The Effect of Prefabricated Vertical Drain Length on Soft Soil Settlement (Case Study: The North Ring Road of Lamongan STA. 3+200)

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ABSTRACT

The Lamongan North Ring Road Section I, which runs from Sta. 0+000 to Sta. 3+265 is indicated to be built on silt or soft clay. This condition is reinforced based on the evidence of soil investigation results using boring which found that the original soil is in the form of clayey silt where the consistency of soft to medium soil is at a depth of 18 to 26 meters below the ground surface as indicated by the N-SPT value < 10. However, based on the results of consolidation tests conducted on the original soil in the laboratory, the Cc value < 0.2 indicates that the soil has a low compressive capacity. The data used as study material is only the data at STA. 3+200. This paper discusses the effect of prefabricated vertical drains (PVD) length on the amount of settlement that occurs in soft silt soil. And it does not analyse the relationship between Cc value and N-SPT. The method used is to compare the installation of PVDs to the thickness of the soft soil. The variation of PVD length represents one-quarter, half, and three-quarters of the soil layer thickness of 6.5m, 16m, and 19.5m. The varied PVD lengths were modelled in PLAXIS2D software with surcharge piles as analogues of construction loads and active traffic. The results show a pattern that leads to the conclusion that the longer the PVD is installed in the compressible soil, the greater the settlement will be. Meanwhile, the settlement time results show that the longer the PVD, the shorter the consolidation time.

Keywords : prefabricated vertical drain, settlement, soft soil

INTRODUCTION

The geological history of the Lamongan Regency is estimated to have started approximately 37 years ago (Oligocene Period) when it was still an ocean (part of East Java basin), so that there was a sequential sedimentation process upwards in the form of carbonate-rich marine sedimentary rock overlays that lasted for 19 million years (Polysene Period). Lamongan Regency came to the surface of the sea due to tectonic activity (Orogenesa Pilo-Pleistosen) that occurred 1.8 million years ago (Najih, 2020). The North Ring Road of Lamongan Project Section I, which stretches from STA. 0+000 to STA. 3+265, is indicated to be built on soft soil in the form of pond areas during the rainy season. The road structures include limestone embankments and flexible pavement. Embankments on soft soils are one of the most common consolidation problems of soil mechanics (Akan, 2021). So, we need soil improvement methods or techniques to reduce infrastructure damage.

Soft soil refers to silt, muddy soil, dredger fill, miscellaneous fill and saturated loose silt and silt. This kind of soil has high compressibility, low strength, high natural water content, large natural void ratio, low shear strength, small permeability coefficient expansion (Jiang, 2020). (Mochtar, 2012) determined the consistency of cohesive soils, clays and silts based on Cone Penetration Test (CPT), Standard Penetration Test (SPT) and Vane Shear Test (VST). The relationship between soil consistency and the range of tests is shown in Table 1.

The main classification of soil improvement methods was into three main techniques: consolidation, soil replacement and using columns (Al-Adhadh, 2019). One goal of soft foundation treatments is to improve the bad foundation characteristics of special soil, thus eliminating or reducing the foundation deformation caused by subsidence or expansion (Jiang, 2020).

Table 1. Soil Consistency

Soil Consistency	**Undrained Shear Strength (Cu)**		**N SPT**	**Conus Resistance (qc)**	
	kPa	ton/m2		kg/cm2	kPa
Very soft	0 – 12.5	0 – 1.25	0 – 2.5	0 - 10	0 - 1000
Soft	12.5 - 25	1.25 -2.5	2.5 - 5	10 - 20	1000 - 2000
Medium	25 - 50	2.5 – 5.0	5 - 10	20 - 40	2000 - 4000
Stiff	50 - 100	5.0 – 10.0	10 - 20	40 - 75	4000 - 7500
Very stiff	100 - 200	10.0 – 20.0	20 - 40	75 - 100	7500 - 15000
Hard	> 200	> 20.0	> 40	> 150	> 15000

Source: Mochtar, 2012

Soil improvement techniques without admixtures are widely used all over the world are soil removal and replacement, preloading technique and the vertical drains. Vertical drains are necessary when the soil preloading is set on the soft soil and has low permeability, which reduces the length of the drainage path. These vertical drains speed up the water to flow out the subsoil construction area which reduces the consolidation time. Wick drains, or as are called pre-fabricated vertical drains or strip drains have no effect on the bearing capacity of soft soil or the shear strength, as they are useful only for accelerating the expected consolidation settlement before construction. This system accelerates the settlement faster than the stone columns (Al-Adhadh, 2019). PVDs are beneficial to stabilize slopes and prove to be effective and safer when slopes are in a critical state (Mohammad et al., 2020).

The process of installation, depth and the width of installation are dependent on soil properties and expected consolidation of soil (Gulhane et.al, 2019). The maintenance of PVDs vertically should be taken care to achieve a larger settlement during PVD installation. Keeping it as right-angled with the horizontal datum line gives significant results (Reang et al., 2020)

Akan (2019) analyzed the effect of loading speeds, vertical drain usage and spacing on consolidation speed, deformation and excess pore pressures in the case of a 6m embankment without PVD and with PVDs having 2m, 1m and 0.5m intervals. The result indicated that (1) both with and without PVDs, the maximum excess pore pressures decrease with the increase in load rate; (2) the minimum vertical deformations and lateral occur for conditions with or without PVD is around 26 cm and 10 cm, respectively; (3) the load rates that cause minimum lateral deformation are 9, 19 and 75 times faster in the situations with PVDs with 2m, 1m and 0.5m of intervals compared to the situation without PVD, respectively. Widoanindyawati et.al (2016) has conducted the back analysis of the settlement with the time restriction of 512 days was producing the settlement 2.53m for various depths of PVD (23, 19, 18, 17, 16, 15 and 10) meters. The result of back analysis for PVD depth above 16 meters resulted in the same settlement, and for the depth below 15 meters resulted smaller settlement. The triangular configuration experienced a greater settlement when compared to the square configuration (Fitriansyah et al., 2024).

The result of settlement analysis using PLAXIS2D with a medium mesh is relatively closer to settlement data in the field, with a percentage difference of 0.142% compared to a coarse mesh and fine mesh (Lubis et al. 2023). Consolidation settlement using PLAXIS 2D and 3D modeling with smear zone gives results that are closer to the field condition than modeling without taking into account the smear zone effect (Hayati, 2020). The greater the permeability value of the disturbed smear zone, the smaller degree of total consolidation that occurs (Mariyana et al. 2021).

To meet the desired degree of consolidation within the allowable project time and cost, the required length of PVDs needs to be decided. For this purpose, a study has been conducted to analyze the effect of variation length on vertical deformation on soft soil. The model structures were limestone preloading collaborated PVDs with the 6.5m (¼$H_{compresible}$), 13m (½$H_{compresible}$) and 19.5m (¾$H_{compresible}$) length at a 1-meter interval and a triangular pattern was analyzed by the Software of PLAXIS 2D.

RESEARCH METHOD

This study was conducted on The North Ring Road of Lamongan Project Section I STA. 3+200. The used soil investigation results such as sieve analysis, Atterberg test, soil physical properties test, boring test, direct shear test, oedometer test and unconfined test to obtain soil parameters. The soil parameter data was calibrated using a set of geotechnical parameter correlations to ensure the soil parameter values were within reasonable limits. The results were used as the basis for back analysis to ensure that the soil parameters used were representative of the field conditions. The back analysis reference is in the form of preloading embankment height, settlement time and total deformation obtained from settlement plate results when reaching 90% consolidation degree. The reference data was the installation of a PVD with 18 meters length at a final surcharge 4.5 meters height resulting a total settlement of 467 mm in 93 days of construction. The data used in modeling with depth variations based on compressible soil. Compressible soil thickness was obtained from soil stratigraphic analysis based on N-SPT values corrected for overburden. The length variation is 6.5m, 13m and 19.5m. In PLAXIS 2D, the embankment was modeled with the Mohr-coulomb and the soil layer was modeled with soft soil. The results of the PLAXIS2D calculation were compared to the total settlement that occurred for each model.

DATA COLLECTION

Modeling soil improvement on the construction for input software of Plaxis2D is shown in Figure 1 used for back analysis. The surcharge backfilling process is caried out in several stages, so that in the model described, backfilling is carried out every 1 metre of height.

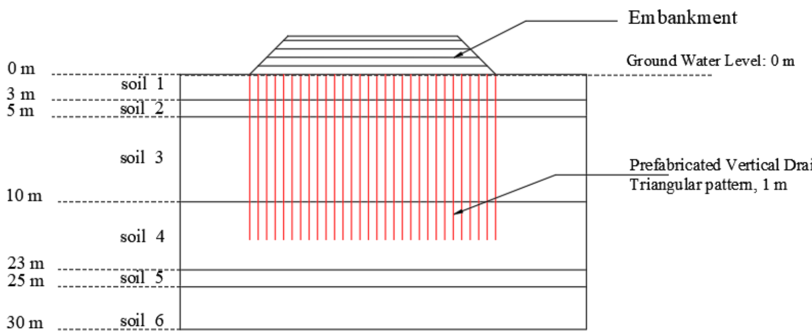

Figure 1. Typical Geometry Modeling

The data results from the back analysis are shown in Table 3 and the calculation staged construction which is used in modeling is shown in Tabel 4.

Table 2. k(x)hp calculation

	PVD Parameter			
No	PVD	Formula	Unit	Besaran
1	Width (a)		mm	100.15
2	Thick (b)		mm	2.58
3	Kh = kx soil		m/day	
	Soil 1			4.75E-02
	Soil 2			6.00E-01
	Soil 3			6.00E-01
	Soil 4			6.00E-01
	Soil 5			6.00E-02
4	Space of Triangular Grid Pattern (s)		m	1
5	Installation depth (l)		m	18
6	Mandrel diameters (dm)	$dm = \sqrt{\frac{4\,A_m}{\pi}}$	mm	125
7	Efektif space (de)	(1,05)s	m	1.05
8	Equivalence PVD diameter (dw)	$\frac{2(a+b)}{\pi}$	mm	65.37
9	Smear area diameter (ds)	(5/2)dm	mm	312.5
10	The permeability in the smeared zone (Ks)	(Kh/Ks) = 2	m/day	
	Soil 1			2.38E-02
	Soil 2			3.00E-01
	Soil 3			3.00E-01
	Soil 4			3.00E-01
	Soil 5			3.00E-01
11	n	de/dw		16.06
12	Khp (without smear zone)	$\frac{K_{hp}}{K_h}$	m/day	
	Soil 1	0.67		1.57E-02
	Soil 2			1.98E-01
	Soil 3			1.98E-01
	Soil 4			1.98E-01
	Soil 5			1.98E-01

Source: Processed by the Author

Table 3a. Soil Parameter

Parameter	**Mohr-Coulomb**	**Soft Soil**					
Identification	Embankment	Layer1	Layer2	Layer3	Layer4	Layer5	Layer6
Type	Drained	Undrained A					
γ_{sat} (kN/m^3)	20.07	17.30	15.80	15.80	15.80	17.30	18.80
γ_{unsat} (kN/m^3)	20.07	17.30	15.80	15.80	15.80	17.30	18.80
e	0.539	1.505	1.963	2.366	1.708	1.626	1,626
E_{ref} (kN/m^2)	25E3	-	-	-	-	-	-
v	0.30	-	-	-	-	-	-
C_{ref} (kN/m^2)	20.00	10.00	10.00	10.00	10.00	10.00	10.00
ϕ (°)	30.00	15.00	15.00	15.00	15.00	15.00	15.00

Table 3b. Soil Parameter

Parameter	Mohr-Coulomb	Soft Soil					
Identification	Embankment	Layer1	Layer2	Layer3	Layer4	Layer5	Layer6
Type	Drained	Undrained A					
k_x (m/day)	1.000	0.04752	0.5996	0.5996	0.5996	0.5996	0.04752
k_y (m/day)	1.000	0.04752	0.5996	0.5996	0.5996	0.5996	0.04752
C_c	-	0.1330	0.1560	0.2094	0.1767	0.1750	0.1750
Cs	-	0.0266	0.0312	0.0419	0.0354	0.0352	0.0352
$k_{(x)hp}$ (m/day)	-	0,0157	0,1980	0.1980	0.1980	0.1980	0.0157

Source: Processed by the Author

Table 4. Calculation phases

No	Staged Construction	Type	Days
1	Initial phase	K_0 procedure	-
2	Instal PVD	Consolidation	2
3	Embankment (1 m)	Consolidation	1
4	Consolidation	Consolidation	1
5	Embankment (1 m)	Consolidation	1
6	Consolidation	Consolidation	1
7	Embankment (1 m)	Consolidation	1
8	Consolidation	Consolidation	1
9	Embankment (1 m)	Consolidation	1
10	Consolidation	Consolidation	83
11	Final Consolidation	Consolidation	-

Source: Processed by the Author

RESEARCH ANALYSIS

Based on the PLAXIS2D results, the settlement that occurred with the application of lengths of 19.5m, 13m and 6.5m are shown in Figure 2, Figure 3 and Figure 4. Figure 2 shows the total settlement on the y-axis for the 19.5m long PVD Model at 90% consolidation stage from 0 m to 0.6423m in 96 days. Figure 3 shows the total settlement on the y-axis for the 13m long PVD Model at 90% consolidation stage from 0 m to 0.6494m in 97 days. Figure 4 shows the total settlement on the y-axis for the 6.5m long PVD Model at 90% consolidation stage from 0 m to 0.6538m in 102 days. The position of settlement plate monitoring point is in the middle of the road alignment below the embankment. To review nodes for each model are node 2927 for the 6.5 m PVDs, node 2879 for the 13m PVDs and node 2709 for the 19.5m PVDs. A recapitulation of the total displacement results for each node is shown in the Table 4.

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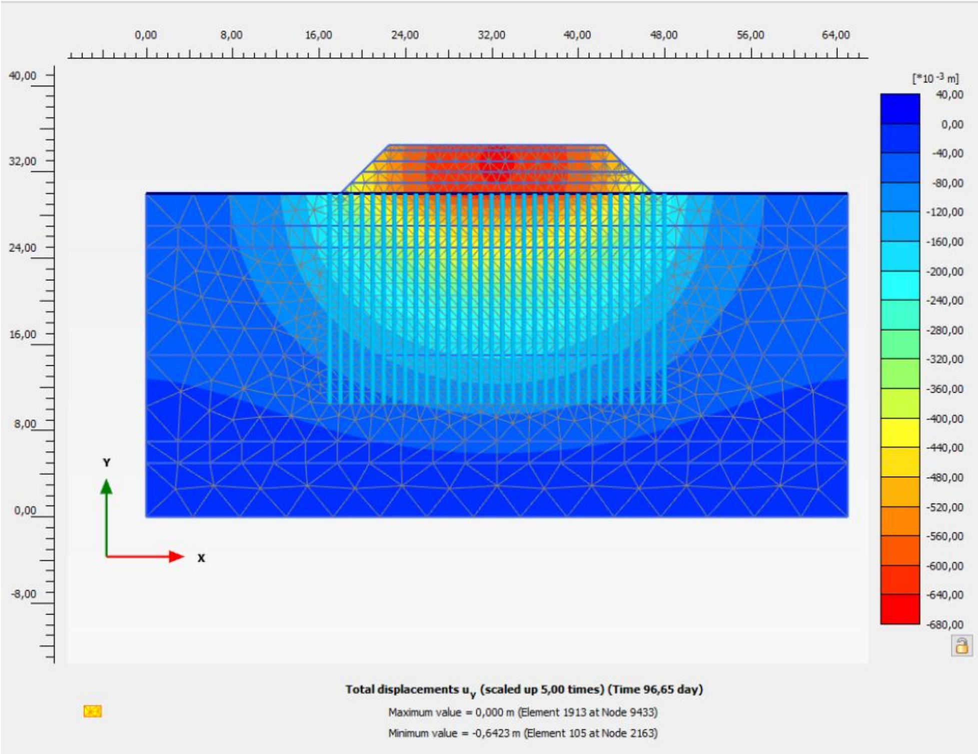

Figure 2. Total displacement Uy for 19.5 m length PVD

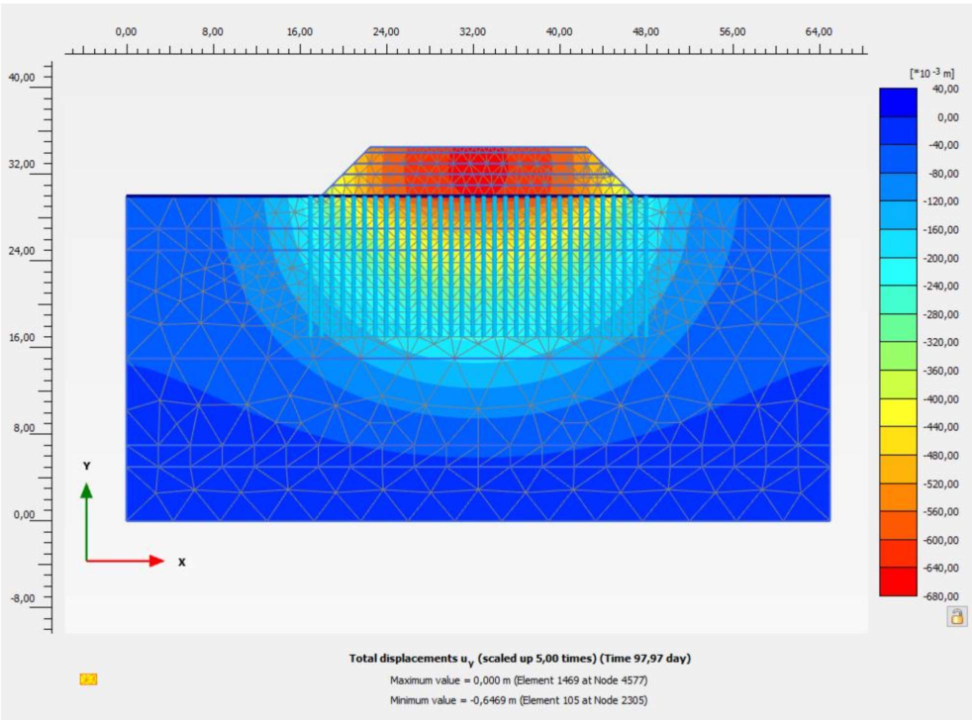

Figure 3. Total displacement Uy for 13 m length PVD

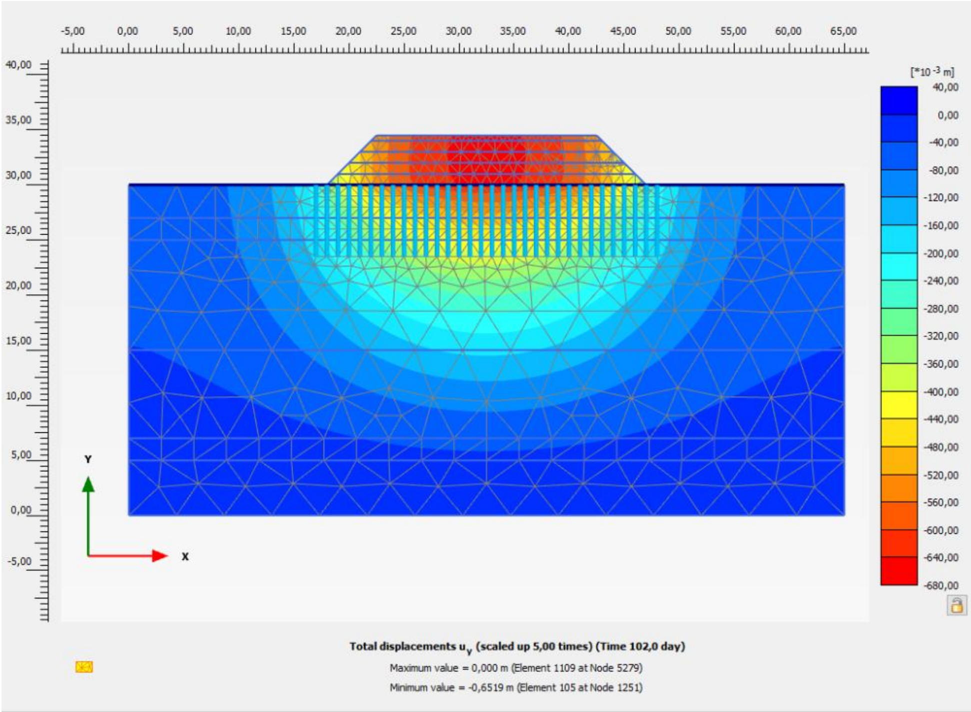

Figure 3. Total displacement Uy for 6.5 m length PVD

Table 4. Recapitulation of modeling results

Variation	Node	Total displacement	Time
		mm	day
PVD 19.5 m	2709	636	96
PVD 13 m	2879	630	97
PVD 6.5 m	2927	646	102

CONCLUSIONS

Based on the results of the analysis presented in the previous chapter, the following points can be concluded:

1. The variation length of PVDs has little effect on total displacement and time of consolidation. The longer PVDs installed has a greater settlement result and has a shorter time.
2. These results may be due to the relatively small value of Cc that the soil is considered not compressible.

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