settlement [13].

The piles serving to keep the base slab must remain in good contact with the subgrade. Installation of poles on the plate influence the controlling and minimize the damage caused by heave at the ground [14]. Pile foundation system is an effective way to support the pile with minimal reduction in total [15].

There are several advantages of piles as a drag heap of which implementation of embankment construction can be completed in a short time, the pile supporting the embankment can reduce total settlement and the differential settlement was not significantly [16]. Pile on peat soil is able to increase the modulus of subgrade reaction [17]. Installed piles under the slab can increase slab stiffness [18]. The pile under the slab in the nailed slab system is used to resist load, reduce settlement, increase stiffness, and increase stability [19]. Bamboo pile with diameter of 2 cm and a length of 20 cm was used as reinforcement in the bottom of the grid of bamboo on peat soil [20–21]. Pile spacing influences downward pressure and deflection on the ratio $s/d \leq 7.5$. Closer pile distance provides reduction downturn and large deflections. Maulana, et al., [20] stated that bamboo pile and grid are able to reduce settlement and deflection, so that stability of embankment maintained. The ratio of grid bamboo width to pile spacing (B/s) of 15 provides reduction settlement approximately 60 % [21]. Some types of mounting pile as reinforcement on peat soil is end bearing piles, friction piles, settlement reducing piles, tension piles, laterally loaded piles, and piles in fills [7]. The efficiency factors of pile group depend on the distance of piles, number of piles, and the length of the pile [22]. The pile length affects vertical and lateral displacement, and a longer pile shows smaller vertical and lateral displacement [23].

Many researchers investigated the soil reinforcement methods including the use of geosynthetic, geogrid, bamboo grid, concrete-grid, and pile [24–28]. Generally, reinforcement used to support the embankment load is geosynthetic. In this research, reinforcement pile used was bamboo grid combined with the piles from the concrete material. There has been limited research on the model of a small scale in the laboratory. Therefore, this paper is concerned with the performance of bamboo grid-concrete pile system related to the effectiveness of the length and pile spacing to settlement and deflection. This research is part of an ongoing investigation on model of the grid combination of bamboo and concrete piles to support the embankment on the ground. The specific objectives are to determine the ratio of pile spacing to diameter based on the ratio of pile length to peat layer depth and bamboo grid width. In addition, the compression behaviour and the deflection distribution of bamboo grid have been observed. Future work will include the effect of bonding piles with bamboo grids and addition of pile cap to ensure connection with bamboo grids on the behaviours of reinforced concrete pile and bamboo grid.

2. Methods

The research was conducted on peat soil using test box measuring 120 cm×90 cm×90 cm, but with the thickness of peat soils of only 50 cm and this layer was followed by solid layer of 50 cm (Fig. 1). The peat soil was compacted layer by layer as thick as 10 cm with a total thickness of 50 cm. The density of each layer is known from core cutter test with a density close to the field density. The same thing was done to achieve the required thickness of the peat (Fig. 2). To facilitate the drainage of water into the peat layer it is necessary to install pipes in each corner and bottom of the test basin. Ground water levels are modeled to the ground level.

Peat soil used was a fibrous peat soil type and classified as soft soil because it has an undrained shear strength (C_u) value of 6.15 kPa less than 12.5 kPa [24]. Reinforcement of peat soils used 2 cm in diameter (d) concrete piles and 60 cm×30 cm bamboo grids (Fig. 3). The concrete pile was distinguished by the length and distance of the pile. The length of the pile (L) used was 15 cm or L/H of 0.3 and 25 cm or L/H = 0.5 with a distance (s) of 5-20 cm or s/d of 2.5-10. The piles were installed in a layer of peat at certain distances and on top of it was laid a bamboo grid.

Embankment load was modeled using the iron bars having dimensions of 1.9 cm×1.9 cm×4 cm as research [12–16]. Load was given gradually every day and each stage was composed of two layers as high as h of 3.8 cm equivalent to the pressure (σ) of 3.02 kPa and a total of three layers of 9.08 kPa (Fig. 4). The settlement of each stage of the load is read at certain times using a dial gauge. In addition to testing the model on a small box, testing was also conducted on a box sized of 2 m×1.5 m (Fig. 5). The lengths of the piles used include 10 cm, 20 cm, 30 cm, and 40 cm with a diameter of 2 cm and a distance of 10 cm. Stages of load are the same as for small box.

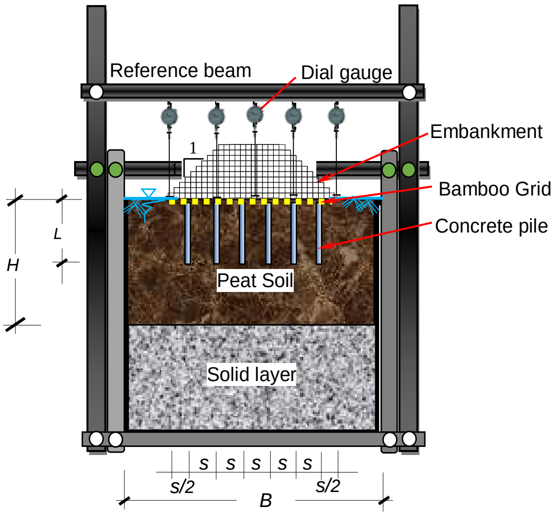

Figure 1. The model test of experimental [24].

(a) (b)

Figure 2. Photographs of (a). Test box with water drainage pipe; (b). Compacted peat soil.

(a) (b)

Figure 3. Photographs of (a). Arrangement of piles; (b). Bamboo grid.

Figure 4. Photographs of embankment load test.

Figure 5. Photographs of embankment load test for box sized of 2 m × 1.5 m.

3. Results and Discussion

The results of embankment load on peat soil reinforced by bamboo grid with and without piles can be seen in Fig. 6 and Fig. 7. Load-settlement curves of the study [25], using concrete-grid for reinforcement of subsoil base under foundation, generally reduces the settlement and increases the bearing capacity of the soil. The piles that reinforced the bamboo grid are seen to influence the peat compression. The longer piles (L of 25 cm) showed a significant effect on behavior change compression of peat (Fig. 7). The shorter piles (L of 15 cm) with a ratio of pile length to peat layer thickness (L/H < 0.5) shows relatively small changes in peat compression except for piles with spacing (s) of 5 cm (Fig. 6).

The significant decrease occurs in the ratio of the distance of the piles to the diameter ($s/d \le 2.5$). This is different if the pile used is longer (L of 25 cm) or equivalent to half the thickness of the peat layer ($L/H \ge 0.5$), as shown in Fig. 7. The friction capacity of the longer pile is noticeably higher than the shorter pile. Long piles showed relatively smaller settlement compared to short piles. Thus, the length of the pile used as a bamboo reinforcement grid on peat soil requires a minimum of half of the thickness of the peat layer ($L/H \ge 0.5$) with the ratio of the distance of the pile to the diameter of the pile ($s/d \le 7.5$). Relation between pressure and settlement for box sized of 2 m×1.5 m is shown in Fig. 8.

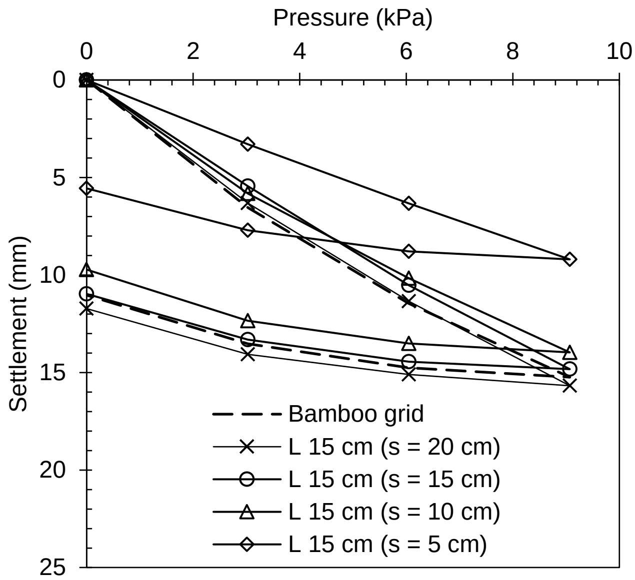

Figure 6. Relation between pressure and settlement for L of 15 cm.

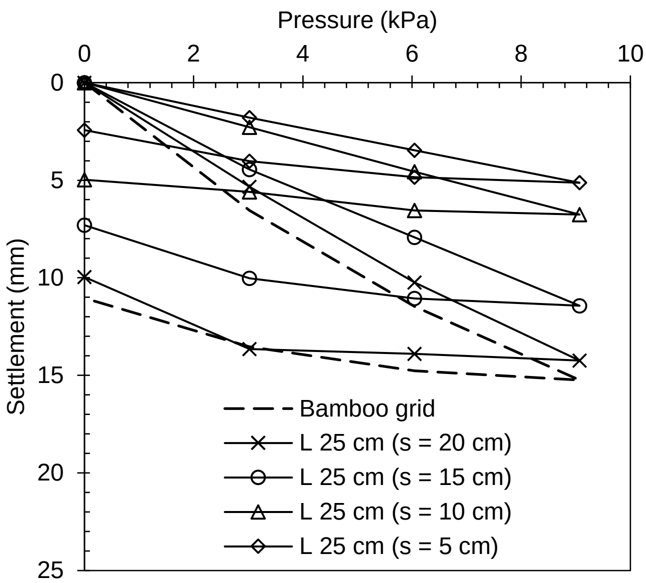

Figure 7. Relation between pressure and settlement for L of 25 cm.

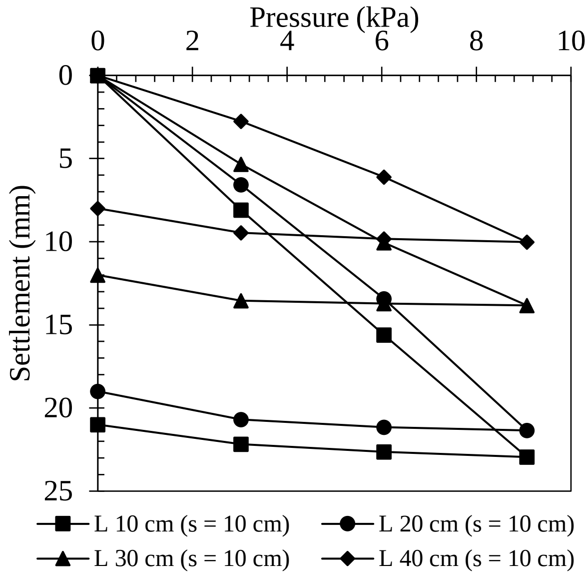

Figure 8. Relation between pressure and settlement for box sized of 2 m×1.5 m.

The results of the embankment load model test conducted in a test box sized of 2 m×1.5 m can be seen in Fig. 8. The compression behavior due to the embankment load shows the same behavior as the load test results from the test box sized 1.2 m×0.9 m (Fig. 6 and Fig. 7). Thus, the size of the larger test box does not have a significant effect on the behavior of the relationship between pressure and settlement. However, the settlement in the box sized of 2 m×1.5 m was relatively higher than the box sized of 1.2 m×0.9 m, this was influenced by the restraint of the test box wall. Further reviews will be made of the furher research that is being carried out this year and next.

The load test consists of embankment load modelled from the iron bars having dimensions of 1.9 cm×1.9 cm×4 cm and it is not the form of a plate load test. The result of the embankment load test shows a high compression curve at the beginning of loading and decreases with increasing loading time. The results of this study indicate high compression at the beginning of the study, this is shown that primary compression on peat soil is fast enough at the beginning of the loading. The results of the research of Waruwu, et al. [19] using a test box sized of 7 m×3.5 m, obtained a compression behavior similar to the results of this study.

The relationship of time and settlement of embankment load test can be seen in Fig. 9 and Fig. 10. The addition of the load is done every day both for grid bamboo with pile reinforcement L of 15 cm and L of 25 cm. The relationship of time and settlement on the pile with the length of 15 cm are shown in Fig. 9, while the pile with the length of 25 cm is shown in Fig. 10. The relationship of time and settlement is approaching the same results of research by Waruwu, et al. [24].

Peat soil is known as a soil type with a dominant consolidation settlement and a rapid period of time. Waruwu, et al. [6] stated that the primary consolidation of the peat soil is about 5 minutes and secondary consolidation is about 253 hours. Based on the results of the research model test on a small laboratory scale, it was found that the time of primary consolidation was the first 10-15 minutes. For this reason, the study used one additional load every day for each stage. The results obtained showed that the increase in the settlement after 15 minutes had very little changes. The settlement in a longer time can be analyzed using the hyperbolic method [9].

The shorter pile with spacing of 10-20 cm shows the settlement that is relatively the same as a bamboo grid without piles. This can be caused by the frictional capacity of the pile which does not significantly support the embankment load. The peat compression with bamboo grid looks better compared to short pile at a spacing of 20 cm, which means that the pile does not contribute to bearing the embankment load. To reach a design level it is sometimes necessary to combine reinforcement with stage construction so that the subgrade can have sufficient bearing capacity for the final embankment load [26]. The deduced differential settlement also increased with an increase in the height of the embankment [16].

The longer pile (L of 25 cm) showed a reduction of the settlement better than the shorter pile (L of 15 cm). The spacing of pile affects the settlement, the spacing of pile that is close shows a small settlement [27]. Peat compression is generally greater at the beginning of loading. This can be caused by the primary compression that occurs in the early minutes and is followed by secondary compression [6]. The compression is becoming lighter along with the length of the pile with a closer distance. Thus, the bamboo grid with the strengthening of the pile has an impact on reducing peat compression.

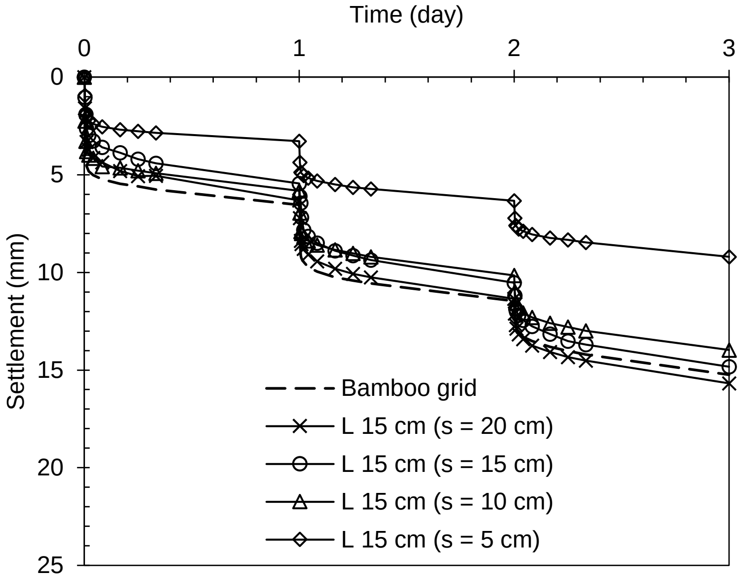

Figure 9. Relation between time and settlement for L of 15 cm.

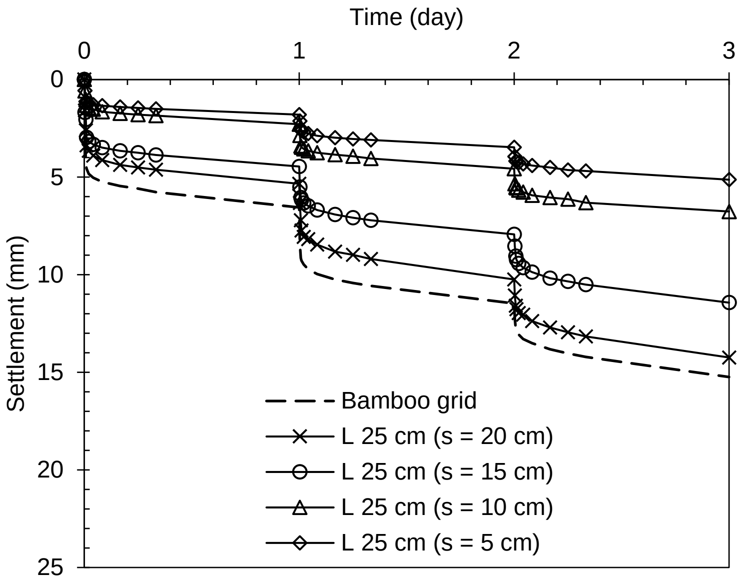

Figure 10. Relation between time and settlement for L of 25 cm.

Effects of embankment load on the behaviour of the deflections of bamboo grid can be seen at Fig. 11 and Fig. 12. The relationship of distance from center of embankment and deflections is approaching the same results of research by Waruwu, et al., [24]. The bamboo grid reinforcement with concrete piles can reduce the deflection of bamboo grid. Longer and denser piles show smaller deflection of bamboo grid compared to shorter piles with longer spacing.

The effect of pile spacing on deflection of bamboo grid for pile with the length L of 15 cm is shown in Fig. 11, while pile length L of 25 cm can be seen in Fig. 12. The deflection of bamboo grids looks smaller at shorter pile spacing, both for shorter pile and for longer piles. But the long piles showed more significant reduction of deflection than the shorter pile. It can be seen that the deflection of a bamboo grid with a short pile spaced 10-20 cm is almost the same as a bamboo grid without a pile except that the pile L of 15 cm with spacing of 5 cm showed deflection that is relatively smaller than a pile with a longer spacing. Whereas on the relatively long pile L = 25 cm shows a significant reduction in deflection of the bamboo grid.

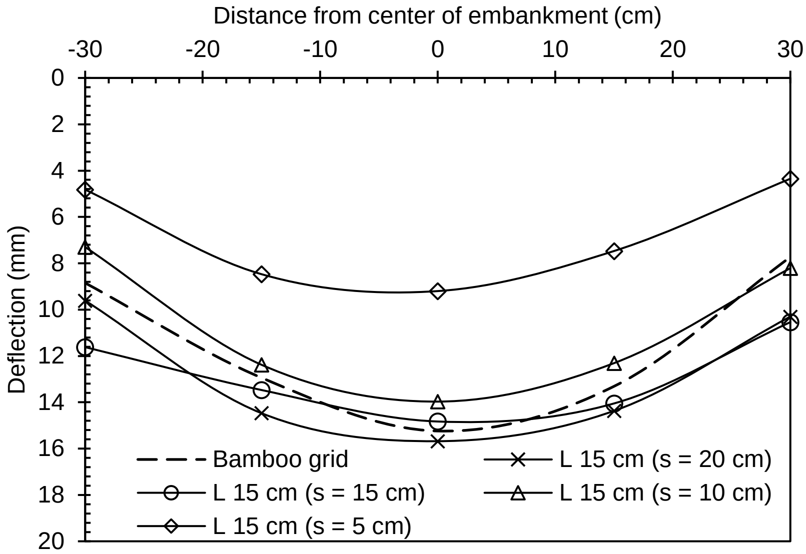

Figure 11. Deflection for L of 15 cm.

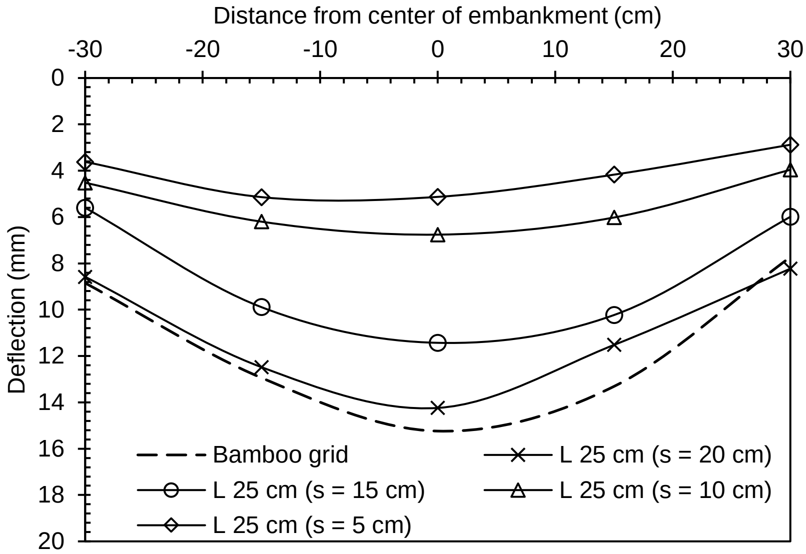

Figure 12. Deflection for L of 25 cm.

The effect of the length of the pile on the deflection of bamboo grid for a pressure of 9.08 kPa can be seen in Fig. 13. Pile with L of 15 cm – spacing of 10-20 cm and pile with L of 25 cm – spacing of 20 cm showed deflection similar to a bamboo grid without a pile. Pile L of 25 cm spacing of 20 cm showed similar deflections to pile L of 15 cm – spacing of 10 cm. The use of bamboo grid and pile concrete reinforcement can increase embankment stability and reduce deflections. Usually, the other reinforcement can increase embankment stability, reduce deformations, improvement of embankment behaviour, cost savings, increase in the feasibility of embankment construction, and the elimination of stage construction [26].

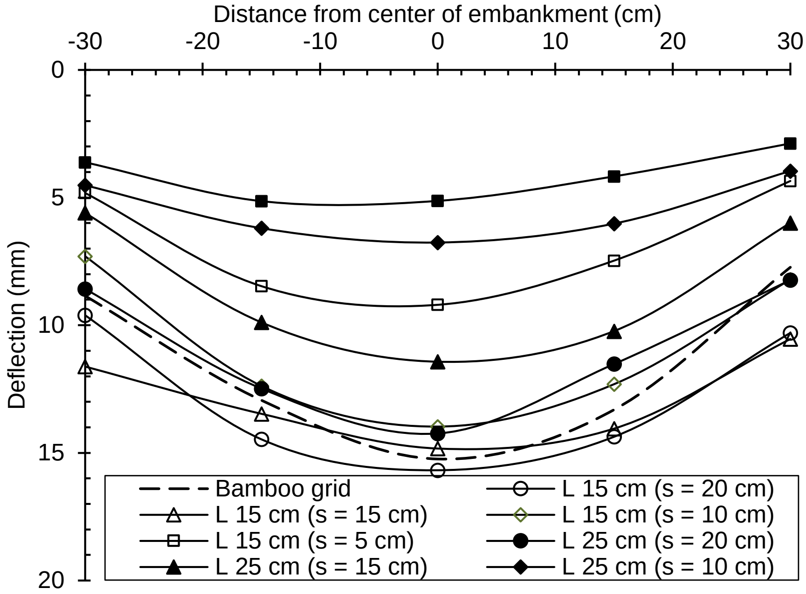

Figure 13. Comparison of deflection L of 15 cm and L of 25 cm.

The performance of concrete pile with bamboo grid as reinforcement on peat soil showed a significant effect on the pile ratio L/H = 0.3 with the ratio $s/d \leq 2.5$ and the pile L/H = 0.5 with a ratio $s/d \leq 7.5$. This approach is the same as the results of the study Oh and Sin [27], it can be estimated that the geogrid reinforcement is practically ineffective at $s/d \approx$ 6-7. The pile with ratio $s/d \approx 5$ gives a significant effect on the settlement reduction [20]. The relationship between L/H and s/d can be described in Fig. 14. This relationship can be approximated by Equation (1). Where *s* of pile spacing, *d* of pile diameter, L of the pile length, and H = peat layer thickness. If the soil layer is relatively thick, then the ratio = pile spacing to the pile diameter can be determined from the ratio of the length to the width of the bamboo grid with piles (L/B) as shown in Fig. 15 and Equation (2). This relationship is a maximum limit to obtain the influence of the installation of pile on a bamboo grid. Better results are obtained at a relatively longer pile with a shorter spacing.

$$\frac{s}{d} \leq \frac{100}{3}\left(\frac{L}{H}\right)^2 - \frac{5}{3}\left(\frac{L}{H}\right) \quad (1)$$

$$\frac{s}{d} \leq 48\left(\frac{L}{B}\right)^2 - 2\left(\frac{L}{B}\right) \quad (2)$$

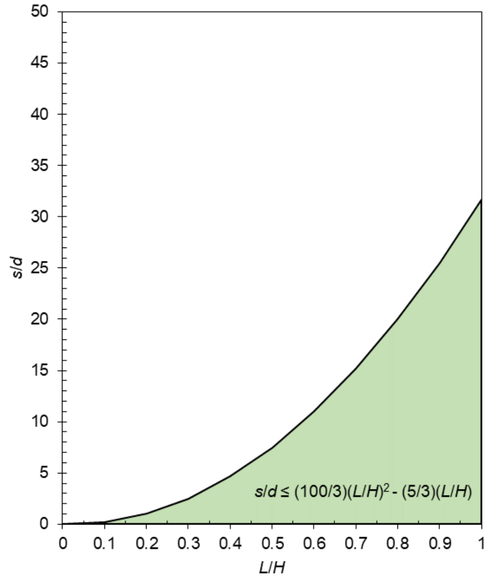

Figure 14. Relation between *L*/*H* and *s*/*d*.

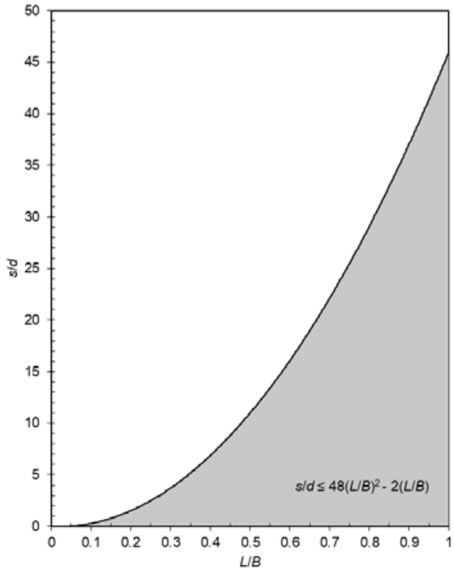

Figure 15. Relation between *L/B* and *s/d.*

4. Conclusion

The following conclusions are based on the results and discussions of this study:

1. Changes in peat soil compression behavior are found on piles with a length of more than half the thickness of the peat layer. Short piles exert less influence on peat compression. Long piles have a higher friction capacity so that decreases are smaller.

2. All types of tests show high peat compression in the initial minutes of loading and are followed by constant compression changes. Compaction of peat becomes smaller as the length of the pile grows closer. Bamboo grids reinforced with concrete piles have an impact on reducing peat compression.

3. Deflection of the bamboo grid is found to be getting smaller at a tight pile spacing, both for the short and long pile. However, the longer pile shows more significant reduction of deflection than the shorter pile. Piles with a length of more than half the thickness of the peat showed a significant effect on reducing the deflection of the bamboo grid.

4. Performance of bamboo grids with concrete piles as reinforcement on peat soil showed a significant effect on the pile ratio L/H = 0.3 or L/B = 0.25 with a ratio of $s/d \leq 2.5$ and pile L/H = 0.5 or L/B = 0.42 with a ratio $s/d \leq 7.5$. Performance of reinforcement is influenced by the ratio of the length of the piles to the thickness of the peat, the ratio of the length of the pile to the width of the bamboo grid, and the ratio of the pile spacing to the diameter of the pile. The length and spacing of the pile affect the settlement, compression, and deflection.

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