Combined Effects of Vertical Drain and Pre-loading to Reduce The Number Of Geotextile Reinforcement For Road Embankment Design

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Abstract. The study of the behavior of embankments reinforced by geosynthetic construction on soft clay soil with and without a prefabricated vertical drain is described. The effect of a pre-loading with stage construction method to construct the embankment, the gain of bearing capacity, as well as the depth of compressible soil was also considered in this study. The limit equilibrium using Bishop and Fellenius methods was used in this study to determine the stability of the embankment. Vertical drain installation, combined with the stage construction method, substantially reduces the number of geotextile reinforcements needed. The number of geotextiles can be reduced by up to twice that compared with foundation soil without PVD. Furthermore, the combined use of geotextile and PVD can improve the performance of embankment height as well as increase the critical height of the embankment with geotextile reinforcements. Without PVD, the embankment will be safe against landslides (without geotextile) of less than 3.5 meters. When using PVD, the embankment critical height can increase by up to 7 meters. This condition occurs when the embankment is constructed using the stage construction method, geotextile reinforcement, as well as PVD installation for soil improvement.

1. Introduction
Low bearing capacity, high consolidation, and hydraulic conductivity are the major problems and considerations in the design and construction of embankments over soft cohesive foundations. To improve the bearing capacity and to reduce the time of consolidation, the vertical drain method that is installed along with the soft soil under the embankment is widely used. Moreover, the vertical drain method is also used to improve the stability of embankments on soft clay soil. For applications in the field, the use of a vertical drain is usually combined with pre-loading [1],[2],[3]. The aim of vertical drain installation is to shorten consolidation time of thick soft soil by providing short horizontal drainage paths [4] to accelerate the dissipation of excess pore water pressure during the pre-loading process to reduce the consolidation time. The use of vertical drains in the form of prefabricated vertical drains (PVD) as a replacement of sand drains has been done since 1970. The use of PVD to substitute the use of a sand drain has the potential to allow for cost-effective construction and eases implementation in the field, thus it can replace the conventional method that has developed long before [2]. The use of PVD in the field has been successful thus it is increasingly applied in various soil improvement works in the
world [3],[5],[6],[7]. The problems that occur on the stability of the embankment also need to be considered.

The problem that can also occur in embankments built on soft soil is the instability of the embankment against the existence of sliding. Sliding usually occurs on high embankments that are built on soft soil. The use of geotextiles as reinforcements of embankments against landslides is increasingly applied in the field [8],[9],[10]. Instrumental research using back analysis on geotextile performance has also been done by [11],[12]. The use of PVD and geotextiles in the field has enormous advantages both for the soil subgrade improvement as well as for the stability of the embankment on it. The design of geotextiles and PVD in the field is not treated separately but it is treated in combination. However, the problem that often occurs in the geotextile requirements design is that the calculations are carried out without considering the combined effect of PVD. In addition, the effect of the stage construction on the embankment is also not considered for geotextile design. Whereas, the use of geotextiles combined with PVD and stage construction is done with the aim of reducing construction costs. These methods are usually used in embankment construction with high elevation [13],[14],[15]. There has been considerable research examining the behavior of geotextiles and PVD construction which are treated separately. However, research that examines the combination of PVD and geotextiles is still very rare.

Research on the effect of a combination of PVD and geotextile use has been studied by [16]. This study was conducted on an embankment built on 15 meters of PVD using three variations of PVD spacing and two soil subgrade plasticity conditions. This research is using the finite element method. The result of this research is the comparison of embankment performance on two soil subgrade types with different characteristics that improved with PVD in two embankment conditions: with geotextile reinforcement and without geotextile reinforcement. This study also considers the embankment stage construction, compression of soil subgrade, and increase in soil bearing capacity due to PVD installation. In general, this study shows that the use of geotextile reinforcement with PVD installation can increase the critical height of an embankment against the landslide when compared with the embankments without geotextile. In addition, the greater the ultimate strength of the geotextile used on the embankment, the higher the short-term failure height of the embankment. These results indicate that the presence of PVD and stage construction greatly affects the critical height of the embankment against landslides and affects the number of geotextiles. Research with similar results but conducted on different soil subgrade conditions has also been done by [17] and [18]. However, there has been a paucity in recent studies about the combined effect of PVD and geotextile. The results of this research have not been able to convey the theory that can be applied in the field, especially for the use of geotextiles. In addition, previous studies have not shown the existence of comparative value of the number of geotextiles when considering the combination of PVD+the construction stage and without considering the combination. Therefore, research on the combined effects of PVD, stage construction of embankment and geotextile is very necessary to be taken into consideration for the implementation of development design in the field.

The use of geotextiles combined with PVD in the field has been applied in most road construction projects in Indonesia. Embankment construction generally occurs with stage construction method with the speed adjusted by the ability of the compaction equipment in the field. Geotextile installation is dependent on the embankment height and the soil subgrade consistency. The higher the embankment the more the number of geotextile layers required. Geotextiles are generally installed in layers until they reach the need for resisting moments to avoid landslides. The required geotextile design is the number of geotextile layers capable of resisting sliding at certain embankment heights. The number of geotextile requirements that have been used in the design in the field has not considered the combined effect of PVD and stage construction. Whereas stage construction for embankment construction is always done in the field and it is very influential to changes in subgrade conditions ([19]) and changes in subgrade parameters. Changes in subgrade parameters due to PVD and stage construction can affect the amount of geotextile reinforcement requirements in the embankment. This condition has never been considered in the previous design. This is neglected because these calculations and analyses are time-consuming, whereas the construction design should be implemented immediately. If the combined effect is
considered, then the number of geotextile needs will be much reduced, and it will reduce the construction costs. Therefore, it is important to know how much influence the combination of PVD and stage construction in the construction of road piles on the number of geotextile needs. In addition, the influence of embankment height and depth of compressible soil will also produce different effects on the number of geotextiles. The results of this study are to understand the combined effect of PVD and stage construction of embankment to the amount of geotextile needed to be safe against landslides. The results of this study are expected to be a reference in the implementation of road embankment construction carried out with a combination of PVD, construction stage and geotextile.

This study has the aim to determine the effect of the use of PVD and embankment stage construction against the number of geotextiles required. The gain of shear strength on soil under the embankment due to the consolidation during the embankment construction is evaluated. The effect of stage construction, rate consolidation, and degree of consolidation due to the spacing of PVD is also examined. A study about geotextile quantity and embankment performance which considers the effect of combination geotextile and PVD on the stability of embankments is proposed.

2. Parameters and Modelling
This research was conducted through several stages of calculation and analysis. The first stage is determining the embankment parameters and subgrade parameters for modelling analysis. The embankment height used in this model is the same as the embankment height in previous studies conducted by [16] and [17]. Whereas the condition of subgrade is adjusted to the condition of soft soil in Java island which consist with mostly soft clay-compressible soil consistency. The next stage is to design the required PVD spacing. This study uses PVD with 1 meter spacing and the depth of PVD installation is same as the depth of the compressible soil. Then, the analysis of the gain of subgrade parameters due to PVD installation is carried out using the formula [20]. Furthermore, with the new subgrade parameters, the slope stability modelling of embankment is carried out every week by considering the settlement of soil-subgrade. The slope stability analysis is used to calculate the number of geotextile requirements. Flowchart of research methods in this study can be seen in Figure 2.

2.1 Selection of embankment and Soil Properties
This present study examines a highway embankment that was constructed on a 10 m, 15 m, and 20 m deep soft clay foundation, as shown in Figure 2. The PVD spacing used is 1 m with a triangular pattern. The embankment stage construction is assumed to be 0.5 m per week. The coefficient consolidation of soil foundation used in this study was 0.5-0.6; the void ratio parameter is 1.2-1.3; the unit weight is 1.6-1.7 t/m³. The soil foundation parameter is relatively the same at each depth. The embankment material was assumed to be a purely frictional granular soil with a friction angle of 30° and a volume weight γ of 19.5 kN/m³. The embankment heights in this study are adjusted to stage construction thickness that is 0.5 meter per week. The net embankment heights in this study are 2-9.5 m that is equivalent to embankment stage construction in week 4 to week 19. The settlement of soil foundation due to each phase reviewed is also taken into consideration with this soil analysis. The foundation soil parameters in this analysis can be seen in Table 1.
2.2 Prefabricated Vertical Drain
The conventional theory of consolidation using vertical drains assumes that the shape of the vertical drain is a circle when viewed from its actual shape (sand drains column). Since the development of a square-shaped PVD is flat, the square shape is then converted into a circle with an equivalent diameter. This understanding of the equivalent diameter is the same as that of the radial water-drainage capacity of PVD. The calculation of the equivalent diameter ($d_w$) value of PVD was first researched and then a formula was produced by [21]. Based on the research, the diameter equivalent value of PVD is influenced by the value of $a$ (width of PVD) and $b$ (the thickness of PVD) (Figure 3). The formula is as follows:

$$d_w = \frac{2(a+b)}{\pi}$$

(1)

Based on existing studies, it is indicated that due to the effect of the corner (the influence of the existing angle on PVD) the value of the equivalent drain diameter is less than the initial value based on the assumption of the length of the flow perimeter. The new formula used is based on the results of the finite-element analysis recommended by [22]. The new formula is written below (Eq. 2). The formula in Equation 2 is used in this study. The dimensions of PVD used in this study were 100 mm x 4 mm based on [2].

$$d'_w = \frac{4(a+b)}{\pi}$$

(2)

The installation process of PVD by inserting a mandrel into the soil can lead to disruption of the soil structure. Therefore, the smear zone (ground damage zone due to pressure by mandrel) may result in
reduced permeability to the soil and increased soil settlement. In some soil conditions, the fine-grain soil layer will experience disturbance and damage to certain areas and will widen in the subsequent layers [23]. The smear zone creates additional reinforcement that must be overcome by excess water. This will, in turn, inhibit the rate of consolidation. The character of the permeability and compressibility of the soil in the smeared area will be different from the undisturbed soil properties; therefore, the properties of vertically drained soil will not be well predicted or accurate if the effects of these smears are not considered. Barron [23] and Hansbo [24], modeled the smear zone by dividing cylindrical soil samples by dewatering with central streaming into 2 zones. The first zone of the smear zone is the zone in the area around the drain and the other is the area that is not affected by the installation of the mandrel.

The area affected by the installation of the mandrel is dependent on the installation procedure. Various correlation relationships were performed to obtain the size of the smear zone. For purposes of designing, [25] state that the diameter of the smear zones (d_s) and the cross-sectional area of the mandrel have the following relationships:

\[ d_s = \frac{(s-6)dm}{2} \]  

(3)

Where \( d_m \) is the diameter of a circle which is equal to the length of a cross-section on a mandrel or the value of the cross-sectional area at the tip of the anchor where the value will be greater. Test results from [26] and [27] resulted in a simpler formula for smear zone calculations. The formulation is:

\[ d_s = 2. \ d_m \]  

(4)

The study conducted by [28] shows that the diameter of the smear zone is 3-4 times greater than the drainage length and the ratio of \( d_s/d_m \) is 4-5. This study uses Equation 4 for PVD calculation design. Based on Rixner et al. [22], there are 2 kinds of PVD installation configuration which are in the form of a rectangular pattern and a triangular pattern (Figure 4). The effective diameter (D_e) due to the installation of the PVD value varies depending on PVD spacing. D_e calculation is:

\[ D_e = 1.13 \ S \] (for square configuration)  

\[ D_e = 1.05 \ S \] (for triangular configuration)  

(5)  

(6)

The square pattern was initially considered more suitable for field construction. However, triangular patterns are more commonly chosen in the field because their water-drainage area covers more than the square pattern. In addition, according to [29] the installation of PVD with a triangular pattern is considered to result in a uniform compression compared with a square pattern. This research was conducted using triangular patterns.

**Figure 4.** PVD installation configuration and area affected by PVD installation (Rixner [22])

### 2.3 Geotextile Design

The important parameter that is needed for geotextile design is the allowable stress of the geotextile. Allowable stress of geotextiles is affected by the reduction factor value so that the value will be smaller than the ultimate tensile strength. The allowable stress is written in the following equation:

\[ \sigma_{al} = \sigma_e \left( \frac{1}{f_d} \cdot \frac{1}{f_e} \cdot \frac{1}{f_{en}} \cdot \frac{1}{f_{m}} \right) \]  

(7)

Where \( \sigma_{al} \) is allowable stress of the geotextile; \( \sigma_e \) is the ultimate tensile strength; \( f_d \) is a reduction factor for mechanical damage; \( f_{en} \) is a reduction factor by environmental conditions; \( f_m \) is a reduction factor for the extrapolation of data geotextile tensile strength, and \( f_e \) is the secure construction factor.

The formulation issued by AASHTO [30] shows a slightly different reduction factor value resulting in different tensile strength values. The tensile capacity of the reinforcement determined from constant
load laboratory testing. The laboratory result is adjusted using reduction factors due to chemical and biological degradation (RF_d) and mechanical damage during installation (RF_ID). The allowable tensile strength of the reinforcement (T_{allow}) is calculated as:

\[ T_{al} = \frac{T_{hl}}{R_t} = \frac{T_{hl}}{R_t \times R_D \times R_C} \]  

(8)

All reduction factors must be based on product-specific testing. The values for RF_D and RF_ID should be less than 1.1. AASHTO [30] recommends RF to be no less than 7 or 3.5 for permanent and temporary wall structures, respectively. The magnitude of creep reduction factor (RF_{CR}) will vary with design life. The maximum design load for a geosynthetic layer in a permanent reinforced wall application is typically reduced to a long-term allowable design load T_{des} where:

\[ T_{al} = \frac{T_{a}}{R_F} \]  

(9)

Here SF is an overall factor of safety to account for uncertainty in problem geometry, soil variability and applied loads and has a minimum value of 1.2. For a reinforced slope FS=1, since the overall factor of safety is accounted for in the stability analyses.

This research a method of slices approach was used together with the assumption of a circular failure surface using Bishop and Fellenius Method. A solution for the factor of safety using the Bishop and Fellenius Method of analysis carried out using the following equation:

\[ F = \left( \frac{M}{M} \right) \frac{1}{u} + \sum \frac{T_a}{M} \times \frac{R_F}{R_u} \]  

(10)

Where MR and MD are the resisting and driving moments for the unreinforced slope, respectively, and R_t is the distance between the circular center and the located geotextile layer. Geotextiles can be designed for more than 1 layer on the embankment. This especially occurs with relatively low tensile strengths of geotextiles. In multi-layer geotextiles, the Rt value can be adjusted to the distance of each layer of geotextile to the center point of the landslide.

A geotextile nonwoven with a tensile strength equivalent to 52 kN/m² was used in this study. The tensile strength is then reduced due to various factors. For design purposes in this study, the tensile strength of the geotextile used after reducing was 16 kN/m². Installation of geotextile on the embankment is done with 0.25 meter/layer. The geotextile is installed thoroughly on the embankment body in accordance with the number of reinforcement requirements.

2.4 The Embankment Modelling for Stability Analysis

An analysis of the embankment stability modeling in this study was using the Limit equilibrium method (LEM) designed by Bishop Simplification [31] and the Fellenius method [32]. LEM is one method to determine the magnitude of the embankment safety factor. Unlike the Finite Element method, this method does not consider the stress-strain relationship and deformation on the soil foundations.

Some researchers have compared the use of the LEM and the finite element method. Comparison of methods performed to find which method is better suited to the actual condition of sliding. Hongjun and Longtan [33] state that the LEM is more appropriate to use to analyze landslide as well as the actual conditions of the field. Thus, in this study, the LEM is preferred based on the above-mentioned reason.

Modeling analysis undertaken in this study is to use the embankment height varies according to the stage construction. Each stage of embankment construction is done within 1 week with a layer thickness is 0.5 meters. In this study, it will be symbolized as: 4w (4 weeks of embankment stage construction); 8w (8 weeks of embankment stage construction); 12w (12 weeks of embankment stage construction); 14w (14 weeks of embankment stage construction); 16w (16 weeks of embankment stage construction) and 19w (19 weeks of embankment stage construction). Each of the embankment phases undertaken the magnitude of the soil foundation settlement and the increase in bearing capacity of the soil subgrade have been observed. The embankment stability analysis is done by assuming the soil foundation that has undergone compression. The compression occurring every week in every stage of construction has been monitored in this study. The amount of compression per week is calculated depending on the foundation soil and the existence of PVD for soil improvement. Calculation of compression is based on the
formulation of one-dimensional consolidation by [34]. The increase in bearing capacity of soil subgrade is based on the formulation of [20]. The modeling of the embankment is shown in Figure 5.

Figure 5. Embankment modeling with stage construction.

3. Result and discussion

3.1 Settlement and un-drained cohesion increase of foundation soils

The soil settlement used in this study was varied according to the depth of the compressible soil. The settlement magnitude is calculated on each variation of embankment height using the stage construction method. 100% compression of soil foundation without PVD is occurring indefinitely. To shorten the consolidation period PVD is then required. The settlement in 6 months installation of PVD is designed ±95% of the total settlement. The settlement magnitude of the soil foundation during the construction period with PVD installation can be seen in Figure 6a. Those settlement magnitudes will then be used to calculate the stability of the embankment after soil foundation settlement. Furthermore, the bearing capacity gain, as a result of the un-drained cohesion (\( C_u \)) increase, is also important to note. The increase in \( C_u \) values occurs as a result of the regular embankment pre-load on the foundation soil. In this study, the increase in \( C_u \) values was monitored by using empirical formulations at each embankment height of the stage construction. The magnitude of the increase in the \( C_u \) occurred as a result of stage construction and installation of PVD, as shown in Fig. 6b.

Figure 6. (a)The settlement magnitude of the soil foundation during the construction period with PVD installation. (b)The magnitude of the increase in the \( C_u \).

The amount of settlement magnitude at each variation of height and the increase in the value of \( C_u \) is used to calculate the stability of the embankment. The result is then used to calculate the number of
geotextiles needed and then to compare the number of geotextiles to the embankment without PVD installation for foundation soils improvement. The modeling of the embankment for analysis in this study can be seen in Figure 5. The existence of a relatively quick compression on the foundation soils improved by PVD leads to the height of embankment designed in the field that must be greater than the height of planning. Hence, there is a net embankment thickness ($H_{\text{net}}$) for embankment height in the field and embankment fill thickness after compression ($H$) for embankment height planning which is also analyzed in this study. The amount of $H_{\text{net}}$, $H$, and settlement are affected by the depth of compressible soil and the soil parameters that determine the soil characteristics. The amount of $H_{\text{net}}$, settlement and $H$ in this study can be seen in Figure 7. Based on the analysis results in the Figure 7 shows that compressible soil thickness can affect the settlement magnitude that occurs. In addition, the settlement magnitude of subgrade is also influenced by compressible soil thickness, but the results are not too significantly different. This settlement magnitude of soil subgrade combined with gain of parameter $Cu$ after PVD installation will be used in the calculation of embankment stability.

3.2 The combined effect of PVD for embankment stability reinforced with geotextile

The soil foundation improvement which is the combined effect of PVD and stage construction use is interesting to observe. There are 2 main advantages of using PVD: shortening the drainage path to accelerate the consolidation and improving the embankment stability due to the strength gain of soil foundation. Geosynthetic reinforcement provides additional embankment stability and tends to force the potential failure surface in soil with higher shear strength [10]. To study the combined effect of PVD and geotextile reinforcement, limit equilibrium analysis was conducted to simulate embankment construction over soft foundations. Preliminary analysis is done by calculating the amount of reinforcement requirement on the foundation soil without PVD improvement. Empirical observations were used to observe $\Delta M_{\text{res}}$ and the amount of geotextile (installed with the spacing of 0.25 meters/layers) on stage construction time by Fellenius and Bishop Methods. Graph of reinforcement of geotextile and $\Delta M_{\text{res}}$ to the height of the embankment according to stage construction with 0.5 meters/week can be seen in Figures 8 to 10.

![Figure 7](image7.png)

Figure 7. The variations of embankment fill thickness and net embankment height.

![Figure 8](image8.png)

Figure 8. The variation of the number of geotextiles and $\Delta M_{\text{res}}$ against the week of stage construction in 10 m foundation soil depth improvement by PVD.
Figure 9. The variation of number of geotextiles and $\Delta$MR against the week of stage construction in 15 m foundation soil depth improvement by PVD.

Figure 10. The variation of number of geotextiles and $\Delta$MR against the week of stage construction in 20 m foundation soil depth improvement by PVD.

The analysis results show, for the soil foundation without PVD, in 7 weeks of construction (equivalent with 3.5 meters of embankment height), the total need for embankment reinforcement with 52 kN/m$^2$ geotextile is exceeding the installed capacity of the geotextile in accordance with the total height of the embankment. Consequently, the installation of a geotextile should be done by adding the geotextile sheet on each layer as needed. Another way is to replace the geotextile with one of larger tensile strength. The same results were obtained in both methods used in this study. This analysis was obtained on foundation soil conditions with a 10-meter depth (Figure 11).

Figure 11. The variation of number of geotextiles and $\Delta$MR against the week of stage construction in 10 m foundation soil depth without improvement by PVD.

Significantly different results are obtained when the foundation soil is improved by PVD. The height of the embankment that has a sufficient amount of reinforcement to the total embankment height will be greater if the foundation soil is improved with PVD. At a 10 m depth of foundation soil, the embankment with 1 layer/0.25-meter geotextile (which is installed in the entire body of the embankment) will be safe against landslides in the 14th week of stage construction that is equivalent with a ±7 meter height. Whereas, stage construction at weeks 16 and 17 are obtained when the depth of incompressible soils is 15 and 20 m. The results are obtained when using the Bishop method. The Fellenius method shows slightly different results. This condition is caused by the value of the safety factor generated by using the Fellenius method is relatively smaller when compared with the bishop method. This causes the amount of geotextile generated from the Fellenius method to tend to be more than the bishop method. The same results were also obtained from research conducted by [35] where the difference of safety factor was 3.89% to 5.56%. The result obtained by the Fellenius method based on Figure 11 is that at a depth of 10 m of the foundation soil, the embankment with 1 layer/0.25 meter geotextile (which is
installed in the entire body of the embankment) will be safe against landslides in the 11th week of stage construction that is equivalent to a ±5.5 m height. Whereas, in the condition of 15 and 20 m of compressible foundation soils, the results show that the 12th and 14th weeks that are equivalent to 6 and 7 m, respectively.

The results summarized in Figures 8-10 show that the amount of geotextile required by the embankment, constructed on a 10 meters compressible soil, is more than the 15 and 20 m of compressible soil. This is because the settlement magnitude of 10 m compressible soil is smaller than the other depth. Thus, the final height of the embankment in the field is greater than the embankment that is built on the 15 and 20 m of compressible soil. In addition, with a relatively small settlement that the embankment deposits into the topsoil of the foundation soil are lesser. In fact, the mixing embankment soil to the foundation soil can simultaneously improve the surface layer of the foundation soil, causing the bearing capacity to increase. A relatively large embankment height and relatively soft consistency of foundation soil causes low embankment stability against sliding. Thus, the amount of geotextile required on the embankment with a thickness of foundation soil of 10 m can be more.

The results show that, by using PVD, the stability of the embankment against sliding will increase. These results are relatively the same as the results from previous studies [16],[17] and [18]. The stability increases are observed two-times more than the non-PVD improvement for foundation soil. In addition, the results show that at the depth of the dominant clay soils with soft consistency as deep as 10 m, the number of geotextiles installed with a spacing of 0.25 meters/layer will be safe against a landslide less than the 7 m embankment height. When the embankment height is more than 7 m it is necessary to increase the tensile strength of the geotextile or to add more geotextile sheets in each layer. Likewise, on foundation soil as deep as 15 and 20 m, the heights of a safe embankment height against the landslide are 8 and 8.5 m, respectively. The result is obtained when using the Bishop method. The Fellenius method produces a lower embankment height than the Bishop method. The result of the relation of compression soil depth and week of stage construction that is safe against the landslide when reinforced with geotextile can be seen in Figure 12.

Figure 12. Stage construction that results geotextile number greater than the maximum height of embankment.

Another result obtained in this study is the difference in numbers of geotextiles as reinforcement of the embankment. The difference is occurring under foundation soil conditions with and without improvement with PVD. Striking differences can be seen from the 7th week of fill construction. Figure 8 shows that the number of geotextiles on soil improved by PVD at week 8 is 2-5 sheets (by the Bishop and Fellenius method). While the results are shown in Fig. 11, where the foundation soil is not improved with PVD, the required geotextile amount is 18-19 sheets. Differences in the number of geotextiles are increasingly rising along with the increase of embankment height in the next week of stage construction. Comparison of the number of geotextiles and ΔMres requirements on the embankment that is built on foundation soils improved with and without PVD can be seen in Table 2 and Table 3.
Table 2. The number of geotextile layers in embankment construction in different weeks of stage construction.

| Week of stage construction | Foundation soil without PVD | Foundation soil with PVD |
|----------------------------|-----------------------------|--------------------------|
| 4w                         | 1-2                         | 1                        |
| 8w                         | 18-19                       | 2-5                      |
| 12w                        | 57-59                       | 13-27                    |
| 14w                        | 85-86                       | 27-34                    |
| 16w                        | 118-121                     | 45-57                    |
| 19w                        | 161-162                     | 50-92                    |

Table 3. \( \Delta \)Moment resistance (kN/m) in different weeks of stage construction.

| Week of stage construction | Foundation soil without PVD | Foundation soil with PVD |
|----------------------------|-----------------------------|--------------------------|
| 4w                         | 32-54                       | 7.9-12.6                 |
| 8w                         | 918-1067                    | 125-242                  |
| 12w                        | 5759-5958                   | 1222-1663                |
| 14w                        | 7471-7645                   | 2522-3280                |
| 16w                        | 12741-12937                 | 4590-5593                |
| 19w                        | 12821-12970                 | 6169-7710                |

4. Conclusion

The use of PVD on the foundation soil combined with stage construction of embankment can greatly affect the performance of the embankment against the landslide. These results are relatively the same as the results of previous studies. The main results that can be obtained from research on the combined effects of PVD, stage construction and geotextile are:

a. The use of PVD can reduce the amount of geotextile need for reinforcement. The condition is caused by the foundation settlement during the construction process and the increase in the \( C_u \) value which can increase the bearing capacity of the soil. Improved performance of the embankment against the landslide can be doubled in foundation soil conditions improved with PVD.

b. The amount of geotextile reinforcement requirements can be reduced by more than a half. Based on the results of the analysis above shows that with the presence of PVD, the amount of geotextile reinforcement needed is greatly reduced to three times. Thus, in designing the road embankment especially on soft clay soils, it is important to pay attention to the combined effects of PVD and embankment stage construction.

c. The existence of pre-loading with stage construction and PVD installation in soil-subgrade will greatly affect the stability of the embankment against landslides. The effect of this combination is the increase in the critical height of the embankment, thus it can lead the embankment safer against landslides. These results support the results of previous studies conducted by [16]

Based on the results of this study, the combined effects of the use of PVD, geotextile and stage construction need to be considered in the implementation of the design. Considering the above three points, the need for geotextile reinforcement will be much less to reduce the project cost budget. Further research is needed especially for the field scale in order to determine the effect of the combined effects of PVD, stage construction and geotextile that applied in the field. The results of the field-scale research will be able to support the results of research from empirical tests that have been carried out previously, including in this study.
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