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Performance of Soft Soil Improved Prefabricated Vertical Drain (PVD) for Road Construction in Pontian, Johor

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Abstract: The use of Prefabricated Vertical Drain (PVD) in soft soil to accelerate the consolidation process is very popular in Malaysia. Practically, installation of full length (100%) of PVD in the soft soil layer performed may incur a high cost of the material and installation time. Hence, this study investigates the effect of the use of various PVD lengths in terms of settlement and excess pore pressure behavior. The Plaxis-2D software was used to model the road construction on soft soil improved with PVD. Various lengths of the PVD such as 100%, 75%, and 50% of the soft soil layer thickness were modeled. The soft soil layer was modeled using the Soft Soil model and Mohr-Coulomb model, and the comparison between both models was investigated. The results show that the installation of various lengths of PVD gives quite a similar settlement rate and dissipation of excess pore water pressure. To reduce the cost of PVD installation, the combination of PVD length of 100% with 50% penetration length is recommended.

Keywords: Soft Soil Improvement, PVD, Numerical Modelling

1. Introduction

Malaysia is one of the growing countries in Southeast Asia that has seen remarkable development in recent years. The accelerated rate of development caused a higher demand in the construction industry. Due to the massive distribution of soft soil in Malaysia, significant economic activities and social growth are focusing along the coastal region, so construction projects on these challenging deposits are inevitable, particularly in road construction. These ground conditions created some problems and would escalate unless the proper steps and management of the site are carried out at an early stage of the planned construction. Specifically, the road in Pontian was reported as having a settlement due to soft soil failure that could pose a risk to road users. Based on the soil investigation carried out by the Centre for Research, Advisory & Technology (CREATE) of PWD, the main cause of the settlement of the soft soil is the increasing surcharge load from the surface pavement. Thus, a proper selection of soft soil improvement methods is vital to maintain the strength of the soil and prevent any incident from occurring.

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This study aims to model the construction of the road improved by PVD using Plaxis-2D software. The settlement behavior can be determined with the proposed model using varies length and spacing of PVD. After data analysis of the soft soil, the most suitable design of PVD can be proposed to improve soft soil on site due to the road construction.

Prefabricated Vertical Drain (PVD), often known as wick or strip drains, were created as a replacement for the regularly used sand drain [1]. PVDs are normally manufactured with a corrugated or channeled synthetic core enclosed by a geotextile filter. The geotextile prevents the soil from accessing the water channels and from overflowing the drain. Geotextiles are porous fabrics that, when used in conjunction with soil, can be isolated, filtered, reinforced, protected or drained. They have moulded channels that speed up the process of soil consolidation and help syphon trapped water in the soft soil strata and bring it to the surface.

PVDs have previously been utilized extensively for accelerated consolidation of low-permeability soils under surface surcharge. PVDs have a major benefit over sand drains in that they do not require drilling, making installation significantly faster. This method has been used to strengthen the soil foundation properties for railways, airports and highways [2]. The use of PVDs reduces the drainage path from the depth of the soil layer to the radius of the drainage impact field, allowing for faster consolidation [3].

2. Materials and Methods

The geometry of PVD used in PLAXIS 2D modelling was varied with different lengths and spacings to determine the result on settlement behavior.

2.1 Soil parameters and properties

Soil parameters used for the modelling are shown in Table 1 below:

Table 1: Soil Parameters and Properties

Soil Material	Very Soft to Soft Clay		Very Stiff to Stiff Clay		Dense Sand	Embankment
Soil Model	Mohr Coulomb	Soft Soil	Mohr Coulomb	Soft Soil	HS Small	Hardening Soil
Drainage Type	Undrained	Undrained	Undrained	Undrained	Drained	Drained
γ (kN/m^3)	14.15	14.15	18.50	18.50	17.00	16.00
γ_{sat} (kN/m^3)	14.15	14.15	18.50	18.50	21.00	19.00
Young's Modulus, E' (kN/m^2)	400	-	700	-	-	-
Poisson Ratio, v'	0.2	-	0.15	-	-	-
Cohesion, c' (kN/m^2)	12	12	41	41	0	1
Friction angle, φ'	9	9	6	6	35	30
Dilatancy angle, ψ	0	0	0	0	5	0
Modified compression index, λ	-	0.168	-	0.1832	-	-
Modified swelling index, κ	-	0.0918	-	0.09231	-	-
E_{50}^{ref} (kN/m^2)	-	-	-	-	42 x 10^3	25 x 10^3
E_{oed}^{ref} (kN/m^2)	-	-	-	-	42 x 10^3	25 x 10^3
E_{ur}^{ref} (kN/m^2)	-	-	-		126 x 10^3	75 x 10^3
Horizontal permeability, k_x (m/day)	0.15 x 10^{-3}	0.15 x 10^{-3}	1.5 x 10^{-3}	1.5 x 10^{-3}	0.5	0.3

Vertical permeability, k_y (m/day)	0.15 x 10^{-3}	0.15 x 10^{-3}	1.5 x 10^{-3}	1.5 x 10^{-3}	0.5	0.3

2.2 Methods

The soft soil will be model using two soil models, Soft Soil Model (SSM) and Mohr-Coulomb Model (MCM). Figure 1 to 3 shows the model of embankment with varies PVD spacing used in this study, while figure 4 to 6 shows the model of embankment with varies PVD length. The embankment layer is 2 m in height, the first two soil layers are soft soil with a depth of 9 m each, and the last layer is dense sand.

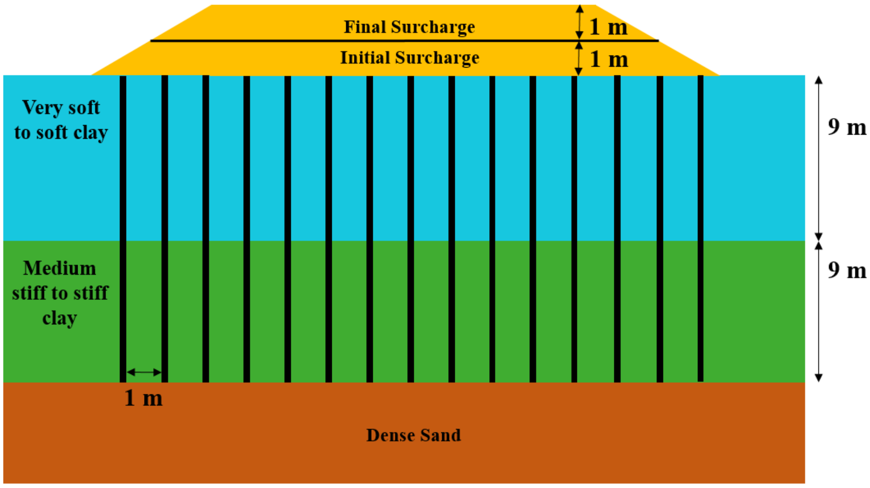

Figure 1: 1 m spacing

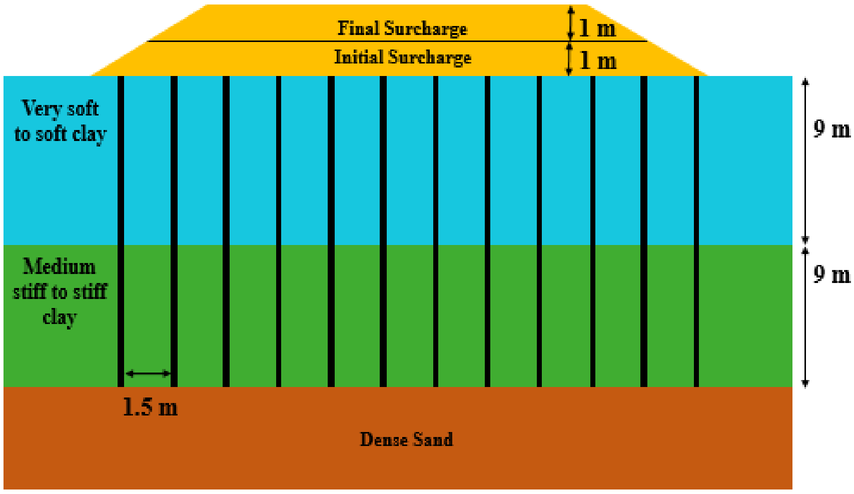

Figure 2: 1.5 m spacing

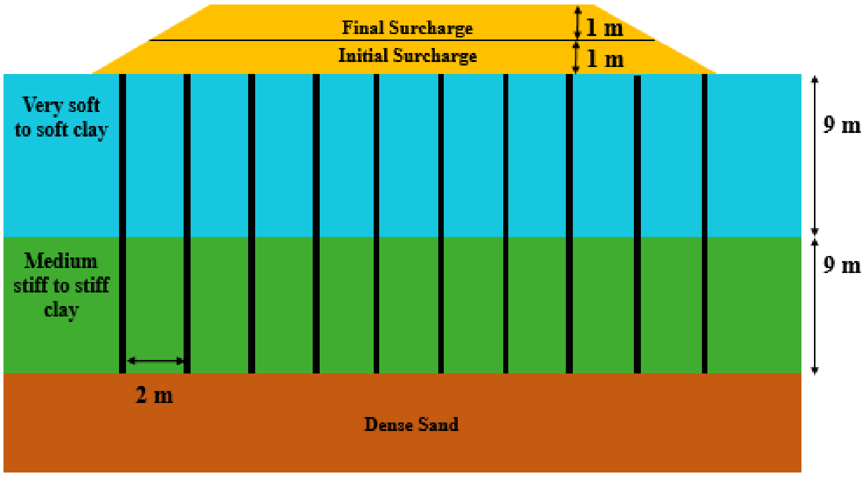

Figure 3: 2.0 m spacing

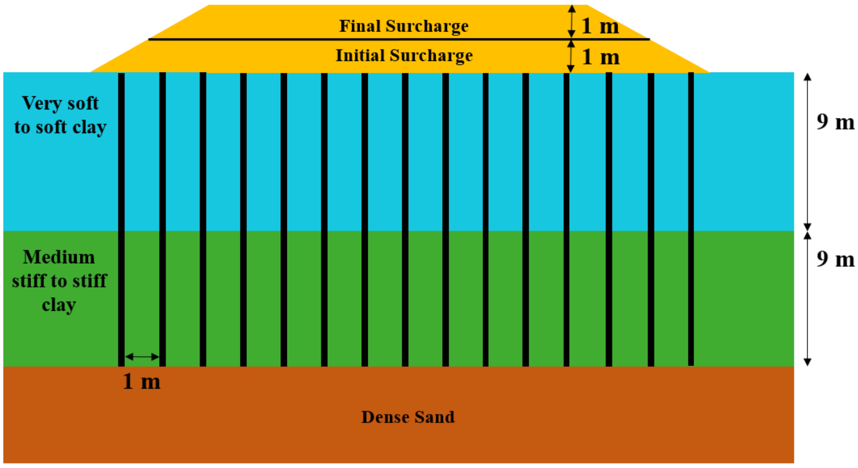

Figure 4: 100% penetration of PVD (18 m)

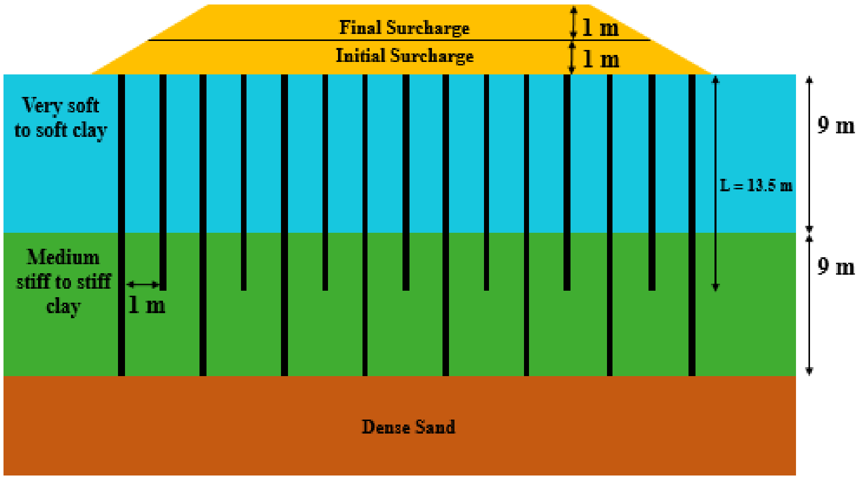

Figure 5: 75% penetration of PVD (13.5 m)

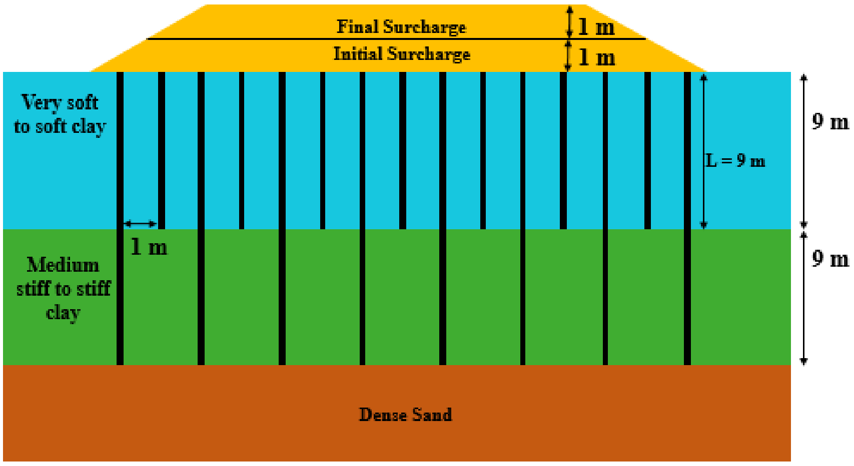

Figure 6: 50% penetration of PVD (9 m)

3. Results and Discussion

The soft soil enhanced PVD results with varying spacing and penetration length have been evaluated in terms of settlement and excess pore pressure.

3.1 Settlement

The primary settlement is considered complete after the soil settlement remains constant with time. The soft soil enhanced PVD results with varying spacing and penetration length have been evaluated in terms of settlement and excess pore pressure. Fourteen models were analyzed in this study where it refers to soft soil improved PVD and a model without PVD with seven models each for the SSM and MCM. Casagrande Method was applied in order to estimate the time taken for each models to reach primary consolidation (t_{100}) and the primary settlement (d_{100}) due to the PVD installation and applied surcharge.

3.1.1 Varies Drain Spacing

Drain with spacing 1 m, 1.5 m, and 2 m were modeled for the Mohr-Coulomb Model and Soft Soil Model. Figure 7 illustrates the graph of settlement vs time for SSM, while Figure 8 is for the MCM.

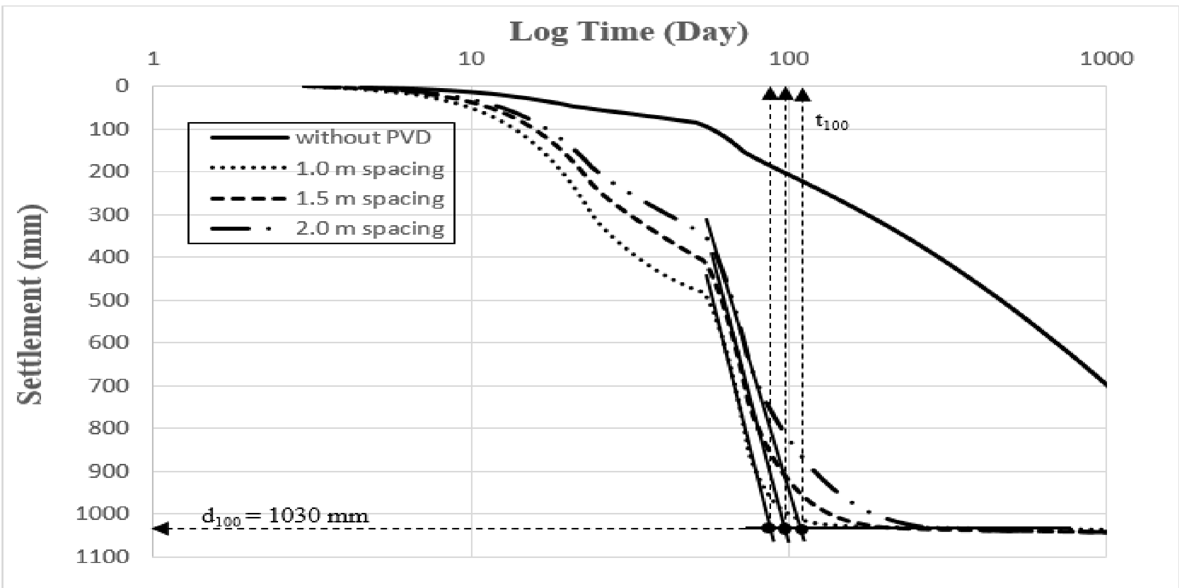

Figure 7: Settlement vs Log Time of varies PVD spacing and without PVD of SSM

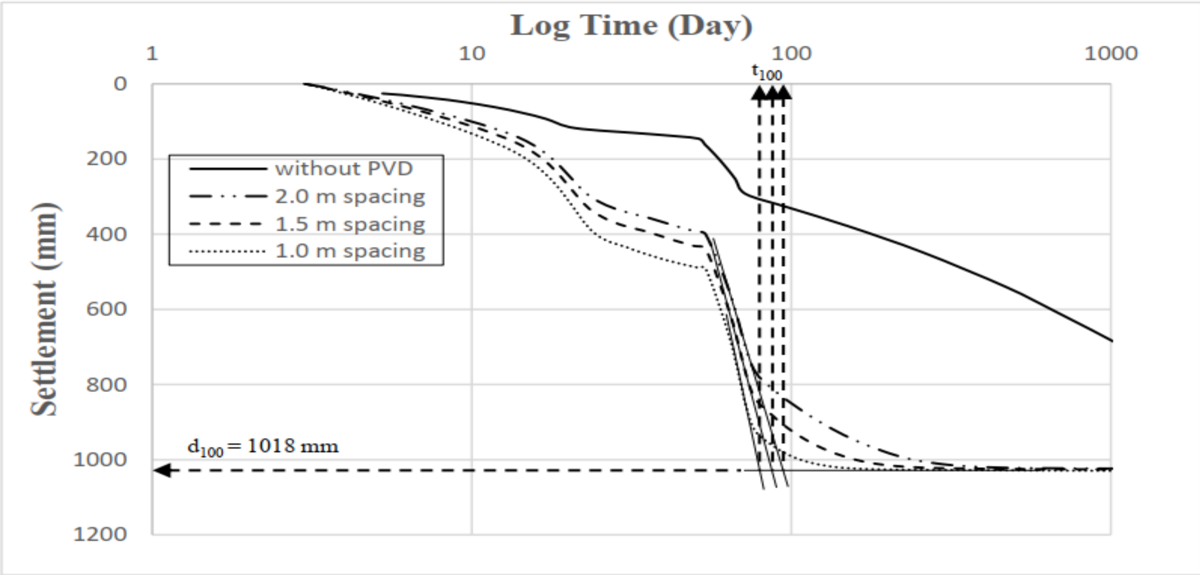

Figure 8: Settlement vs Log Time of varies PVD spacing and without PVD of MCM

Table 2 summarize the primary settlement (d_{100}), and time taken for different PVD spacing to reach primary settlement (t_{100}), and without PVD.

Table 2: Result for varies spacing of PVD and without PVD

		Spacing (m)	Primary settlement, d_{100} (mm)	Time (days)
Soft Soil Model	With PVD	1	1030	86
		1.5	1030	98
		2	1030	113
	Without PVD	-	1030	3700
Mohr-Coulomb Model	With PVD	1	1018	80
		1.5	1018	88
		2	1018	95
	Without PVD	-	1018	4400

Based on both graph, it clearly proved that usage of 1 m PVD spacing enhance the performance of the soft soil where it reduces the time taken to reach t_{100}. Table 2 shows the primary settlement, and time taken for different PVD spacing to reach primary settlement and without PVD. However, there is a difference in value of the primary settlement achieve between Soft Soil Model and Mohr-Coulomb model. This difference is because the Mohr-Coulomb model is a first-order model that only incorporates a small number of features that are observed in real soil behavior. The Soft Soil model is better describing the plastic deformation because it assumes a logarithmic relationship between volumetric strain and effective mean stress. Materials with high compressibility, such as clayey silts, peat, and normally consolidated clays are ideal for the Soft Soil model.

3.1.2 Varies Drain Penetration Length

Three different models were analyzed, uniform PVD length with 100% penetration PVD (18.0 m), alternating PVD length with 75% penetration (13.5 m), and alternating PVD length with 50% penetration (9.0 m). Figure 9 and 10 shows the settlement vs log time of varies PVD spacing and without PVD of SSM, and MCM respectively

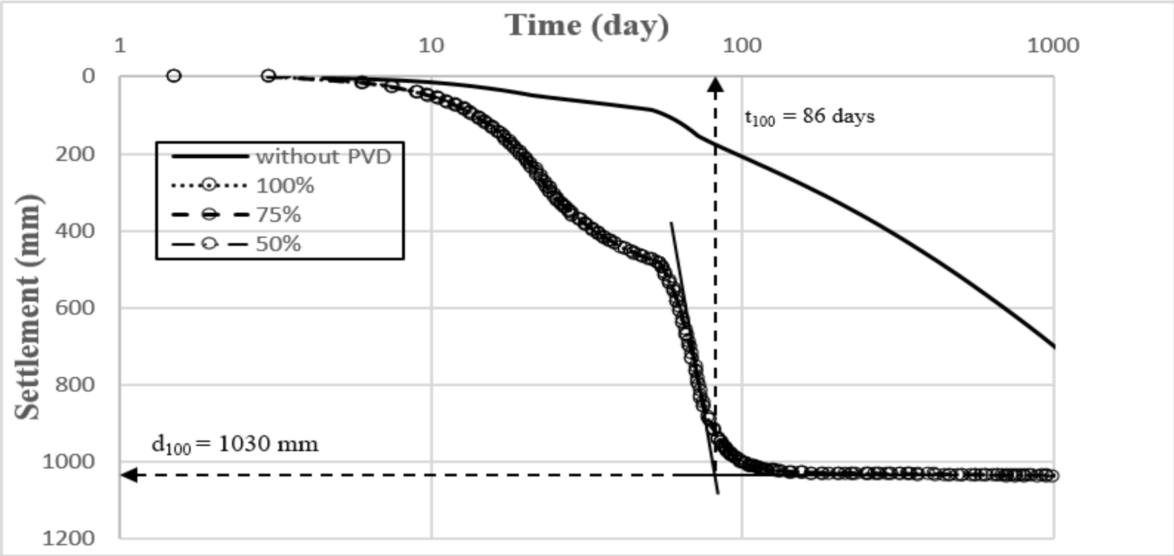

Figure 9: Settlement vs Log Time of varies PVD spacing and without PVD of SSM

Table 3 summarize the primary settlement (d_{100}), and time taken for different PVD penetration length to reach primary settlement (t_{100}), and without PVD.

Table 3: Result for varies penetration length of PVD and without PVD

		Penetration (%)	Primary settlement, d_{100} (mm)	Time (days)
Soft Soil Model	With PVD	100	1030	86
		75	1030	86
		50	1030	86
	Without PVD	-	1030	3700
Mohr-Coulomb Model	With PVD	100	1018	80
		75	1018	80
		50	1018	80
	Without PVD	-	1018	4400

3.2 Excess Pore Water Pressure

Variations in effective stress, which are caused by changes in pore water pressure, are associated to consolidation. Excess pore water pressure occurs when an external or internal force is applied to the soil layer, and it is defined as an increase in pore water pressure across the soil layer. The models analyzed in this study exert external load of 2 m surcharge.

3.2.1 Varies Drain Spacing

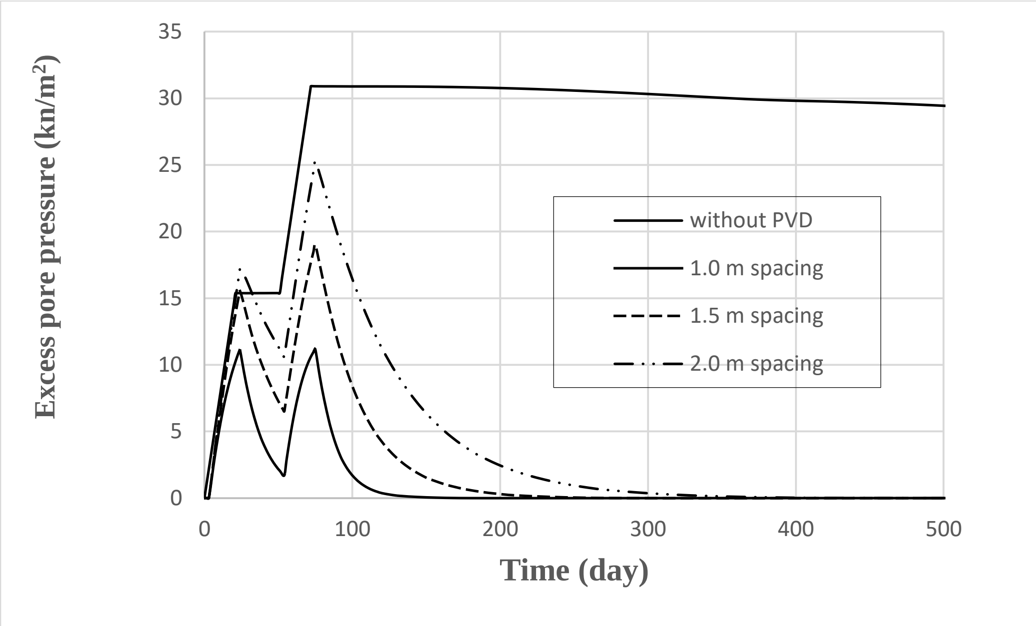

Figure 11: Excess pore pressure vs time of varies PVD spacing and without PVD of SSM

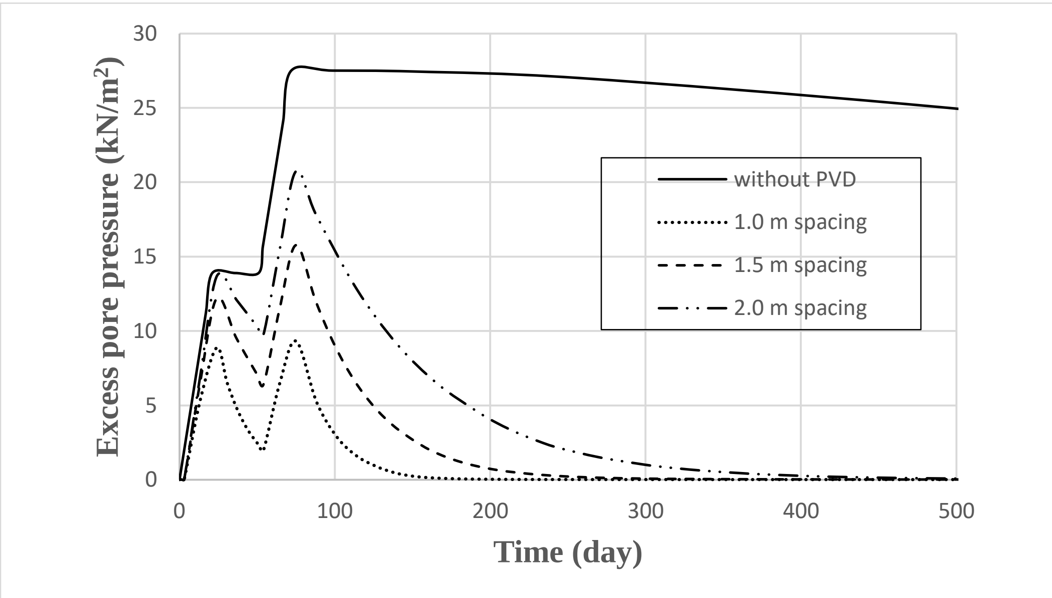

Figure 12: Excess pore pressure vs time of varies PVD spacing and without PVD of MCM

The graphs plotted in this subchapter were to analyze the time taken for each models with different PVD spacing to reach minimum excess pore water pressure at 1.00 kN/m^2. Figure 11 and 12 shows graph of excess pore pressure vs time of varies PVD spacing and without PVD of SSM and MCM. Table 4 summarize the result for excess pore pressure with varies PVD spacing and without PVD.

Table 4: Result for excess pore pressure with varies PVD spacing and without PVD

		Spacing (m)	Time to reach minimum excess pore pressure of 1.00 kN/m^2 (day)	Maximum pore pressure at the end of preloading time (kN/m^2)
Soft Soil Model	With PVD	1	107	11.2
		1.5	164	19

		2	247	25.2
	Without PVD	-	5561	30.9
Mohr-Coulomb Model	With PVD	1	125	9.3
		1.5	188	15.8
		2	300	20.8
	Without PVD	-	6104	27.5

3.2.2 Varies Drain Penetration Length

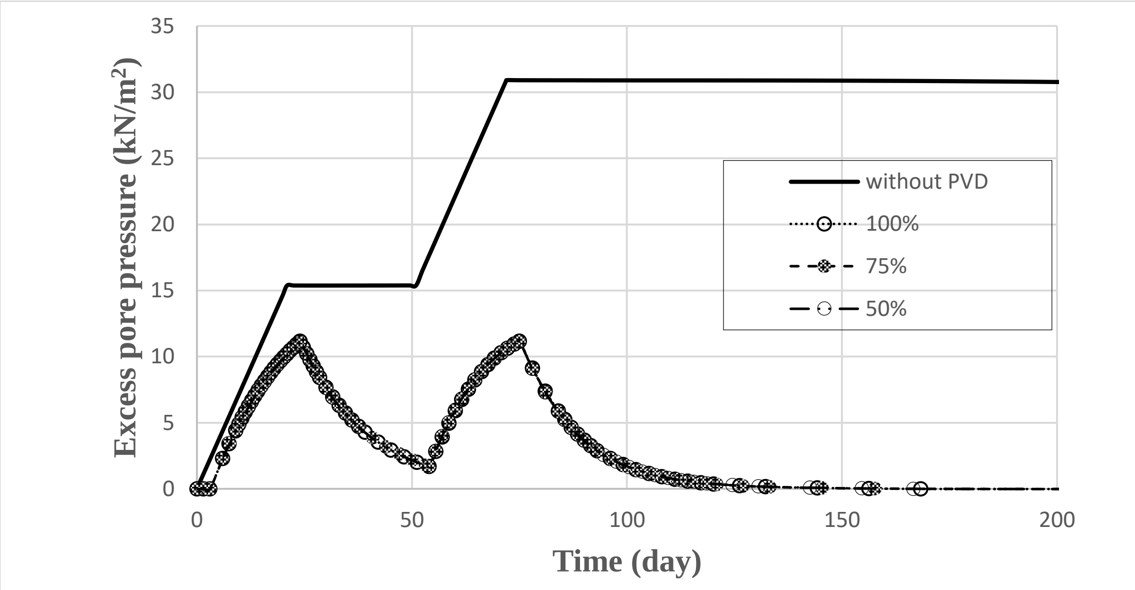

Figure 13: Excess pore pressure vs time of varies PVD penetration length and without PVD of SSM

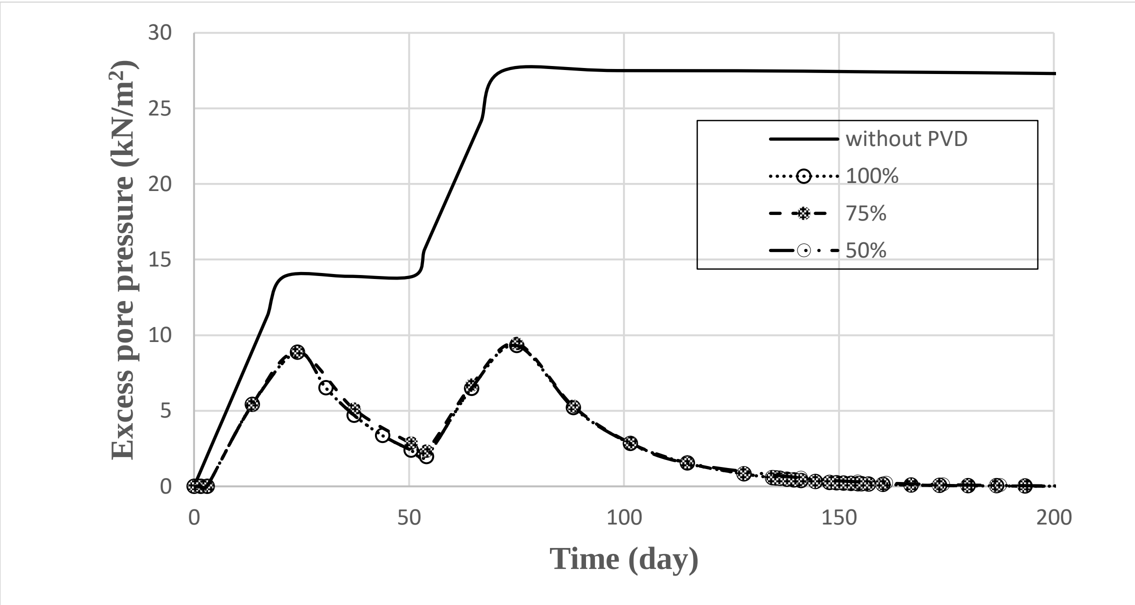

Figure 14: Excess pore pressure vs time of varies PVD penetration length and without PVD of MCM

Graph plotted in Figure 13 and 14 shows the graph of excess pore pressure vs time of varies PVD spacing and without PVD of SSM and MCM. Table 5 summarize the result for excess pore pressure with varies PVD penetration length and without PVD.

Table 5: Result for excess pore pressure with varies PVD penetration length and without PVD

		Penetration (%)	Time to reach minimum excess pore pressure of 1.00 kN/m^2 (day)	Maximum pore pressure at the end of preloading time (kN/m^2)
Soft Soil Model	With PVD	100	107	11.2
		75	107	11.2
		50	107	11.1
	Without PVD	-	5561	30.9
Mohr-Coulomb Model	With PVD	100	125	9.3
		75	125	9.3
		50	130	9.3
	Without PVD	-	6104	27.5

4. Conclusion

The following conclusions can be drawn based on the data and results analysis:

1. The time taken to reach primary settlements (t_{100}) for Soft Soil Model of PVD with 1 m spacing is shorter than 1.5 m spacing, 2 m spacing and without PVD which is 86 days, 98 days, 113 days and 3700 days respectively. While the time taken to reach primary settlements for Mohr-Coulomb Model of PVD with 1 m spacing is also shorter than 1.5 m spacing, 2 m spacing and without PVD which is 80 days, 88 days, 95 days and 4400 days respectively. The less the distance of the spacing, the shorter the time taken to reach the primary settlements.
2. The time to reach the primary settlements for the Soft Soil Model of 100% penetration PVD is the same as alternating PVD length with 75% penetration and alternating PVD length with 50% penetration, which is 86 days. For Mohr-Coulomb Model, the result for the three models is also constant with each other, which is 80 days. So, using alternating PVD length with 50 % penetration from original depth will give more advantage in terms of cost.
3. The comparison of Soft Soil Model of the time taken to reach minimum excess pore water pressure between 1 m PVD spacing, 1.5 m PVD spacing, 2 m spacing and without PVD took 107 days, 164 days, 247 days, and 5561 days respectively. While for Mohr-Coulomb Model, it took 125 days, 188 days, 300 days, and 6104 days for 1 m PVD spacing, 1.5 m PVD spacing, 2 m spacing, and without PVD respectively. This result shows that excess pore water pressure for 1 m spacing dissipates faster compare to the others. The less the distance of the spacing, the higher the rate of dissipation of excess pore water pressure.
4. The comparison of Soft Soil Model of excess pore water pressure between l m spacing, 1.5 m spacing and 2 m spacing shows that maximum pore-pressure reached at the end of the preloading period for 1 m spacing is lower than 1.5 m spacing and 2 m spacing. The difference between 1 m spacing and 1.5 m spacing is 7.8 kN/m^2, while the difference between 1 m spacing and 2 m spacing is 14 kN/m^2. Thus, using 1 m spacing is more preferable to be used.
5. In terms of PVD penetration length for the Soft Soil Model, the 100% penetration length of PVD has a similar rate of dissipation of excess pore water pressure with 50% and 75% penetration which is 107 days. There is no significant effect on the settlement and dissipation of excess pore water pressure. For the Mohr-Coulomb Model, the 100% penetration length of PVD has the same time to reach the minimum excess pore pressure as to 75% penetration of PVD which is 125 days. The 50% penetration only has a slight difference which took 130 days. So, it is clear that using alternating depth with 50% penetration is suitable to be applied and economical.
6. Based on the data analysis of this study, the most suitable design recommended applying for road construction in Pontian Johor is using alternating PVD length with 50% penetration length and with 1 m spacing. This is because the performance of the PVD is reliable and

this PVD model is economical and efficient compared to using 100% PVD penetration length but still achieves a short time of primary settlement and reaching minimum excess pore pressure.

7. The successful modelling of the soft soil improved PVD in this study would be a lesson learned for a real construction project on road construction in Pontian Johor.

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