BEHAVIOR OF NAILED-SLAB SYSTEM ON PEAT SOIL UNDER LOADING

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ABSTRACT

This research observed the behavior of nailed-slab system on fibrous peat soil. The nailed-slab system which consists of slabs and piles is used as a reinforcement to support embankment on peat soil. This study aims to identify the behavior of the nailed-slab system through a series of loading in a small-scale model. The testing consisted of direct load test, stage loadtest for load increment duration of 24 hours, and loading-unloading on slab with and without piles.The embankment load was modelled from iron bars materials sized 1.9 cm x 1.9 cm and lengths of 4 cm to produce a significant settlement. The settlementwas observed at the center of the loads and at several other points.

Results show that monolithic piles reduce the settlement of slab on the peat soil. In addition, the bearing capacity of the nailed-slab system isaffected by the loadingrate and preloading time. Stageloading with longer period produces higher bearing capacity than direct load. Likewise, the embankment with loading-unloading generate better bearing capacity of the nailed-slab systemthanstageloading for load increment duration of 24 hours.

Keywords: nailed-slab system; settlement; bearing capacity; loading-unloading;fibrous peat.

A. INTRODUCTION

Peat is one of the problematic subgrade compared to inorganic soil. This type of soil has high water content, high compression, low bearing capacity,and low shear strength. Mesri and Ajlouni (2007) stated that peat deposits are the partly decomposed and fragmented remains of plants. Fibrous peat particles, which have a hollow cellular structure largely full of water, are quite large and very compressible and bendable. To that reason, improvement to peat soil is necessary to be able to support large loads and avoid compression when subjected to imposed load. Peat usually has very low shear strength and the determination of shear strength is somehow a difficult job in geotechnical because the difficulties consist of organic content and degree of humification, origin of soil, and water content (Kazemian et al., 2011)

Conventional surcharge preloading method is simple, mature and extensive application. This method involves the placement and removal of fill of similar to or greater than the permanent load. After the consolidation satisfied, the surcharge fill is often needed to remove.The shear strengths of consolidated soft ground were larger than that of unconsolidated soft ground, the increments of which were between 35%-80% (Yang et al., 2010).For improvement of peat deposits, preloading and surcharging are effective methods. Surcharging efforts corresponding to effective surcharge ratios of 1 to 2 may be required to substantially reduce post-construction secondary settlements (Mesri and Ajlouni, 2007).

Waruwu et al. (2016) statedthat preloading using the loading-unloading method is capable to speed upthe compressibility of peat soils. This method is suitable for peat soils that have a high compressibility in a long period. Preloading method is suitable for ground improvement of peat and highly organic soil (Kamao, 2016). After unloading, the settlement deformation rate is significantly reduced and settlement quickly stabilize, with no significant rebound deformation. This progress reflects that surcharge preloading is capable of accelerating the compression of a deformed subgrade soil to reduce late settlement rate, the total settlement amount, and post-construction settlement value (Ojekunle et al., 2015).Embankments can be safely constructed over peat soils using reinforcement in combination with appropriate construction rates. The major effect of reinforcement is to reduce lateral spreading and increase stability (Rowe and Li, 2005). Nailed-slab system which consists of slabs and piles can function as the reinforcement to support embankment and lateral force on peat soil. Piles installed in the ground increases the values of modulus of subgrade reaction. Piles are useful to keep the bottom of the slab in good contact with the subgrade, so that cavity formation under the slab can be minimized (Hardiyatmo, 2011).The piles function as slab stiffener; nailed-slab system has higher bearing capacity and vibration resistance (Puri et al., 2014).

This study also aims to identify the behavior of nailed-slab system through a series of loading in a small-scale models and settlement estimation from several analytical methods.

B. LITERATURE STUDY

Peat settlement can be reduced by preloading. This is essentially done by placing embankment above peat surface. Different from clay which requires longer consolidation time, particularly for thicker layer, the preloading of highly permeable peat soil is more practical due to shorter application time.Applying embankment on peat soil can improve compression behavior (Waruwu et al. 2016). To produce uniform settlement with increased bearing capacity when bearing recurring loads, a nailed-slab system is necessary as reinforcement. The installation of piles on soft soil with differential settlements can increase frictional force resistance of subgrade soil around the piles, therefore reducing differential settlement (Hardiyatmo, 2008).

The settlement of soil under the embankment happens during and after the placing of embankment. In stability analysis, the height of embankment assumed in the calculation must take into account settlement which happens during construction. Consolidation settlement can be estimated using Asaoka, hyperbolic, and finite element methods.

Asaoka Method

Asaoka method can be used to analyze consolidation settlement (Asaoka, 1978). This method employs the constants of gradient β_1 and linear intersectionβ_o on the vertical axis (abscissa) of S_n and S_{n-1} relation abscissa(Huat et al., 2004). Final settlement is the linear intersection of S_n and S_{n-1} relation with the 45° line (Li, 2014).This method generally corresponds to observation curve (Waruwu et al., 2016).

$$s_f = \frac{\beta_o}{1-\beta_1} \tag{1}$$

$$s_t = s_f(1-\exp((\ln\frac{\beta_1}{\Delta t})t)) \tag{2}$$

Hyperbolic Method

The analysis of settlement from the verification of experiment result can also employ the hyperbolic method, which was proposed by Tan et al. (1991). This method calculates parametersα and β as intersection and slope of the linear line in the relation of ratiobetween *t/s* as ordinate and *t* as abscissa(Huat et al., 2004). The hyperbolic relation between field settlement *(s)*and consolidation time*(t)*is obtained from Eq. (3) and final settlement*(s_f)*is analyzed using Eq. (4).

$$s = \frac{t}{\alpha+\beta t} \tag{3}$$

$$s_f = \frac{1}{\beta} \tag{4}$$

Finite Element Method

Finite element method (FEM) is categorized as a numerical method, with a better ability compared to conventional methods. This method is generally capable of properly modelling various complex conditions, such as the behavior of nonlinear stress-strain, non-homogenous conditions, and geometrical changes during embankment construction. The solutions to embankment cases in geotechnical field tend to opt for plane strain modelling. The finite element modelling comprised two-dimensional plane strain analysis. It was carried out using PLAXIS (Brinkgreve, 2002).

The cylindrical shape of piles can be idealized into continuous wall element(Fig.1).This affects the value of normal stiffness, flexural rigidity, and pile weight (Ryltenius, 2011).If a wide strip was taken as long as the pile spacing *(L_r=s)* 0.1 m perpendicular pictures in a row of piles, then the normal stiffness for plane strain pile can be calculated by using Eq. (5). Analogously, the flexural rigidity for plane strain pile is inputted as Eq. (6), and the weight for plane strain pile as Eq. (7).

$$EA_{psp} = \frac{EA_p}{L_r} \tag{5}$$

$$EI_{psp} = \frac{EI_p}{L_r} \tag{6}$$

$$w_{psp} = \frac{w_p}{L_r} \tag{7}$$

Whereas EA_{psp} is the normal stiffness for plane strain pile, EA_pisthe normal stiffness for one pile, $L_r$isthe pile spacing, $EI_{psp}$is the flexural rigidity for plane strain pile, EI_pisthe flexural rigidity for one pile, w_{psp}isthe weight for plane strain pile, and w_p isthe weight for one pile.

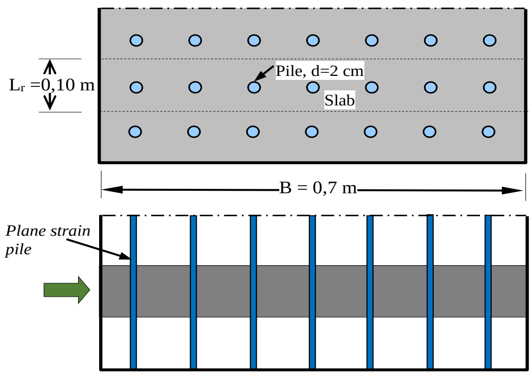

Figure 1. Plane strain model for slabs with piles

C. RESEARCH METHODS

This researchs used peat soil with specific gravity (G_s) = 1.34, density (γ_b) = 10.75 kN/m^3, moisture content (w) = 970.86%, organic content (O_c) = 99%, fiber content (F_c) = 35.21%, andash content (A_c) = 1% (Waruwu et al., 2016). Peat soil was compacted every 10 cm to the thickness of 50 cm with density closeto the filed condition. Small-scale models test performed on the concrete slabsized 30x30 cm^{2}and 70x120 cm^2, with and without piles. The concrete piles had diameter of 2 cm andlengths of 15 cm and 35 cm respectively (a real structure that corresponds to geometrical scale 1:10).The piles were casted monolithically or non-monolithically on the slabs with a distance between center to center of 10 cm.

Embankment load test with small-scale model used box testing (Fig. 2).The test box has 7 m × 3.5 m × 1.5 m in size. The thickness of peat layer is H of 50 cm, and the rest was filled with solidlayer. To produce a significant settlement, the embankment load was modelled from iron bars material sized 1.9cm x 1.9cm with the lengthsof 4cm placed on the surface of peat soil. The unit weight of iron bars (γ) was approximately 71.62 kN/m^3.

Direct load test was given for every embankment height ofh = 38 mm, equivalent to the pressure (σ) of 2.72 kPa. Loadingwasconducted by applying load sufficient to cause collapsed, and when the rate of increase in deflection is instant load and less than 0.03 mm/min. Stage load varied according to the load increment duration of 24 hours.The loading-unloading was conducted by increasing the load for 24 hours, to be later added with the second layer, followed by unloading stage then reloadingof the third and fourth layers, when the embankment load with the height of h = 57 mm, equivalent to the pressure (σ) of 4.08 kPa. Uniform and non-uniform loads were used in the experiment (Fig. 3).

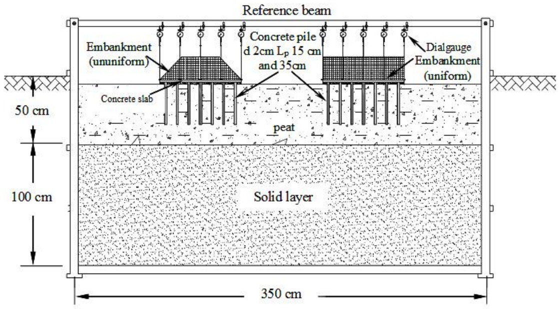

Figure 2. Thesmall-scale models

Figure 3. Photographs of embankment model test: (a) Non-uniform load; (b) Uniform load

D. RESULTS AND DISCUSSION

The result of the initial testing consisted of the result of direct load test on slabs with and without piles, comparison with gradual loading and loading-unloading. The result of the subsequent testing describes the result of embankment load test on uniform and non-uniform loading-unloading method. The results of the observational testing were then compared to the result of analyses using Asaoka Method, Hyperbolic Method, and FEM.

Direct Load Test

The direct load test resulted in higher bearing capacity in nailed-slab system as compared to slabs with no piles, particularly in monolithic piles (M) with slabs (Fig. 4). In non-monolithic piles (NM), the increase in bearing capacity took place only to longer piles, while shorter piles generated the bearing capacity which was almost similar to slabs without piles (Fig. 5).

Effect of Loading Rate

The time required during the loading can affect peat bearing capacity under loading, either for slabs without piles or slabs with piles (Fig. 6 and Fig. 7). Longer loading period gives better bearing capacity improvement compared to direct loading. This was apparent in the load test with load increment duration (LID) of 24-hours, where the bearing capacity was higher than that of the direct load test.

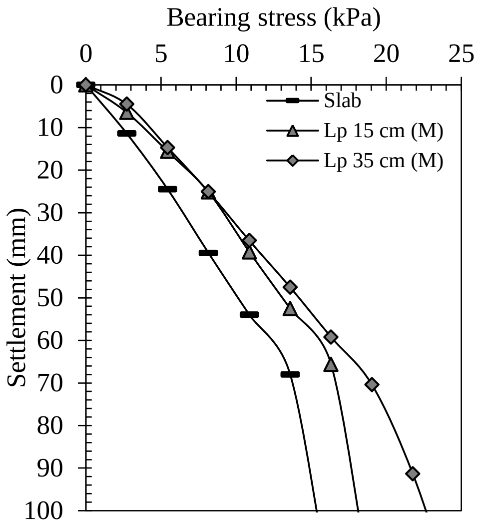

Figure 4. Bearing stress-settlement at the center curves for slab with monolithic piles

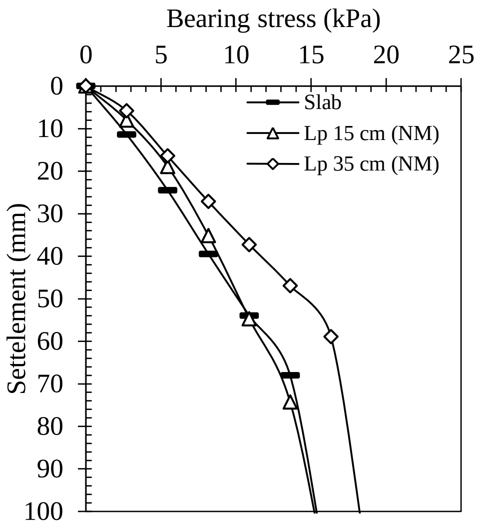

Figure 5. Bearing stress-settlement at the center curves for slab with non-monolithic piles

Test system using loading-unloading presented better result compared to stage loading with load increment duration (LID) of 24-hours, where peat compression change was larger at initial loading, and gradually reduced at larger loads which consequently increased the bearing capacity of the nailed-slab system.

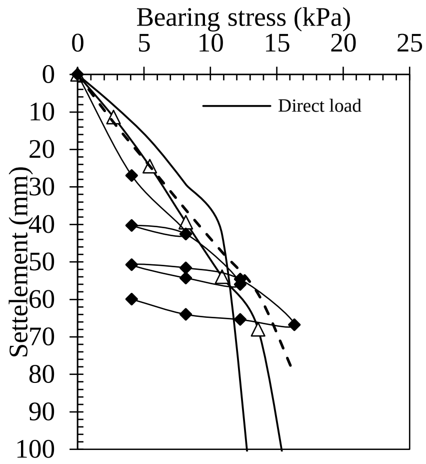

Figure 6. Typical settlement data at the center under different load rate

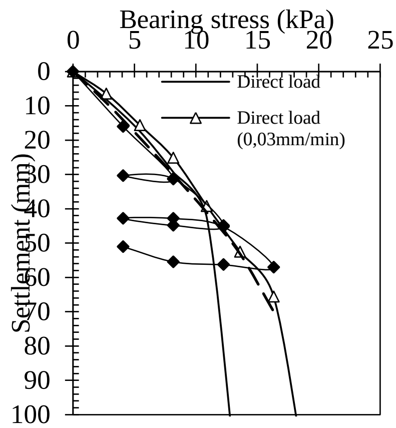

Figure 7. Typical settlement data at slabs with 15-cm piles under different load conditions

Result of Embankment Loading

The nailed-slab system behavior under loading is distinguished based on two loading sequences (uniform and non-uniform loads). The result of the tests on these uniform and non-uniform loads can be found in Fig. 8 and Fig. 9. The tests were performed on slabs without piles, slabs with monolithic piles (M) and slabs with non-monolithic piles (NM). Both types of test showed that pile length(L_p) of 35 cm and monolithic piles resulted in lower settlement compared to pile length (L_p) of 15 cm and non-monolithic piles.

Effect of pile to deflection of slab as seen in Fig. 10 and Fig. 11, the piles were capable of reducing slab deflection. Slabs with monolithic piles were more stable under loading. This can be seen from the tendency of flatter deflection in slabs with monolithic piles compared to slabs with non-monolithic piles. The length and monolithic piles were stiffer and more stable when subjected to imposed embankment load.

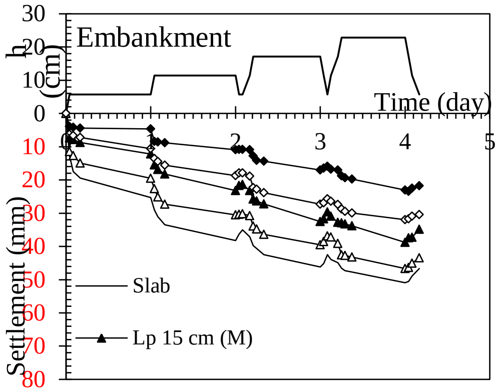

Figure 8. Effect of load increment to settlement at the center for non-uniform load

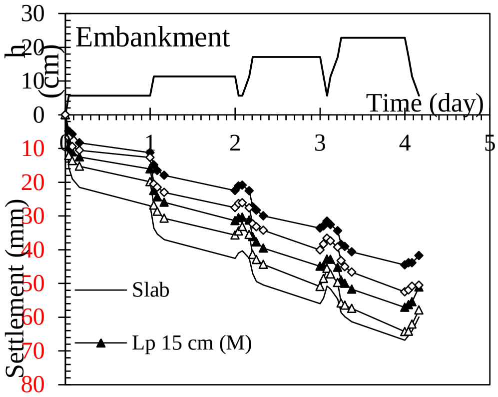

Figure 9. Effect of load increment to settlement at the center for uniform load

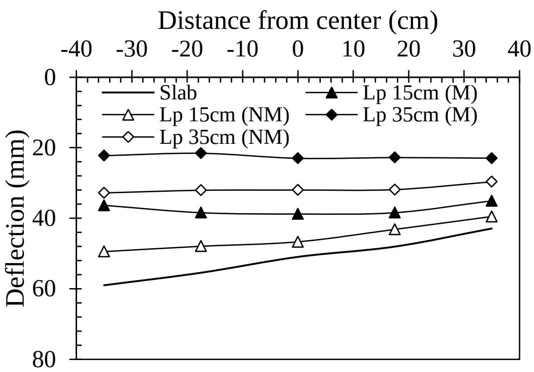

Figure 10. Deflection alongslabfor non-uniform loadof 16.33 kPa

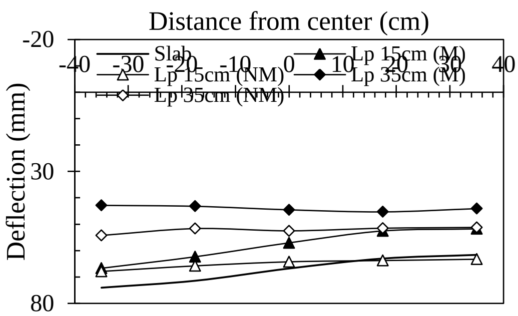

Figure 11. Deflection along slab for the uniform load of16.33 kPa

Effect of LoadingSequences

The use of different load sequences on three types of testing generated similar effect on the settlements (Fig. 12 to Fig. 14). The settlement due to non-uniform loads was lower than the settlement due to uniform loads. Peat compression behavior due to non-uniform loads was less sloping than the peat compression behavior due to uniform loads. Apart from smaller loading, this may be caused by loading-unloading system application. The embankment with loading-unloading showed decreasing peat compression, which happened not only to non-uniform loads, but also to uniform loads.

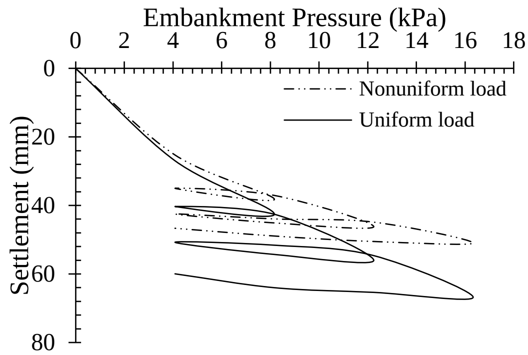

Figure 12. Relation between pressure and settlement of slab

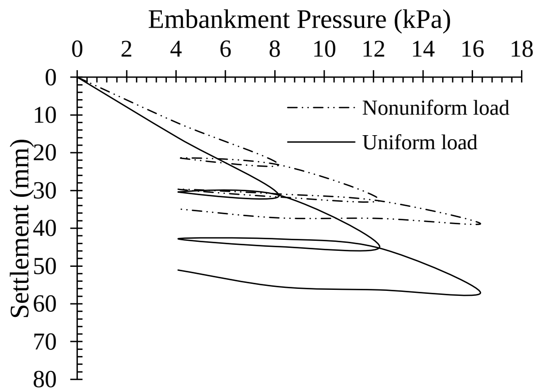

Figure 13. Relation between pressure and settlement of slab with 15-cm piles

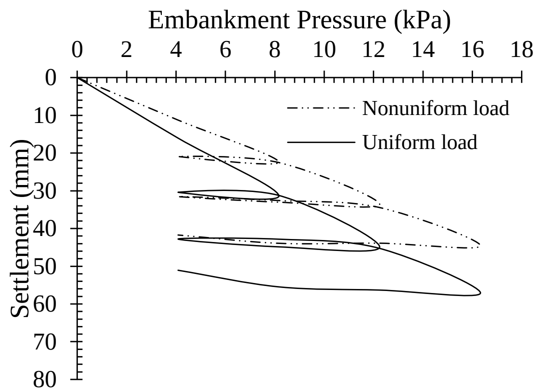

Figure 14. Relation between pressure and settlement of slab with 35-cm piles

The Behavior of Peat Compression underEmbankment with Loading-Unloading

The effect of theembankment withloading-unloading can be seen in Fig. 15 and Fig. 16. During initial load, peat compression was very high. However, following unloading with removal of preloading, rebound due to swelling occurred immediately for all typical experimental (Fig. 15). Soil swelling during unloading was apparently affected by piles installation, where soil swelling in slabs with piles was smaller compared to in slabs without piles. Figure 16 shows the effect of loading cycle on the compression behavior. The more frequent the loading cycle, the lower peat compression, particularly in slabs without piles and slabs with shorter piles (Fig. 16.a and Fig. 16.b). The change in compression due to loading-unloading system in slabs with piles length of 35 cm showed insignificant result (Fig. 16.c).

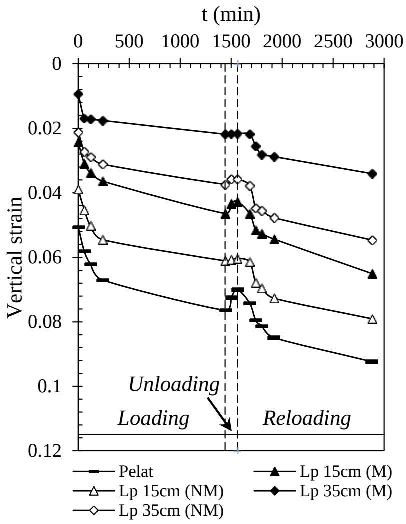

Figure 15. Relation between time and strain under loading-unloading

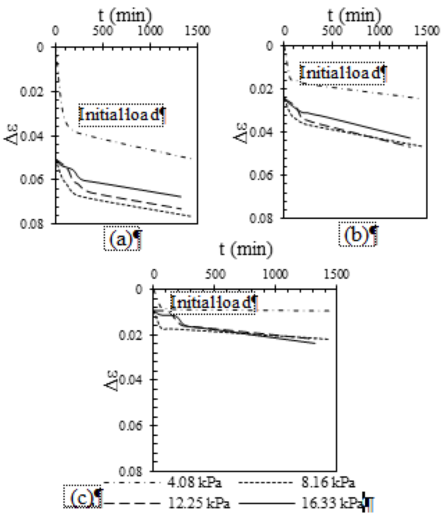

Figure 16. Compression after unloading on slabs: (a) without piles; (b) 15-cm piles; (c) 35-cm piles

Comparison between Calculated and ObservedSettlement

As seen from Fig. 17, the calculated settlement using Asaoka and hyperbolic methods generated almost similar results with field observation. Similarly, FEM result was not so different from the observation on slabs without piles.Fig. 18 presents the comparison between the calculated and observed data. The calculated settlement using Asaoka method, hyperbolic method, and numerical FEM method showed slightly higher results compared to the observation data of slabs with piles. In this case, field application is better as safer results were shown.

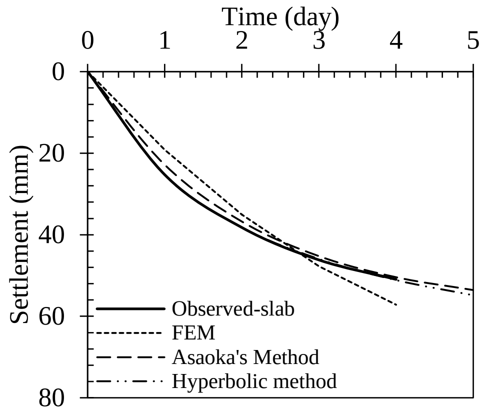

Figure 17. Comparison betweencalculated and observed settlement of slabfor center loading

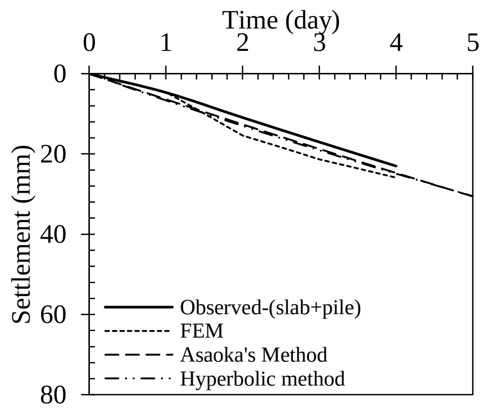

Figure 18. Comparison between calculated and observed settlement of slab with 35cm pilescenter loading

E. CONCLUSION

1. The loading rate and preloading timeaffects the bearing capacity of nailed-slab system and the characteristics settlement of peat soil. Stage loading with longer period produces higher bearing capacity than direct load. Likewise, the loading-unloading generate better bearing capacity of the nailed-slab system thanstage loading for LID of 24 hours.

2. The embankment with loading-unloading affect the compression behavior. The initial settlement is largein loading stage, but the increment settlement gradually became smaller with time in reloading stage.
3. Piles are capable to reducethe settlement and deflection of the slab. Slab with monolithic piles are more stable andstiffer than non-monolithic piles under loading.

ACKNOWLEDGMENT

The authors would like to thank the head and the technicians of the Soil Mechanics Laboratory of Gadjah Mada University for their help during the experimental work. Great appreciation is also given to Ministry of Research, Technology and Higher Education of the Republic of Indonesia for the financial support.

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