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3-Dimensional Numerical Simulation of Nailed Slab System Settlement Behavior on Soft Soil

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ABSTRACT

The design of the YIA airport rail line is on soft soil with a depth of 12-16 m. The design of the rail line uses a 4 m high embankment. Reinforcement is carried out by the method of a nailed slab system. The nailed slab system consists of a monolithically connected slab and pile. This method is believed to be able to reduce the settlement that occurs in the foundation soil effectively. This study aims to determine the effect of using a nailed slab system that varies in length, distance, and arrangement. The data used are boring and laboratory tests. Effect of variations in length (8 m; 10 m; 12 m and 14 m), distance (0.8 m; 1.2 m; 1.6 m; and 2 m), and pile arrangement (uniform; V and W) on soil settlement foundation is done with the RS3 program. The results showed that each additional 2 m of pile length could reduce the total settlement by 48.63%-82.31% of the unreinforced foundation soil. The decrease in permits was fulfilled at the length of the piles of 12 m and 14 m. Pile spacing of 0.8 m, 1.2 m, 1.6 m, and 2 m reduced the total settlement by 69.47%, 68.78%, 67.22%, and 60.90%, respectively. On piles with a length of 12 m, distances of 0.8 m and 1.2 m fulfilled the allowable reduction. The use of the V arrangement gave the greatest reduction of 71.77% while the uniform arrangement was 68.78% and the W arrangement was 68.56%. The use of a nailed slab system as foundation soil reinforcement due to embankment load can reduce settlement effectively.

1. Introduction

Indonesia is a country with 20 million hectares of soft soil or 10 percent of the total land owned. Soft soil in Indonesia is spread all over the mainland, especially in the area around the coast [1]. Soft soil has low permeability, low shear strength, and high compressibility. These properties cause soft soil to have a low bearing capacity, and large deformation when getting additional stress. Thus, reinforcement is needed to strengthen or improved before construction is carried out on soft soil. One of the construction projects in Yogyakarta, namely the YIA Airport Railway, was built on soft soil with varying depths of 12-16 m. The N-SPT value in this layer ranges from 0-3 with soft clay soil types. From DED, it was found that an embankment with a height of 4 m above the layer will be constructed. Thus, an analysis is needed to determine the bearing capacity of the foundation soil and the value of settlement that occurs after the construction is built. Then, reinforcement or improvement is needed to support the embankment on the soft soil.

As described by [2] that the reinforcement of embankment construction on soft soil can be carried out by using piles. Reinforcement with piles is effective in increasing the bearing capacity of the foundation soil and is easy to construct. The piles used can be either end-bearing or skin-resisting piles. According to the type of construction, pile slabs with standard types, inclined, slabs as roads and raised piles can be used.

One of the reinforcement systems that utilize the interaction of slabs and piles to distribute the load is the nailed slab system. The nailed slab system is a soil reinforcement construction that consists of slabs and piles connected monolithically. In general, the nailed slab system consists of reinforced concrete slabs with a thickness of 12-20 cm supported by mini concrete piles with a length of 150-200 cm and a diameter of 15-20 cm as shown in Figure 1. Area A is the area supported by each pile on the system.

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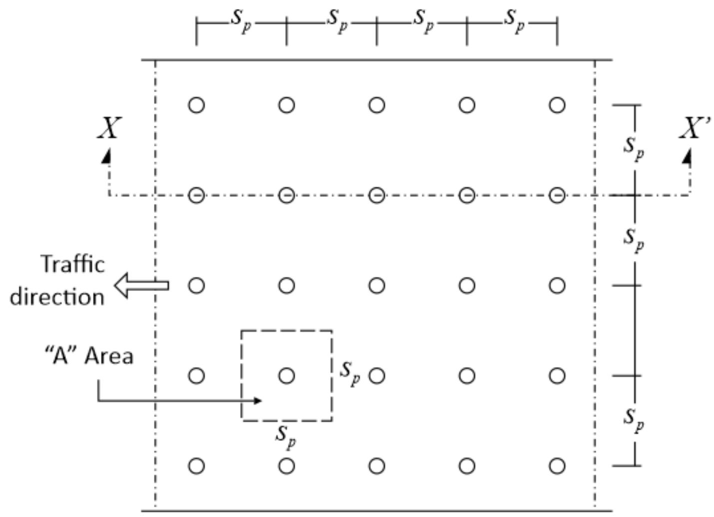
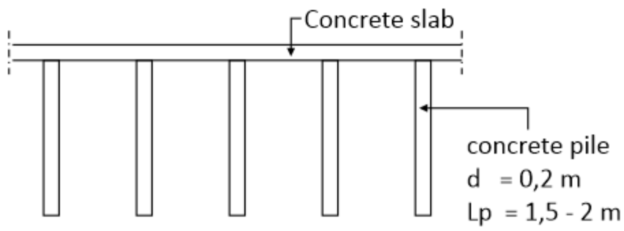


(a) Nailed Slab System Plan

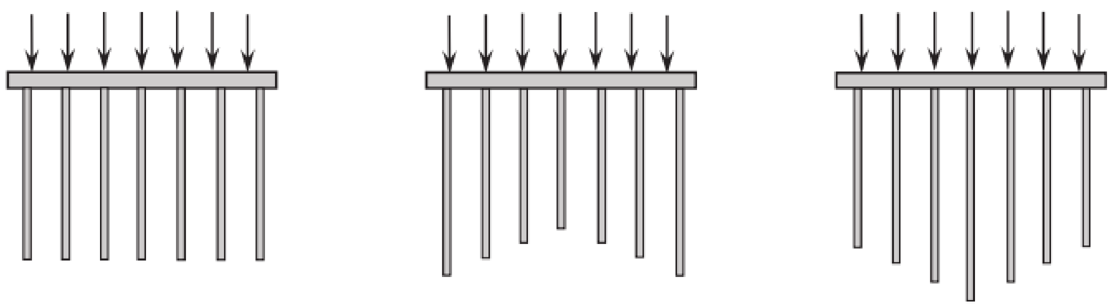


(b) Intersection *X-X'*

Figure 1. Nailed Slab System; (a) Nailed Slab System Plan; (b) Intersection *X-X'* [3]

The pile function is to increase the bearing capacity and maintain the interface between the slab and soil to prevent excessive deformation. The nailed slab system has better resistance to repetitive loads. The nailed slab system piles can reduce the differential settlement along the slab, therefore the system is suitable for use in foundation soils that are affected by the differential settlement, such as soft clay [4]. The increase in pile spacing offsets the benefits of increasing pile length to reduce settlement. Therefore, a trade-off between the pile spacing and length should be examined to achieve an economical design [5].

Pile spacing, pile length, pile arrangement, and slab thickness on the nailed slab system are parameters that affect the bearing capacity and settlement behavior of the foundation soil. [6] found that the pile arrangement in the raft foundation reinforced with the V arrangement was greater in reducing settlement compared to the uniform arrangement and W arrangement shown in Figure 2. The total pile length in each arrangement is the same, therefore the total weight between the arrangement is proportional. The length difference between W and V shapes is 3 m.



(a) (b) (c)

Figure 2. Various Pile arrangement: (a) Uniform; (b) *W*; (c) *V* [6]

The required settlement limit for railroad embankments refers to [7] as less than or equal to 10 cm. With the description above, in this study, an analysis of the behavior of foundation soil settlement due to a load of railroad embankments on soft soil with the reinforcement of the nailed slab system was carried out with various pile lengths, pile distance, slab thickness, and pile arrangement. Analysis of the nailed slab system was carried out with the RS3 program. A series of numerical analyzes have been carried out to fulfill the objectives of this study.

2. Research Method

2.1 Immediate Settlement

Immediate settlement (S_i) was analyzed according to [8]. The formulation of S_i, expressed as Equation 1.

$$S_i = I_1 I_0 \frac{q_b B}{E_u} \tag{1}$$

The immediate settlement of footing on clay can be evaluated based on the representative value of Young's modulus Eu. Where the I_1 is the influence factor for the shape of the footing and the thickness of the clay, I_0 is the factor for the depth of embedment, q_b is unit load at the base of the footing and B is the pile width.

2.2 Consolidation Settlement

The consolidation settlement calculation is based on the type of clay in the field. Clay is divided into two conditions, normally consolidated (NC) and Overconsolidated (OC). This condition is determined from Equation 2.

$$OCR = \frac{p_c'}{p_o'} \tag{2}$$

Where p_c' is the preconsolidation pressure value and p_o' is the overburden pressure of the soil at a certain depth. The values of p_c' and p_o' were obtained from the graph of e log p of the consolidation test results. The value of OCR=1 indicates that the soil is normally consolidated and OCR>1 is overconsolidated.

Consolidated settlement value, Sc is calculated based on soil type using Equation 3 for NC clay. While on OC clay it is determined by Equation 4 for the value of $p_1' < p_c'$ and Equation 5 for $p_1' > p_c'$.

$$S_c = C_c \frac{H}{1 + e_o} log \frac{p_1'}{p_o'} \tag{3}$$

$$S_c = C_r \frac{H}{1 + e_o} log \frac{p_1'}{p_o'} \tag{4}$$

$$S_c = C_r \frac{H}{1 + e_o} log \frac{p_c'}{p_o'} + C_c \frac{H}{1 + e_o} log \frac{p_1'}{p_o'} \tag{5}$$

Where S_c is the consolidation settlement (m), C_r is the recompression index, C_c is the compression index, H is the soil thickness (m), p_c' is the prakonsolidation pressure (kN/m^2), e_o is the void ratio, Δp is the stress increment (kN/m^2), p_o' is the initial overburden pressure (kN/m^2).

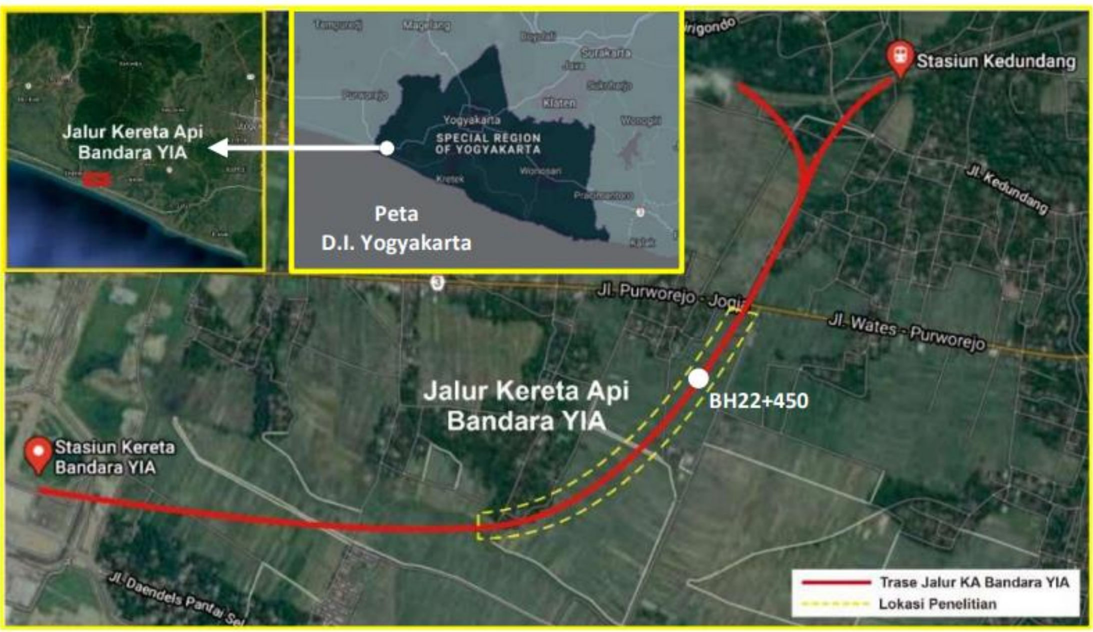


Figure 3. Research Location

2.3 Stress Distribution

The soil stress increment occurs due to the influence of the load on the surface. The additional value of the stress due to the trapezoidal embankment load is calculated by Equation 6, where I was the influence factor and q is the embankment distributed load (kN/m^2) [4].

$$\Delta\sigma_z = qI \tag{6}$$

This study using data from boring log and laboratory test result. Then, the parameters obtained from the test results are used as input values in the RS3 numerical simulation program.

2.4 Research Location

The research located in the YIA Railway Station on boring number of BH 22+450 as showed on Figure 3. The project located in alluvial area along the coastal line.

2.5 Soil Data

The soil investigation result shows that the soft clay with N-SPT value of 2 existed at 0-16 m depth. Then, followed by silty sand, silty clay, and sandstone. The groundwater table is at 1 m depth.

2.6 Soil Parameter

Soil parameters used in the RS3 program were specific gravity, Poisson ratio (v), modulus of elasticity (E_s), cohesion (c_u), internal friction angle (φ), and coefficient of permeability (K). Soil behavior was determined by elastic-plastic with Mohr-Coulomb failure criterion. The parameter used in the analysis is shown in Table 4.

2.7 Structure Parameter

Table 5 shows the structure parameter of the slab and pile used were specific gravity (γ), Poisson ratio (v), and young modulus (E_c). The input value of slab and pile refers to [9].

2.8 Nailed Slab System Parameter Variation

Variation of pile length, pile spacing, and slab thickness showed in Table 1 dan Table 2. The variation of the pile arrangement refers to [6] where the total length in a row of piles in the entire arrangement is the same. The pile plan, variation of pile and pile length arrangement is shown in Figure 5, Figure 6, and Table 3 respectively. The used load is according to the 4 m embankment height.

Table 1. Pile Length Variation

Pile spacing, S_p (m)	Pile length, L_p (m)			
1.2	8	10	12	14

Table 2. Pile Spacing variation

Pile length, L_p (m)	Pile spacing, S_p (m)			
12	0.8	1.2	1.6	2

Table 3. Pile Length Variation

Pile number	Pile length, L (m)		
	Uniform	*V*	*W*
P_1-P_4 and P_{15}-P_{18}	12	11.2	12.7
P_5-P_7 and P_{12}-P_{14}		12.2	11.7
P_8-P_{11}		13.2	10.7

2.9 Soil Parameter

The research model and soil stratigraphy are shown in Figure 4 including soil profile, embankment, pile, and configuration.

Table 4. Soil Input Parameter

Parameter	Soil Classification						
	Soft Clay	*Soft Clay*	*Silty Sand*	*Silty Clay*	*Sand-stone*	Embankment	Unit
Behavior	Un drained	Un drained	drained	Un drained	drained	drained	-
γ_b	16	15	18	17	20	17	kN/m^3
E_u	2200	2200	30000	25000	45000	25000	kN/m^2
v	0.3	0,3	0.2	0.3	0.2	0.2	-
c_u	23	29	1	57	1	10	kN/m^2
φ	10	9	35	4	45	35	°
e	1.34	1.49	0.5	1.53	0.5	0.5	-
K	3.5×10^{-4}	3.4×10^{-4}	1.00	1.2×10^{-4}	1.00	1×10^{-3}	m/day
Cv	0.00457	0.00456	-	0.0022	-	-	m^2/day
mv	0.091	0.092	-	0.063	-	-	m^2/kN
Cc	0.821	0.688	-	0.628	-	-	
Cr	0.078	0.095	-	0.036	-	-	

Table 5. Structure Input Parameter [9]

Parameter	Slab	Pile	Unit
Material model	Elastic	Elastic	-
f_c'	29	29	MPa
E	25,310,274	25,310,274	kN/m^2
ν	0.25	0.25	-
γ	24	24	kN/m^3
Thickness/Diameter	0.15	0.2	m

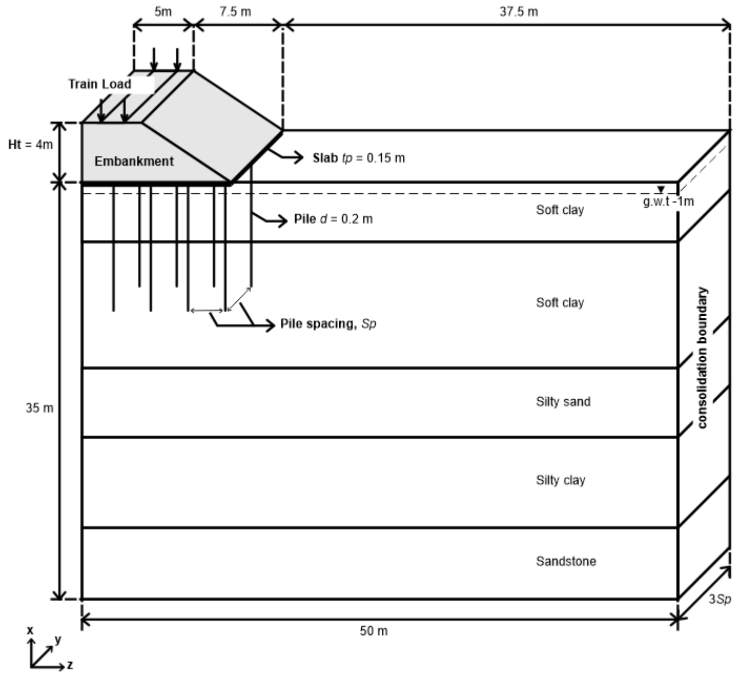


Figure 4. Soil and Structure Model

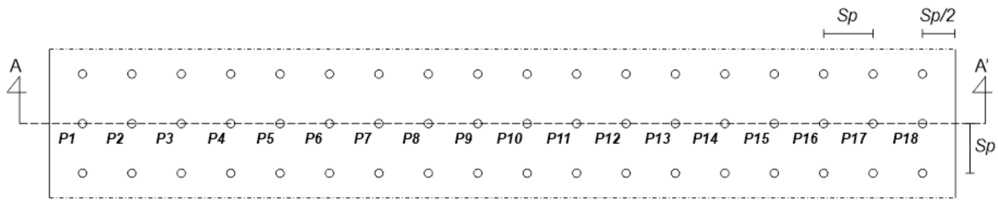
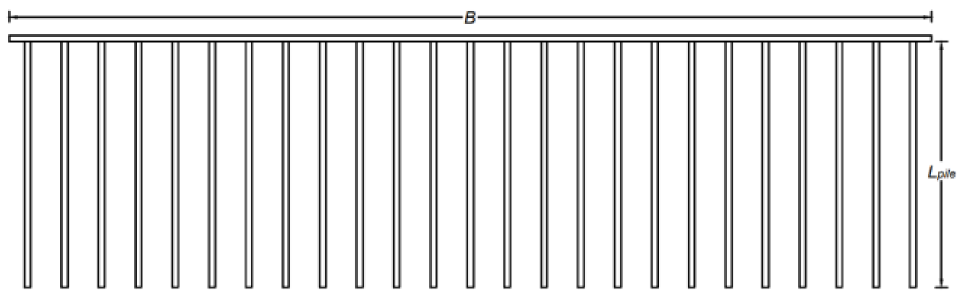
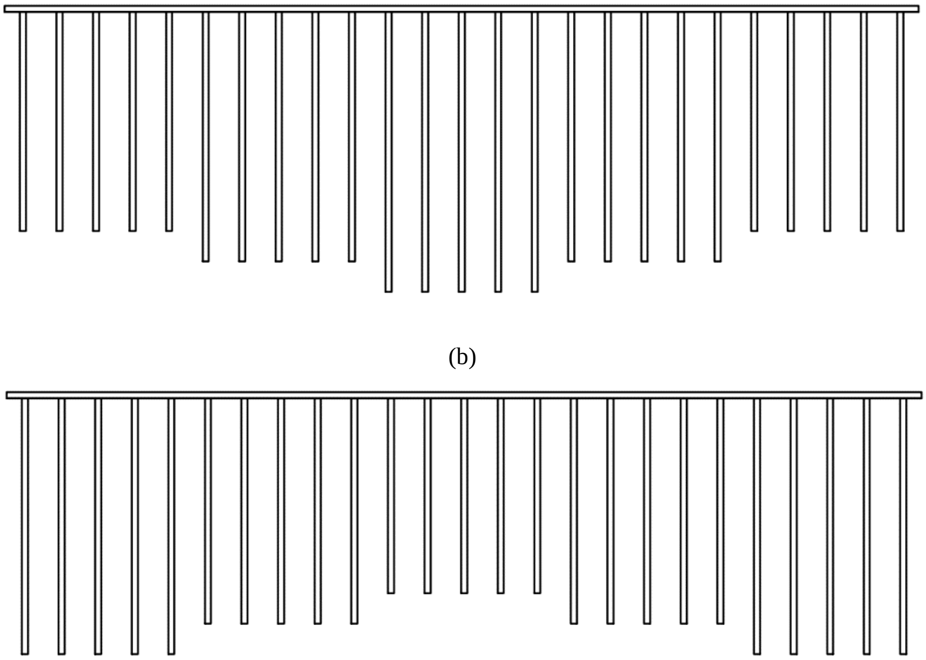


Figure 5. Pile Arrangement Plan



(a)



(b)

(c)

Figure 6. Varioust Pile Arrangement; (a) Uniform, (b) *V* Shape and (c) *W* Shape

2.10 Rocscience RS3 Modeling

The nailed slab system settlement analysis was carried out using the 3-dimensional numerical program RS3. The interface value between the soil and the structure is described by the normal stiffness (K_n) and the shear stiffness (K_s) was determined by Equation 6 and Equation 7 refers to [10].

$$K_s = \frac{G_i}{t_i} \tag{6}$$

$$K_n = \frac{E_{oed,i}}{t_i} \tag{7}$$

The value of shear modulus and modulus elasticity at the interface of G_i and E_i is obtained from Equation 8 and Equation 9. The value of the shear modulus (G_s) and the modulus elasticity of the soil (E_s) is obtained from Equation 10 and Equation 11. The reduction factor value between the structure and soil is shown in Table 6**.**

$$E_i = 2G_i \cdot \frac{1 - v_i}{1 - 2v_i} \tag{8}$$

$$G_i = R_{inter}^2 \cdot G_s \tag{9}$$

$$G_s = \frac{E_s}{2(1 + v')} \tag{10}$$

$$E_s = 500 - 1500\, c_u \tag{11}$$

Table 6. Material Interface Value (R_{inter}) [11]

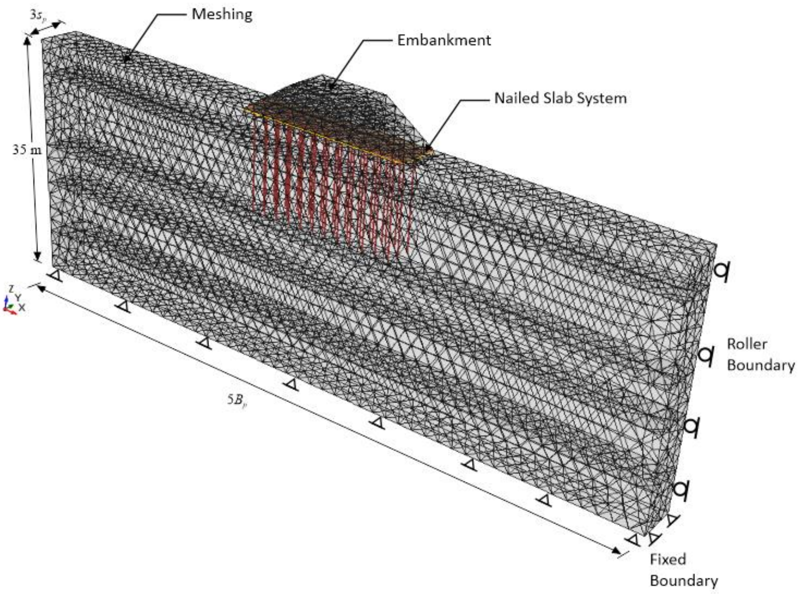
Material	R_{inter}
Clay-steel	0.50
Clay-concrete	0.70-1.00
Sand-steel	0.60
Sand-concrete	0.80-1.00
Soil-Geotextile	0.50-0.90

The interface was defined with zero cohesive strength and 2/3 of the cohesive strength of clay, whereas the interface was assumed to have zero cohesive strength and 2/3 of the friction strength of sand for a cohesionless material [12].

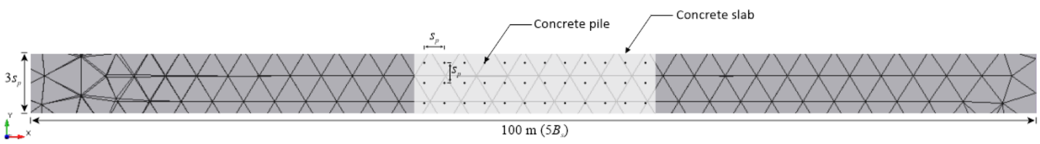
Figure 7 shows the geometric model with a fine-sized 10-nodal tetrahedral mesh type. The model restrained is based on [13]. The support at the geometric boundary of the xz plane is locked to the y direction, the yz plane is locked to the x,y direction, and the bottom is locked to the x,y,z direction or restrained. The analysis stage is shown in Table 7.

Table 7. Construction and Analysis Stages

No.	Construction stages
1.	Initial Condition
2.	Nailed Slab (NS) Installation
3.	1 m Embankment
4.	2 m Embankment
5.	3 m Embankment
6.	4 m Embankment
7.	Consolidation



(a) Meshing Model



(b) Pile Arrangement

Figure 7. 3-Dimensional Geometry Model

3. Research Result

3.1 Influence of Pile Length

Based on the results of the analysis, it was found that the use of the nailed slab system can reduce the settlement that occurs due to the embankment load properly. The nailed slab system used to determine the effect of pile length has a distance of S_p = 1.2 m and slab thickness, T_p = 0.15 m. The pile length used was 8 m, 10 m, 12 m dan 14 m. Table 8 shows the settlement that occurs in each phase of construction and consolidation. The value of the settlement is reduced as the length of the pile increases. The total settlement due to embankment load on the foundation soil is reduced by 48.63%-82.30% for every 2 m addition of pile length.

Figure 8 shows the relation between the use of the nailed slab system and the consolidation settlement at various pile lengths. The results of the analysis show that the length of the pile greatly affects the reduction in the settlement because the longer the pile, the greater the resistance of skin friction. This increases the bearing capacity of the foundation soil and the safety factor of the nailed slab system

Table 8. Immediate and Consolidation Settlement on Various Pile Length

Type of Settlement	Analysis Stages	Settlement (m)				
		Without NS	L_p = 8 m	L_p = 10 m	L_p = 12 m	L_p = 14 m
Immediate	Initial Condition	0	0	0	0	0
	NS Installation	0	0.007	0.006	0.006	0.005
	1 m Embankment	0.042	0.024	0.018	0.017	0.013
	2 m Embankment	0.087	0.042	0.030	0.028	0.021
	3 m Embankment	0.129	0.058	0.042	0.039	0.029
	4 m Embankment	0.164	0.072	0.054	0.048	0.036
Consolidation	Post Embankment	0.143	0.086	0.067	0.048	0.018
Total Settlement	=	0.307	0.158	0.121	0.096	0.054

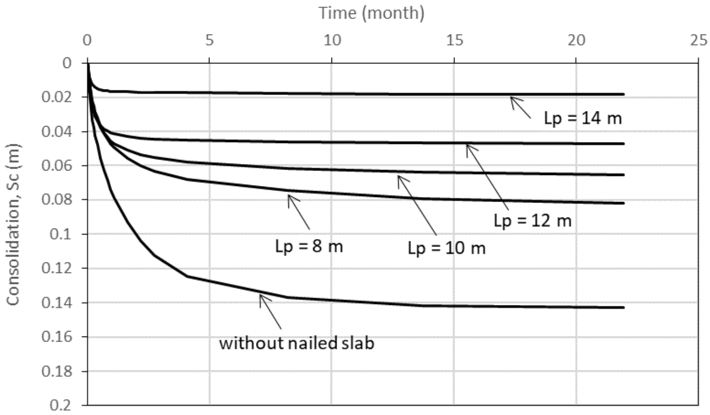


Figure 8. Consolidation Settlement Graphic on Various Pile Length

3.2 Influence of Pile Spacing

The effect of pile spacing is also carried out in this study. Pile spacing S_p is varied from 0.8 m, 1.2 m, 1.6 m, and 2 m or 4*D*, 6*D*, 8*D*, and 10*D*. The pile length, L_p used to check the pile spacing effect is 12 m. The results of the analysis show that the immediate settlement of the foundation soil increases with the increase in pile spacing as shown in Table 9. Immediate settlement at the end of the construction period increases by 9%-20% for every additional 2*D* distance. The consolidation settlement that occurs in the foundation soil also increases as the pile spacing increases. However, it was found that the pile distance of 1.2 m reduced the consolidation settlement better than other distances. Figure 9 shows a graph of the consolidation settlement that occurred due to various distances. The settlement increases as the distance between the piles increases, S_p. Due to consolidation settlement, S_p = 1.2 m gives the greatest reduction from other distances.

Table 9. Immediate and Consolidation Settlement on Various Pile Length

Type of Settlement	Analysis Stages	Settlement (m) S_p = 0.8 m	S_p = 1.2 m	S_p = 1.6 m	S_p = 2 m
Immediate	Initial Condition	0	0	0	0
	NS Installation	0.008	0.006	0.004	0.003
	1 m Embankment	0.017	0.017	0.014	0.013
	2 m Embankment	0.027	0.028	0.026	0.026
	3 m Embankment	0.036	0.039	0.038	0.042
	4 m Embankment	0.044	0.048	0.050	0.060
Consolidation	Post Embankment	0.050	0.048	0.051	0.060
Total Settlement	=	0.094	0.096	0.101	0.120

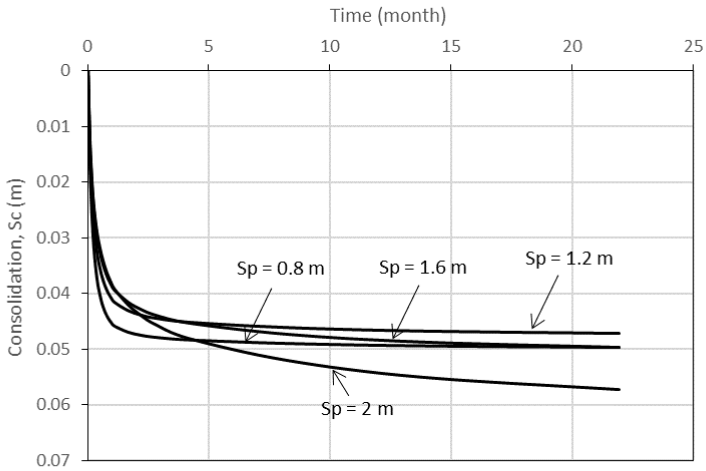


Figure 9. Consolidation Settlement Graphic on Various Pile Length

3.3 Influence of Pile Configuration

The results of the influence of the pile arrangement on settlement are shown in this study. The arrangement used is uniform, *V* and *W*. In the V arrangement the longer pile is placed at the center of the load, while in the *W* arrangement, the shorter pile is placed at the center of the embankment load. The total length of the poles used is 216 m. Table 10 shows that the settlement of piles with *V* arrangement reduces settlement better than other piles, which is 71.77%. The uniform pile reduces the settlement by 68.78% and the W arrangement by 68.56%

Figure 10 shows the consolidation settlement relation in each pile arrangement. It is found that the settlement that occurs in the uniform arrangement and *W* is in adjacent values. In the *V* pile arrangement, the settlement that occurs is reduced by 10% better than others. The deflection that occurs on the slab is shown in Figure 11.

Table 10. Immediate and Consolidation Settlement on Various Pile Length

Type of Settlement	Analysis Stages	Settlement (m)		
		Uniform	*V*	*W*
Immediate	Initial Condition	0	0	0
	NS Installation	0.006	0.005	0.006
	1 m Embankment	0.017	0.015	0.017
	2 m Embankment	0.028	0.025	0.028
	3 m Embankment	0.039	0.034	0.039
	4 m Embankment	0.048	0.043	0.048
Consolidation	Post Embankment	0.048	0.044	0.048
Total Settlement	=	0.096	0.087	0.097

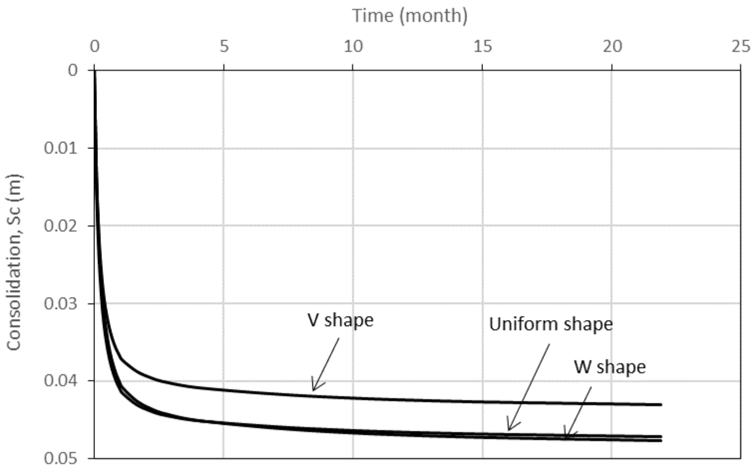


Figure 10. Consolidation Settlement Graphic on Various Pile Length

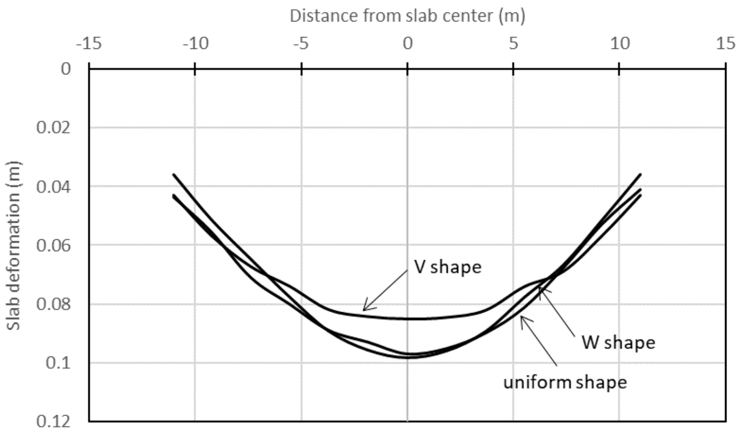


Figure 11. Slab Deformation on Various Pile Arrangement

4. Conclusion

Based on the study results, it can be concluded that the use of a nailed slab system as soil reinforcement in supporting embankment loads can reduce the settlement behavior that occurs. The use of a nailed slab system can reduce the immediate settlement and consolidation settlement effectively.

Variations in length, spacing, and arrangement of the pile influenced the reduction of settlement. The longer pile increases the settlement reduction. The increase in pile spacing affected greater settlement. Pile spacing of 1.2 m provides the greatest reduction in consolidation settlement among others.

The V pile arrangement gave the most effective settlement reduction. The V shape provides greater skin resistance at the largest load concentration, so the settlement is reduced effectively.

References

[1] Departemen Permukiman dan Parasarana Wilayah, "Panduan Geoteknik 1 Proses Pembentukan dan Sifat-sifat Tanah Lunak," *Pedoman Kimpraswil No Pt T-8-2002-B*, no. 1, p. 162, 2002.

[2] Pusat Litbang Prasarana Transportasi, "Panduan Geoteknik 4 Desain dan Konstruksi," *Pus. Litbang Prasarana Transp.*, no. 1, 2001.

[3] H. C. Hardiyatmo, *Analisis dan Perancangan Fondasi II*, 4th ed. Yogyakarta: Gadjah Mada University Press, 2018.

[4] H. C. Hardiyatmo, *Mekanika Tanah 2*, 6th ed. Yogyakarta: Gadjah Mada University Press, 2019.

[5] A. Sinha and A. M. Hanna, "3D Numerical Model for Piled Raft Foundation," *Int. J. Geomech.*, vol. 17, no. 2, p. 04016055, 2017, doi: 10.1061/(asce)gm.1943-5622.0000674.

[6] S. Mali and B. Singh, "3D Numerical Modeling of Large Piled-Raft Foundation on Clayey Soils for Different Loadings and Pile-Raft Configurations," *Stud. Geotech. Mech.*, no. December, 2019, doi: 10.2478/sgem-2019-0026.

[7] Badan Standarisasi Nasional, "Sni 8460-2017," *Persyaratan Peranc. Geotek.*, vol. 8460, p. 2017, 2017.

[8] K. C. Foye, P. Basu, and M. Prezzi, "Immediate Settlement of Shallow Foundations Bearing on Clay," *Int. J. Geomech.*, vol. 8, no. 5, pp. 300–310, 2008, DOI: 10.1061/(ASCE)1532-3641(2008)8:5(300).

[9] A. Puri, H. C. Hardiyatmo, B. Suhendro, and A. Rifa'i, "Perilaku Perkerasan Sistem Pelat Terpaku pada Tanah Lunak," *Prosidin Konf. Nas. Pascasarj. Tek. Sipil 2015*, pp. 1689–1699, 2015.

[10] R. B. Brinkgreve, E. Engin, and W. M. Swolfs, *Plaxis 3D 2015 Manual*, 1st ed. Netherlands: Plaxis, 2015.

[11] D. Waterman, *Structural elements in Plaxis*, 1st ed. Rotterdam: A.A alkema Publisher, 2006.

[12] H. Zhou, G. Zheng, J. Liu, X. Yu, X. Yang, and T. Zhang, "Performance of embankments with rigid columns embedded in an inclined underlying stratum: centrifuge and numerical modelling," *Acta Geotech.*, vol. 14, no. 5, pp. 1571–1584, 2019, DOI: 10.1007/s11440-019-00825-7.

[13] F. Azizi, *Applied Analyses in Geotechnics*. New York: E & FN Spon, 2000.