Alternative of Soil Improvement Methods on Organic Soil Using Preloading and Vertical Piles for Embankment with Varied Heights. Case Study: Construction of Batanjung Port Access Road in Pulang Pisau Regency, Central Kalimantan

Dedy Manudianto[1, a)], Noor Endah[2, b)] & Hardy Pangihutan Siahaan[3, c)]

[1)]Magister Student, Civil Engineering Departement, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia
[2)]Civil Engineering Departement, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia
[3)]Central Kalimantan BPJN, Directorate General of Highways, Ministry of Public Works, and Housing of the Republic Indonesia

Correspondent : [a)]dedy.manudianto@pu.go.id, [b)]noor_endah@ce.its.ac.id & [c)]siahaan90@yahoo.com

ABSTRACT

The Central Kalimantan is a province with great potential for economic development. Several development plans have been launched by the government, one of which is the construction of the Batanjung Industrial Estate, Batanjung Port , and its access. The Batanjung Port development plan is in line with the Central Kalimantan Provincial Spatial Plan (RTRW) for 2015-2035, and has been stipulated in the National Medium-Term Development Plan (RPJMN) 2020-2024 and the Strategic Plan of the Ministry of General Works and Public Housing for 2020-2024. Therefore, it is necessary to build an access road to the Port of Batanjung, Central Kalimantan.

However, constructing new roads requires cautious construction plan considering the type of soil in Central Kalimantan Province which is dominated by soft soils and organic soils formed by weathered plants and has a high groundwater table. Problems that generally arise include the occurrence of long and large compression (settlement) and road embankment slides. Common efforts to increase the bearing capacity of organic soil in Central Kalimantan are the installation of galam wood driven piles into the soil and the use of geosynthetic such as geotextiles. Therefore, in this study a new road embankment using national road standards is planned by observing the 5-year and 50-year Flood Water Levels (FWL) in Central Kalimantan Province. The construction use mechanical soil improvement in the form of PVD, wood piles, micropile, and geotextiles for varying road embankment heights. Then the planning results are analyzed to find out the most efficient method in terms of material use.

Based on the analysis, the most efficient soil improvement method is the PVD method to accelerate consolidation rather than the micropile method to reduce the amount of compression. In addition, the most efficient reinforcement is by using geotextiles instead of galam wood piles. These results can be appled to both 5-year and 50-year FWL.

Keywords : Central Kalimantan, organic soil, soft soil, PVD, driven wood piles, micropile, compression, sliding stability.

INTRODUCTION

The Central Kalimantan is a province with great potential for local economic development. Following up on this, the Government of Central Kalimantan Province undertook the construction of the Port of Tanjung which part of Industrial Area (KI) that regulated through Regional Regulation of the Province of Central Kalimantan Number 5 of 2015 concerning the Regional Spatial Plan of the Province (RTRW) of Central Kalimantan for 2015 – 2035, Presidential Regulation of the Republic of Indonesia Number 18 of 2020 concerning the 2020-2024 National Medium Term Development Plan (RPJMN), and Regulation of the Minister of Public Works and Public Housing (PUPR) Number 23 of 2020 concerning the Strategic Plan of the Ministry of Public Works and Public Housing for 2020–2024 **(Figure 1)**. Therefore, in this study it is planned to build a new road as access to the Port of Batanjung through the Food Estate area that connects Belanti Village, Pulang Pisau Regency with Batanjung Village, Kapuas Regency.

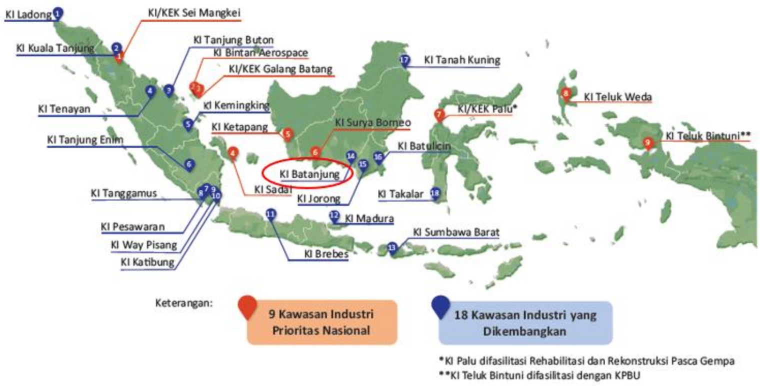


Figure 1. Location of the Port of Batanjung in Central Kalimantan

One of the things to consider in planning for the construction of a new road is the flood water level at the location. Beside causing the interruption of transportation routes, the flood level can damage the existing road condition. In addition to paying attention to the condition of the flood water table, the construction of a new road requires careful planning considering the type of soil in Central Kalimantan Province. The soil is dominated by soil formed from weathered layers of vegetation and has a high ground water table **(Figure 2)**.

Figure 2. Organic Soil in Central Kalimantan

The results of a soil investigation in Pulang Pisau Regency, Central Kalimantan, it is consist of a layer of organic soil with a thickness of 15.0 meters with a value of Standard Penetration Test (NSPT) is 1. Then followed by fine sandy clay with a thickness of 13.0 meters with an SPT value of 4-15.

Common efforts to improve the of organic / peat soils in Central Kalimantan are using a vertical pile of galam wood, and combining it with corduroy wood at the top of the vertical pile (**Figure 3**). The use of galam wood in Central Kalimantan is supported by the availability of galam wood in Central Kalimantan which is very abundant. In addition to the galam wood niche, precast micropile is also often used in construction work.

Figure 3. Soil Improvement used in Central Kalimantan

Based on the existing problem conditions, it is necessary to do study of perencanaan jalan di atas tanah organik Kalimantan Tengah. In this study a new road embankment using national road standards is planned by observing the 5-year and 50-year Flood Water Levels (FWL) in Central Kalimantan Province. The construction use mechanical soil improvement in the form of PVD, wood piles, micropile, and geotextiles for varying road embankment heights. Then the planning results are analyzed to find out the most efficient method in terms of material use.

LITERATURE REVIEW

Soil is an accumulation of natural bodies that occupy a large part of the earth's surface which is never separated from the planning of civil buildings. Soil is seen as a natural object consisting of inorganic materials called minerals and organic materials obtained from weathered rocks. According to the constituent materials, soils are divided into coarse-grained soils, fine-grained soils and organic soils. In general, the earth element consists of 3 phases, namely earth, air, and water. However, the soil phase in organic soils contains organic fibers that affect their behavior.

Soil Classification

Soil classification is important to carried out for verification of the results of physical and mechanical parameter testing in a study, predicting possible behavior that will occur in the field or in the laboratory, and determination of the use of land such as as embankment material. According to Edil (2016), the determination of soil classification is based on organic content (OC) as follows:

1. OC 0% -5% = inorganic soil (the effect of organic content is very small).
2. OC 5%-25% = organic clay or organic silt (organic content slightly affects soil parameters but behaves like inorganic soil);
3. OC 25%-75% = silty organic soil or organic clay soil (organic content affects soil parameters and behavior, but calculations can still use soil mechanics formulas in general)
4. OC > 75% = peat soil (soil behavior and soil mechanics formula calculations are different from the soil in general)

Based on Kimpraswil Guidelines No. Pt T-8-2002-B, the classification of organic or inorganic soils can be determined using the results of the USCS classification (**Figure 4**).

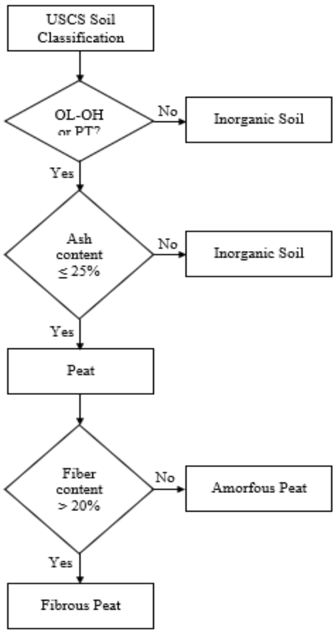


Figure 4. Flow chart of organic or inorganic soil classification

Rate and Time of Consolidation Settlement

For organic soils, the compression that occurs in the form of immediate consolidation compression, primary consolidation compression, secondary consolidation, and tertiary consolidation (due to decomposition of organic fibers). According to Gibson & Lo (1961), organic soil compression is affected by the relationship between vertical strain (ε) and loading time (t) from consolidation tests in the laboratory (**Figure 5**). Model assumptions of compression behavior that occurs in organic soils are shown in **Figure 6**.

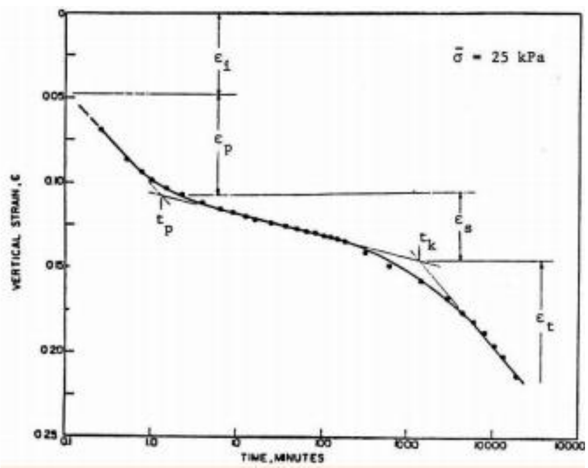


Figure 5. Flow chart of organic or inorganic soil classification

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Volume 5, Special Issue 1, February 2023

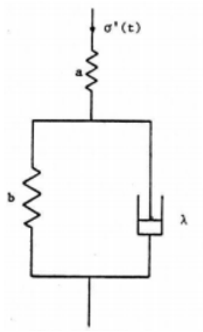


Figure 6. Model assumptions of compression behavior that occurs in organic soils

For inorganic soil, there are two definitions based on the stress history:

1. Normally consolidated soil (NC-Soil), in which the current effective overburden stress is the maximum stress that the soil has ever occured.
2. Over consolidated soil, Over Consolidated Soil (OC-Soil), in which the current effective overburden stress is less than the stress occured by the soil.

The soil is referred to as NC-soil or OC-soil depending on the value of the Over Consolidation Ratio (OCR). OCR is defined as the ratio of the effective past overburden pressure (σc') to the effective overburden pressure (σo'). Soil is classified as NC-soil when OCR=1, while soil is classified as OC-soil when OCR>1. The amount of consolidation compression in fine-grained soils is influenced by several parameters, namely cc, cs, e0, σc', σo', and the load on the soil (Δσ). The amount of compression in the field (Sc) is calculated using the following formula:

For NC-*soil* :

$$S_c = \frac{H}{1+e_0}\left[C_c \log\left(\frac{\sigma_o' + \Delta\sigma}{\sigma_o'}\right)\right] \quad ....(1)$$

For OC-*soil*

1. If $\sigma_o' + \Delta\sigma \leq \sigma_o'$:

$$S_c = \frac{H}{1+e_0}\left[C_s \log\left(\frac{\sigma_o' + \Delta\sigma}{\sigma_o'}\right)\right] \quad ....(2)$$

2. If $\sigma_o' + \Delta\sigma > \sigma_c'$:

$$S_c = \left[\frac{H}{1+e_0} C_s \log\left(\frac{\sigma_c'}{\sigma_o'}\right)\right] + \left[\frac{H}{1+e_0} C_c \log\left(\frac{\sigma_o' + \Delta\sigma}{\sigma_o'}\right)\right] \quad ....(3)$$

Which :

H = thickness of compressible soil layer
e_0 = void ratio
C_c = compression index
σ_o' = effective overburden stress
$\Delta\sigma$ = increase of stress
C_s = swelling index
σ'_c = preconsolidation stress

The time required to reach a certain degree of consolidation (U) is calculated by the following formula:

$$t = \frac{T \times {H_{dr}}^2}{C_v} \quad ....(4)$$

which:

T = time factor:

$= \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2$ for $U_{average} \leq 60\%$; and ….(5)

= 1,781 – 0,933 log (100-U%) fo $U_{average} > 60\%$ ….(6)

H_{dr} = drainage path

C_v = Coefficient of consolidation in vertical direction

Rate of Settlement Value for Road Embankment

Rate of settlement is the rate of compression that occurs in a compressible layer that will still occur in the future According to Geotechnical Guidebook 4 Design and Construction of Road Embankments on Soft Soils (Transportation Infrastructure Research and Development Center, 2001), allowed rate of settlement for road embankment is 2,0 cm for the first year. The limit on the maximum RoS value is intended to maintain road conditions through preservation activities which can be carried out periodically every year. Therefore, the road embankment design should nod exceed this provision.

Using of Prefabricated Vertical Drain (PVD)

PVD is used to speed up the consolidation time that occurs.). In principle, the use of PVD is done to reduce the size of the Hdr, which was originally a vertical distance to a horizontal distance between PVDs. Thus, the consolidation time (t) can be achieved in a short time. This theory establishes the relationship between the size of the drain diameter, the distance between the drains, the coefficient of consolidation, and the average degree of consolidation. Because PVD is made from factory-made synthetic materials, the quality of the material is maintained and it is resistant to conditions in the soil.

Increasing of Undrained Shear Strength (Cu) for Compressed Soil

Considering Ardana and Mochtar (1999), it is known that there is a relationship between Cu and σo'. The increase in soil carrying capacity due to compression can be calculated by the following equation :

If Plasticity Index, PI < 120%:

$$C_u(kg/cm^2) = 0{,}0737 + (0{,}1899 - 0{,}0016\,PI)\sigma_o{}' \quad ….(7)$$

If Plasticity Index, PI > 120%:

$$C_u(kg/cm^2) = 0{,}0737 + (0{,}0454 - 0{,}00004\,PI)\sigma_o{}' \quad ….(8)$$

Increasing of Void Ratio for Compressed Soil

Increasing of void ratio calculated by the following equation :

$$e = e_0 - \left[(1 + e_o)x\left(\frac{\Delta H}{H}\right)\right] \quad ….(9)$$

Increasing of Density for Compressed Soil

Increasing of density calculated by the following equation :

$$\gamma_{baru} = \left[\frac{GS}{(1+w_c)}\right]/(1 + e_{baru})x\gamma_w \quad ….(10)$$

Soil Improvement Method using Vertical Piles for Organic Soil

Vertical piles is one type of soil reinforcement which can be made from wood or concrete. The vertical pile method is very effective for use on peat which has a layer thickness of 3-4 meters with a layer of sand underneath (Yulianto and Harwadi, 2009; Yulianto and Mochtar, NE., 2012). This is because the load from the upperstructure can be transferred properly to the layer beneath the peat.

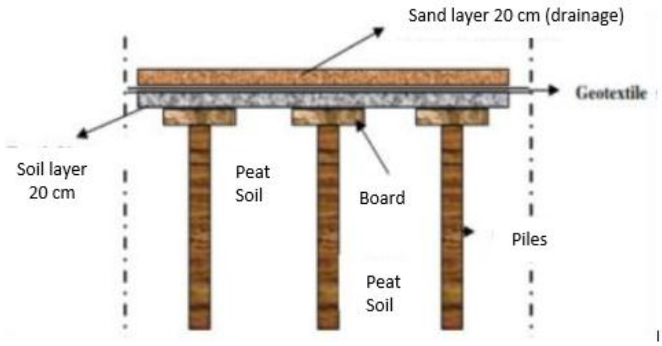


Figure 7. Soil improvement method using vertical piles

Geotextiles as Reinforcement of Road Embankment Stability

In principle, geotextiles can increase soil stability due to the addition of the tensile strength ($T_{allowable}$) for each geosynthetic material. The type of geosynthetic that is usually used is woven geotextiles since its high tensile strength and the usage for embankment material separator.

The design of the geotextile depends on the planned increase in the moment of resistance (ΔMR) so that it reaches the planned Safety Factor (SF). To design the embankments on soft soil reinforced with geotextiles, the stability that is most reviewed is overall stability. Overall Stability is the stability of the embankment and its subgrade when viewed from failure according to the circular slip plane.

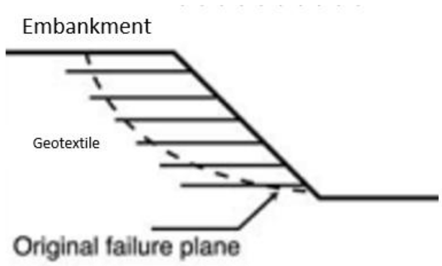


Figure 8. Geotextile as reinforcement of road embankment

Piles as Reinforcement of Road Embankment Stability

The piles serves as a wedge to resist sliding along a circular sliding plane as shown in Figure 8. With the existence of these crevices, forces and moments will arise which provide additional resistance to collapse, so that the stability of the structure and soil will be increased.

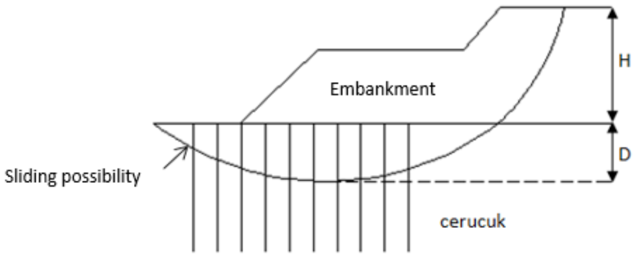


Figure 9. Vertical piles as reinforcement of road embankment

Minimum Embankment Height Based on Flood Water Level

Regarding of Road Pavement Design Manual Rev. 2017 (Ministry of Public Works, and Housing of the Republic Indonesia, 2017), the road height have to designed 1 meter above Flood Water Level (FWL). Since in this study using 2 FWL considered (5 years is 0,2 m and 50 years is 50 cm), then the road height that will be calculated is 1,2 m for 5 years FWL and 1,5 m for 50 years FWL.

Analysis of Embankment Stability

To analyze the safety factor of overall stability, the XSTABL program is used in this study. The XSTABL program is a program that use Limit Equilibrium Method using the Bishop approach method. Limit Equilibrium is a method that uses the principle of force balance, and this method is also known as the wedge method because the slope area of the slope is divided into several parts. The Bishop method (Simplified Bishop Method) ignores the frictional forces between the slices and then assumes that the normal force is sufficient to define the forces between the slices, and assumes that the forces acting on the sides of the slices have a zero resultant in the vertical direction. (Bishop, 1955). This method is calculated by approaching the failure surface solution which is considered circular, so it fits with this study.

RESEARCH METHOD

Based on the collection and analysis of the primary data and secondary data, with the following details:

1. Literature Study
2. The literature studied is about organic and inorganic soil and its soil imprevement method.
3. Field Data Collection
4. The need for field data collection includes location data used, subgrade properties, flood water level, Detailed Engineering Design, data of reinforcements used, and required material cost in Central Kalimantan region.
5. Calculation of consolidation in organic soil
6. Calculation of PVD needed
7. Calculation of embankment reinforcement needed
8. Calculation the volume of material needed

DATA ANALYSIS

Flood Water Level (FWL) at Location

In Gadabung Village, Pulang Pisau Regency, Central Kalimantan Province, the 5 years FWL is 20 cm, while the 50 years FWL is 50 cm.

Location Subgrade Properties

Based on primary data (CPT test) and collected secondary data (boring and SPT test) it is known that the subgrade layer at the location of study is as follows:

Table 1. Subgrade Layer and Its Consistency

Location	Depth	$qc_{average}$ (kg/cm^2)	$FR_{average}$	N-SPT	Type of Soil	Soil Consistency
Gadabung Village	0 – 15	3	5	1	Organic Soil	Very soft
	15 – 24	8,7	4	6-15	Sandy Clay	Medium to Stiff
	24 – 26	20	3	12-33	Sandy Clay	Medium
	26 – 27	107	3	45-56	Sandy Clay	Stiff

Then the sample of very soft soil (considered compressible soil) layer tested in the laboratory to determine its USCS classification and parameters, with the following results as shown in **Table 2**.

Table 2. USCS Soil Classification Result

Parameter	Result
Shieve pass #200	92,43%
LL	55,17%
LLR	0,723 (0,75)
Organic Content	11,53%
Classification	Organic with high plasticity

Table 3. Soil Parameter

Depth (m)	Jenis Tanah	γ_{sat} kN/m^3	e	Wc %	Gs	LL %	IP %	Cu (t/m^2)	Cc	Cs	Cv cm^2/dt
0 – 15	Organic Soil	14,8	1,44	67	2,17	55,17	19,72	1,3	0,41	0,081	0,0025
15 – 24	Sandy Clay	15,4	1,25	52	2,29	49,51	17,67	2,4	0,38	0,145	0,0008
24 – 26	Sandy Clay	15,7	1,26	49	2,39	46,5	16,96	2,9	0,35	0,145	0,0008

Loads Properties

The design road load is shown as follows:

Table 4. Road Pavement Load

No.	Material	Thickness (m)	Density (t/m^3)	Load (t/m^2)
1	AC-WC	0,030	2,309	0,069
2	AC-Base	0,035	2,32	0,081
3	Sub-base (A-Class)	0,250	2,314	0,579
4	Sub-base (B-Class)	0,125	2,311	0,288
	Total	0,440		1,016

Table 5. Properties of Embankment Material

No	Parameter	Unit	H_{akhir} = 1,5 m	H_{akhir} = 1,2 m
1	Thickness	m	1,060	0,760
2	Density	t/m^3	2,206	2,206
3	Load	t/m^2	2,338	1,677
3	Kohession (c)	kPa	2	2
4	Internal angle friction (ϕ)	^{o}	30	30

The technical properties of soil improvement used is shown as follows:

1. PVD and PHD
   Width = 100 mm
   Thickness = 3 mm
2. Geotextile
   Tensile strength = 37 kN/m
   Width = 4 m
3. Galam wooden pile
   Diameter = 100 mm
   Length = 4 m
   E = 125.000 kg/cm^2 (1^{st} class)
   σ Max. = 150 Kg/cm^2
4. Concrete Micropile
   Dimension = 200 mm x 200 mm
   Length = 6 m
   Ult. moment = 2,65 ton.m
   P allowable = 49,08 ton

Central Kalimantan Material Cost

The average Central Kalimantan province material cost showed in **Table 6**.

Table 6. Material Cost at Central Kalimantan Province

No	Material		cost/unit
1	PVD	Rp	7.000,00 / m
2	PHD	Rp	23.500,00 / m
3	Selected embankment layer	Rp	302.568,42 / m
4	Pavement layer	Rp	852.831,47 / m
5	Geotextile Woven 150 kN/m	Rp	6.500,00 / m^2
6	Galam wood 4m	Rp	20.000,00 / pcs
7	Concrete micropile K-450 (20 cm x 20 cm)	Rp	129.150,00 / m

RESULT

Consolidation Settlement without Soil Improvement Method

By using equation (3), the total settlement that will occur (both for 50 years FWL and 5 years FWL) is around 80 cm. Then by using equation (4), the time needed for the subgrade to reach U 90% is 24 years, with the graph of the relationship between settlement to time shown in the **Figure 10**. RoS > 2 cm in the first year, and the compression takes a very long time.

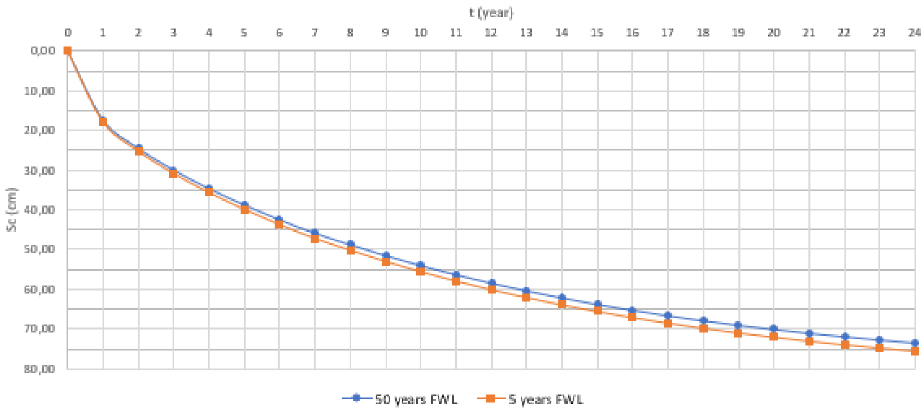


Figure 10. Graph of relationship between settlement and compression time

Therefore, soil improvement methods are needed. In this study, two methods of soil improvement were used, namely :

1. Applying initial load method with combination of PVD; and
2. The vertical pile method to reduce the amount of consolidation.

Initial Load Method with Combination of PVD

In this study PVD designed with various length of PVD (L_{PVD}), that are 15 m (thickness of compressible soil), 13 m, 12 m, and 10 m. It should be noted that if the PVD is not installed as thick as the total compressible layer (15 m), the soil layer beneath the PVD will remain compressed for a very long time. For example, if the thickness of compressible soil is 15 m and LPVD = 13 m, then there is remaining 2 m thick compressible soil which has been compressed for a very long time. Therefore it is necessary to calculate the amount and time of compression that occurs in the compressible layer under the installed PVD.

Regarding to calculations, it is obtained that the shorter the L_{PVD} used, the smaller the $H_{initial}$ required. This is caused by the shorter the LPVD, the smaller the thickness of the compressible layer under consideration, which causes the Sc value to decrease, so that the $H_{initial}$ required is also smaller.

Table 7. Result of $H_{initial}$ embankment with its RoS in First Year

years of FWL	Height of FWL (m)	H_{final} road (m)	$H_{pavement}$ (m)	H_{final} embankment (m)	L_{PVD}	$H_{initial}$ embankment (m)	Sc in installed PVD (m)	RoS rest of layer (cm/ year)
50 years	0,5	1,5	0,44	1,06	15m	1,80	0,74	0
					13m	1,70	0,64	1,49
					12m	1,65	0,59	2,32
					10m	1,60	0,54	3,96
5 years	0,2	1,2	0,44	0,76	15m	1,45	0,69	0
					13m	1,40	0,64	1,53
					12m	1,35	0,59	2,36
					10m	1,30	0,54	4,05

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Volume 5, Special Issue 1, February 2023

According to **Table 6** it shows that L_{PVD} that required to result RoS < 2cm/year is L_{PVD} = 13 m, and also the most efficient. This applies for both 50 years FWL and 5 years FWL.

After L_{PVD} required known, then the distance of PVD installation can be calculated, it shown on **Figure 11** and **Figure 12**.

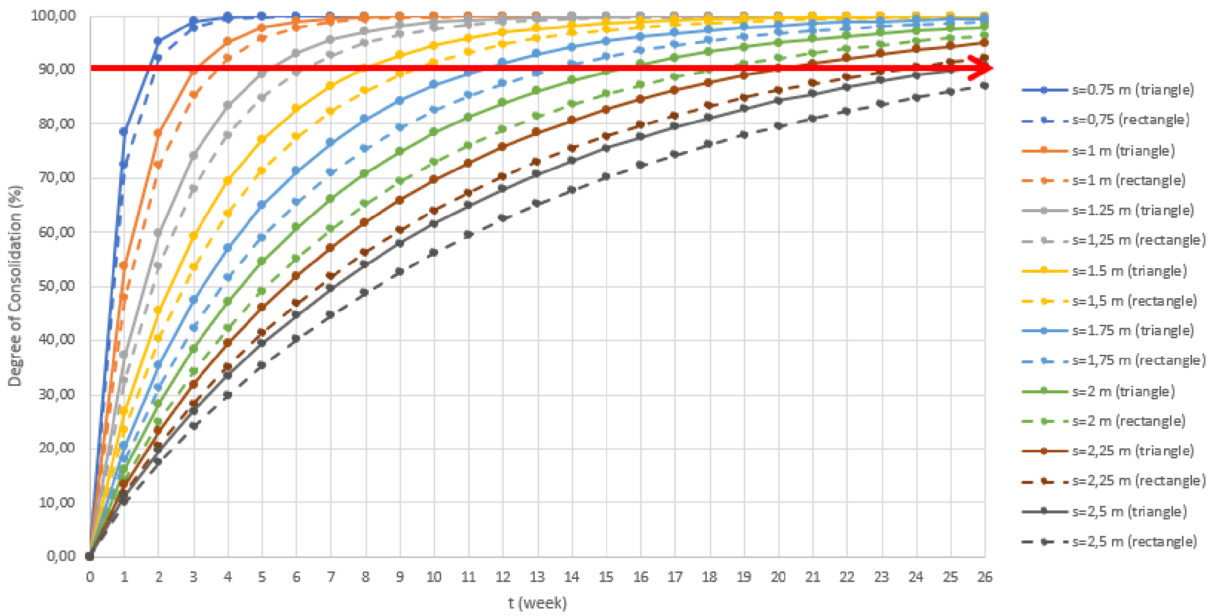


Figure 11. Graph of relationship between distance, pattern of PVD installation, time and degree of consolidation for 50 years FWL

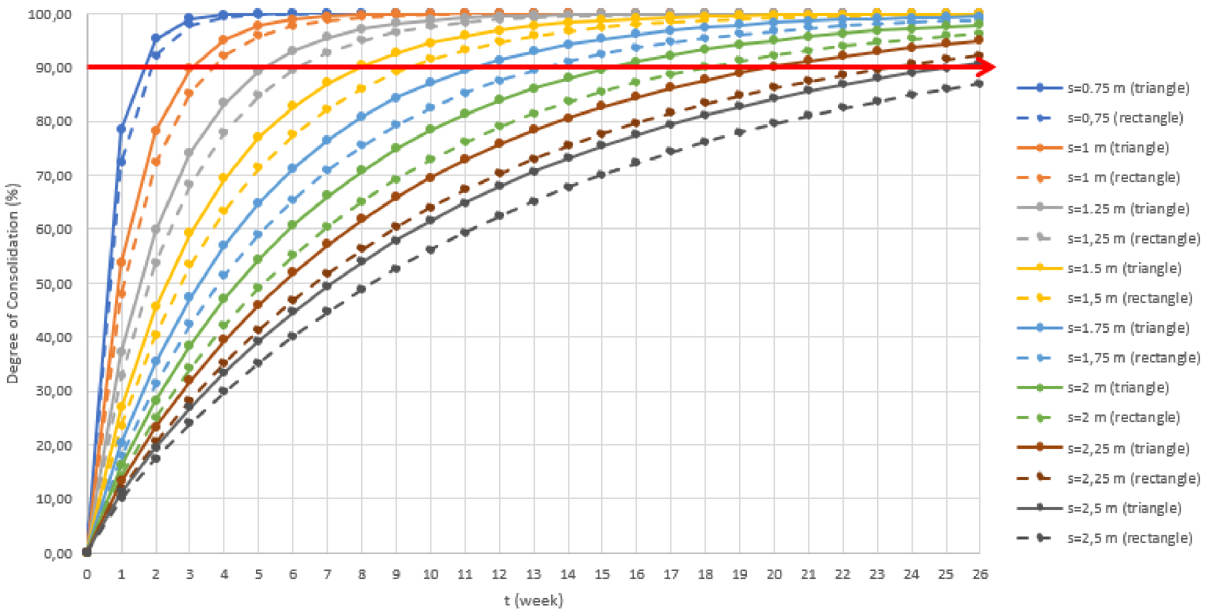
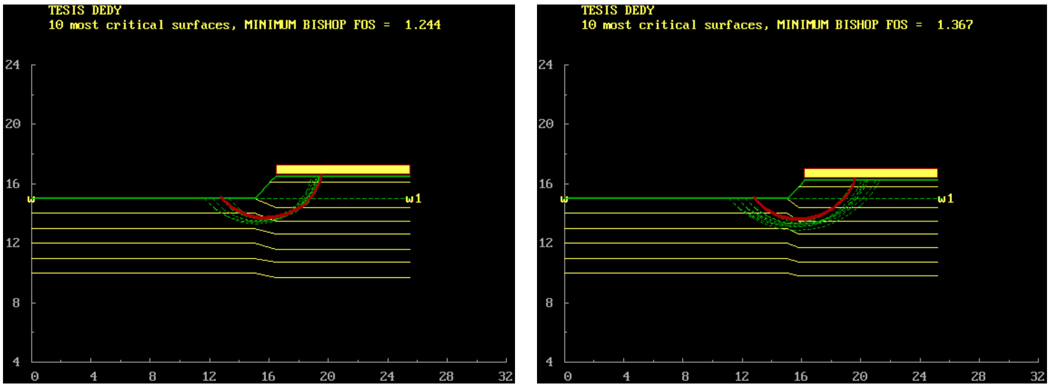


Figure 12. Graph of relationship between distance, pattern of PVD installation, time and degree of consolidation for 5 years FWL

This variation in the installation distance between the PVDs allows the job owner to freely adjust the duration of the completion of the work along with the work costs incurred. To analyze the volume and cost of materials, this study uses the duration of PVD compression with t=24 weeks.

Then by applying $H_{initial\ embankment}$, $H_{pavement}$, and traffic load, stability analysis was performed using XSTABL, with the following results:



a) b)

Figure 13. Sliding area for a) H_{road} = 1.5 m; and b) H_{road} = 1,2 m

Table 8. Result Ammount of Geotextile and Galam Wood Pile Required

No	FWL	H_{final} road	ΔMR (kN.m)	Geotextile Required, per m road length	Galam wood pile Required per m road length
1	5 years	1,2 m	36,5	1 layer, 12 m^2	4 pcs
2	50 years	1,5 m	79,8	3 layers, 35 m^2	7 pcs

Vertical Pile Method to Decrease Settlement

In this study piles are designed with various length, that are 4 m (Galam wood), 10 m concrete micropile, and 11 m concrete micropile. The It should be noted that if the pile is not installed as thick as the total compressible layer (15 m), the soil layer beneath the piles will remain compressed for a very long time. For example, if the thickness of compressible soil is 15 m and L piles = 4 m, then there is remaining 11 m thick compressible soil that will be compressed for a very long time. Therefore it is necessary to calculate the amount and time of compression that occurs in the compressible layer under the installed piles.

The calculation result of the rate of settlement of the vertical piles is displayed as **Table 9**.

Table 9. Result of RoS Year-1 Calculation

No	Material	Rate of Settlement (RoS) Year-1		Note
		50 year FWL	5 year FWL	
1	Galam wood 4m	7,90	7,73	> 2 cm / year (not fulfilled the criteria)
2	Concrete micropile 10 m	2,10	2,04	> 2 cm / year (not fulfilled the criteria)
3	Concrete micropile 11 m	1,55	1,52	< 2 cm/year (fulfilled the criteria)

From the calculatin, it require 48 piles to bear the designed load (road embankment, pavement layer, and traffic load). This result applies for both 50 years FWL and 5 years FWL. And it does not no need additional reinforcement (geotextile nor piles) because the it reached more than SF = 1,5 already.

After all of the required material for both methods calculated, then the total material cost calculation is carried out.

CONCLUSION

Based on the results of data collection and analysis that has been done, it can be concluded as follows:

1. The most economical and the most efficient method for design of road embankment on organic soil is using the preloading method with a combination of PVD, rather than the vertical pile method.
2. The most economical and efficient road embankment reinforcement is using reinforcement using geotextiles rather than wood piles even though the price difference is not so much.
3. It is recommended to do soil improvement for road embankment construction with preloading method combination with PVD and strengthening the embankment using geotextiles as its reinforcement because it produces the most efficient volume of material so that material costs become more economical.

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