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Comparison the Analysis Results of Soil Improvement PVD Preloading & Stone Column Methods for Accelerating Soil Consolidation

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Abstract

The third runway plan for Soekarno-Hatta Airport will be right on land which is quite dominated by soft soil, which of course is very prone to large subsidence at a relatively slow time. Because the time factor is very narrow while the target is constantly being pursued, it is necessary to have an appropriate soil improvement method to overcome this problem. There are two options, (1) Prefabricated Vertical Draining (PVD) and (2) Stone Column. Both are installed in a triangle pattern at two different distances. The effectiveness analysis between the two was carried out based on references from FHWA (1983) and Priebe (1995). The final output of this final project report is the result of reduction obtained and the length of time required to achieve the degree of consolidation in accordance with the requirements, with comparisons based on the results shown by the time vs settlement curve. The author's initial hypothesis considers that the use of PVD is superior to the use of Stone Columns in this case because the decline time is faster even though the resulting decrease is not much different from that produced by Stone Column.

Keywords
Land subsidence, Consolidation Time, PVD, Stone Column

1. Introduction

The passenger growth rate which is predicted to continue to rise is the reason why PT Angkasa Pura II decided to build a third runway from Soekarno Hatta airport. This runway is expected to be able to meet the needs and accommodate the increasing number of passengers in the future. Therefore, a runway plan with high specifications was made, which would be able to accommodate large aircraft. This third runway is right on the north side of the airport, which is adjacent to Runway 2. However, the soil conditions in that area are mostly dominated by soft soil, with a little hard soil layer, as is the characteristic of the soil in Jakarta. These conditions make the possibility of a decline in danger lurking in the future. So that we need a soil improvement method that can accelerate the process of land subsidence so that the runway construction to be built will be safe.

There are two choices of soil improvement methods that can be used in this case, namely the Prefabricated Vertical Design (PVD) method and the Stone Column method. This method has advantages and disadvantages of each, so further analysis is needed to find the most effective and efficient method to use in this case.

This problem was also found in the case at the Samarinda Baru Airport Runway, which was built in 2013, where the planned runway to be built is right over an area dominated by soft soil. The planner chooses the PVD and Stone Column methods. PVD itself was chosen because it is widely used, but it is not able to increase soil bearing capacity. Unlike the stone column, which can increase the bearing capacity of the soil but is not effective if used at a certain depth.

Soil conditions in the Jakarta area are quite unique, because even though the soil is dominated by soft soil, it also has a hard soil layer (lens) so it needs more in-depth analysis to determine an effective and efficient soil improvement method. That is the aim of this research, where calculations based on the theories of one-dimensional consolidation on unimproved soil will be compared with the decrease that will be obtained if the soil improvement method in the form of PVD or Stone Column is used. The consolidated time rate curve is an output that will illustrate the analysis that will be carried out, to find the answer to this research hypothesis.

2. Theoris

. In general, land settlements caused by loading can be divided into two major groups, such as;

a. Consolidation Settlement = the result of changes in the volume of water saturated soil as a result of the discharge of water that occupies the soil pores.

b. Immediate Settlement = which is the result of elastic deformation of dry, wet and water saturated soil without any change in water content. The calculation of immediate reduction is generally based on the decrease derived from the elasticity theory.

The vertical consolidation coefficient (Cv) determines the velocity of water flowing in the vertical direction in the soil. Since consolidation generally takes place in one direction, that is, in a vertical direction, the coefficient of consolidation is very influential on the speed at which the consolidation will occur. The Cv can be found using the following equation:

$$Cv = \frac{Tv \times H^2}{t}$$

Cv = coefficient of consolidation (cm2/s)
Tv = time factor depending on the degree of consolidation
t = time taken to reach the degree of consolidation U% (s)
h = thickness of soil (cm)
The amount of consolidation reduction can be found using the equation:

$$s = \frac{Cc \times H}{1 + eo} log \frac{po + \Delta p}{po}$$

The amount of consolidation reduction can be found using the equation:
If (Po + P) <Pc

$$S = \frac{Cs}{1 + e_o} H \, log \frac{P_0 + \Delta p}{P_0}$$

If (Po + P)> Pc

$$S = \frac{Cs}{(1 + e_o)} H \log\left(\frac{P_0 + \Delta p}{P_0}\right) + \frac{Cc}{(1 + e_o)} H \log\left(\frac{P_0 + \Delta p}{P_0}\right)$$

Verruijt, (2010) proposed a theory for calculating the time of consolidation from one-dimensional consolidation for saturated clay soils. Several variables that are important to understand in determining the time and degree of consolidation according to Terzaghi (1925) will be defined below.

a. The compressibility coefficient can be defined as the average land subsidence shown by the change in the void ratio (Δe) to the change in stress (Δσ).
b. The Volume Compressibility Coefficient (mv) is the average decrease in soil volume relative to the initial thickness due to increased stress
c. The coefficient of consolidation defined in this section is the coefficient of consolidation due to vertical drainage.
d. The time factor is a dimensionless number.

The degree of consolidation states the percentage of consolidation that has occurred in a soil layer. Because the consolidation process is related to excess air pore dissipation, then at a depth z and time t

$$U_Z = \frac{u_o + u_z}{u_o}$$

Meanwhile, according to Technology, (n.d.), the degree of consolidation for 0% <U <100%

$$\frac{U\%}{100} = \frac{\left(\frac{4T_v}{\pi}\right)^{0,5}}{[1 + \left(\frac{4\mathrm{Tv}}{\pi}\right)^{2,8}]^{0,179}}$$

$$T_v = \frac{\left(\frac{\pi}{4}\right) \times \left(\frac{U\%}{100}\right)^2}{[1 - (100 - \mathrm{U\%})^{5,6}]^{0,357}}$$

2.1 Prefabricated Vertical Drain

The theory and analysis developed in calculating the effect of PVD on the degree of consolidation assumes that PVD is circular. Lastiasih et al., (2017) suggested that if the circumference of the band-shaped and circle of the PVD were the same, it would result in the same degree of consolidation.

The equation of the degree of consolidation in stabilized soil using the PVD system according to Carrillo in Maiti & Bidinger (1981) is as follows:

$$U_c = 1 - (1 - U_h)(1 - U_v)$$

Where :
Uc = degree of soil consolidation due to vertical and radial flows.
Uh = degree of radial consolidation
Uv = degree of vertical consolidation.
The amount of time to consolidate due to the use of PVD is determined using the equation:

$$t = \left(\frac{D^2}{8 \times Ch}\right) \times 2F(n) \times \ln\left(\frac{1}{1 - U_h}\right)$$

Where :
t = the time it takes to reach Uh (s)
D = the circle's equivalent diameter (cm)
1.13 x S for rectilinear pattern
1.05 x S for triangular arrangement
Ch = horizontal flow consolidation coefficient (cm2 / s)
F (n) = the drag factor caused by the distance between the PVDs.
Uh = degree of horizontal soil consolidation (%)

2.2 Stone Column

Soil subsidence resulting from the use of a stone column must pay attention to the push factor (punching), so that the calculation in this method the improvement factor n2 is used to reduce soil subsidence.

Broadly speaking, the analyzed land subsidence is divided into 3 types;

1. Soil subsidence in layers reinforced by stone columns
   In this section, land subsidence can use terzhagi theory by using $n2$ to reduce soil subsidence that occurs for conditions without a reinforced stone column.
2. Soil subsidence in layers that are not reinforced by stone columns
   In this section, the working stress is equal to the total working load, σ
3. Soil subsidence due to the effect of punching on the stone column
   Soil subsidence due to punching can be calculated using the principle of land subsidence due to loading on the deep foundation, where the load works at a depth of 2/3 of the stone column length and uses the 2: 1 method for stress distribution at each depth.

Then the predicted amount of land subsidence due to the punching can be calculated through the equation

$$S_p' = \frac{S_p \times S_0}{(S_p + S_0)}$$

Where
S'_p = decrease due to reduced punching
S_p = decrease due to calculated punching
S_0 = settlement in the reinforced soil layer prior to the stone column

3. Result and Analysis

The results of the tests / observations were compared with the calculations obtained based on initial theory and literature review. Then the two results (calculation and testing) are compared again, whether they meet the requirements in the initial plan / specification. This end result will form the basis for drawing conclusions to answer research questions and hypotheses.

The object of this case study is located in Tangerang, West Java, namely the construction of Runway 3 at Soekarno Hatta International Airport. The Runway development is divided into 2 parts, where the Section 1 is the object of the case study in this final project.

The runway is planned to span 3000 meters with a width of 60 meters. The data used are soil data on the runway plan STA 0 + 250 to STA 1 + 100, so it is known that there are 4 SPTs conducted at 3 bore hole points out of a total of 75 bore hole points made along the runway area. The bore hole points that are used as the basis for the analysis in this final project are;

a. DB-01 at station 0 + 540
b. DB-03 at station 0 + 740
c. DB-06 at station 1 + 020

While the loads that are planned for the runway design are;

a. Equivalent pavement load = 24 kN / m2
b. Aircraft equivalent load = 15 kN / m2

The load is calculated for the planned runway design, which is 3000 m long with 60 m long shoulders. While the design standards used to design runways are AC 150 / 5300-13, Airport Design, a guideline published by the FAA (Federal Aviation Administration) in 2012 that has been updated 15 times since it was first published in 1989.

After knowing the soil data and its interpretation, as well as a cross section plan, it can be concluded that the parameters will be used as a design reference. The selection of parameters and soil profiles that are used as references is found at the DB-06 bore hole at station 1 + 020

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These points are selected based on the depth of the largest layer of soft clay and the elevation of the elevation embankment. Therefore, it is obtained soil parameters for design reference and soil profile;

Table 1. Mohr-Coulomb modeling design reference parameters

PARAMETER			EMBANK-MENT	1st Soil Layer	2nd Soil Layer	3rd Soil Layer
Model			MC	MC	MC	MC
Soil Sample Type			Drained	Undrained	Drained	Drained
Soil Density (Underwater)	γ_{unsat}	kN/m^3	14,51	16,93	17,9	15,4
Soil Density	γ_{sat}	kN/m^3	14,51	21,95	22,4	19
Permeability x	k_x	m/day	0,864	0,00864	0,864	0,864
Permeability v	k_y	m/day	0,864	0,00864	0,864	0,864
Modulus of Elasticity (stiffness)	E_u	kN/m^2	13000	1500	8000	14000
	E'	kN/m^2	13000	1500	8000	14000
Poisson's Ratio	υ (μ)		0,3	0,2	0,35	0,4
Soil cohesion	C_{ref}	kN/m^2	0	5	52,1	26,3
Inner sliding angle	φ		35	10	5	3
Dilation angle (psi)	ψ	(*6,9 kN/m2)	0	0	0	0

Table 2. Soft Soil modeling design reference parameters

PARAMETER			EMBANK-MENT	1st Soil Layer	2nd Soil Layer	3rd Soil Layer
Model			SS	SS	SS	SS
Soil Sample Type			Drained	Undrained	Drained	Drained
Soil Density (Underwater)	γ_{unsat}	kN/m^3	14,51	0,00	17,9	15,4
Soil Density	γ_{sat}	kN/m^3	14,51	9,80	22,4	19
Permeability x	k_x	m/hari	0,864	0,00864	0,864	0,864
Permeability v	k_y	m/hari	0,864	0,00864	0,864	0,864
Compression Index	Cc		0,32	0,23	0,23	0,76
Swelling Index	Cs		0,064	0,046	0,046	0,152
Initial Void Ratio	eo		0,8	0,82	0,94	1,89
Cohesion	C	kN/m^2	52,1	52,1	52,1	26,3
Inner sliding angle	φ		35	10	5	3
Dilation angle (psi)	ψ		0	0	0	0

3.1 Unimproved Soil Conditions

In this analysis, the operational embankment design is calculated based on the equivalent height of the following factors, namely;

a. Land Elevation = 3 m; bj of land = 15 kN / m2
b. Sand Blanket = 1 m; bj of sand = 18 kN / m2
c. Pavement = 0.8 m; bj of concrete = 24kN / m2
d. Airplane = 15 kN / m2

So, the equivalent height of the factors above is;

a. Pavement equivalent height $= \frac{24\ \text{kN/m}^2}{15\ \text{kN/m}^2} \times 0{,}8\ m = 1{,}28$ m

b. Plane equivalent height $= \frac{\gamma\ \text{plane}}{\gamma\ \text{embankment}} = \frac{15\ \text{kN/m}^3}{15\ \text{kN/m}^2} = 1\ m$

So, the required heap height, namely;

H embankment = 0.6 m + 3 m + 1 m + 1.28 m = 5.88 m

In order to overcome the excess load when the runway starts to operate, the design of the planned embankment must be larger than the operational embankment size, so that the total embankment height is = 6.5 m. The stockpiling is carried out in stages, where the stage 1 = up to 3 meters, and the second stage is up to 6.5 meters.

The analysis of land subsidence using the following manual calculation refers to the theory of one-dimensional consolidation by Terzaghi, where the increase in vertical stress on the soil under the embankment is caused by the loading of the embankment itself. So that the following table can be obtained;

Table 3. Calculation of Land Subsidence Due to 1ST Embankment Layer

Depth Interval			γ_m	σo'	Δσo (Elevation of Embankment)			Cc	eo	Sc
					qo	I	Δσo			
M			kN/m3	kN/m2	kN/m2		kN/m2			M
0	-	1	16,93	16,93	46,52308	0,458	46,06508	0,32	1,29	0,079741
1	-	2	16,93	33,86	46,52308	0,458	46,06508	0,32	1,29	0,052122
2	-	3	16,93	50,79	46,52308	0,458	46,06508	0,32	1,29	0,039175
3	-	4	16,93	67,72	46,52308	0,458	46,06508	0,32	1,29	0,031493
4	-	5	16,93	84,65	46,52308	0,458	46,06508	0,32	1,29	0,026368
5	-	6	17,9	102,55	46,52308	0,458	46,06508	0,32	1,29	0,022516
6	-	7	17,9	120,45	46,52308	0,458	46,06508	0,32	1,29	0,019654
					46,52308		**Total Settlement**			**0,271068**
7	-	8	15,43	135,88	46,52308	0,458	46,06508	0,32	1,29	0,017717
8	-	9	15,43	151,31	46,52308	0,458	46,06508	0,32	1,29	0,016129
9	-	10	15,43	166,74	46,52308	0,458	46,06508	0,32	1,29	0,014804
					46,52308		**Total Settlement**			**0,048650**
10	-	11	15,43	182,17	46,52308	0,458	46,06508	0,32	1,29	0,013681
11	-	12	15,43	197,6	46,52308	0,458	46,06508	0,32	1,29	0,012717
12	-	13	15,43	213,03	46,52308	0,458	46,06508	0,32	1,29	0,011880
13	-	14	15,43	228,46	46,52308	0,458	46,06508	0,32	1,29	0,011147
14	-	15	15,43	243,89	46,52308	0,458	46,06508	0,32	1,29	0,010499
15	-	16	15,43	259,32	46,52308	0,458	46,06508	0,32	1,29	0,009923
16	-	17	15,43	274,75	46,52308	0,458	46,06508	0,32	1,29	0,009407
17	-	18	15,43	290,18	46,52308	0,458	46,06508	0,32	1,29	0,008942
18	-	19	15,43	305,61	46,52308	0,458	46,06508	0,32	1,29	0,008520
19	-	20	15,43	321,04	46,52308	0,458	46,06508	0,32	1,29	0,008137
20	-	21	15,43	336,47	46,52308	0,458	46,06508	0,32	1,29	0,007787
21	-	22	15,43	351,9	46,52308	0,458	46,06508	0,32	1,29	0,007466
22	-	23	15,43	367,33	46,52308	0,458	46,06508	0,32	1,29	0,007170
23	-	24	15,43	382,76	46,52308	0,458	46,06508	0,32	1,29	0,006897
24	-	25	15,43	398,19	46,52308	0,458	46,06508	0,32	1,29	0,006643
25	-	26	15,43	413,62	46,52308	0,458	46,06508	0,32	1,29	0,006408
26	-	27	15,43	429,05	46,52308	0,458	46,06508	0,32	1,29	0,006189
27	-	28	15,43	444,48	46,52308	0,458	46,06508	0,32	1,29	0,005985
28	-	29	15,43	459,91	46,52308	0,458	46,06508	0,32	1,29	0,005793
29	-	30	15,43	475,34	46,52308	0,458	46,06508	0,32	1,29	0,005613
							Total Settlement			**0,170805**
								Total ALL Settlement		**0,490523**

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Table 4. Calculation of Land Subsidence Due to 2nd Embankment Layer

Depth Interval			γm	σo'	Δσo (Timbunan Elevasi)			Cc	eo	Sc
					qo	I	Δσo			
m			kN/m3	kN/m2	kN/m2		kN/m2			m
0	-	1	16,93	16,93	100,8	0,458	100,342	0,32	1,29	0,117455
1	-	2	16,93	33,86	100,8	0,458	100,342	0,32	1,29	0,083573
2	-	3	16,93	50,79	100,8	0,458	100,342	0,32	1,29	0,066177
3	-	4	16,93	67,72	100,8	0,458	100,342	0,32	1,29	0,055162
4	-	5	16,93	84,65	100,8	0,458	100,342	0,32	1,29	0,047445
5	-	6	17,9	102,55	100,8	0,458	100,342	0,32	1,29	0,041408
6	-	7	17,9	120,45	100,8	0,458	100,342	0,32	1,29	0,036776
							Total Settlement			0,447996
7	-	8	15,43	135,88	100,8	0,458	100,342	0,32	1,29	0,033560
8	-	9	15,43	151,31	100,8	0,458	100,342	0,32	1,29	0,030873
9	-	10	15,43	166,74	100,8	0,458	100,342	0,32	1,29	0,028591
							Total Settlement			0,093024
10	-	11	15,43	182,17	100,8	0,458	100,342	0,32	1,29	0,026628
11	-	12	15,43	197,6	100,8	0,458	100,342	0,32	1,29	0,024922
12	-	13	15,43	213,03	100,8	0,458	100,342	0,32	1,29	0,023423
13	-	14	15,43	228,46	100,8	0,458	100,342	0,32	1,29	0,022096
14	-	15	15,43	243,89	100,8	0,458	100,342	0,32	1,29	0,020913
15	-	16	15,43	259,32	100,8	0,458	100,342	0,32	1,29	0,019851
16	-	17	15,43	274,75	100,8	0,458	100,342	0,32	1,29	0,018893
17	-	18	15,43	290,18	100,8	0,458	100,342	0,32	1,29	0,018023
18	-	19	15,43	305,61	100,8	0,458	100,342	0,32	1,29	0,017231
19	-	20	15,43	321,04	100,8	0,458	100,342	0,32	1,29	0,016505
20	-	21	15,43	336,47	100,8	0,458	100,342	0,32	1,29	0,015839
21	-	22	15,43	351,9	100,8	0,458	100,342	0,32	1,29	0,015225
22	-	23	15,43	367,33	100,8	0,458	100,342	0,32	1,29	0,014656
23	-	24	15,43	382,76	100,8	0,458	100,342	0,32	1,29	0,014129
24	-	25	15,43	398,19	100,8	0,458	100,342	0,32	1,29	0,013639
25	-	26	15,43	413,62	100,8	0,458	100,342	0,32	1,29	0,013181
26	-	27	15,43	429,05	100,8	0,458	100,342	0,32	1,29	0,012754
27	-	28	15,43	444,48	100,8	0,458	100,342	0,32	1,29	0,012353
28	-	29	15,43	459,91	100,8	0,458	100,342	0,32	1,29	0,011977
29	-	30	15,43	475,34	100,8	0,458	100,342	0,32	1,29	0,011623
							Total Settlement			0,343861
							Total ALL Settlement			0,884881

This consolidation time calculation refers to the theory put forward by Terzaghi, namely one-dimensional consolidation, shown in the following graphs and tables;

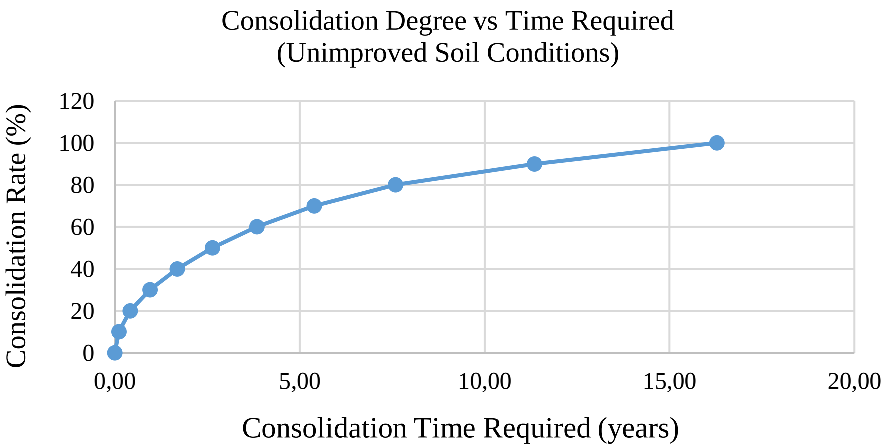

Figure 1. Consolidation Curves for Original Soil Conditions

Step to:	H Embankment	Land subsidence (m)		
	m	1-D Consolidation	PLAXIS 2D (MC)	PLAXIS (SS)
1	3	0,490523	0,424330	0,529300
2	6,5	0,884881	0,774950	0,842380

Figure 2. Resume Land Subsidence of Unimproved Soil conditions

This graph shows that the original soil which is not reinforced / soil improvement to reach a consolidation degree of 90% requires a consolidation period of up to 11 years. This is certainly not feasible to do so soil improvement is needed to accelerate the consolidation that occurs

3.2 The Effectiveness of Using PVD

In analyzing the effectiveness of the use of PVD, what needs to be considered is the construction time and land subsidence that will occur if the PVD is given to a land to accelerate the consolidation process. In this case, the following PVD specifications are used

Table 5. PVD specifications used

Parameter	Nilai	
Tipe	Daehan V-Dek-706	
a	100	mm
b	3,39	mm
dw	52	mm
Panjang	10	m
S	1000	mm
Pola Pemasangan	Segitiga	
de	1050	mm

The calculation of the time of consolidation in the soil given by PVD is based on the theory of Barron and Hansbo, which considers the effect of the radial direction drainage factor on the consolidation that occurs. The following is a table of the results of calculating the time for land consolidation given by PVD

Table 6. Calculation of Consolidation Time with PVD

Ur %	Th	Uv %	Tv	U(v,r)	t detik	t hari	t bulan	t tahun
0,000	0,000	0,000%	0	0,000	0	0,00	0,00	0,00
0,050	0,014	0,002%	9E-11	0,050	44284	0,51	0,03	0,00
0,100	0,030	0,003%	1,8E-10	0,100	90964	1,05	0,05	0,00
0,150	0,046	0,004%	2,7E-10	0,150	140312	1,62	0,08	0,01
0,200	0,063	0,004%	3,6E-10	0,200	192653	2,23	0,11	0,01
0,250	0,081	0,005%	4,5E-10	0,250	248373	2,87	0,14	0,01
0,300	0,101	0,005%	5,4E-10	0,300	307938	3,56	0,18	0,01
0,350	0,121	0,005%	6,3E-10	0,350	371920	4,30	0,22	0,02
0,400	0,144	0,006%	7,2E-10	0,400	441025	5,10	0,26	0,02
0,450	0,169	0,006%	8,1E-10	0,450	516147	5,97	0,30	0,02
0,500	0,195	0,006%	9E-10	0,500	598434	6,93	0,35	0,03
0,550	0,225	0,007%	9,9E-10	0,550	689398	7,98	0,40	0,03
0,600	0,258	0,007%	1,08E-09	0,600	791087	9,16	0,46	0,04
0,650	0,296	0,007%	1,17E-09	0,650	906372	10,49	0,52	0,04
0,700	0,339	0,008%	1,26E-09	0,700	1039459	12,03	0,60	0,05
0,750	0,391	0,008%	1,35E-09	0,750	1196868	13,85	0,69	0,06
0,800	0,454	0,008%	1,44E-09	0,800	1389521	16,08	0,80	0,07
0,850	0,535	0,008%	1,53E-09	0,850	1637893	18,96	0,95	0,08
0,900	0,649	0,009%	1,62E-09	0,900	1987955	23,01	1,15	0,10
0,950	0,845	0,009%	1,71E-09	0,950	2586388	29,94	1,50	0,12
1,000	2,597	0,009%	1,8E-09	1,000	7951818	92,03	4,60	0,38

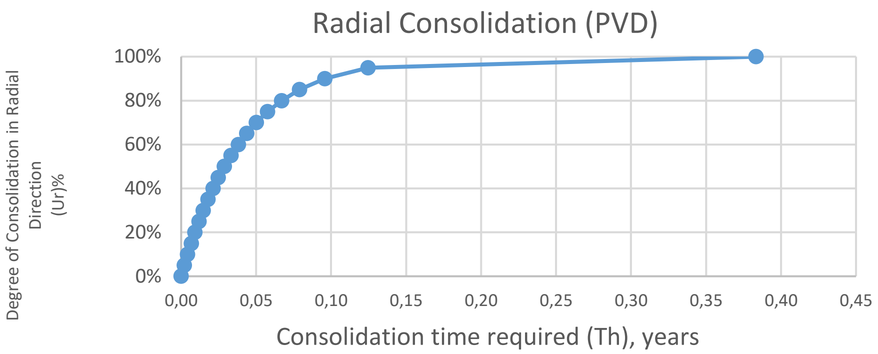

Figure 3. the results of the calculation of the time for land consolidation given by PVD

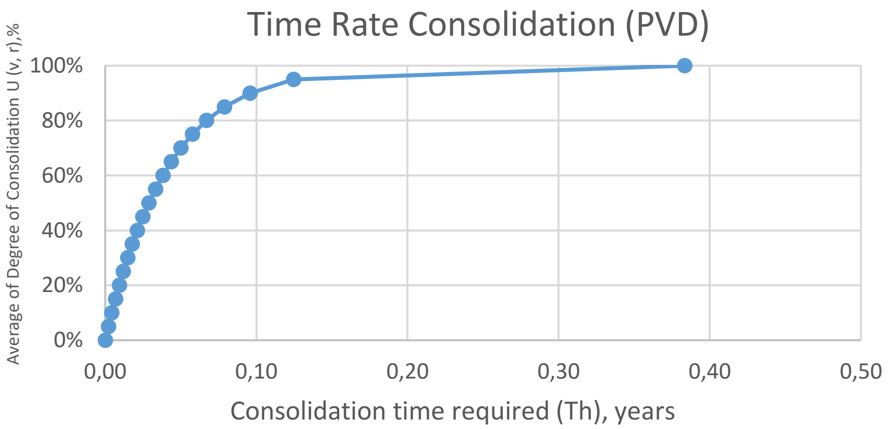

Figure 4. Time of Condition Consolidation with PVD Reinforcement

Based on the two graphs above, it is known that the degree of consolidation on the soil which is reinforced with PVD will be generated on the day

U (v, r) = 80% → t = 16 days

U (v, r) = 90% → t = 23 days.

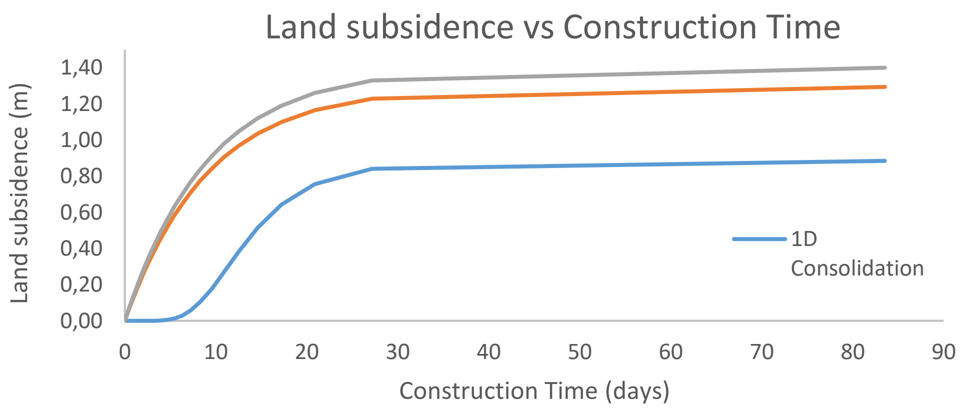

Figure 5. Time Rate of Condition Consolidation with PVD Reinforcement

Acceleration of consolidation can occur in soil that is given PVD, due to the flow of water from the soft soil layers that can be channeled through the planted bands. These bands act as "paths" that accelerate the process of pore water discharge from the soft soil layer, where soil grains can be retained through the geotextile layer that covers the band.

The process of installing PVD causes the soil to become “disturbed”, so it is necessary to take into account the possible conditions for the area affected by this. This affected area will change the permeability coefficient. This change can be obtained from the above calculations, so that the influence factor is found in the form of the degree of consolidation in the radial direction.

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3.3 Effectiveness of Using Stone Columns

In this case study, the Stone Column used has specifications;

Table 7. Stone Column specifications used

Parameter	Nilai	
D	500	mm
L	6	m
Φc	42	o
Ec	100000	kN/m^2
Dc	120000	mm
Vc	0,25	
Spasi	1,5	m
Pola Pemasangan	Segitiga	

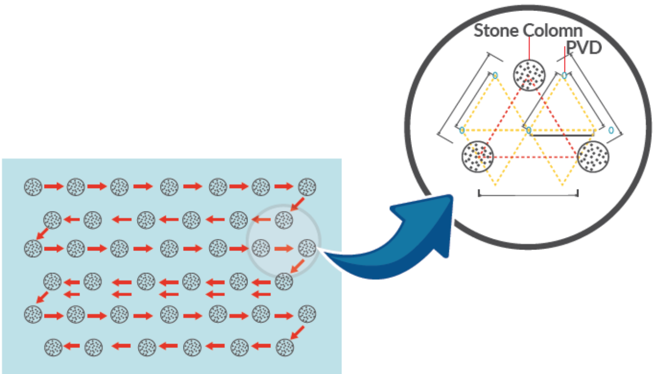


Figure 6. The pattern of stone column

The land subsidence that occurs is divided into 3 parts, among others;

a. Soil subsidence in areas reinforced by stone columns (Su)

The decrease that occurs can use the amount of improvement factor that has been sought ($n2$).

b. Land subsidence in areas that are not reinforced by stone columns (Sl)

The amount of land subsidence under the stone column was calculated using Terzaghi's theory of one-dimensional consolidation.

c. Additional land subsidence due to punching ($S'p$)

Because the soft soil under the stone column is considered unable to withstand the stress concentration in the stone column, it can be assumed that the stone column will compress the soil layer directly below it.

The following is the result of calculating the total reduction using the Priebe method;

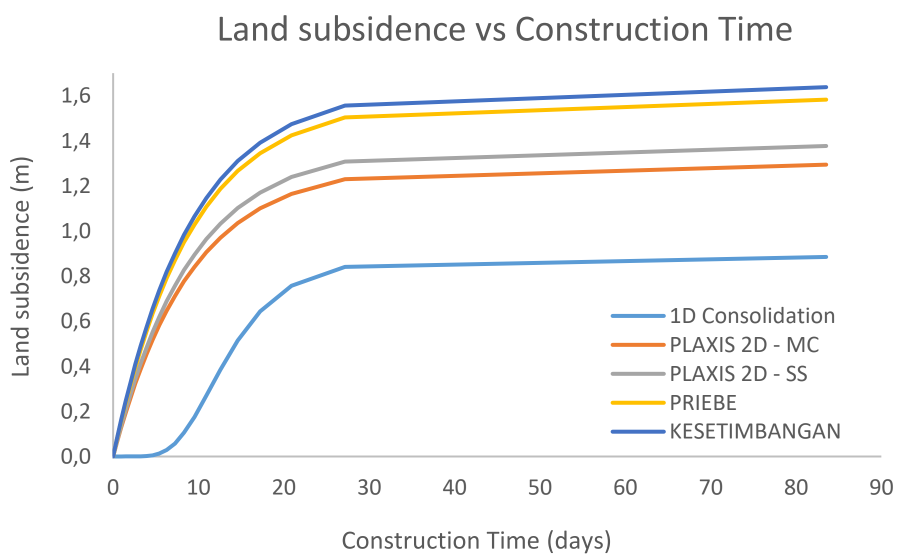
Table 8. Table of Construction Time needed to get the degree of descent based on each method

Hari		1D-Consolidation	PRIEBE	KESETIM-BANGAN	PLAXIS MC	PLAXIS SS
0,0000	0%	0,000	0,000	0,000	0,000	0,000
0,4652	5%	0,000	0,079	0,082	0,065	0,069
0,9556	10%	0,000	0,158	0,164	0,129	0,138
1,4740	15%	0,000	0,237	0,246	0,194	0,207
2,0239	20%	0,000	0,316	0,328	0,259	0,275
2,6092	25%	0,000	0,396	0,409	0,324	0,344
3,2350	30%	0,001	0,475	0,491	0,388	0,413
3,9071	35%	0,002	0,554	0,573	0,453	0,482
4,6331	40%	0,005	0,633	0,655	0,518	0,551
5,4223	45%	0,013	0,712	0,737	0,582	0,620
6,2867	50%	0,029	0,791	0,819	0,647	0,688
7,2423	55%	0,058	0,870	0,901	0,712	0,757
8,3106	60%	0,105	0,949	0,983	0,776	0,826
9,5217	65%	0,176	1,029	1,065	0,841	0,895
10,9198	70%	0,270	1,108	1,146	0,906	0,964
12,5735	75%	0,386	1,187	1,228	0,971	1,033
14,5973	80%	0,514	1,266	1,310	1,035	1,102
17,2066	85%	0,643	1,345	1,392	1,100	1,170
20,8841	90%	0,757	1,424	1,474	1,165	1,239
27,1708	95%	0,841	1,503	1,556	1,229	1,308
83,5363	100%	0,885	1,582	1,638	1,294	1,377

The amount of land subsidence obtained using 3 calculation methods, namely the Priebe method, equilibrium method, and modeling in PLAXIS for each stage can be seen in the following table and figure below.

Table 9. Resume of Land subsidence by Stone Column

Resume Penurunan Tanah						
Tahap ke	H Timbunan	Penurunan Tanah (m)				
	m	1-D Consolidation	Priebe	Kesetim - bangan	PLAXIS 2D (MC)	PLAXIS 2D (SS)
1	3,0000	0,4905	0,8407	1,1020	0,8937	1,1653
2	6,5000	0,8849	1,5824	1,6378	1,2940	1,3769



VOLUME 3 | NUMBER 1 | JANUARY 2021
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By using a space of 1.5 meters, Stone Column is able to accelerate the consolidation process to reach

a. U = 80% → t = 18 days
b. U = 90% → t = 26 days

Consolidation acceleration can occur in soils given Stone Columns, because stone columns can also drain water on soft soils with overconsolidated conditions. Water that is difficult to move because the soil is too fine can find its way to the surface through the installed stone column. In addition, the soil pressure can also increase the carrying capacity. However, the permeability coefficient of a stone column with PVD itself is different, so the use of these two materials needs to be considered carefully.

4. Conclussion

1) Pada hasil analisis data awal, tanah tanpa mengalami perkuatan tanah memerlukan jumlah tahapan timbunan sebanyak 4 kali untuk mencapai ketinggian timbunan 6,5 meter, dengan tahap 1 = 3m, dan tahap 2 = 6,5 m. Setelah dilakukan analisis, waktu konsolidasi vertical didapatkan nilai;
   a. U = 80% → t = 7.5 years
   b. U = 90% → t = 11.3 years
2) So it was concluded that to reach the heap height of 6.5 meters with the consolidation time for each stage is determined to be 80% and at the end of the embankment stage 90% of the consolidation will be waited for a construction time of 18.8 years (7.5 years + 11.3 years) and this is not feasible to do in the field.
3) The existence of PVD proved to be quite effective in accelerating the consolidation process that occurred. The contribution of radial drainage can accelerate the consolidation process. By using 1 meter PVD spacing is able to accelerate the consolidation process to reach
   a. U = 80% → t = 16 days
   b. U = 90% → t = 23 days

Even though it is able to accelerate the consolidation process, PVD does not have a direct effect in increasing the bearing capacity of the soil, so that 2 stages of embankment are still needed to reach a height of 6.5 meters with a total construction time of 39 days (16 days + 23 days)

4) Stone Column proved to be quite effective in increasing bearing capacity and accelerating the consolidation process. By using a space of 1.5 meters, Stone Column is able to accelerate the consolidation process to reach
   a. U = 80% → t = 18 days
   b. U = 90% → t = 26 days

So the total construction time = 44 days (18 days + 26 days)

5) Based on the large resume table of land subsidence with construction time, it can be concluded that the PVD method of soil improvement produces 5 days faster consolidation time when compared to the Stone Column method.
6) If the time required to carry out all of these soil improvements in the field is for a month, then it is necessary to consider choosing the PVD method as the soil improvement method, because the resulting consolidation time is faster and the cost is cheaper when compared to the Stone Column method.

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