VOLUME 22 | NUMBER 01 | JULY 2022
https://ejournal.worldconference.id/index.php/neutron
E-ISSN: 2685-3272 | P-ISSN 1412-0860

Analysis of Land Subsidence Using A Combination of Preloading and Prefabricated Vertical Drain Methods

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Abstract

Pertamina Balongan Indramayu's New Construction Jetty & Temporary Access Road Construction Project is the construction of a new jetty (silting prevention pier) located on a loamed land, which consists of dredging work on the area to be built by the jetty, protection of existing pipes, and erection of piles. In the implementation of the jetty construction, there are several reviews that need to be considered, such as soil elastic subsidence and soil consolidation subsidence. The method used for land subsidence is the Preloading method and is combined with the use of PVD to increase the time of decline. The results of this study found an elastic decrease using the Preloading method, a result of 0.7765 meters was obtained due to the presence of a stockpile load and an implementation load of 22.1312 kN/m^2 on Elv. ± 1.00 m – STA. 0 + 025 m. Meanwhile, the decrease in consolidation ($S_c + S_s$) using the Preloading method, obtained a result of 4,949 meters due to the heap load and implementation load of 27,201 kN/m^2 on Elv. ± 1.00 m – STA. 0 + 025 m and the length of time it takes to achieve the degree of consolidation of the plan (U_v = 90 %) using the Preloading method obtained results, which is 297 days. When the Preloading method is combined with using the Prefabricated Vertical Drain (PVD) method, the result of the length of time (t) needed to achieve the degree of consolidation of the plan (U_v = 90 %) is 158 days using a quadrilateral pattern installation PVD with a distance of 0.8 meters.

Keywords
Consolidation; Preloading; Prefabricated Vertical Drain.

1. Introduction

1.1. Background

Clay soil is a type of soil that is quite detrimental to construction because it has low soil carrying capacity, high moisture content, and is difficult to drain due to relatively low soil permeability. It is known that there are several methods that can be used to increase soil strength, one of which is the soil improvement method, which is carried out using the preloading method with a combination of Prefabricated Vertical Drains (PVD). This method is used to speed up the time of consolidation and the degree of consolidation. (Ronal, 2021).

The decreasing case is caused by several things, including underground erosion that brings soil grains to flow, so that there is a reduction in volume in the soil. In addition, a decrease can occur due to vibration, because it can cause the movement of soil grains that crowd the surrounding space, so that the volume of the soil decreases. Pertamina Balongan Indramayu's New Construction Jetty & Temporary Access Road Construction Project is the construction of a new jetty (silting prevention pier), which consists of dredging work on the area to be built by the jetty, protection of existing pipes, and erection of piles. In the implementation of the jetty construction, there are several reviews that need to be considered, such as soil elastic subsidence and soil consolidation subsidence. Therefore, a soil improvement method is needed that can increase the strength of the soil carried out, namely the preloading method. Furthermore, this method is carried out by installing a vertical drainage system in the form of a Prefabricated Vabricated Drain.

1.2. Problem Formula

1. How much does the elastic decrease and consolidation decrease by using the preloading method?
2. How long does it take to achieve the required degree of consolidation using the preloading method?
3. How long does it take to achieve the required degree of consolidation by using a combination of the preloading method and the prefabricated vertical drain method?

1.3. Purposes and Objectives of the Study

1. By using preloading and knowing the amount of elastic decrease and consolidation decrease.
2. Knowing the time required to achieve the required degree of consolidation using preloading.

3. By knowing the time required to achieve the required degree of consolidation by using a combination of the preloading method and the prefabricated vertical drain

2. Literature Review

2.1. Subsidence of Elastic Soil (S_i)

Elastic subsidence (S_i) is a land subsidence that occurs in elastic conditions.

S_i = P · B · 1 - μ2Es ·IP

Information :
S_i= Elastic subsidence (m)
P = Net Pressure Charged (kN)
B = Width of the Foundation (m)
μ = Poissons' Ratio Ground Number
E_s = Modulus of Soil Elasticity (kN/m^2)
IP = Influence Factor For Bending Foundation Type & Rigid Foundation

2.2. A Decrease in Primary Consolidation (S_c)

Clay soils are normally consolidated when the preconsolidation pressure (pc') is equal to the effective pressure of overburden (po'). Whereas clay soils are under over-consolidated conditions if the preconsolidation pressure is greater than the effective overburden pressure that exists at the present time (pc' > po'). For normally consolidated clay, you can use the following equation:

$$\boldsymbol{S_c = \frac{C_cH}{1+e0}log(\frac{P_0+\Delta P}{P_0})}$$

When the soil is overconsolidated→ $(po + \Delta p) \leq pc$, so :

$$\boldsymbol{S_c = \frac{C_cH}{1+e0}log(\frac{P_0+\Delta P}{P_0})}$$

When the soil is overconsolidated→ $(po + \Delta p) > pc$, so :

$$\boldsymbol{S_c = \frac{C_sH}{1+e0}log\frac{P_c}{P_0} + \frac{C_cH}{1+e0}\ log(\frac{P_0+\Delta P}{P_0})}$$

Information :
S_c = Primary consolidation decrease(m)
C_s = Expansion index
C_c = Compression coefficient
H= Thickness of compressed clay soil sublayer (m)
e_o = porous number
p_o = Effective sublayer overburden pressure (kN/m^2)
p = Vertical pressure addition for sub-layers (kN/m^2)

2.3. Secondary Consolidation Decrease (S_s)

The decrease in secondary consolidation (S_s) is a decrease caused by the plastic adjustment of the soil grains when the primary consolidation process has ended, so as to use the equation

$$\boldsymbol{S_s = \frac{C_{re}H}{1+e0}log(\frac{P_0+\Delta P}{P_0})}$$

2.4. Preloading Method

Preloading increases the carrying capacity and reduces the compressibility of soft soils. Preloading makes loose sand soils dense or makes clay and silt soils consolidate (Hausmann, 1990). A simple solution for preloading is preloading by using a backlog. Although it can be carried out on any type of soil, preloading is more effectively applied to soft, cohesive soils.

2.5. Prefabricated Vertical Drain Method

To accelerate the occurrence of settlement, it is necessary to reduce the length of the pore waterway. This can be done by installing a Prefabricated Vertical Drain (PVD) in the ground at a certain distance with a triangular or quadrilateral formation. PVD (Prefabricated Vertical Drain) is one of the geosynthetics products that function as a drainage. The function of PVD in soft clay soil improvement work preloading method with the use of PVD is to speed up the process time.

3. Research Methods

The stages of this research will be presented in the form of a flowchart as below:

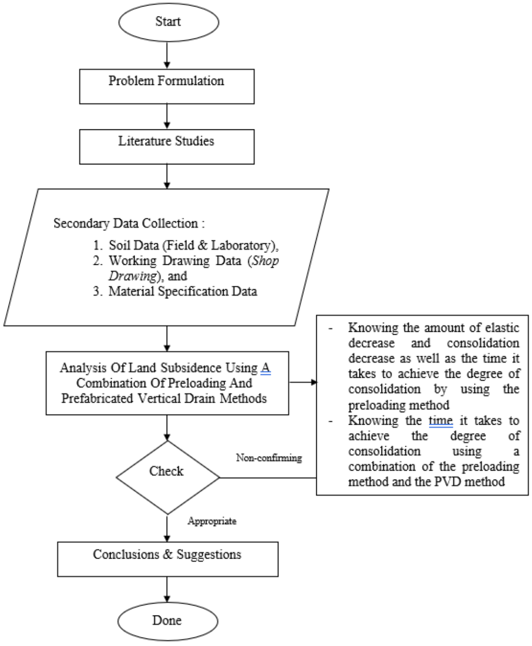

Figure 2. 1 Flowchart
(Source : Writer, 2022)

4. Results And Analysis

4.1. Consolidation Decrease Calculation Using the Preloading Method

4.1.1. Ground Stress Calculation

1. Overburden on Effective Voltage ($\Delta\sigma'0$)

The calculation of the effective voltage of overburden ($\Delta\sigma'_0$), which is as follows:

1) Layer I – A

$H_{(I-A)}$ = 1,00 m

$\gamma_{(I-A)}$ = 10,14 kN/m^3

$\sigma'_{0(I-A)}$ = $[(\gamma_{dry(I-A)} \cdot \frac{H_{(I-A)}}{2})]$

= $[(10{,}14 \cdot \frac{1{,}00}{2})]$

= 5.07 kN/m^2

2) Layer II – A

$H_{(II-A)}$ = 1,45 m

$\gamma_{eff\ (II-A)}$ = 10,14 kN/m^3

$\sigma'_{0(II-A)}$ = $(\gamma_{dry(I-A)} \cdot H_{(I-A)} + (\gamma_{eff(II-A)} \cdot \frac{H_{(II-A)}}{2})]$

= $[(10{,}14 \cdot 1{,}00) + (10{,}14 \cdot \frac{1{,}45}{2})]$

= 17.4915 kN/m^2

2. Voltage Addition ($\Delta\sigma'_0$)

The calculation of the addition ofvoltage ($\Delta\sigma'_0$), which is as follows:

1) Layer I – A

a_{Pile} = 0,25 m

b_{Pile} = 4,40 m

$z_{(I-A)}$ = 0,50 m

q_{0Total} = 22,131 kN/m^2

$I_{(I-A)}$ = 0,500

$\Delta\sigma'_{0(I-A)}$ = $(2 \cdot q_{0Total} \cdot I_{(I-A)})$

= $(2 \cdot 22{,}131 \cdot 0{,}500)$

= 22,131 kN/m^2

2) Layer II – A

a_{Pile} = 0,25 m

b_{Pile} = 4,40 m

$z_{(II-A)}$ = 1,73 m

q_{0Total} = 22,131 kN/m^2

$I_{(II-A)}$ = 0,446

$\Delta\sigma'_{0(II-A)} = (2 \cdot q_{0Total} \cdot I(I_{I-A}))$

$= (2 \cdot 22,131 \cdot 0,446)$

$= 19,741$ kN/m^2

4.1.2. Elastic Drop Calculation (S_i)

The stages of calculating the elasticdecrease (S_i) with the preloading method, are as follows:

1) Layer I – A

B_{Pile} = 4,40 m

A_{Pile} = 0,25 m

$\Delta\sigma'_{0(I-A)}$ = 22,131 kN/m^2

$E_{s(I-A)}$ = 2298,25 kN/m^2

$\mu_{(I-A)}$ = 0,25

$I_{p(I-A)}$ = 1,024

$$S_{i\,(I-A)} = \Delta\sigma'_{0(I-A)} \cdot (b_{Pile} + 2 \cdot a_{Pile}) \cdot \frac{1-\mu_{(I-A)}{}^{2}}{Es(I-A)} \cdot I_{p(I-A)}$$

$$= 22,131 \cdot (4,40 \cdot 2 \cdot 0,25) \cdot \frac{1-0,25^{2}}{2298,25} \cdot 1,024$$

$$= 0,0453 \text{ m}$$

2) LayerII – A

B_{Pile} = 4,40 m

a_{Pile} = 0,25 m

$\Delta\sigma'_{0(II-A)}$ = 19,741 kN/m^2

$E_{s(II-A)}$ = 2298,25 kN/m^2

$\mu_{(II-A)}$ = 0,25

$I_{p(II-A)}$ = 1,024

$$S_{i\,(II-A)} = \Delta\sigma'_{0(II-A)} \cdot (b_{Pile} + 2 \cdot a_{Pile}) \cdot \frac{1-\mu_{(II-A)}{}^{2}}{Es(II-A)} \cdot I_{p(II-A)}$$

$$= 19,741 \cdot (4,40 \cdot 2 \cdot 0,25) \cdot \frac{1-0,25^{2}}{2298,25} \cdot 1,024$$

$$= 0,0404 \text{ m}$$

Recapitulation of Elastic Decrease S_i to Elv. ± 2.00 meters can be shown in the table below.

Table 1. Recapitulation of Si Calculation (Elv. ± 0.25 meter s/d Elv. ± 1,00 meter)

No.	STA. Point (m)	± Pile (m)	Si Settlement (m)
1	0 + 025	0,25	0,1567
2	0 + 025	0,50	0,2075
3	0 + 025	0,75	0,1826
4	0 + 025	1,00	0,2297
Total Elastic Decrease (Si)			0,7765

(Source : Data Processing Results)

4.1.3. Calculation of Primary ConsolidationDecrease (S_c)

As for the calculation of the decrease in primary consolidation (S_c), it can be carried out using the results of the analysis of the determination of soil properties.

1) Layer I – A

$H_{(I-A)}$ = 1,00 m

$C_{s(I-A)}$ = 0,21

$e_{0(I-A)}$ = 1,54

$\sigma'_{0(I-A)}$ = 5,070 kN/m^2

$\Sigma\sigma'_{0(I-A)}$ = 27,2012 kN/m^2

$$S_{c\,(I-A)} = \frac{C_{c(I-A)} \cdot H_{(I-A)}}{1+e_{0(I-A)}} \cdot \log\left(\frac{\Sigma\sigma'_{0(I-A)}}{\sigma'_{0(I-A)}}\right)$$

$$= \frac{0{,}21 \cdot 1{,}00}{1+1{,}54} \cdot \log\left(\frac{27{,}2012}{5{,}070}\right)$$

$= 0{,}4194$ m

2) Layer II – A

$H_{(II-A)}$ = 1,45 m
$C_{s(II-A)}$ = 0,21
$e_{0(II-A)}$ = 1,54
$\sigma'_{0(II-A)}$ = 17,492 kN/m^2
$\Sigma\sigma'_{0(II-A)}$ = 37,2325 kN/m^2

$$S_{c\,(II-A)} = \frac{C_{s(II-A)} \cdot H_{(II-A)}}{1+e_{0(II-A)}} \cdot \log\left(\frac{\Sigma\sigma'_{0(II-A)}}{\sigma'_{0(II-A)}}\right)$$

$$= \frac{0{,}21 \cdot 1{,}45}{1+1{,}54} \cdot \log\left(\frac{37{,}2325}{17{,}492}\right)$$

$= 0{,}0393$ m

Primary Descent Recapitulation of S_c to Elv. ± 2.00 meters can be shown in the table below.

Table 2. Recapitulation of Sc Calculation (Elv. ± 0.25 m s/d Elv. ± 1.00 m)

No.	STA. Point (m)	± Pile (m)	Sc Settlement (m)
1	0 + 025	0,25	0,4022
2	0 + 025	0,50	0,5290
3	0 + 025	0,75	0,5477
4	0 + 025	1,00	0,6474
Total Decrease in Primary Consolidation (Sc)			2,1263

(Source : Data Processing Results)

4.1.4. Calculation of Secondary Consolidation Decrease (S_s)

The stages of calculating the decrease in secondary consolidation (S_s) by the preloading method can be done in the following way:

1) Layer I – A

$H_{(I-A)}$ = 1,00 m
$C_{re(I-A)}$ = 0,63
$e_{0(I-A)}$ = 1,54
$\sigma'_{0(I-A)}$ = 5,070 kN/m^2
$\Sigma\sigma'_{0(I-A)}$ = 27,2012 kN/m^2

$$S_{s(I-A)} = \frac{C_{re(I-A)} \cdot H_{(I-A)}}{1+e_{0(I-A)}} \cdot \log\left(\frac{\Sigma\sigma'_{0(I-A)}}{\sigma'_{0(I-A)}}\right)$$

$$= \frac{0{,}63 \cdot 1{,}00}{1+1{,}54} \cdot \log\left(\frac{27{,}2012}{5{,}070}\right)$$

$= 0{,}1810$ m

2) Layer II – A

$H_{(II-A)}$ = 1,45 m
$C_{re(II-A)}$ = 0,21
$e_{0(II-A)}$ = 0,63
$\sigma'_{0(II-A)}$ = 17,492 kN/m^2
$\Sigma\sigma'_{0(II-A)}$ = 37,2325 kN/m^2

$$S_{s(II-A)} = \frac{C_{re(II-A)} \cdot H_{(II-A)}}{1+e_{0(II-A)}} \cdot \log\left(\frac{\Sigma\sigma'_{0(II-A)}}{\sigma'_{0(II-A)}}\right)$$

$$= \frac{0{,}63 \cdot 1{,}45}{1+1{,}54} \cdot \log\left(\frac{37{,}2325}{17{,}492}\right) \cdot 0$$

$= 0{,}1180$ m

Recapitulation of Secondary Descent Ss to Elv. ± 2.00 meters can be shown in the table below.

Tabel 3. Recapitulation of S_s Calculation(Elv. ± 0.25 m $^s/_d$ Elv. ± 1.00 m)

No.	**STA. Point (m)**	**± Pile (m)**	**S_s Settlement (m)**
1	0 + 025	0,25	0,5458
2	0 + 025	0,50	0,6998
3	0 + 025	0,75	0,7017
4	0 + 025	1,00	0,8750
Total Decrease in Secondary Consolidation (S_s)			**2,8223**

(Source : Data Processing Results)

4.1.5. Calculation of Consolidation Time (t) & Degree of Consolidation (U_v)

The following recapitulation of thecalculation of the consolidation time (t) and degree of consolidation (U_v) with U_v = 50 %, can be explained in one of thepieces (STA. 0 + 025 – Elv. ± 0.25 meters) :

Table 4. Recapitulation of Calculation t & U_v= 50 % (Elv. ± 0.25 m $^s/_d$ Elv. ± 1.00 m)

No	STA.Point (m)	± Pi le (m)	Score s of Hdr2 (Uv = 50 %)	Scor es of Uv (Uv = 50%)	Scor es of Tv (Uv = 50%)	Scor es of Cv (m2/ hari)	Scor es of t (Hari)
1	0 +025	0,25	32,00	50,00	0,197	0,731	68,944
2	0 +025	0,50	31,31	50,00	0,197	0,746	64,972
3	0 +025	0,75	30,49	50,00	0,197	0,766	60,040
4	0 +025	1,00	29,68	50,00	0,197	0,787	55,378

(Source : Data Processing Results)

The following recapitulation of the calculation of the consolidation time (t) and degree of consolidation (U_v) with U_v = 90 %, can be described in one of the pieces (STA. 0 + 025 – Elv. ± 0.25 meters) :

Table 5. Recapitulation of Calculation t & U_v= 90 % (Elv. ± 0.25 m $^s/_d$ Elv. ± 1.00 m

No	**STA .Point (m)**	**± Pile (m)**	**Scores of H_{dr}^2 (U_v = 90%)**	**Scores of U_v (U_v = 90%)**	**Scores of T_v (U_v = 90%)**	**Scores of C_v (m^2/hari)**	**Scores oft (Hari)**
1	0 +025	0,25	32,00	90,00	0,848	0,731	**296,775**
2	0 +025	0,50	31,31	90,00	0,848	0,746	**279,677**
3	0 +025	0,75	30,49	90,00	0,848	0,766	**258,447**
4	0 +025	1,00	29,68	90,00	0,848	0,787	**238,378**

(Source : Data Processing Results)

4.1.6. Prefabricated Vertical Drain (PVD)

Based on the results of the analysis using the Prefabricated Vertical Drain (PVD) method, a consolidation time of 388 days was obtained to achieve a consolidation degree of >90%. Meanwhile, the consolidation time required using the preloading method is 297 days. This shows that the installation of a quadrilateral pattern Prefabricated Vertical Drain (PVD) with a distance of (S) = 1.00 meters is not enough to speed up the consolidation time. So, it is necessary to install PVD at a tighter distance than what is currently used at a distance of 0.80 meters.

Based on the results of the analysis using the Prefabricated Vertical Drain (PVD) method, the quadrilateral installation pattern with a distance of 0.80 m obtained a consolidation time of 158 days to achieve a degree of consolidation of >90%.

5. Conclusion

From the calculation results, the elastic decrease using the Preloadingmethod, obtained a result of 0.7765 metersdue to the presence of a stockpile load andan implementation load of 22.1312 kN/m^2 on Elv. ± 1.00 m – STA. 0 + 025 m. Meanwhile, the decrease in consolidation ($S_c + S_s$) using the Preloading method, obtained a result of 4,949 meters due to theheap load and implementation load of 27,201 kN/m^2 on Elv. ± 1.00 m – STA.0 + 025 m.

Based on the calculation results, the length of time it takes to achieve the degree of consolidation of the plan (U_v = 50 %) using the preloading method is 69 days. Meanwhile, the length of time (t) required to achieve the degree of consolidation of the plan (U_v = 90 %) using the method.

When the preloading method is combined with using the Prefabricated Vertical Drain (PVD) method, the result is the length of time (t) needed to achieve the degree of consolidation of the plan (U_v = 90 %) is 158 days using a quadrilateral pattern installation of PVD with a distance of 0.8 meters. Installation with such distances is considered faster to achieve the degree of consolidation of the plan (U_v = 90 %) compared to the quadrilateral installation pattern with a distance of 1.00 meters, which takes 388 days. The use of the preloading method is faster than combining using the Prefabricated Vertical Drain (PVD) method of mounting a quadrilateral installation pattern of 1.0 meters. This is because the heap layer is relatively small, which makes the consolidation time quite fast. Thus, the use of the Prefabricated Vertical Drain (PVD) method of a quadrilateral installation pattern with a distance of 0.8 meters is considered more effective to use and combine when the stockpile is relatively small.

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