Acceleration of Consolidation of Soft Clay Layers with Prefabricated Vertical Drain (PVD) Method

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Abstrak **Soil consolidation settlement is a geotechnical problem often found in embankment cases, especially on soft soils. The decrease in consolidation is caused by the release of pore water from the soil caused by increased stress in the soil mass. Soft clay is a cohesive soil which is the largest part of the soil consisting of very small grains such as clay or silt. The properties of the soft clay layer have a small shear force. Based on the soil test in the laboratory, the density was 2.75, the coefficient of compression (Cc) was 0.40, and the coefficient of expansion (Cs) was 0.03, so it was classified as soft clay. From the results of calculations without using PVD that have been carried out, the time needed to reach the 95% consolidation degree is 60 days with a decrease of 7 cm. Meanwhile, by using PVD, the time required is 30 days with a large reduction of 15 cm. From the analysis that has been done, it can be concluded that the use of PVD can accelerate the consolidation time.**

Keywords: **Soft Soil, Settlement, Degree of Consolidation, Prefabricated Vertical Drain (PVD)**

I. Introduction

Land subsidence is a problem often found in construction on soft soil in addition to soil movement and shift. Soils with a soft consistency and low permeability will be slow to drain pore water in the soil. If the soil is given a load, then the water and air that fills the pores of the soil will come out, resulting in soil compression, which indicates a decrease in the soil. [7], [8].

The decline in civil engineering construction due to the consolidation process of supporting soil is one of the main aspects of the geotechnical field, especially in the soft clay soil layer. The consolidation process is a pore water dissipation process concerning a function of time. At first, the 1-D consolidation theory was discovered by Terzaghi (1925), assuming a constant value of the consolidation coefficient (Cv) and the flow that occurs in one direction (vertical direction) during the consolidation process. Bolt (1941) developed Terzaghi's 1-D consolidation theory by assuming the consolidation coefficient (Cv), the effective vertical stress, and the working excess pore water pressure as a function of the transient flow that occurs during the consolidation process in three directions (multi-dimensional case). [1].

Coping with large settlements and long settlement times in loaded soft clays is a problem that must be considered because soft clays have low voids density. Generally, the soft clay layer consists of soil that is mostly very small grains and has large compressibility and a small permeability coefficient, so that if the construction load exceeds the critical bearing capacity, soil damage will occur. Even though the intensity of the load is less than the critical bearing capacity, in the long term, the magnitude of the settlement will continue to increase, so that it will cause the soil surface around the construction to rise or fall, or there is a decrease in groundwater level or water draining in the middle of construction which ultimately results in damage. around construction [2], [3], [4].

One of the appropriate soil improvement methods for soft clay soil conditions is through a combination of preloading. The combination of this method is carried out by providing an initial load in the form of preloading on clay soil that has been given a drainage system in the form of vertical drainage or horizontal drainage. [1], [4].

With the drain installation, the time required for soil subsidence is shorter. These drains can be filled with sand (a material with high permeability), or synthetic drains can be used in tape. Conventional drain, known as the sand drain, has been abandoned, and its function has been replaced by prefabricated drains that use geotextiles or synthetic materials. [5].

To overcome this, it is necessary to handle the soil so that groundwater can come out and the soil can be compressed to increase its carrying capacity. The addition of PVD to increase soil permeability and the addition of preloading load is one of the methods commonly used to treat soft soils. The preloading and vertical drainage methods can increase the shear strength of soft soil and remove pore water in the soil. Provide an alternative repair system for soft clay soils that can increase the bearing capacity and reduce settlement due to consolidation.[6], [9] pembebanan awal (preloading) dan drainase vertikal mampu untuk meningkatkan kekuatan geser tanah lunak dan mengeluarkan air pori dalam tanah. Memberikan alternatif sistem perbaikan pada tanah lempung lunak yang dapat meningkatkan daya dukung mereduksi penurunan akibat konsolidasi [6], [9]

II. Literature Studi

1. Soil Stress

The stress in the soil can be caused by the load acting on the soil, which can be the load of the soil itself (overburden pressure) or the stress due to the external load applied vertically to the soil. The stress consists of total normal stress (σ), pore water stress (u), effective stress (σ'), and stress due to external load (Δσ).

2. Settlement

The decrease is divided into two, namely the immediate settlement (immediate settlement) and the consolidation settlement (consolidation settlement). For consolidation decline, there are several cases in the calculation of the decline. There is a normal consolidation which is formulated as:

$$Sc = \frac{C_c H}{1+eo} Log\left(\frac{\sigma' + \Delta\sigma'}{\sigma'}\right) \quad (1)$$

Meanwhile, for land that is over consolidated (OC), the magnitude of the decrease is:

1). For condition : (σ' + Δσ) ≤ σc', that :

$$Sc = \frac{C_s H}{1+eo} Log\left(\frac{\sigma' + \Delta\sigma'}{\sigma'}\right) \quad (2)$$

2). For condition : (σ' + Δσ) > σc, that :

$$Sc = \frac{C_s H}{1+eo} Log\left(\frac{\sigma c'}{\sigma'}\right) + \frac{C_c . H}{1+e0} \log\left(\frac{\sigma' + \Delta\sigma'}{\sigma'}\right) \quad (3)$$

Dimana :

S_c = Compression due to primary consolidation process (m)
H = Thickness of the soil layer *compressible* (m)
eo = Void Ratio
Cc = Soil compression index
Cs = Index swelling
Δσ = Addition of vertical effective stress (t/m^2)
σo = Overburden effective stress (t/m^2)
σc = Preconsolidation effective stress (t/m^2)

3. Vertical Consolidation Coefficient (Cv)

Determine the velocity of water flow in the vertical direction in the soil. Because consolidation generally takes place in one direction, namely the vertical direction, the coefficient of consolidation is very influential on the speed of consolidation that will occur. The price of CV can be found using the following equation:

$$Cv = \frac{Tv . H^2}{t} \quad (4)$$

Where :

Cv = Consolidation coefficient (cm^2/dtk)
Tv = The time factor depends on the degree of consolidation (cm)
t = the time required to reach the degree of consolidation U% (dtk)
H = Soil layer thickness (m)

4. Soil Consolidation Time

In soils that are not consolidated with the use of Prefabricated Vertical Drain (PVD), the flow that occurs is only in the vertical direction. According to Terzaghi in Das (1985), the length of time for consolidation in the field can be calculated as follows:

$$t = \frac{(H_{dr^2}) . \; Tv}{Cv} \quad (5)$$

Where :

t = Time required to complete consolidation (detik)
Tv = time factor
H_{dr} = Distance of pore water in the soil layer to flow (m)
Cv = vertical direction consolidation coefficient (cm^2/dtk)

5. Prefabricated vertical drain (PVD)

Prefabricated vertical drain (PVD) is where artificial channels are installed vertically on soft soil. This method's implementation in the field is combined with the preloading method to get the shortest time during consolidation.

The degree of consolidation of the average U can be found by:

$$U = 1 - (1-Uh)(1-Uv) \times 100\% \quad (6)$$

Where:

U = the average degree of soil consolidation due to vertical and radial flows
Uh = degree of radial consolidation
Uv = degree of vertical consolidation.

Preloading

Preloading is a temporary load placed on a construction site, optimizing PVD performance and improving the bearing capacity of the subgrade where the construction will be erected.

Prefabricated Vertical Drain (PVD)

The time for the decline to occur tends to be very long. Prefabricated Vertical Drain (PVD) accelerates the consolidation settlement rate by shortening the clay's flow path. The commonly used PVD size is 100 mm wide and 3-7 mm thick. It consists of an outer part as a filter jacket and a drain core (the core is where the pore water flows). The function of the filter jacket is as a filter to limit the entry of fine soil particles that will block the flow of water. While the function of the drain core is as a flow path, ensuring a straight vertical flow path, its rigid nature provides strength to horizontal pressure and flow. The Prefabricated Vertical Drain section can be seen in the following picture:

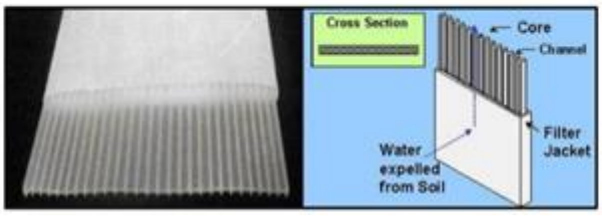


Figure 1. Prefabricated Vertical Drain

the amount of consolidation time due to the use of Prefabricated Vertical Drain (PVD) is sought by the equation:

$$t = \frac{D^2}{8C_h} F(n) \ln\left(\frac{1}{1 - U_h}\right) \quad (7)$$

Where :
t = consolidation time to achieve U_h (dtk)
D = circle equivalent diameter (cm)

Rectangular pattern = 1,13 x S
Triangle Pattern = 1,05 x S

Ch = horizontal flow consolidation coefficient (cm^2/dtk)
Cv = vertical flow consolidation coefficient (cm^2/dtk)
F(n) = Resistance factor due to PVD distance.

Square mounting pattern

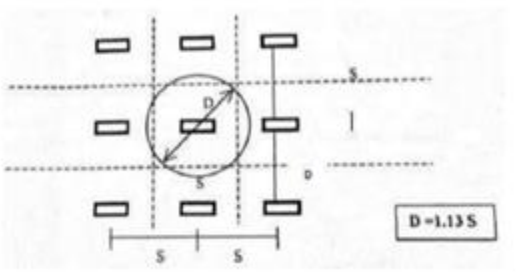


Figure 2: Square Installation Pattern

Triangle mounting pattern

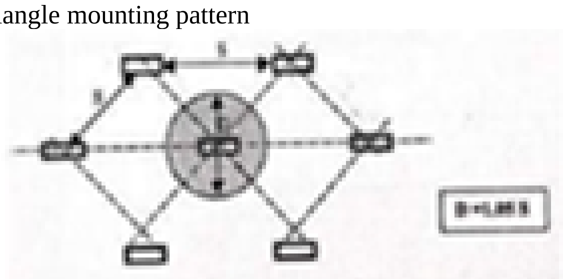


Figure 3: Triangular mounting pattern

III. MATERIAL AND METHOD

1). Location
The research was conducted at the Soil Mechanics Laboratory, Department of Civil Engineering, Hasanuddin University, Gowa, South Sulawesi. Soft soil was taken around the research site, and Sirtu was taken from the Pasir Mine, Borisalo.

2). Examination of Soil Material Characteristics

The soil characteristic tests used were moisture content, bulk density, specific gravity, sieve analysis, Atterberg limits, consolidation, compaction, permeability, free compressive strength, and direct shear following the required test standards (SNI, ASTM, AASHTO).

3). Research Standards

Table 1. Standards for Testing Physical Characteristics

Test	Standard
Moisture Content and Filling Weight	ASTM D2216-71
Specific gravity	ASTM D854-58(72)
Sieve Analysis	ASTM D1140-54,
	D421-58 & D422-63
Permeability	ASTM D2434-68
Atterberg Limit	ASTM D3080 - 72
Consolidation	ASTM D1140 -54

Table 2. Mechanical Characteristics Test

Test	Standard
Compaction	ASTM D1557-70 &
	AASHTO T99 -70
Kuat Tekan Bebas	ASTM D2166 -66
Direct Shear	ASTM D3080, AASHTO T236

4). Research Design
The modeling is made into 2 (two) variations, namely without reinforcement and adding a prefabricated drain.

a. No Reinforcement
The clay is put into a test tank measuring 100 cm x 100 cm x 150 cm to a height of 50 cm (subgrade). During the reconstruction period, the soil was saturated by filling it with water and then controlling it. After the test tank is filled with clay, the gravel material is added above the subgrade layer as high as 40 cm. Finally, the dial indicator (dial gauge) is placed in five (5) positions.

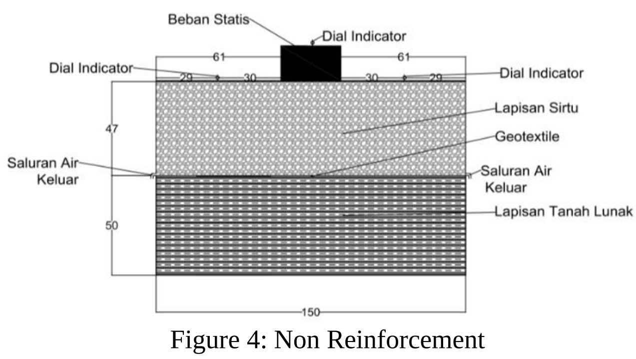


Figure 4: Non Reinforcement

b. With Prefabricated Vertical Drain.

The clay is put into a test tank measuring 100 cm x 100 cm x 150 cm to a height of 50 cm (subgrade). During the reconstruction period, the soil was saturated by filling it with water and then controlling it. After the test tank is filled with soil, the sand is inserted above the subgrade layer as high as 40 cm. After that, a Prefabricated Vertical Drain (PVD) is installed into the subgrade to a depth of 50cm with a distance between installation points of 30 cm. Finally, the dial indicator (dial gauge) is placed in five (5) positions.

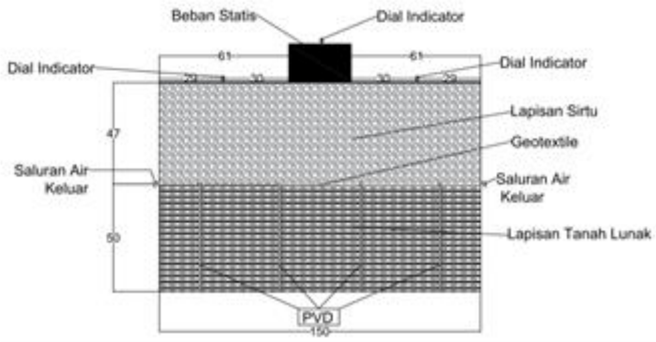


Figure 5: With Prefabricated Vertical Drain.

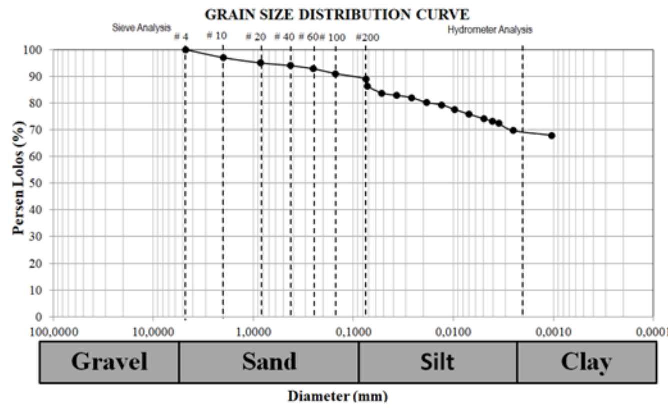
IV. Results and Discussion

1). Soil Material

Basic Physical and Mechanical Properties

Based on the results of laboratory tests on soil samples, it is known that the average water content (ω) is very high, namely 64.77%, with a degree of saturation of 98.13%, specific gravity 2.75, wet density 1.58 t/m3, and dry weight of 0.785 t/m3. While the void ratio (e) and the porosity level (n), the test results showed 2.24 and 69.135%, respectively. Based on these results, it can be seen that the soil condition is near perfect saturation.

While the results of the size distribution test granules, namely through sieve analysis and hydrometer tests, showed that 54.10% of the soil grains passed the 0.075 mm sieve diameter with the coefficient of uniformity (Cu) and coefficient of curvature (Cc) being 1.5 and 16.67.



The results of testing the physical and mechanical properties of the soil are shown in the following table:

Table. 3. Result of Testing Fisik Characteristic of soil

Test	Test Result	
	Value	Unit
Compaction • Berat Isi kering Opt • Opt water content (w_{opt})	 1,17 25,67	 gr/cm^3 %
Consolidation • Indekx Pemampatan,Cc • Koefisien Kembang, Cs • Cu • Koefisien Konsolidasi, Cv	 0,400 0,031 10.787 7.8E^{-04}	 - - KN/m^3 cm^2/dtk
Direct shear • Cohesi, c • Sudut Geser Dalam, φ	 0,104 17,32	 Kg/cm^2 o

Tables. 4. Results of Testing Mechanical Characteristics of Soil

Test	Test Result	
	Value	Unit
Water Conten (w)	3,82	%
Specific Gravity (Gs)	2,75	-
Void Ratio (e)	1,622	
Berat Vol Basah, (γbasah)	1,580	gr/cm^3
Berat Vol Kering, γd	0,962	gr/cm^3
Sieve Analisis • Tanah Butir Kasar • Tanah Butir Halus	 45,90 54,10	 % %
Permeabily	1.934.10^{-7}	cm/s
UCT (q_u)	0,052	kg/cm^2
Atterberg Limit • Liquid Limit, LL • Plastic Limit, PL • Shringke Limit, SL • Indeks Plastisitas, IP	 50,36 37,23 30,86 13,12	 % % % %

Table 5. Calculation of Consolidation Time for Vertical Direction without Reinforcement

Degree of Consolidation		Time Factor (Tv)	The thickness of the clay layer (H)	Cv Mean	Time achieve consolidation (t)	
	%		Cm	cm^2/day	Minute	Day
U	0,00	0,000	50	2727,32	0,000	0.000
	10,00	0,008			0,007	0.000
	20,00	0,031			0,028	0.000

	30,00	0,071			0,065	0.000
	40,00	0,126			0,115	0.000
	50,00	0,197			0,181	0.000
	60,00	0,287			0,263	0.000
	70,00	0,403			0,369	0.000
	80,00	0,567			0,520	0.000
	90,00	0,848			0,777	0.001

From the table, it is found that the degree of consolidation) is 100% with a time factor (Tv) of 0.848 and Cv is 2727.32 cm2/day.

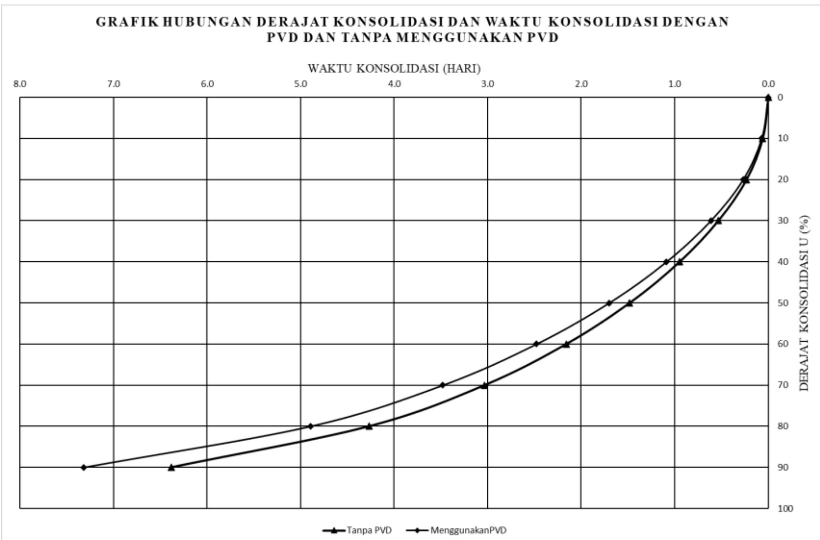
Table 4. Calculation of Consolidation Time for Vertical Direction Using Prefabricated Vertical Drain

Degree of Consolidation		Time Factor (Tv)	The thickness of the clay layer (H)	Cv Mean	Time achieve consolidation (t)	
	%		cm	cm^2/day	Minute	day
U	0,00	0,000	50,00	588,86	0,000	0,000
	10,00	0,008			0,034	0,000
	20,00	0,031			0,132	0,000
	30,00	0,071			0,301	0,000
	40,00	0,126			0,535	0,000
	50,00	0,197			0,836	0,001
	60,00	0,287			1,218	0,001
	70,00	0,403			1,711	0,001
	80,00	0,567			2,407	0,002
	90,00	0,848			3,600	0,003
	100,00	-			-	-

From the table, it is found that Cv is 2727.32 cm2/day.

Table 4. Calculation of the Consolidation Coefficient of Vertical Direction

Model	CV	ΣH	Average Cv		Average Ch		H First
	cm^2/s	cm	cm^2/s	cm^2/hari	cm^2/s	cm^2/hari	
Non PVD	26,40	50,00	1,8940	2727,32	45,4	65431,2	50
Using PVD	122,27	50,00	0,4089	588,86	45,6	65709,6	50



V. Conclusions

From the research on evaluating the performance of soil improvement using geotechnical instruments, it can be concluded:

From the modeling results, it can be seen that the maximum decrease that occurs in the prefabricated drain variation is 8.32 mm, with a consolidation travel time of 1.04 days. From this, it is known that the significant effect of adding prefabricated drain into the model will accelerate the rate of soil consolidation by 92.198%.

Acknowledgment

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