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Acceleration Time Analysis of Consolidation Rate Using Prefabricated Vertical Drain (PVD) in Underpass Project Completion

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Abstract. Completion of projects on time becomes a top priority while taking into account the required technical factors. One of the obstacles in the Bulak Kapal underpass project Bekasi is the soil condition at the project site, which has high compressibility properties such as soft clay. One method to overcome large settlements and accelerate settlement times is to use Pre-Fabricated Vertical Drain (PVD). This study aims to compare the decrease in soil consolidation without PVD and by using PVD and knowing excess pore pressure for each variation. Variations used in this study are landfill time, which is 4weeksand8weeksofthe gradual embankment, and the distance of PVD is 1.2 m, 1.6 m, and 2 m. These variations are modeled in Plaxis to determine the decrease in consolidation, the value of pore pressure, and the acceleration time of consolidation. From the modeling results on Plaxis, it can be seen that the installation distance of PVD significantly influences the time required for the consolidation process. Consolidation settlement using PVD can accelerate the settlement time up to 3.04 times faster than settlement without PVD.

INTRODUCTION

Currently, infrastructure development in Indonesia is being pushed to run very quickly during the Covid-19 pandemic. In some areas of Bekasi, especially Bulak Kapal, with its heavy traffic and often severe traffic jams, it will be increasingly disrupted by the ongoing road construction project. Completion of projects on time becomes a top priority while taking into account the required technical factors. One of the obstacles in the Bulak Kapal underpass project Bekasi is the soil condition at the project site, which has high compressibility properties such as soft clay.

Clays are formed from silicate basic skeleton mineral particles with a diameter of less than 4 mm. Clay soils have a small permeability coefficient (k) compared to non-cohesive soils (sand and gravel). When a low-permeability saturated soil layer is loaded, the pore water pressure in the soil will increase. The difference in pore water pressure in the soil layer results in water flowing into the soil layer with lower pore water pressure followed by soil subsidence (consolidation). Soft clay has a very compressible nature, where the deformation or settlement that occurs due to an increase in surface tension, consequence, be very large and take a long time. Since the low permeability coefficient will slow down the process of water drainage from the voids between soil grains, efforts are needed to accelerate the process of soil settlement.

One method to overcome large settlements and accelerate settlement times is to use Pre-Fabricated Vertical Drain (PVD). PVD will cause pore-water flow in radial/horizontal direction and vertical flow, which causes pore water to be removed more quickly. So that with the condition of the soil being loaded with pre-loading following the design load, the process of subsidence using PVD becomes faster. However, limited conditions in the project area make it difficult to carry out landfills on surface soil to provide incremental stress to accelerate the consolidation process. The speed of accumulation of soil piles will also affect the increased excess pore water pressure in the soil, which will then slowly dissipate through the soil grain cavities. For clay soils with low permeability, it takes a long time for the water to come out of the voids between the soil grains completely. Therefore the vertical drainage method using prefabricated materials known as PVD function to speed up the process. Analysis related to land subsidence can be done by modeling the soil that will be reviewed through the Plaxis 2D application to examine the effect of embankment time on soil subsidence using PVD.

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In saturated soft clay soils, the total stress will be transmitted to the pore water and soil grains. This means that total stress ($\Delta\sigma$) will be divided into effective stress and pore water stress. At the end of primary consolidation (after pore water stress U = 0), soil settlement still occurs due to the plastic adjustment of soil grains called secondary consolidation.

PVD is a geocomposite material consisting of a core layer made of polypropylene/polyethylene and a filter layer made of spun-bond geotextile material. Its main function is to accelerate draining pore water so that the soil consolidation process becomes faster. From the previous study, PVD can accelerate consolidation time of reclaimed land, heaps on soft soil such as peat soil, the opening of new land for stacking fields and highways, railroads, and airstrips, port construction, and stacking fields, as well as residential and industrial land[1]. Thus, the settlement of the existing land has been completed (90% – 95%) during the service life of the building.

Improving soil conditions using the Preloading and Prefabricated Vertical Drain method on the toll road construction project on soft clay soil with low bearing capacity has proven to accelerate consolidation settlement. The result of the total settlement of 90% consolidation obtained is around 0.7 m to 1.2 m, using a triangular or rectangular fitting pattern with a varied distance of 0.9 m to 1.3 m. At the degree of consolidation 90%, it took only 15 weeks to 24 weeks with PVD, while it took up to 65 years[2–5]. From a previous study, the transition zone produced by the smear zone of PVD and sand lens is important for the correct estimation of the degree of consolidation and quality management in the construction stage[6–9].In comparison to the ordinary PVD, air booster vacuum pre-loading technology was used, where the thickness of the soft soil layers was more effective for the ground improvement of the deep marine clay layers more than 20 m. In addition, dissipation of the pore water pressure almost vanished after 10 weeks or reached almost 60% of the total drainage volume[10].

Furthermore, using PVD mixed with Geotextile also can shorten the consolidation time by around 95% to 98%[11]. It is just, the use of Geotextiles will require a significant additional cost on-project. Modeling in Soft Soil using Plaxis Program on embankment construction with PVD makes the consolidation process faster for underpass project completion than embankment construction without PVD. Hence the soft soil strength parameter in embankments with PVD is greater than in embankment construction without PVD so that the settlement is smaller. This study will observe the effect of PDV to accelerate the consolidation process by providing a gradual pre-loading load due to limitations in the field.

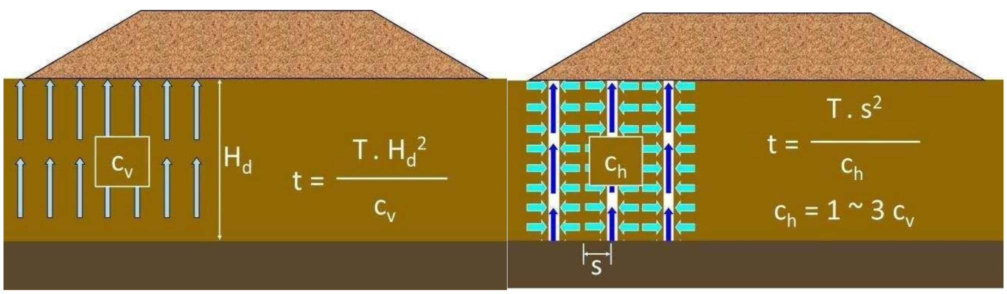


FIGURE 1. Consolidated Process with and without using PVD (source: Kuswanda, 2016)

METHODS OF RESEARCH

This study will focus on analyzing changes in pore water pressure in soft soil due to gradual embankment loads using Plaxis Version 7.2. The results in this study are fluctuations in excess pore water pressure during the construction period of 4 weeks and 8 weeks. Since at the beginning of each construction, each layer of embankment the soil experiences loading and the pore water has not been dissipated so that the excess pore water pressure increases, meanwhile during the consolidation period there is a decrease in water pressure.

Modeling on PLAXIS with design embankment height to be maintained (H) is +4.00 from ground level (+0.00). A settlement calculation due to initial loading sequentially gradual loads time is 4 weeks and 8 weeks respectively. Calculating the settlement through modeling on Plaxis according to the embankment height with the precise geometry lines is important in the initial stage. Input soil material in material sets based on field data need an appropriate correlation and interpretation of soil behavior. Determining the distance of PVD installation varies based on manual calculations to compare the simulation results obtained. The result of consolidation settlement and pore water pressure excess without PVD at 4 weeks and 8 weeks is compared with the result using PVD. The results of the pore pressure excess are observed at a depth of 5,10, and 15m, instead of total settlement in the middle of the pile. The location of this study is Bulak Kapal, Bekasi West Java, in October 2020. Field testing, which consists of 4 (four) drill holes carried out at a depth of ± 30.45 m, measuring every 2 meters Standard Penetration Test (SPT) referring to ASTM D1586and undisturbed samples according to ASTM D 1587 procedure from the hole drill, for laboratory testing purposes.

FIGURE 2. Location of Study (source: GoogleEarth)

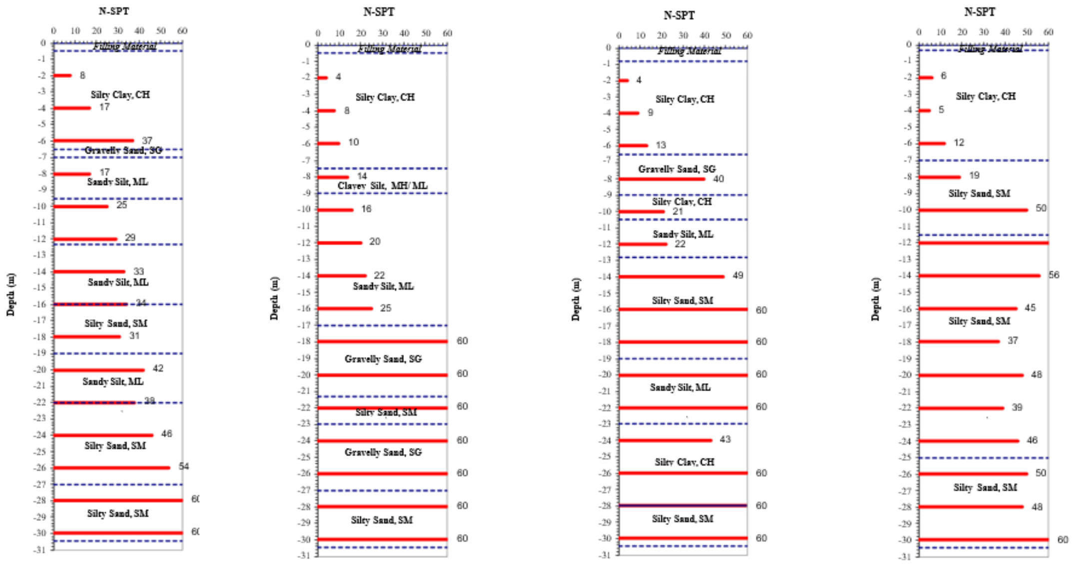
RESULT AND DISCUSSION

Hard soil layers with N – SPT > 50 are found at depths of ± 10.0 m to ± 26.0 m which sit on the "Dense to Very Dense" soil layer Silty Sand/Silty Sand, SM.

The parameters obtained as correlation with field testing can be seen in Table 1. The type of material used in this analysis is Mohr-Coulomb with soil types of Silty Clay (CL) and Sandy Silt (ML) as shown in the Stratigraphy from Figure 3.

TABLE 1. Parameters Input for PLAXIS Modeling

Parameter	Unit	Layer			
		0	1	2	3
Height (H)	m	4	7	17	1
Model		Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Type		unsaturated	unsaturated	unsaturated	unsaturated
$_{bulk}$	kN/m^3	16	17	19	15
γ_{sat}	kN/m^3	17	18	20	16
K_x	m/day	0.0001	0.0001	0.0001	0.0001
K_y	m/day	0.0001	0.0001	0.0001	0.0001
E_{50}	kN/m^2	10000	2080		2310
ν	-	0.5	0.35	0.35	0.5
c	kN/m^2	15	28.73	57.5	8.4
ϕ	°	20	37	41	26.7
ψ	°	0	0	0	0
R_{inter}		0.85	1	1	1



(a) (b) (c) (d)

FIGURE 3. NSPT Testing on Site: (a) BH-1, (b) BH-2, (c) BH-3, and (d) BH-4

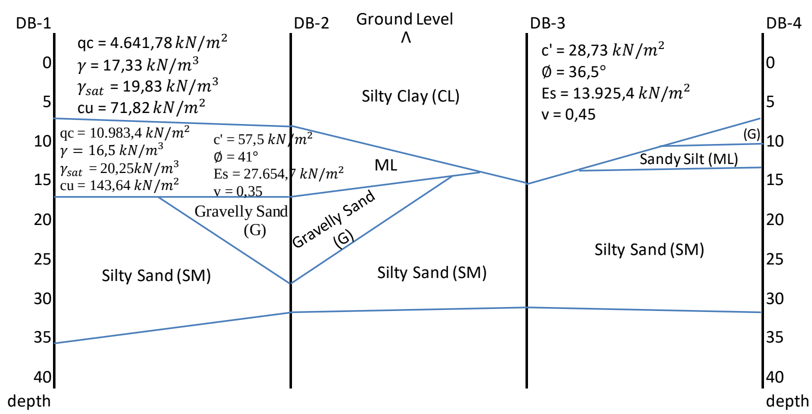
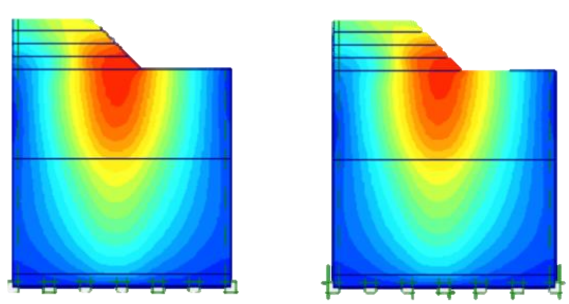


FIGURE 4. Soil Stratigraphy

The results of the settlement due to the 4m-embankment load obtained through modeling on plaxis without PVD can be seen in Table 2 and Figure 3 as follow:

TABLE 2. Consolidation Time and Settlement without PVD

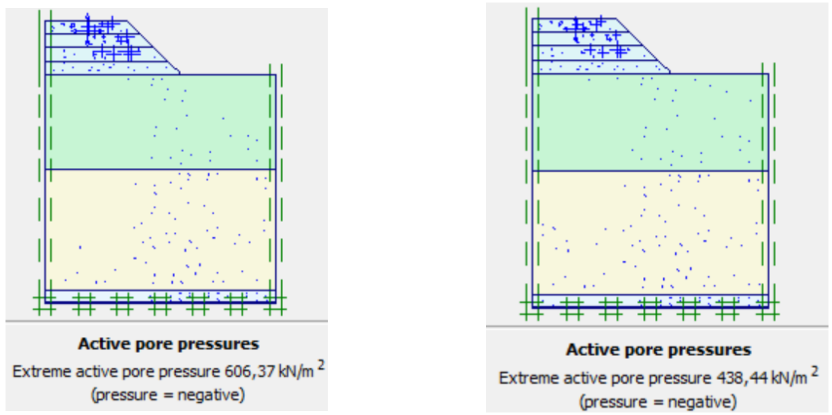
Loading (weeks)	Consolidation Time 90% (years)	Consolidation settlement 90% (m)	Active Pore Pressure (kN/m²)	Effective Stresses (kN/m²)
4	24	0.44	606.37	-346.4
8	21	0.45	438.44	-346.8



(a) Total displacements Extreme U_{tot} 44,86*10^{-3}m

(b) Total displacement Extreme U_{tot} 44,02*10^{-3}m

FIGURE 5. Time and Consolidation settlement due to Loading Without PVD for 4 Weeks and 8 Weeks



(a) (b)

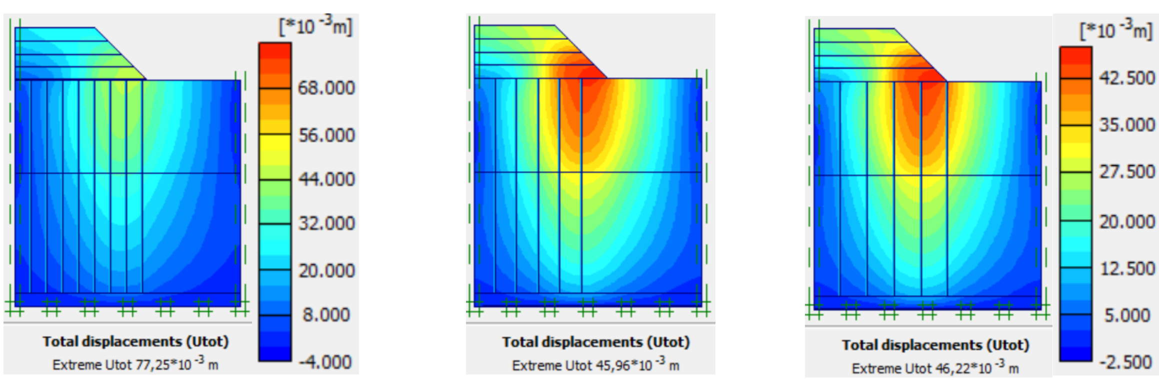
FIGURE 6. Active Pore Pressure Without PVD for 4 Weeks and 8 Weeks

It can be seen from Figure 4, that the first 4 weeks of gradual loading will increase the pore water pressure, which is quite high, and then it will decrease by 28% at loading in the 8th week. Meanwhile, the settlement results from the 4m-embankment load obtained through modelling on plaxis using PVD can be seen in Table 3, Figure 5, and Figure 6. The PVD installation distance for each layer is made equal to the installation distance of 1.2 m, 1.6 m, and 2 m.

TABLE 3. Consolidation Time and Settlement Using PVD

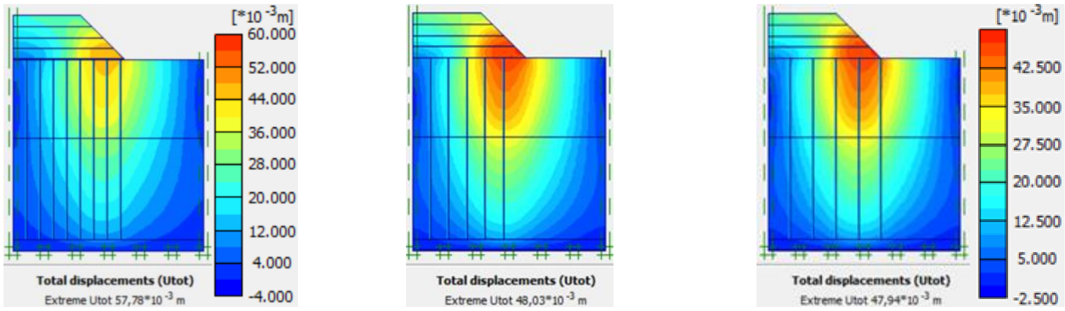
Spacing Distance (m)	Loading (weeks)	Consolidation Time 90% (years)	Consolidation settlement 90% (m)	Active Pore Pressure (kN/m²)	Effective Stresses (kN/m²)
1.2	4	7.78	0.77	-184.77	-202.73
	8	7.00	0.57	-185.33	-203.02
1.6	4	8.35	0.45	-156.34	-346.50
	8	8.35	0.48	-146.98	-346.61
2	4	8.35	0.46	308.3	-346.72
	8	8.35	0.47	0.562	-347.00

Therefore, from the modelling results on Plaxis, it can be seen that the installation distance of PVD significantly influences the time required for the consolidation process. Consolidation settlement using PVD can accelerate the settlement time up to 3.04 times faster than settlement without PVD. Thus, the pore water pressure decreases significantly after 8 weeks of gradual loading at 2m from 308.3kN/m^{2}to 0,562 kN/m^2. Instead, the effective stress of 4 weeks gradual loading of 347 kN/m^2 is relatively constant compared to the effective stress of soil of 346.72kN/m^2



(a) (b) (c)

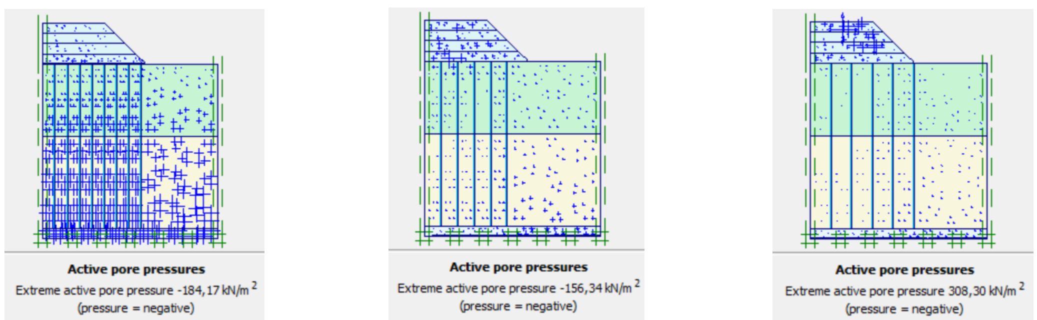
FIGURE 7. Time and Consolidation Settlement Due to Loading Using PVD for 4 Weeks (a) Total settlement spacing 1.2m; (a) Total settlement spacing 1.6 m; (a) Total settlement spacing 2.0 m



(a) (b) (c)

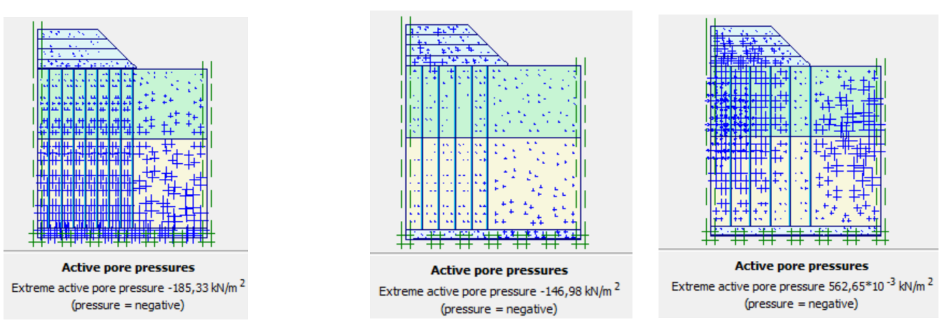
FIGURE 8. Time and Consolidation Settlement Due to Loading Using PVD for 8 Weeks (a) Total settlement spacing 1.2 m; (b) Total settlement spacing 1.6 m; (c) Total settlement spacing 2.0 m

Likewise, the results of extreme pore pressure due to the 4m embankment load obtained through modelling on Plaxis using PVD can be seen in Figure 7. On the contrary, in Figure 8, the farthest distance of 2m PVD installation shows a relatively high pore-water pressure value so that it can be harmful to the bearing capacity of the soil.



(a) (b) (c)

FIGURE 9. Active Pore Pressure Using PVD for 4 weeks (a) Total Pore Pressure spacing 1.2 m; (b) Total Pore Pressure spacing 1.6 m; (c) Total Pore Pressure spacing 2.0 m



(a) (b) (c)

FIGURE 10. Active Pore Pressure Using PVD for 8 weeks (a) Total Pore Pressure spacing 1.2 m; (b) Total Pore Pressure spacing 1.6 m; (c) Total Pore Pressure spacing 2.0 m

The result of consolidation settlement with variations in PVD spacing and embankment loading can be seen in Table 4.

TABLE 4. Accelerationof Time Consolidation in 4 Weeks and 8 Weeks Loading Using PVD

Consolidation Time without PVD (years)	Spacing Distance (m)	4-week Loading (years)	Acceleration of Settlement	Consolidation Time without PVD (years)	Spacing Distance (m)	8-week Loading (years)	Acceleration of Settlement
	1.2	7.8	3.07x		1.2	7	3.0x
24	1.6	8.3	2.87x	21	1.6	8.35	2.52x
	2.0	8.35	2.87x		2.0	8.35	2.52x

CONCLUSIONS

The distance of PVD is very influential in the consolidation process to accelerate the settlement time for soil consolidation up to 3.04 times of the settlement without PVD. The effect of gradual loading of the embankment is also an important factor for the consolidation settlement time. It is necessary to use instruments such as a piezometer in the future when conducting further soil subsidence analysis. It is necessary to consider the cost of selecting the appropriate installation pattern and the distance between PVD so that the selection of PVD gets the right results and costs according to the time of execution of the work or project before time completion project.

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