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Analysis of Soft Soil Improvement Using Prefabricated Vertical Drains (PVD): A Case Study of Rorotan, Cilincing, North Jakarta

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ABSTRACT

Soft soils in the Rorotan area of North Jakarta frequently encounter significant stability and settlement issues, which can affect the structures situated on them. This study focuses on applying the Prefabricated Vertical Drain (PVD) method to expedite the soil consolidation process, aiming to enhance soil strength and reduce the potential for settlement. The analysis uses boring log data and laboratory test results from the RDF construction project as secondary data and includes calculations of settlement magnitude and consolidation duration. The study results indicate that PVD installation considerably speeds up soil consolidation and improves soil bearing capacity compared to conventional soil improvement techniques. Using Prefabricated Vertical Drains (PVD) of 100 mm x 30 mm and a depth of 12 meters, the consolidation process can be shortened to just a few months. For PVD spacing of 1.5 meters, the consolidation time can be reduced to 6 months. With 1.8 meters spacing, it becomes 12 months; 2 meters spacing requires 15 months; 2.5 meters spacing takes 27 months; and 3 meters spacing needs 39 months. The study highlights a reduction in consolidation time from 277.58 months with a settlement of 0.835 meters to a few months, depending on the spacing used, reflecting a 97.8% reduction in time.

Keywords: Prefabricated Vertical Drain (PVD); soil improvement; soil consolidation; soil strength; sof soil; Rorotan; North Jakarta.

INTRODUCTION

Soft soils often present significant challenges in construction projects due to their characteristics, which can lead to substantial settlement and low structural stability. In the Rorotan area of North Jakarta, where soft soils with high moisture content are prevalent, the RDF (Refuse Derived Fuel) construction project faces difficulties related to soil stability. Such soils require specific interventions to improve soil strength and reduce the potential for settlement, which can affect the integrity of structures built on top. One effective method to accelerate the consolidation process of soft soils is the use of Prefabricated Vertical Drains (PVDs). According to Terzaghi and Peck (1967), PVDs expedite the drainage of pore water from soft soils, thus accelerating the consolidation process and enhancing the stability of the underlying soil (Terzaghi & Peck, 1967).

This study aims to evaluate the effectiveness of PVDs in improving soft soils in Rorotan by testing various PVD installation spacing configurations. Using boring log data and laboratory test results from the RDF project, this analysis compares different PVD spacings—1.5 meters, 1.8 meters, 2.0 meters, 2.5 meters, and 3.0 meters—regarding consolidation time and soil settlement. The goal is to determine the most efficient PVD configuration for accelerating soil consolidation and to provide practical recommendations for PVD application in future soil improvement projects. As noted by Hansbo (1981), selecting the appropriate PVD spacing can significantly impact the rate of consolidation and the effectiveness of soil improvement (Hansbo, 1981).

RESEARCH METHODS

Materials

In this research writing, the author undertakes several stages and implementations to achieve the aims and objectives of the study. To reach these goals, the following steps are carried out:

1. Literature Review

a. Collecting literature on the research topic, including books and scientific articles.
b. Defining the scope of the problem and identifying the data needs for the study.

2. Data Collection

a. Boring Log Data: Soil samples are collected from various depths to obtain a representative overview of the soil conditions.
b. Laboratory Data: Analyzing laboratory test results to obtain soil parameters such as shear strength, consolidation, and compressibility.

3. Data Analysis

a. Determining the thickness of the soft soil layer based on NSPT (Standard Penetration Test) data.
b. Determining consolidation parameters based on laboratory data.
c. Calculating settlement magnitude and consolidation time.
d. Analyzing PVD (Prefabricated Vertical Drain) performance.

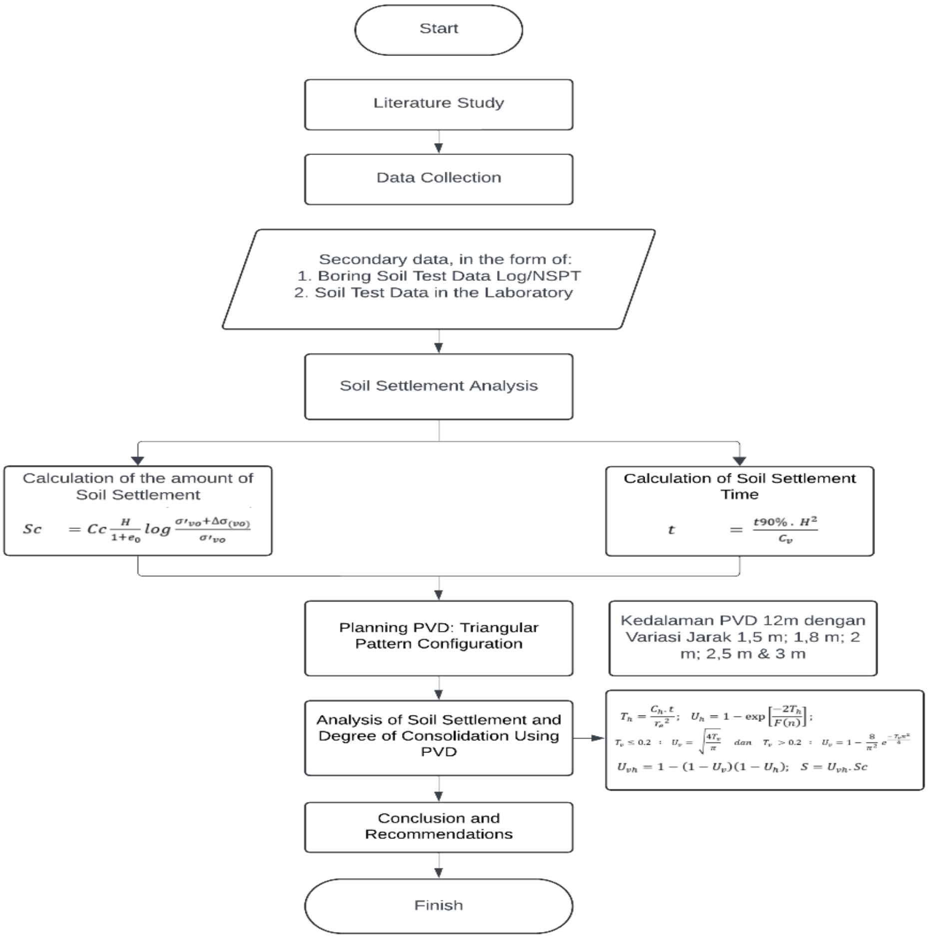

Figure 1. Flow chart

Methods

The research methodology involved a multi-step approach to evaluate the effectiveness of Prefabricated Vertical Drains (PVD) in improving soil consolidation. The primary data sources

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included boring log data and laboratory testing results obtained from the RDF (Refuse Derived Fuel) construction project located in Rorotan, North Jakarta. The boring logs provided crucial information about soil layers, including depth, soil type, and initial conditions, while laboratory tests offered detailed parameters such as soil compressibility, shear strength, and permeability. These data were essential for accurate analysis and assessment of the soil's response to PVD installation.

Data Analysis

The analysis involved calculating both the settlement and consolidation time for each PVD spacing configuration. Settlement calculations were performed to estimate the amount of soil compression and its variation with different PVD spacings. The degree of consolidation was evaluated by applying Terzaghi's one-dimensional consolidation theory, which involved determining the effective drainage path length for each spacing and estimating the time required for a specified degree of consolidation. Comparative analysis was conducted to identify the optimal PVD spacing that would minimize consolidation time and maximize soil stability. The results were used to provide recommendations for PVD installation practices in similar soil conditions.

RESULT AND DISCUSSION

Soil Data Analysis

The soil data used in this study is secondary data obtained from the RDF construction project, including N-SPT data and laboratory test results. The locations of the boreholes and SPT can be seen in Figure 2.

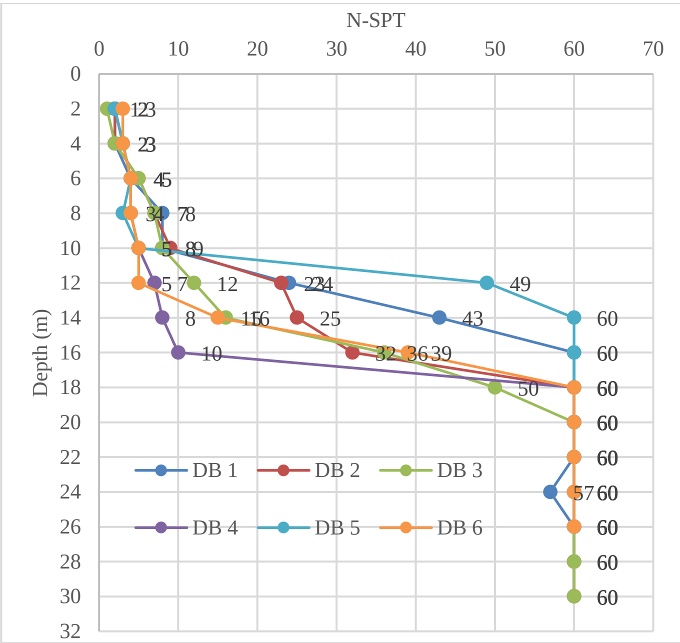

Figure 2. Relationship Between N-SPT Values and Depth

Based on Figure 2, soil samples were collected from six test points at different depths: DB-1, DB-2, and DB-3 at a depth of 30 meters, and DB-4, DB-5, and DB-6 at a depth of 26 meters. N-SPT values were recorded at every 2-meter interval, and the soil consistency ranged from very soft to soft up to a depth of 12 meters.

Soil parameter data from laboratory tests were collected from borehole samples DB-1, DB-2, DB-3, DB-4, DB-5, and DB-6. The analyzed soil parameters included moisture content, liquid limit (LL), plastic limit (PL), initial void ratio (e0), plasticity index (PI), saturated unit weight (γsat), unit weight of water (γw), dry unit weight (γd), vertical consolidation coefficient (Cv), compression index (Cc), and swelling index (Cs). The results of these soil parameter analyses are detailed in Table 1.

For the vertical consolidation coefficient (Cv), data were obtained from consolidation tests under assumed loads, and combined to calculate $Cv_{gabungan}$, which was determined to be 0.0017 cm²/s. The horizontal consolidation coefficient (Ch) was estimated using the assumption that Ch = 2 × Cv.

Borlog	Depth	Water Content	PL	LL	e_0	PI	Cu (UU) kPa	γ (kN/m³)	γd (kN/m³)	Cv (cm²/sec)	Cc	Cs
DB 1	4	34,089	36,390	67,790	1,709	31,400	12,200	15.660	11.690	0.00137	0.583	0.062
	6	35,119	35,011	65,604	1,453	30,593	24,900	15.830	11.720	0.00150	0.485	0.064
	8	34,551	35,609	66,779	1,163	31,170	62,400	15.970	11.870	0.00169	0.376	0.051
DB 2	6	34,210	36,145	66,743	1,341	30,598	37,100	15.850	11.810	0.00161	0.450	0.050
	8	34,198	36,145	69,011	1,313	32,866	43,000	15.900	11.850	0.00164	0.408	0.052
	10	34,010	36,009	68,855	0,921	32,846	132,600	15.940	11.890	0.00191	0.280	0.035
DB 3	4	34,210	34,098	64,273	1,650	30,175	12,500	15.650	11.780	0.00138	0.562	0.059
	6	34,010	36,087	69,686	1,144	33,599	68,200	15.790	11.920	0.00173	0.365	0.047
	8	35,198	35,117	67,788	1,191	32,671	68,200	16.100	11.780	0.00170	0.376	0.047
DB 4	6	37,426	35,033	67,790	1,269	32,757	12,300	16.070	11.700	0.00164	0.488	0.051
	12	36,166	35,556	68,191	0,892	32,635	37,300	16.050	11.790	0.00192	0.369	0.040
	14	35,025	34,218	63,395	0,875	29,177	24,900	15.860	11.750	0.00191	0.264	0.034
DB 5	2	38,055	36,229	68,975	1,144	32,746	42,000	16.330	11.840	0.00175	0.461	0.049
	6	35,991	35,066	66,361	1,096	31,295	67,900	16.200	11.86	0.00176	0.382	0.036
	10	35,633	35,066	65,961	1,117	30,895	131,600	16.180	11.930	0.00177	0.340	0.055
DB 6	2	37,189	36,228	67,795	1,264	31,567	12,400	15.830	11.540	0.00165	0.414	0.061
	6	36,885	35,397	67,210	1,117	31,813	62,000	16.240	11.870	0.00177	0.340	0.055
	12	34,561	33,697	64,015	0,940	30,318	59,800	15.810	11.760	0.00185	0.296	0.037
Rata-Rata		**35,363**	**35,395**	**67,012**	**1,284**	**31,618**	**50,628**	**15.9589**	**11.7972**	**0.0017**	**0.4022**	**0.0492**

Figure 3. Soil parameter data

From the secondary data of the parameters mentioned above, the average values were used to calculate the settlement magnitude and consolidation time.

Table 1. Soil parameters used

Parameters	Value
e0	1.284
Cs	0.049
Cc	0.402
Ch (m²/day)	0.02933
Cv (m²/day)	0.01466
γ_w (kN/m³)	9.8
γ_{clay} (kN/m³)	15.96
γ_{pile} (kN/m³)	15.96

Changes in moisture and mass can be seen in Figure 3. It can be seen that each variation of the addition of bread has almost the same trend, where the largest decrease in mass occurs on the first day. Changes in mass tend to start steady after the first day. Meanwhile, moisture began to decrease on the fifth day.

Soil Improvement Method Selection

From the boring data, it was observed that the soil condition in the area consists of silty clay, and the soil consistency is categorized as very soft to soft. Laboratory data revealed that the percentage of silt is greater than that of clay and there is also a sand content present. Therefore, the appropriate

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method for soil improvement in this case is the use of Prefabricated Vertical Drains (PVD) to accelerate the consolidation process.

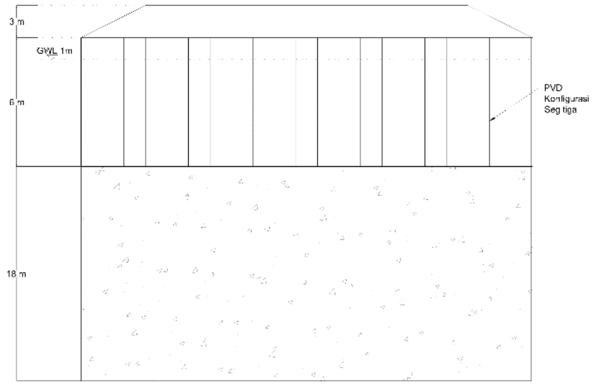

Figure 4. Soil modeling with PVD

Consolidation Settlement Analysis

In the consolidation settlement analysis, it was assumed that a fill depth of 3 meters would be placed, and a load of 15 kPa would be applied on top of it.

Calculation of Settlement

Based on the given parameters in Table 2, the primary consolidation settlement can be calculated as follows:

$$Sc = Cc\frac{H}{1+e_0}log\frac{\sigma'_{vo}+\Delta\sigma_{(vo)}}{\sigma'_{vo}}$$

Based on the calculation, the maximum settlement is 0.83858 meters, which is equivalent to 83.858 cm.

Consolidation Time Analysis

Using the parameter data from 2, the time required to achieve 90% consolidation. The consolidation time was estimated using Terzaghi's one-dimensional consolidation theory

$$t = \frac{t90\% .\ H^2}{C_v}$$

It would take approximately 22.8 years for natural settlement to occur.

Table 2. Natural settlement without PVD per years

U%	Tv	Time (year)	Settlement (cm)
5	0.002	0.05	0.04193
10	0.008	0.21	0.08386
15	0.018	0.48	0.12579
20	0.031	0.85	0.16772
25	0.049	1.32	0.20965
30	0.071	1.90	0.25158
35	0.096	2.59	0.29350
40	0.126	3.38	0.33543
45	0.159	4.28	0.37736
50	0.196	5.28	0.41929
55	0.238	6.39	0.46122
60	0.283	7.61	0.50315
65	0.340	9.16	0.54508
70	0.403	10.84	0.58701
75	0.477	12.83	0.62894

U%	Tv	Time (year)	Settlement (cm)
80	0.567	15.26	0.67087
85	0.684	18.39	0.71280
90	0.848	22.81	0.75473
95	1.129	30.37	0.79666
99	1.781	47.92	0.83020

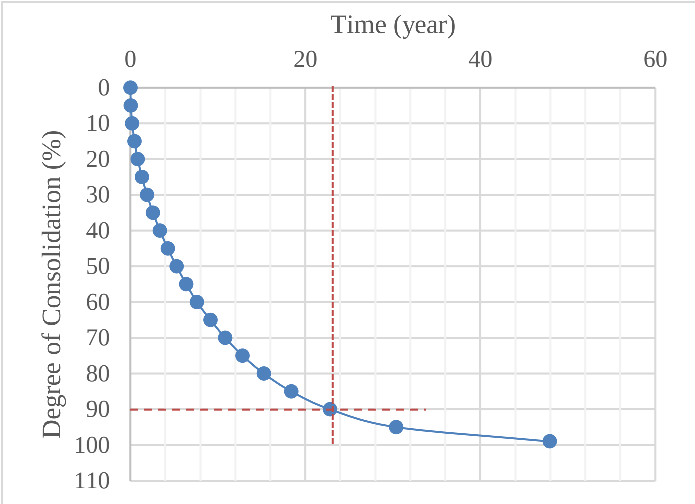

Figure 5. Relationship between natural consolidation time without prefabricated vertical drains (PVD) and 90% degree of consolidation

Indraratna and Rujikiatkamjorn, (2004), conducted laboratory tests to determine the efficiency of Prefabricated Vertical Drains (PVDs) as an alternative soil improvement method for accelerating the consolidation process.

Subsequently, Indraratna and Rujikiatkamjorn, (2012), applied the PVD method to expedite the consolidation of soil embankments in the construction of highways, railway embankments, and airport runways. The numerical analysis of these construction projects yielded highly satisfactory results. Therefore, this study will utilize PVDs to enhance soil bearing capacity and accelerate the consolidation process, employing various configurations and spacings between the PVDs. However, the predictions will be calculated using analytical methods, and observations will be made with several measuring instruments post-construction.

Planning for Prefabricated Vertical Drains (PVD)

In the analysis of soft soil depth, it is known that the depth of the soft soil is 12 meters. The PVD installation spacings to be used are 1.5 meters, 1.8 meters, 2.0 meters, 2.5 meters, and 3.0 meters. The pattern for PVD installation will follow a triangular pattern. The results of the analysis can be seen in Table 3 below.

Table 3. Results of the analysis of settlement time using PVD

No	Space (m)	Time (month)	U_{vh} (%)	Settlement (cm)
1	1.5	6	99.93%	83.799
2	1.8	9	99.92%	83.788
3	2	15	99.99%	83.850
4	2.5	20	99.94%	83.806
5	3	30	99.93%	83.803

Based on the variations in the spacing of Prefabricated Vertical Drains (PVDs) in a triangular pattern, it takes 2 to 9 months less time to achieve a 90% degree of consolidation.

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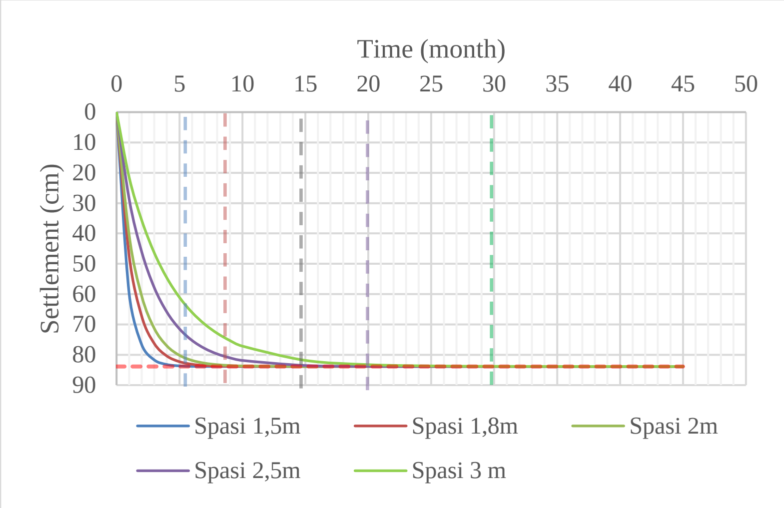

Figure 6. Relationship Between Spacing, Consolidation Time, and Settlement of Prefabricated Vertical Drains (PVD) in Triangular Pattern

This figure illustrates the relationship between the spacing of Prefabricated Vertical Drains (PVD), the time required for consolidation, and the amount of settlement achieved. The PVDs are arranged in a triangular pattern, and the figure shows how variations in spacing affect the consolidation efficiency and the rate of settlement.

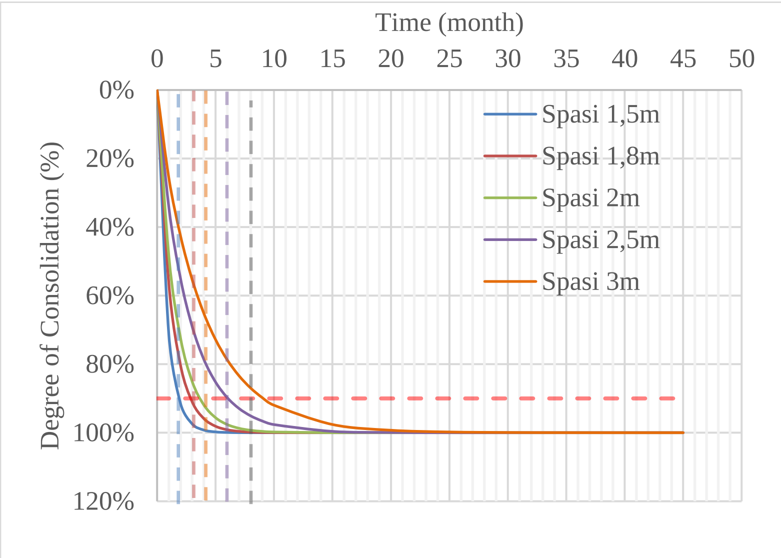

Figure 7. Relationship Between Spacing, Consolidation Time, and Degree of Consolidation of Prefabricated Vertical Drains (PVD) in Triangular Pattern

CONCLUSION

In conclusion, the analysis of soil consolidation in the Rorotan area of Cilincing, North Jakarta, underscores the significant impact of Prefabricated Vertical Drains (PVDs) on accelerating soil stabilization. Without the use of PVDs, the maximum natural settlement is projected to reach 0.83858 meters (83.858 cm), with the time required to achieve a 90% degree of consolidation extending to approximately 277.578 months, or 22.8 years. This extensive duration clearly highlights the urgent need for soil improvement interventions to ensure timely and effective stabilization of the ground. For the specific soil conditions in the Rorotan area, characterized by soft soil, the study utilized PVDs of dimensions 100 mm x 30 mm and a depth of 12 meters. The PVDs were installed following a triangular pattern with varying spacings of 1.5 meters, 1.8 meters, 2.0 meters, 2.5 meters, and 3.0 meters. The application of PVD markedly enhances the efficiency of soil consolidation processes. Specifically, with a spacing of 1.5 meters, the time required to complete soil compression is reduced to 6 months. Increasing the spacing to 1.8 meters extends this period to 12 months, while spacings of 2.0 meters, 2.5 meters, and 3.0 meters result in consolidation times of 15 months, 27 months, and 39 months, respectively. The results clearly demonstrate that the use of PVD significantly shortens the consolidation duration compared to natural settlement processes. Furthermore, the effectiveness of PVDs is closely related to their spacing, with closer intervals offering more rapid consolidation. This study provides compelling evidence that implementing PVD can substantially accelerate the process of soil consolidation, making it a highly effective method for improving soil stability in challenging geotechnical conditions.

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