

# Research on the acceleration of settlement by installing vertical drain and preloading with sand

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**Abstract.** The container yard, which facilitated the Container Terminal of the Jakarta International Container Terminal (Terminal Peti Kemas Koja), at Tanjung Priok Jakarta is located on a land which the subsurface soil is predominated by a compressible clay layer, from 5.00 to 22.00 m depth. The load from containers quite high and will stay for a long period. Without soil improvement, the estimated consolidation settlement is 1.418 m, which will take place in a very long time. Soil improvement has carried out by accelerating consolidation, by installing vertical jute fiber-drain, and loading the soil by a preload of sand to elevation of +8.50 m. To investigate the effectiveness of the installed vertical jute fiber-drain, geotechnical instruments also installed, which are settlement plate, standpipe piezometers, pneumatic piezometers, magnetic extensometers, and inclinometers. Vertical jute fiber-drain is a Prefabricated Vertical Drain (PVD) made of natural jute fiber and coconut coir designed to accelerate consolidation of soft clayey soil. It has high tensile strength to withstand installation stresses and excellent water discharge capacity. The cross section of natural fiber PVD measures 80-120 mm in width and 8–12 mm in thickness and have a tensile strength of above 7 kN. The present drain differs from the others drain is that its manufactured in existing jute mills machinery, the manufacturing process entails low energy consumption, and has capability of varying the width, thickness and weight per linear meter to suit different soft clayey soil conditions. An important feature of the jute burlap is its swelling nature that allows it to function as filter without clogging and it's biodegradable, hence environmentally friendly.

**Keywords:** compressible clay layer, soil improvement, vertical drains, environment

## 1. Introduction

The subsurface clay soil will settle if loaded by fill; the amount of consolidation settlement depends mainly on the compressibility of the subsurface clay and on the thickness of fill. The time required for consolidation depends on 2 main factors, namely on the permeability of the consolidating soil (linearly) and on the drainage path length (exponentially). The clay soil has a very small coefficient of



permeability, causing very long time required for completing consolidation, especially if the consolidating compressible soil is very thick, meaning the drainage paths are very long.

Due to the load of the preload, the pore water pressure in the soil will increase, according to the size of the preload. In the sand layer, this increase in pore pressures decreases rapidly, reaching the equilibrium. In a clay layer located between 5 to 22 meters deep, this increase in pore pressures causes the pore water to move in search of a more permeable closer spot.

One reclaimed area located on top of compressible clay soil, say 20 m thickness. Consolidation settlement calculation shows that if the ground surface elevation filled to a design level of +6.00 m, settlement will occur about 1.60 m; and the 90% consolidation will reach in a very long period, of more than 15 years. This will cause continuous filling and repair of the area and the revetment to maintain the design level elevation. To avoid such problem, the consolidation settlement has to *accelerated*, so it will complete before the reclaimed area to be use. This has earlier used to do through vertical sand drains.

## 2. Research on accelerate of soil consolidation.

The container yard located on a land which the subsurface soil is predominated by compressible clay layer, from 5.00 to 22.00 m depth with the estimated consolidation settlement is 1.418 m will be repaired by speeding up consolidation, by installing Prefabricated Vertical Drain (PVD) and load it with Preload. The cheaper material PVD used in this area is Jute Fiber-drain that has plugged into the ground with a special tool to a depth of 14 – 16 m, so it is a very permeable vertical groove. The distance between the PVD Jute Fiber-drain is 1.30 meters, fitted with a triangular pattern, with an equivalent diameter of 10 cm. The upper end of the Jute Fiber-drain already plugged into the ground, were given more length, to ensure the drainage of water into the sand layer piled on top (sand blanket), which also serves as a drainage reservoir of all Jute Fiber-drain and as a preload (surcharge).

Because of the installed PVD that is close enough to each other, it is expected that the pore water from the clay layer will reach PVD in a relatively short time, so that in a relatively short time pore water pressure will achieve balance or consolidation will occur.

In this way, it expected after preloading and after most of the consolidation is completed, the soil becomes more compact and becomes less compressibility. Before the ground in this project is loaded with preload, the consolidation test results show that the above clay soil is almost normally consolidated (NC) or also be call slightly over consolidated. The load of preload and sand piles is quite large, and larger than the largest load ever received by the previous soil, so the preload becomes the new pre-consolidation pressure for the clay soil. After the consolidation is complete, and the preload sand pile is shift out, the clay soil becomes over consolidated (OC). The clay soil that over consolidated has compression index  $C_r$  much smaller than the compression index  $C_c$  at the time the clay still normally consolidated. Accordingly, the consolidation settlement due to the container workload at the time of the container yard in operation will be quite small.

## 3. Original Soil Condition

Subsoil in the area of the container yard plan has undergone a soil investigation by drilling at a depth of 30.00 meters, i.e. at B-13, 14 and B-16 drill points. From the cut image, it shown that there is a layer of clay that has high compressibility, which is not uniformly thick.

**At B-13 drill point**, the top layer of 5.00 m thick, is a not very dense layer of sand, with N (SPT) 14 to 15. The sand layer is mixed slightly 5-7 % clay, the soil type weight is flat - 1.71 t/m<sup>3</sup> with specific gravity  $G_s$  of 2,681. Below the sand layer, at 5.00 to 15.00 m depth is a soft clay layer, with N (SPT) of 1 to 6, high compressibility, while at 15.00 m to 22.00 m depth is dense clay until very solid with N (SPT) 12 to 21. This Soft clay has high enough of water content, which in some examples of soil, the moisture content was above its liquid limit. High compressibility was show by its high compression index, between 0.680 to 1.060, and the high pore-number (void ratio) between 2.11 to 2.31.

At solid clay until very solid clay water content is also high, but the compression index  $C_c = 0.215$  to  $0.331$  is lower, with pores value (void ratio) between  $1.42$  and  $1.52$  at  $15.00$  m to  $20.00$  m depth, and  $C_c = 0.418$  with pore value  $2.09$  at  $20.00$  m to  $22.00$  m depth. Below the clay layer, at  $22.00$  m to  $29.00$  m depth, is a tuff sandstone layer with an  $N$  (SPT) greater than  $60$ .

**At B-14 drill point**, which lies between CY-1 and CY-2, the top layer of  $8.00$  m thick is a sand layer that is not very dense, with  $N$  (SPT)  $1$  to  $4$ . This sand layer is mixed with  $19.74\%$  to  $69.64\%$  clay with soil type weight averaged  $1.69$  t/m<sup>3</sup> and specific gravity  $G_s$  of  $2.67$ . Below the sand layer, at  $8.00$  m to  $24.00$  m depth is a soft clay layer,  $N$  (SPT)  $3$  to  $9$ , high compressibility, and has high moisture content, in some samples the water content is above its liquid limit. High compressibility shown by its high compression index, ranging from  $0.473$  to  $0.477$  at  $8.00$  m to  $15.00$  m depth, and  $1.63$  to  $0.906$  at  $15.00$  m to  $20.00$  m depth. The clay deepest layer between  $20.00$  m to  $34.00$  m depth has a small compression index that is  $0.13$  to  $0.28$ . At this point, no solid clay layer found. Below the clay layer, at  $24.00$  m to  $30.00$  m depth is a sandy clay stone layer with an  $N$  (SPT) greater than  $60$ .

**At B-16 drill point**, located in CY-2 area, the top layer of  $5.00$  m thick is a layer of sand that is not very dense, with  $N$  (SPT)  $12$ . This sand layer is mixed slightly  $15.45\%$  to  $18.66\%$  clay, the soil type weight averaged  $1.58$  t/m<sup>3</sup> with a specific gravity  $G_s$  of  $2.69$ .

Below the sand layer, at  $5.00$  m to  $14.00$  m depth is a soft clay layer, with  $N$  (SPT)  $5$  and  $6$ , with high compressibility, the soft clay has quite high moisture content, i.e. between  $62\%$  and  $93\%$ . High compressibility has shown by its high compression index, range from  $0.44$  to  $0.69$ .

The denser clay, located under the soft clay, to  $25$  m depth, this clay is brown tuff clay with an  $N$  value (SPT)  $16$  to  $26$ , the soil type weight of  $2$  to  $1.6$  and average specific gravity  $G_s$   $2.00$ . From this  $N$  value, the layer looks denser than the top layer, but its compression index value is higher, that is  $0.62$  to  $0.64$ . It was more compressible, and has a pore value (void ratio)  $1.99$  to  $2.30$ . Below the clay layer, at  $25.00$  m to  $30.00$  m depth, is a hard tuff coating with an  $N$  (SPT) greater than  $60$ .

In addition to these three drill points, additional drilling on CY-1 area of  $4$  drill points was done, with each depth of  $17.25$  m (up to  $-16.00$  m) adjacent to the position of the geotechnical instruments. At the point near the edge of the sea, B-3 and B-4 points adjacent to instrument point  $4$  and  $5$ , there is a layer of sand from  $1.25$  m to  $4.50$  m depth, and below is a sandy loam layer to  $8.00$  m depth, and further to  $17.25$  m depth is a clay layer. The layers at the B-4 drill point location have greater compressibility than the layers at the B-3 drill point. At the more westward points (about  $120$  m from the seashore), i.e. at points B-1 and B-2, each very close to the point of instruments  $5$  and  $6$ , there is also a layer of thick ash from  $1.50$  m to  $3.00$  m. Then below is a sandy clay layer up to  $7.00$  m depth, followed by a soft coat layer to  $17.25$  m depth, which has almost the same compressibility as the B-1 and B-2 drill points.

## 4. Preloading

### 4.1 Preload material

For preloading (surcharge) the material used are sea sand deposits derived from the area around Tanjung Kait-Bekasi and Tanjung Bungin-Tangerang. The original ground at  $+1.00$  m then was stacked gradually with preloading material until elevation  $+9.20$  m (initial plan is  $+8.50$  m). Preload sand dumping schedule has adjusted with the availability of sand material at the project site. The material is a mixture of sand and water poured into the landfill location by spraying it through the pump. The sea sand from both of those locations has examined in the soil mechanics laboratory. The sand includes a uniformly graded classification, with a grain size ranging from  $0.10$  to  $1.00$  mm.

Before the vertical drain and geotechnical instrument are install, the project site has been stacking out with preloading materials as above, to reach the height of  $+2.33$  m, which then flattened and well compressed according to the working elevation. The subsequent layer to a height of  $+3.50$  m (also flattened and well compacted) would be a compacted sub-grade layer. The elevation above  $+3.50$  m

height is not compacted its function is only as preload, which will then be moved after the compacted soil layer reaches a sufficient degree of consolidation.

On the other hand, the installation of natural fiber PVD has done gradually according to the schedule set, and followed by the installation of geotechnical instruments then conducted monitoring in the form of field data retrieval. Periodically the height of the preload should measure and closely watched, through each point of the geotechnical instrument. The preload height measured by binding optically with fixed points outside the project area that not affected by the soil declining settlement.

#### 4.2 Elevation plan and implementation of embankment pile

Elevation of preloading plan from the original soil surface (calculated average elevation of +1.50 m to LWS) until the peak of preload elevation planned to reach +8.50 m. The solid sand type weight is calculated at 1.70 ton/m<sup>3</sup>, so the preload load  $p = (8.50 - 1.50) \times 1.70 = 11.90$  ton/m<sup>3</sup>.

In the implementation of sand dumping at the project site, the compaction of the embankment is only up to an average elevation of 2.30 m and then the sand sprayed / spread over without compacting. After tested, the type weight of the compressed sand = 1.70 ton/m<sup>3</sup> and without compacted only 1.50 ton/m<sup>3</sup>. Because of that, the height of the preload raised to +9.20 m, because after the measurement turns out the original ground level elevation averaged only +1.10 m.

So the preload became  $P = [(2.30 - 1.10) \times 1.70] + [(9.20 - 2.30) \times 1.50] = 12.39$  ton/m<sup>3</sup>.

It should be noted that the load  $P = 12.39$  ton/m<sup>3</sup> has a high water content, so if the water is dry due to evaporation, the  $P$  value may decrease.

#### 5. Prefabricated Vertical Drain

The Prefabricated Vertical Drain (PVD) used in the Jakarta International Container Terminal (Terminal Peti Kemas Koja) project at Tanjung Priok Jakarta was made of natural jute fiber and coconut coir, designed to accelerate consolidation of soft clayey soil. The natural fiber PVD reported in this paper is made of organic materials, jute or kenaf fiber and coconut shell fiber. This natural fiber PVD has high tensile strength to withstand installation stresses and excellent water discharge capacity. The natural fiber PVD core consist of four axial coir strands enveloped within the filter comprising two layers of burlap cloth to form a rectangular strip measuring 80-120 mm by 8-12 mm. Three continuous stitches running longitudinally in PVD's. The cross section of natural fiber PVD measures 80-120 mm in width and 8-12 mm in thickness and have a tensile strength of above 7 KN. In general, the properties of this drain found comparable with other typical synthetic drains. The present drain differs from the others drain is that it is manufacture in existing jute mills machinery, the manufacturing process entails low energy consumption, and has capability of varying the width, thickness and weight per linear meter to suit different soft clayey soil conditions. An important feature of the jute burlap is its swelling nature that allows it to functions as filter without clogging it is biodegradable and hence environmentally friendly.

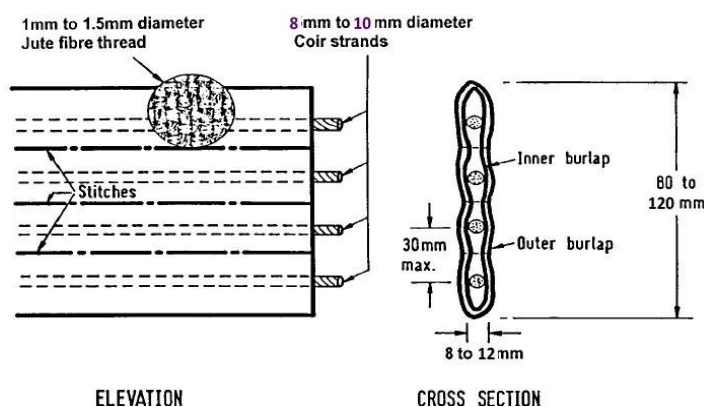


Figure 1. Cross section of natural fibers PVD



Figure 2. PVD material made of natural fibers

Tabel.1 Relevant physical properties of natural fibers PVD Fiberdrain®

Properties	Typical Value tested by B4T	Test Method	Min Spec by FHWA*
<b>I. Filter material</b>			
	Natural (Coir / Jute) fiber		
Weight (gram/m <sup>2</sup> )	600-650	ASTM D3776	
Grab tensile strength (kN)	9.19	ASTM D4632	0.356
Trapezoidal tear (kN)	0.8465	ASTM D4533	0.111
Mullen burst strength (kN/m <sup>2</sup> )	> 1,382	ASTM D3786	898
Puncture strength (kN)	0.631	ASTM D4833	0.223
Elongation at break (%)	42	ASTM D4632	
Permeability (m/sec)	2.48x10 <sup>-4</sup>	ASTM D4491	
A.O.S. (□m)	75-90	ASTM D4751	90 -120
<b>II. Drain properties</b>			
Discharge capacity (m <sup>3</sup> /sec)	9.2x10 <sup>-5</sup> at 100 kPa	ASTM D4716	5 x10 <sup>-5</sup> at 100 kPa
	7.2x10 <sup>-5</sup> at 200 kPa	ASTM D4716	
	5.3x10 <sup>-5</sup> at 300 kPa	ASTM D4716	
Weight (gram/m)	300		
Width (mm)	80 -100		
Thickness (mm)	8 -10		
Bale length (m)	250, 500 & 1,000		
Bale weight (kg)	75, 150 & 300		

## 6. Consolidation

This clay layer will lead to a decrease in the consolidation at the container yard terminal, for examples estimated base on soil data from B-13 drill point, without any soil improvement work, the land decrease will reach 1,054 meters in the long term. The time needed to consolidate depends on two major factors, namely, from the soil permeability (linearly) and from the length of the drainage path (exponentially).

### 6.1 Accelerate Consolidation.

To avoid frequent maintenance work due to land settlement subsidence in container yard terminal, the best way is to speed up the consolidation process in that area. The land decrease due to consolidation in very long time should be accelerate, in order for consolidation to occur before the container yard terminal is used.

With the onset of consolidation, the soil will become high dense, the compressibility becomes lower and become over consolidated. Accelerate the consolidation is done by shortening the drainage path.

The installation of natural fiber PVD, is to install vertical drainage columns of highly permeable material, the drainage path from the pore water becomes shorter to reach a more permeable layer, i.e. half of the distance between the PVD columns, which previously had very long path up to the surface ground. The success and effectiveness of natural fiber PVD is highly dependent on a number of factors, including under-surface geotechnical conditions, consolidated clay properties and PVD material specifications used.

Installation of natural fiber PVD done by displacement, by pressing steel pipe, round or square and contains natural fiber PVD inside, into the soil until the depth of 14 - 16 meters. With distance of 1.3 m an equilateral triangle pattern and equivalent diameter of 10 cm. After the natural jute fiber PVD columns installed, the soil surface loaded with sand gradually until it reaches a thickness of 8.0 m above the soil surface. This sand layer has to a flexible load or free strain, so that the load has evenly distributed in all places and will be a drainage layer of water flow that also serves as a preload load for consolidation.

With the load from the preload / surcharge, the pore water pressure in the soil will increase, so that this pore water will flow in search of a layer with greater permeability. In clayed the discharge of pore water is very difficult compared to the sand soil layer, due to the low permeability of clay soil. With

PVD columns method, the nearest permeable place is the PVD column, the water path has thus been shortened, so the consolidation will be accelerated.

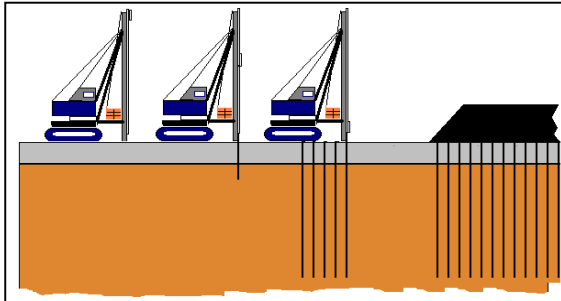


Figure 3. Sequence of installation of PVD



Figure 4. Installation of Fibredrain® at project site

## 6.2 The formula used for soil consolidation calculation.

Calculation settlement formula estimated in addition to the amount of settlement as well as the processing time, also associated with natural fiber PVD.

The amount of total settlement in  $i^{th}$  layer is calculation using the following formula:

$$S_i = \frac{H_i C_{ci}}{(1 + e_{oi})} \log_{10} \left( \frac{P_{oi} + \Delta P}{P_{oi}} \right) \dots \dots \dots (5.2.1), \text{ where:}$$

- $S$  = Consolidation settlement
- $H$  = the thickness of the layer that computed the value of  $s$
- $C_c$  = Compression index
- $e_0$  = initial void ratio
- $P_0$  = effective overburden pressure
- $\Delta P$  = pressure difference due to load in the middle layer

On the other hand, the calculation of the time for soil settlement with natural fiber PVD done with the following formula:

$$t = \frac{D^2}{8 C_h} \left[ \ln \left( \frac{D}{d} \right) - \frac{3}{4} \right] \ln \frac{1}{1 - U_h} \dots \dots \dots (5.2.2)$$

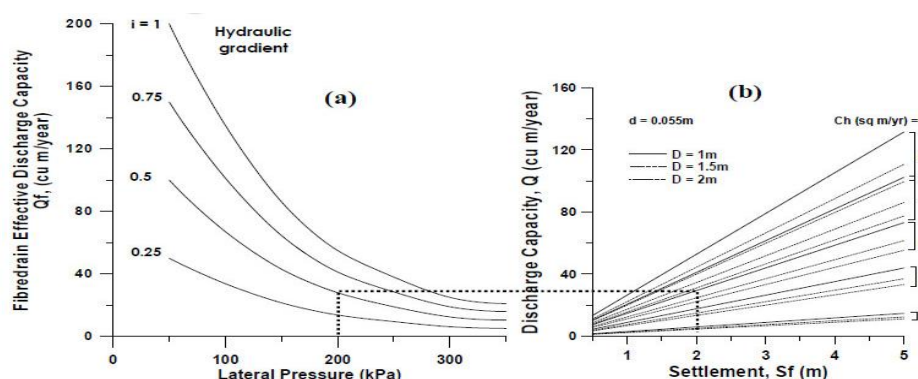


Figure 5. Design chart for fiberdrain

From the Design Chart, obtain the value of  $D$  and  $C_h$  corresponding to the hydraulic gradient, lateral pressure and final settlement.

Substitute  $D$  and  $C_h$  in **Degree of consolidation**  $U = 1 - \exp[-8C_h t / (D^2 \mu)]$  ..... (5.2.3), where:

- $C_h$  = Apparent coefficient of consolidation with horizontal flow
- $D$  = Influence diameter of natural fiber PVD
- $t$  = Time
- $\mu = \ln(D/d) - 3/4$
- $d$  = Equivalent drain diameter =  $1/2$  (drain width + drain thickness)

## 7. Geotechnical Instrument

The installed geotechnical instruments are settlement plate, standpipe piezometer, pneumatic piezometer, magnetic extensometer and inclinometer at some point at CY-1 location also every other CY after natural fiber PVD installed. For areas named CY-1, there are seven places geotechnical instrument placement group plots, called point 1 through 7 and conducted the same in other CY areas. The list of geotechnical instruments groups installed in each area of CY is as follows (as shown on Table 2 for CY-1):

Table 2: List of geotechnical instruments installed at CY-1

At point 1:- Settlement Plate SP-1 - Standpipe Piezometer, 15 m, St-1 - Inclinometer, IN-1	At point 2:- Settlement Plate SP-2 - Standpipe Piezometer, 15 m, St-3 - Inclinometer, IN-3
At point 3:- Settlement Plate SP-3 - Standpipe Piezometer, 5 m, St-2 - Pneumatic Piezometer (5, 10, 15 m) PP-1 - Magnetic Extensometer, -3.848 m, ME-1	At point 4:- Settlement Plate SP-4 - Standpipe Piezometer, 10 m, St-4 - Pneumatic Piezometer (5, 10 m), PP-2 - Magnetic Extensometer, -4.656 m, ME-2
At point 5:- Settlement Plate SP-5 - Pneumatic Piezometer (5 m), PP-3 - Magnetic Extensometer, -2.548 m, ME-3	At point 6:- Settlement Plate SP-6 - Pneumatic Piezometer (5 m), PP-4 - Magnetic Extensometer, -4.351 m, ME-4
At point 7:- Settlement Plate SP-7 - Inclinometer, IN-4	At point 7a:- Inclinometer, IN-3

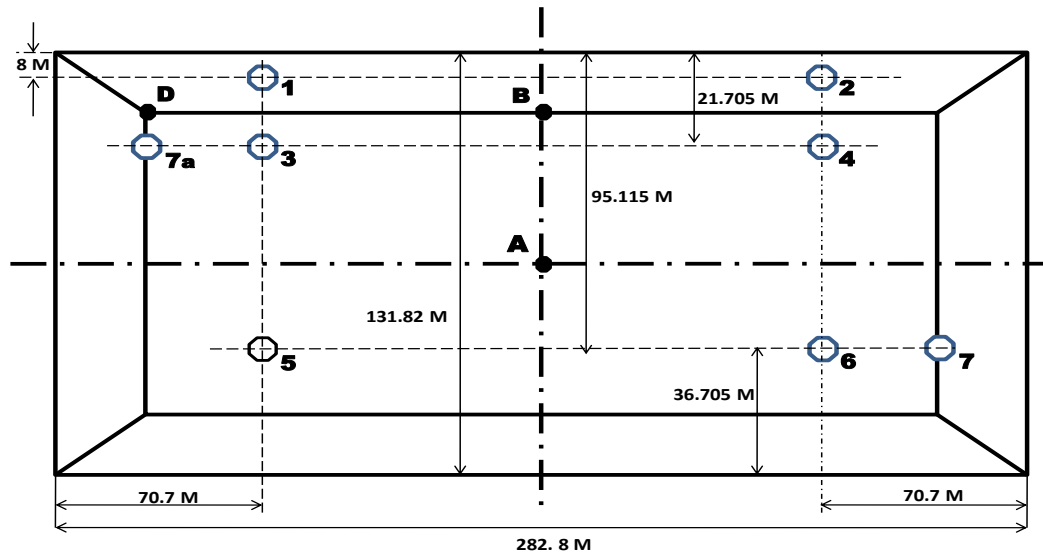


Figure 6. Position of Geotechnical instruments and calculation settlement points (A,B, D) for CY-1

### 8. Calculation of consolidation settlement (at some point under the sand pile)

In the container yard area, the sitting plate is planned to receive 3 stack-high loads and at the time of the digging can be 4 piles. The load calculation is the number of stacks calculated by 3.5 stack-high. Weight for 1 container and its contents is calculated 33 to 35 ton, so for 3.5 stack-high weigh between = 115.5 to 122.5 ton, with container size 6 ft width x 20 ft length (1.83 m x 6.096 m). The weight of the sitting plate at the 4 foot base of the container is  $P_s = 4 \times \frac{1}{4} \times (33 \text{ to } 35) \times 3.5 = 115.5 \text{ to } 122.5$  tons. The load  $P_C$  calculated as a split load.

$$P_C = \frac{(115.5 \text{ to } 122.5)}{1.83 \times 6.096} = (10.35 \text{ to } 10.98) \text{ ton/m}^2.$$

The weight of the sitting plate itself and its hardness ranges from  $0.30 \times 2.2$  to  $0.70 \times 2.2 = 0.66$  ton/m<sup>2</sup> to 1.54 ton/m<sup>2</sup> then the weight of  $P_C$  is set at between 11 to 12 ton/m<sup>2</sup>.

During the implementation of the soil improvement, the pre-loads overlaid at 7.40 meters, from the original soil +1.10 m LWS. The sand type weight at the site ranges from 1.55 ton/m<sup>3</sup> to 1.60 ton/m<sup>3</sup>, therefore the height of the preload is raised up to +9.20 m LWS.

While the required load is  $P_R = 7 \times 1.70 = 11.90$  ton/m<sup>3</sup>.

#### 8.1 Consolidation of settlement without acceleration

In the soil layer at the location of container accumulation due to the container load of  $P_C = 12$  tons/m<sup>3</sup> calculate shall decrease the surface soil with total of  $S$  (settlement) = 141.863 cm.

Consolidation settlement of such amount shall take place within the following time:

$$t = \frac{U_v^2 \cdot \pi \cdot H_{eq}^2}{4 C_{v1}} = \frac{(90\%)^2 \times \pi \times (1446.72)^2}{4 \times 0.00160} = 832.192.674 \text{ sec} = 9.632 \text{ days} = 26.4 \text{ year}.$$



### 8.2 Consolidation of settlement with acceleration

By installing natural fiber PVD to an average depth of  $-15$  meters and preloading up to  $+9.20$  m elevation, within 4 months after preload elevation is achieved, and the preload load is gradually increased, the amount of settlement is calculated as:  $S = 142.30$  cm.

### 8.3 Geotechnical instruments

Monitoring results of Settlement plate show the occurrence of settlement as in the Table 3 below:

Table 3. Settlement-plate monitoring results

No.	Location of SP (Table 2 & Figure 4)	Settlement (cm)
1.	3	128.70
2.	4	104.10
3.	5	161.70
4.	6	142.20
5.	7	140.60
Average		<b>135.50</b>

The average settlement  $S$  from monitoring result =  $135.50$  cm, this was 95% from the theoretical calculations, where  $s$  from the calculation result reaches =  $142.30$  cm for the same period. Since the preload done gradually and the preload load maintained for the next 4 months at the same elevation at  $+9.20$  m height, the settlement calculated based on the amount of preload associated with the time of the preload implementation the difference is quite small

### 8.4 Settlement result

In addition to the above mentioned settlement figures, the settlements at the edge of the slope (B) and in the embankment (D), as shown in Figure 6 were calculated. The results of monitoring, obtained the following settlement figures:

Point A,  $S_A = 141.663$  cm; point B,  $S_B = 122.139$  cm and point D,  $S_D = 92,584$  cm. While at point 1 and 2 located on the slope:  $S_1 = 69.70$  cm and  $S_2 = 65.50$  cm, when compared to settlement at point D ( $S_D$ ), the settlement at point 1 and 2 reaches 70.7 – 75.3 % against  $S_D$ .

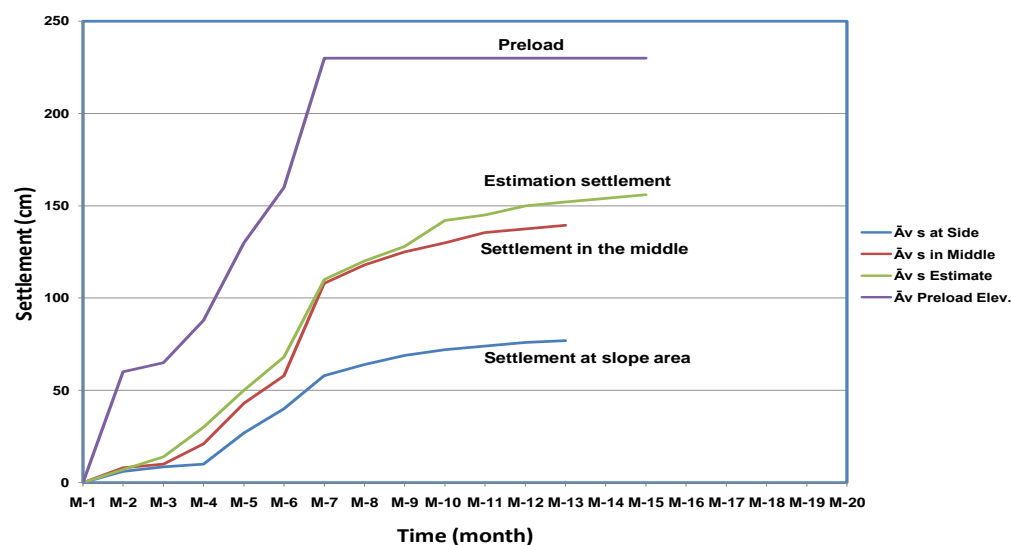


Figure 7. The graph of settlement (cm) versus time (month) of natural fiber PVD

From the settlement curve of the calculation results, after reaching 1.423 m settlement it is seen that the curve line is almost flat, and from the curve it can be estimated that the settlement will stop at an average rate of 1.60 m, thus settlement has reached more than 84%.

## 9. Degree of consolidation

The degree of consolidation calculated from comparison of settlement result of observation to calculation result, can also be calculate from change of pore water pressure caused by change of load, with formula as follows:

$$U_z = 100\% [1 - \Delta u / \Delta p]$$

$U_z$  = degree of consolidation,

$\Delta u$  = the difference of initial and final pore pressure whereas

$\Delta p$  = pressure difference due to initial and final load causing changes in pore pressures

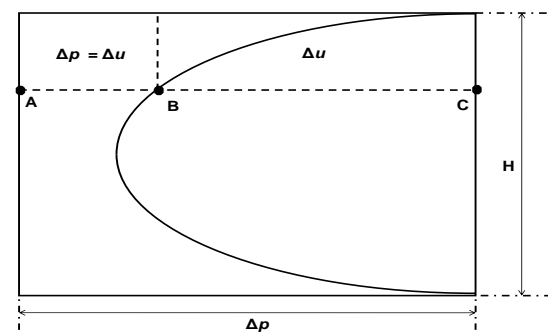


Figure 8. Pore water pressure chart during consolidation process.

The 100 % degree of consolidation means that the pore pressure due to the load has fully dissipated so that  $\Delta u = 0$ . As for the field observations, the degree of consolidation in the ninth month has reached the following magnitude:

- At the layer +1.50 m until -14.50 m depths where the natural fiber PVD has installed, the degree of consolidation reached 99.67%
- At the layers between depths of 14.50 - 22.00 m where there is no natural fiber PVD, the degree of consolidation has only reached 43.22%.

From the observation and monitoring of pore water pressure through standpipe and pneumatic piezometer, the calculation of the average degree of consolidation obtained as follows:

- At depth -5.00 m the degree of consolidation = 91.00 %
- At depth -10.0 m the degree of consolidation = 48.09 %
- At depth -15.0 m the degree of consolidation = 82.91 %

From the calculation of the degree of consolidation, it can be concluded that under layer -15.00 m there is also a layer that serves as drainage, whereas at layer -10.00 m, pore-water could not dissipation quickly hence resulting in slow pore water pressure down.

## 10. Conclusion

From the field performance of PVD made from natural material in the Container Terminal of the Jakarta International Container Terminal (Terminal Peti Kemas Kojja), at Tanjung Priok Jakarta Indonesia, the following conclusions are as follow.

**10.1.** The PVD made from natural fibers have similar performance as drains, and have superior advantages in certain fields of usage, compare with Sand Drains and other material PVDs. Especially under the circumstance that the dredging of marine sand has prohibited legally by environmental reasons.

**10.2.** Through monitoring and reading of geotechnical instruments, the average settlement ( $S$ ) reached 135.50 cm this was 95.22 % from the theoretical calculations, where estimate settlement ( $S_e$ ) 142.30 cm for the 4 months period.

**10.3.** From the settlement curve of the calculation results, after reaching 1.423 m settlement it is seem that the curve line is almost flat, and from the curve it can be estimate that the residual settlement was very small for long period.

**10.4.** In the layer +1.50 m until –14.50 m depth at the Jakarta International Container Terminal, Tanjung Priok Jakarta Indonesia, where the natural fiber PVD has installed, the degree of soil consolidation reached 99.67 %.

**10.5.** The clogging and kinking potential of PVDs from natural fiber is negligible

**10.6.** The PVDs from natural fiber is biodegradable and requires low energy consumption in production from natural fiber, hence ecologically harmonious and environmentally friendly.

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