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OPTIMUM LENGTH OF PVDS AT HAARAJOKI EMBANKMENT

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ملخص البحث

في هذه الدراسة، تم أخذ جسر بالقياس الطبيعي تم رصده حقلياً، تم بنائه بمدينة هاراجوكي بفنلندا، كمرجع لاختيار طريقة مناسبة لتمثيل المصارف الرأسية الجاهزة (PVDs). تم استخدام نموذج التربة اللينة مع الزحف (SSCM) في التحليل العددي. تم الاخذ في الاعتبار منطقة التشوية (Smear zone). تم تطابق نتائج الطريقة المختارة مع النتائج المرصودة حقلياً. تم أستخدام طريقة العناصر المحددة للعثور علي الطول الأمثل للمصارف الرأسية (PVDs).

ABSTRACT

In this study, a field monitored data of a full-scale test embankment, namely Haarajoki embankment in Finland, has been taken as a reference to choose a PVD's modeling approach. Soft soil creep model has been used in the analysis. The effect of smear zone has been taken into consideration. The verification was implemented and analyzed results of the chosen method were in good agreement with observed results. A finite element model has been utilized to find the optimum length of the PVDs.

INTRODUCTION

Vertical drains are often installed in soft clayey soils to improve their overall drainage properties and ultimately their strength and stiffness. PVDs are most commonly used these days to accelerate the consolidation of soft soil deposits, Because of their speed of installation and reduced cost. In the field, PVDs are installed by using a mandrel, which is pushed into the subsoil with a PVD inside it. The mandrel is subsequently withdrawn leaving the PVD in the subsoil. This process creates a completely disturbed zone around the PVD, called the smear zone, with an effective radius of r_s (diameter d_s). The hydraulic conductivity in the smear zone, k_s, may be reduced to a very low value.

Embankments are not placed on the ground instantaneously. In general, they are applied gradually over a certain time period which can be referred to as the construction time. It is also known that the hydraulic conductivity and compressibility coefficient of soils are function of the void ratio. Consequently, as the void ratio decreases during the consolidation process, both hydraulic conductivity and compressibility coefficients of soils are expected to change (Berry & Wilkinson, 1996); (Tavenas, et al., 1983); (Indraratna, et al., 2005); (Hsu & Liu, 2013). Several studies have also suggested that the disturbed region around a PVD comprises two distinct zones: the smeared and the transition zones (Gabr, et al., 1996); (Chai & Miura, 1999); (Indraratna & Redana, 1998); (Sharma & Xiao, 2000); (Sathananthan & Indraratna, 2006); (Ghandeharioon, et al., 2012).

Design method for PVD's has been proposed by (Chai, et al., 2008). In which, equations are derived to calculate the length of the unimproved layer. i.e. It is possible to leave a layer adjacent to the bottom drainage boundary without prefabricated vertical drain (PVD) improvement and achieve approximately the same degree of consolidation as a fully penetrated case. This depth is designated as an optimum PVD installation depth under a surcharge load.

HAARAJOKI TEST EMBANKMENT

The Test embankment constructed at Haarajoki, Finland in 1997 by the Finnish National Road Administration. Several finite element studies have been published in recent years for the Haarajoki embankment (Yildiz, et al., 2009); (Amardeep, 2015); (Rezania, et al., 2017). The geotechnical conditions and the monitoring data of studied case history were previously presented by FinnRA 1997 and Näätänen et al. 1998.

GEOMETRY OF TEST EMBANKMENT

The embankment was founded on soft soil deposits in Haarajoki, Finland. Half of the embankment is constructed on an area improved with prefabricated vertical drains and the other half is constructed on natural deposits without and additional ground improvement as shown in Figure 1. The embankment is 2.9 m high and 100 m long, 8 m wide, and the slope have a gradient of 2:1. The embankment itself was constructed in 0.5 m thick layers and each layer was applied and compacted within 2 days. In the improved area, the vertical drains were installed in a regular pattern with 1 m spacing.

THE SUBSURFACE CONDITIONS

Haarajoki test embankment is founded on a 2 m thick dry crust layer overlying a 20.2 m thick soft clay deposit. The layers below the soft clay consist of silt and till material, based on cone penetration tests, and can be considered as permeable. The groundwater table is at the ground surface. The subsoil is divided into nine sublayers with different compressibility parameters and over consolidation ratios. The water content of the soft clay layers varies between 75 and 112% depending on the depth and is almost the same, or greater than, the liquid limit. The bulk density varies from 14 to 17 kN/m^3 and specific gravity varies from 2.73 to 2.79. The undrained shear strength was determined by fall cone tests and field vane tests to be between 15 and 42 kN/m^2. The soil parameters of the subsoil were estimated by FinnRA 1997. The values of permeability have been reported by Näätänen et al. 1998 based on a vertical and horizontal constant rate of strain. Back analysis has been performed by (Yildiz & Uysal, 2015) to re-estimate the permeability of soft clay to correspond the field monitoring. Table (1) shows the parameters of the physical properties for Haarajoki sub-soil.

At the PVD's zone, the drain adopted at the site had an average width of 98.7 mm with a discharge capacity of 157 m^3 /year and spacing 1m. The equivalent diameter of the drain (D_w), calculated according to the formulation proposed by (Hansbo, 1979) is 67 mm.

In order to acquire quite accurate results considering the smear effect, especially with advanced constitutive models of soft clay, the ratios of (k_h/k_s) and (D_s/D_w) can be estimated 20 and 8, respectively. These values of the ratios (k_h/k_s) and (D_s/D_w) were recommended by (Yildiz, et al., 2009). Where (k_h/k_s) is the hydraulic conductivity ratio, i.e., the value of hydraulic conductivity in the undisturbed zone (k_h) divided by that in the smear zone (k_s). On the other hand, (D_s) is the diameter of the smear zone.

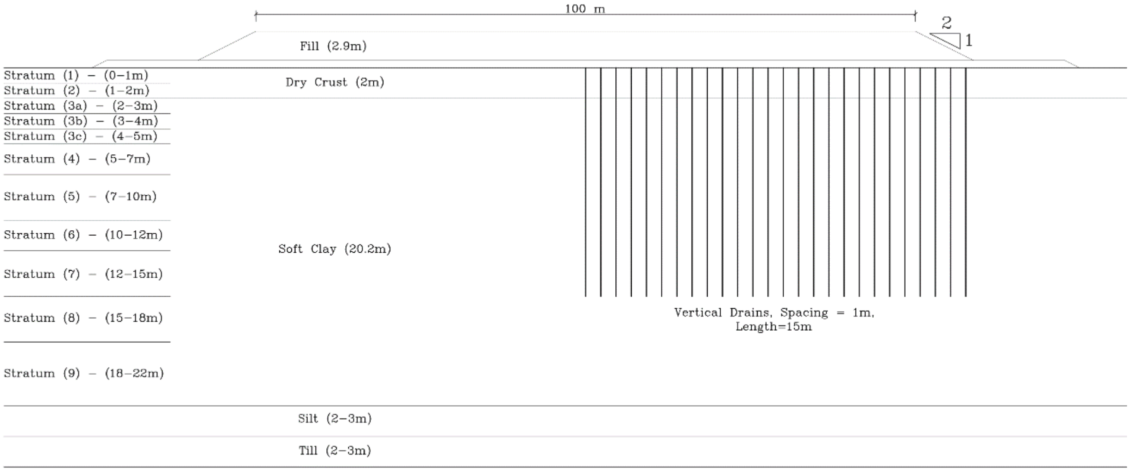

Figure 1: Longitudinal section at Haarajoki Embankment (NTS)

Table 1: Basic soil parameters:

	Depth	*Wn*	*PL*	*LL*	*PI*	γ *(KN/m^3)*	*c'*	*phi '*	e_0	C_k
Stratum 1	*0-1*	*37.5*	*29.6*	*88*	*58.4*	*17.00*	*2.40*	*36.90*	*1.40*	*0.70*
Stratum 2	*1-2*	*48.6*	*28.5*	*88*	*59.5*	*17.00*	*2.10*	*36.90*	*1.40*	*0.70*
Stratum 3a	*2-3*	*80*	*27.3*	*85.5*	*58.2*	*14.00*	*1.71*	*28.80*	*2.90*	*1.45*
Stratum 3b	*3-4*	*103*	*28.9*	*95.6*	*66.7*	*14.00*	*1.53*	*28.80*	*2.90*	*1.45*
Stratum 3c	*4-5*	*103*	*30.5*	*99.5*	*69*	*14.00*	*1.35*	*28.80*	*2.90*	*1.45*
Stratum 4	*5-7*	*104*	*29.7*	*95.8*	*66.1*	*14.00*	*1.40*	*27.70*	*2.60*	*1.30*
Stratum 5	*7-10*	*88*	*28.8*	*91*	*62.2*	*15.00*	*1.87*	*27.00*	*2.60*	*1.30*
Stratum 6	*10-12*	*85*	*30.25*	*80.5*	*50.25*	*15.00*	*2.42*	*27.00*	*2.35*	*1.18*
Stratum 7	*12-15*	*95*	*29.4*	*79*	*49.6*	*15.00*	*2.87*	*28.80*	*2.20*	*1.10*
Stratum 8	*15-18*	*78*	*29.4*	*79*	*49.6*	*16.00*	*3.26*	*36.90*	*2.00*	*1.00*
Stratum 9	*18-22*	*70*	*29.4*	*79*	*49.6*	*17.00*	*3.53*	*36.90*	*1.40*	*0.70*

Table 2: Soft soil creep model parameters:

	λ^*	κ^*	μ^*	*OCR*	K_0	$K_{0\,nc}$	K_v *(m/day)*	K_h *(m/day)*
Stratum 1	*0.050*	*0.0035*	*0.000965*	*22.85*	*5.275*	*0.400*	*1.73E-04*	*3.46E-04*
Stratum 2	*0.088*	*0.0038*	*0.000965*	*6.66*	*1.662*	*0.400*	*1.73E-04*	*3.46E-04*
Stratum 3a	*0.341*	*0.0085*	*0.001340*	*3.56*	*1.393*	*0.518*	*5.18E-05*	*1.04E-04*
Stratum 3b	*0.341*	*0.0085*	*0.001340*	*2.55*	*1.048*	*0.518*	*5.18E-05*	*1.04E-04*
Stratum 3c	*0.341*	*0.0085*	*0.001340*	*1.88*	*0.819*	*0.518*	*5.18E-05*	*1.04E-04*
Stratum 4	*0.267*	*0.0103*	*0.001210*	*1.56*	*0.736*	*0.535*	*4.32E-05*	*8.64E-05*
Stratum 5	*0.181*	*0.0072*	*0.001210*	*1.50*	*0.731*	*0.546*	*4.32E-05*	*8.64E-05*
Stratum 6	*0.346*	*0.0093*	*0.000830*	*1.49*	*0.727*	*0.546*	*4.32E-05*	*8.64E-05*
Stratum 7	*0.331*	*0.0103*	*0.000679*	*1.44*	*0.669*	*0.518*	*4.32E-05*	*8.64E-05*
Stratum 8	*0.150*	*0.0087*	*0.000463*	*1.31*	*0.469*	*0.400*	*4.32E-05*	*8.64E-05*
Stratum 9	*0.042*	*0.0038*	*0.000618*	*1.11*	*0.424*	*0.400*	*1.73E-04*	*3.46E-04*

NUMERICAL MODEL DESCRIPTION

A geotechnical software based on 2D finite element model in which soft soil formation has been simulated using soft soil creep model (SSCM). A finite element mesh with 15-noded triangular elements is used for the analysis. The geometry of the finite element model is shown in Figure 2. The right boundary is assumed at 80m distance from the centerline. The bottom boundary is assumed to be fixed in both horizontal and vertical directions. The left and right vertical boundaries are only restricted horizontally. Drainage is allowed at the ground level, while the boundary at the bottom is considered impermeable. Impermeable drainage boundaries are also assigned to the lateral boundaries. Based on ground data, the water table is assumed to be at the ground surface. For the side of the embankment that was built on improved soil, PVDs are represented in the model using the drain element in PLAXIS. Groundwater head is assumed to be at ground level for all drains. In order to model PVDs a matching technique proposed by (Hird, et al., 1992), an approach developed by (Indraratna & Redana, 1997) and a simple approximate approach developed by (Chai & Miura, 2001) has been applied.

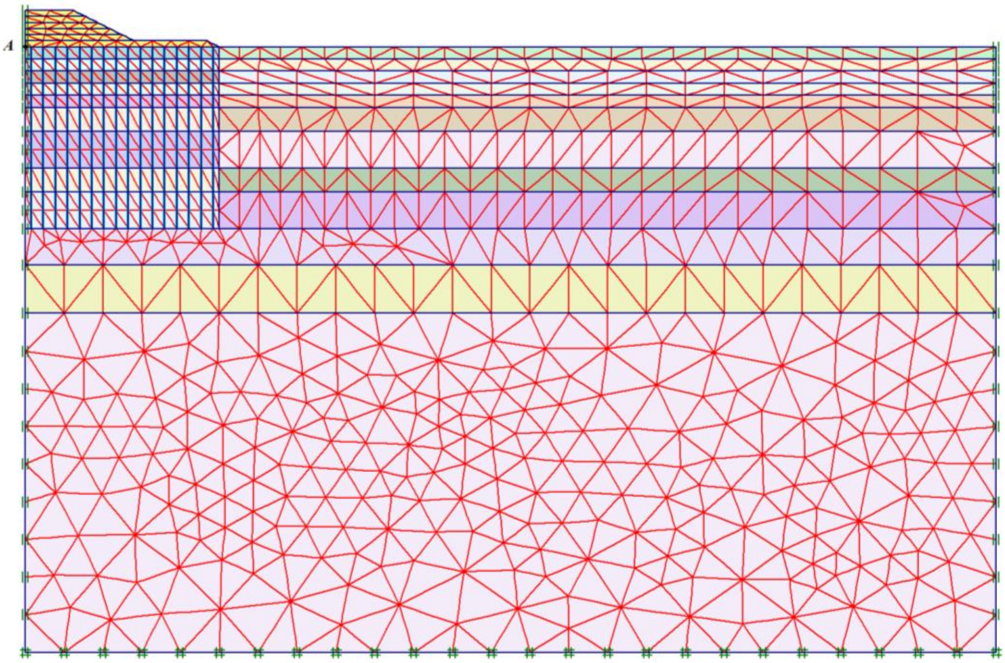

Figure 2: Finite element mesh set with boundary conditions

NUMERICAL MODEL VERIDICATION

Figure 3 represents the time – settlement relationship calculated at point A (center of the embankment) using (Hird, et al., 1992), (Indraratna & Redana, 1997) and (Chai & Miura, 2001) approaches. These results have been compared with the field monitored data at the center of the embankment. The comparison shows that the results achieved from (Hird, et al., 1992) and (Indraratna & Redana, 1997) approaches are quite identical and pretty close to field monitored data. While, (Chai & Miura, 2001) approach slightly overestimates the settlement along the time.

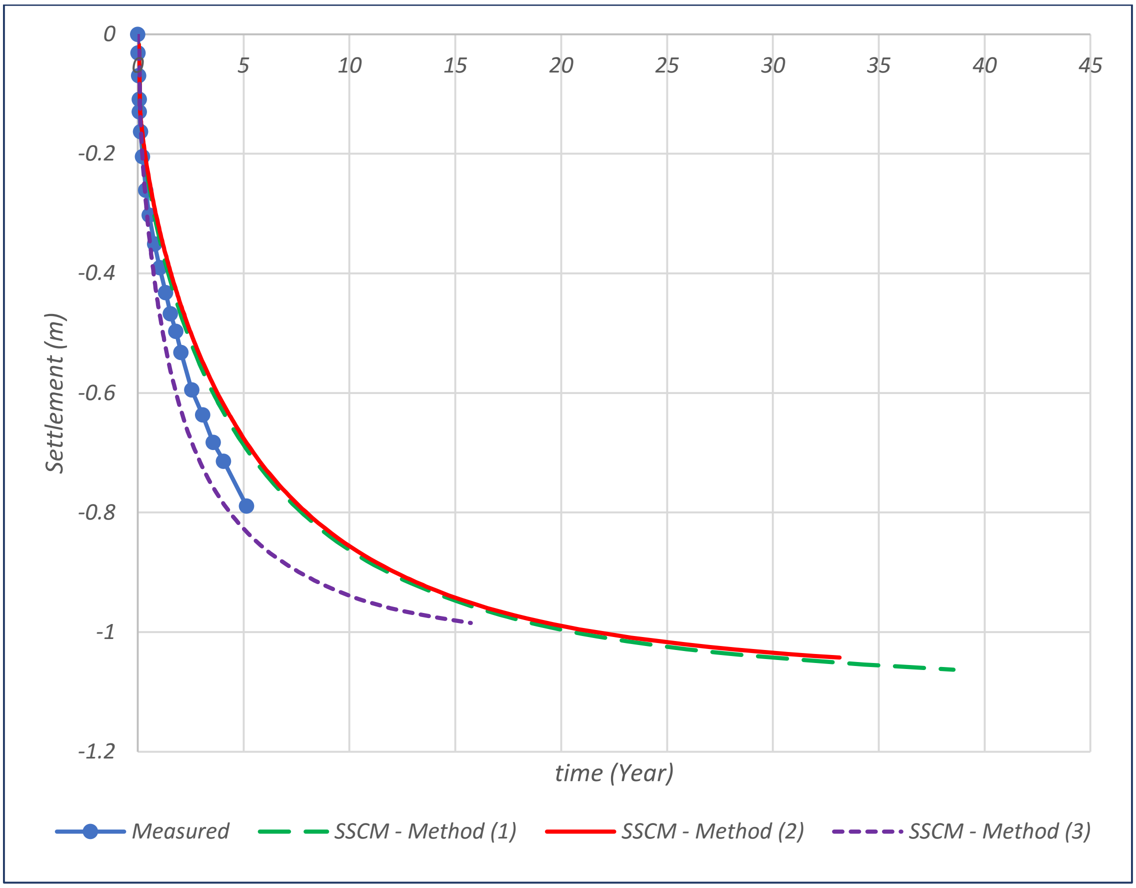

Figure 3: Time – settlement curve at the center of the improved embankment using SSCM

UTILIZING THE NUMERICAL ANALYSIS TO DETERMINE OPTIMUM LENGTH OF PVD'S

Analysis has been performed to investigate the optimum length of PVDs at the Haarajoki embankment. The spacing of PVDs has been assumed to be 1m and 2m. Construction rate is used as similar to the used in the Harajooki case study. Finite element model has been used to simulate the PVD's with various lengths from 5m to 22m with embankment height 3m. Figure 4 and Figure 5 shows a comparison between time-settlement curves of different PVD's length with spacing 1m and 2m, respectively.

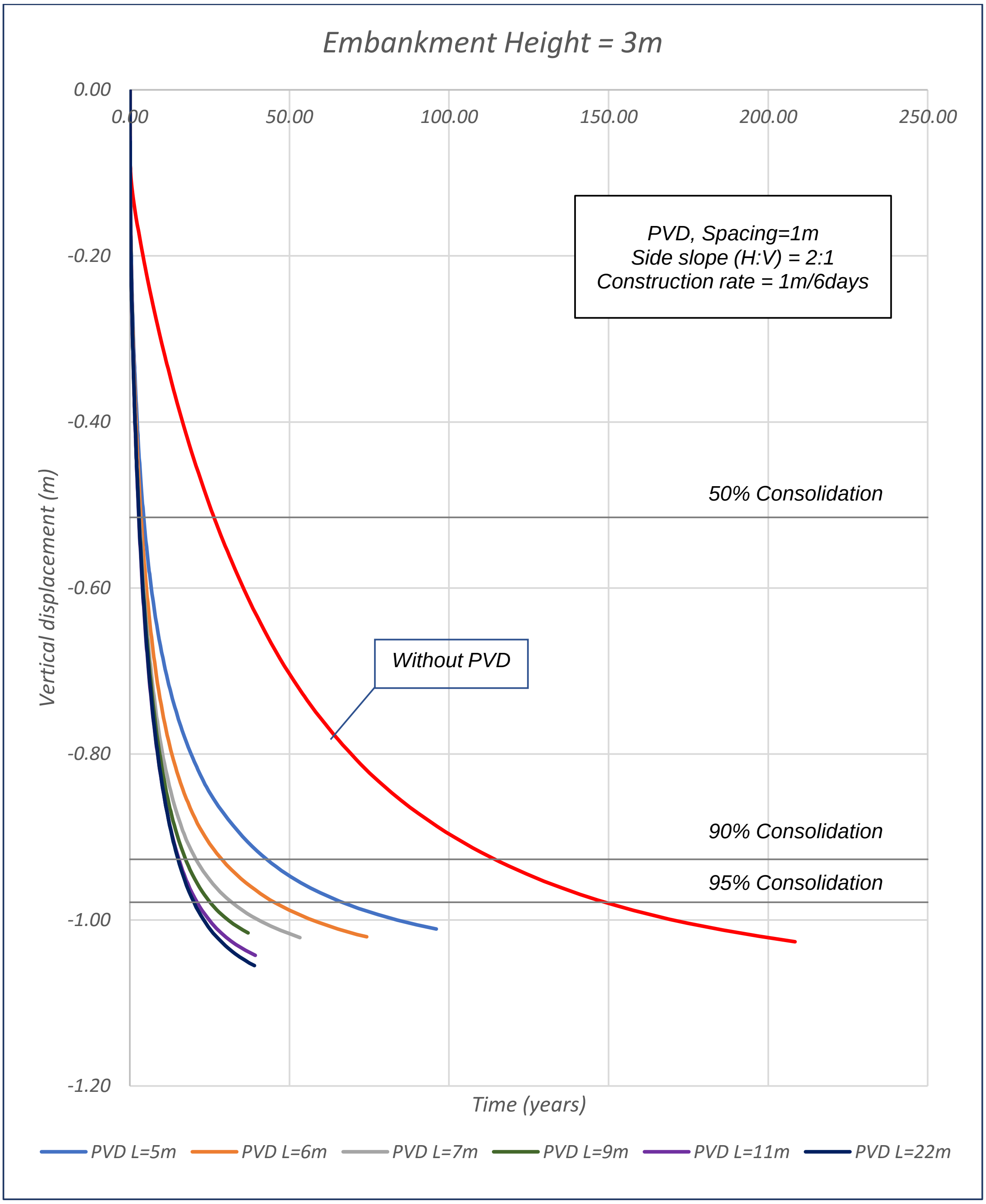

Figure 4: Time – settlement curve at the center of the improved embankment with different PVD's length with spacing 1m.

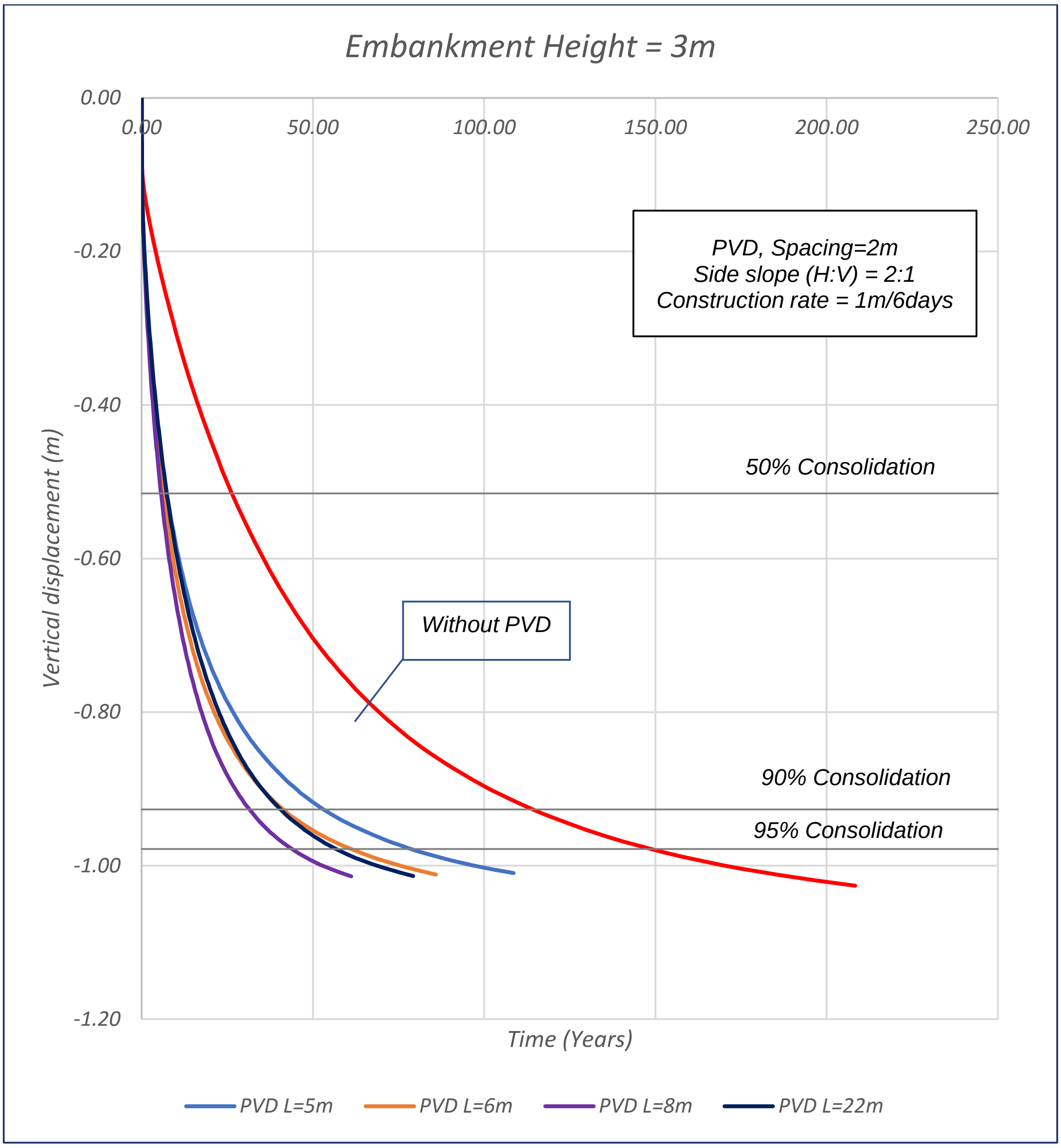

Figure 5: Time – settlement curve at the center of the improved embankment with different PVD's length with spacing 2m.

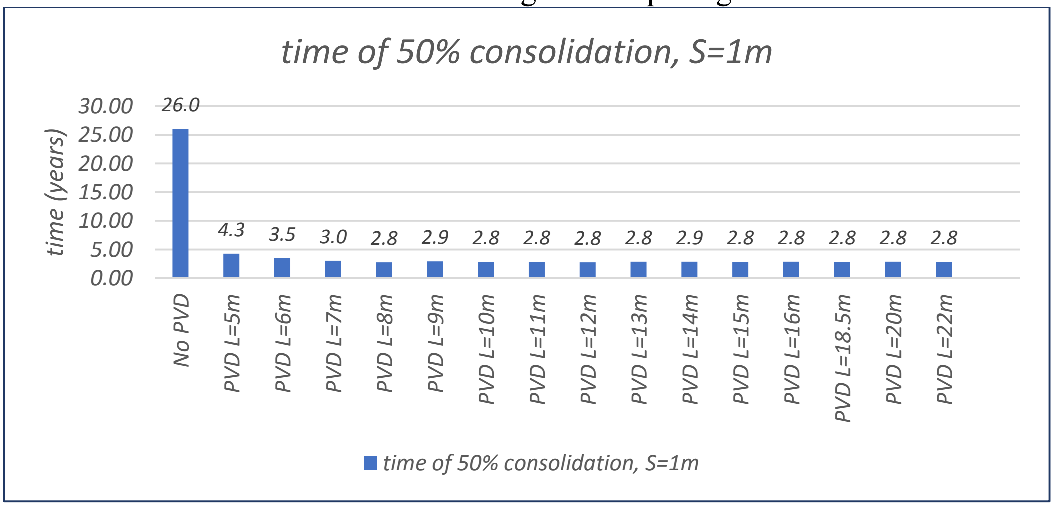

Figure 6: Time of 50% consolidation with respect to PVD's length with spacing 1m

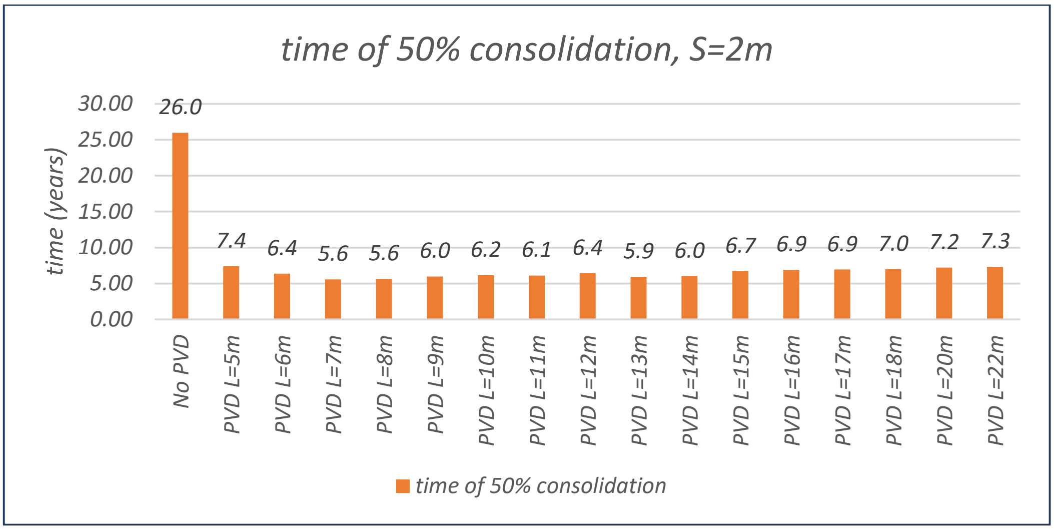

Figure 7: Time of 50% consolidation with respect to PVD's length with spacing 2m

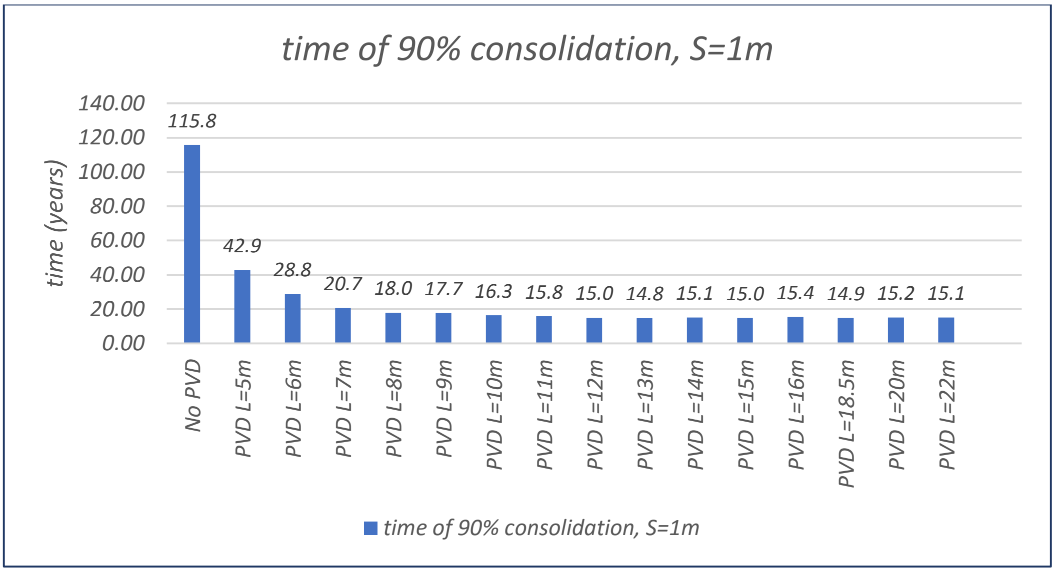

Figure 8: Time of 90% consolidation with respect to PVD's length with spacing 1m

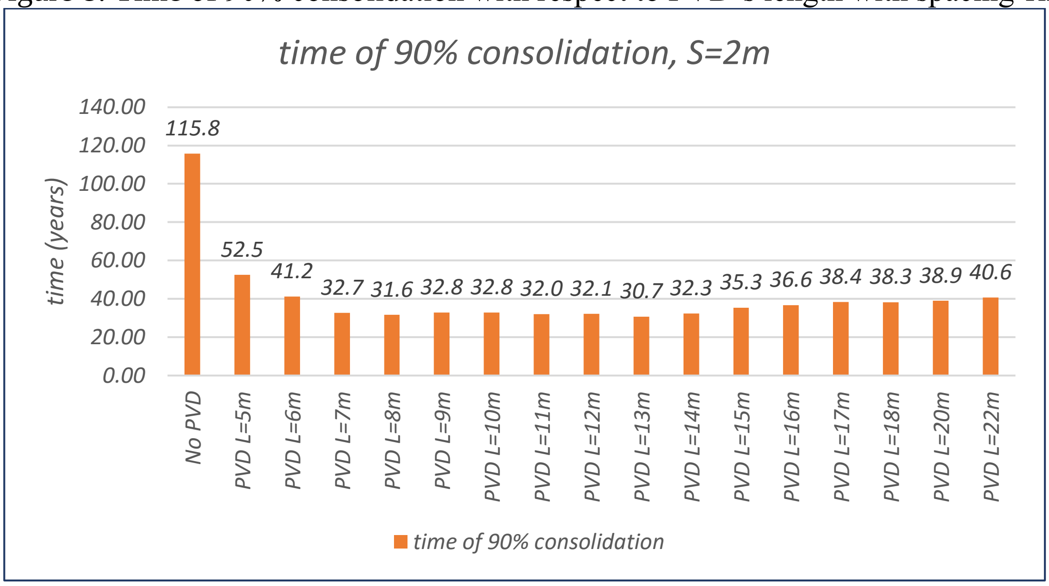

Figure 9: Time of 90% consolidation with respect to PVD's length with spacing 2m

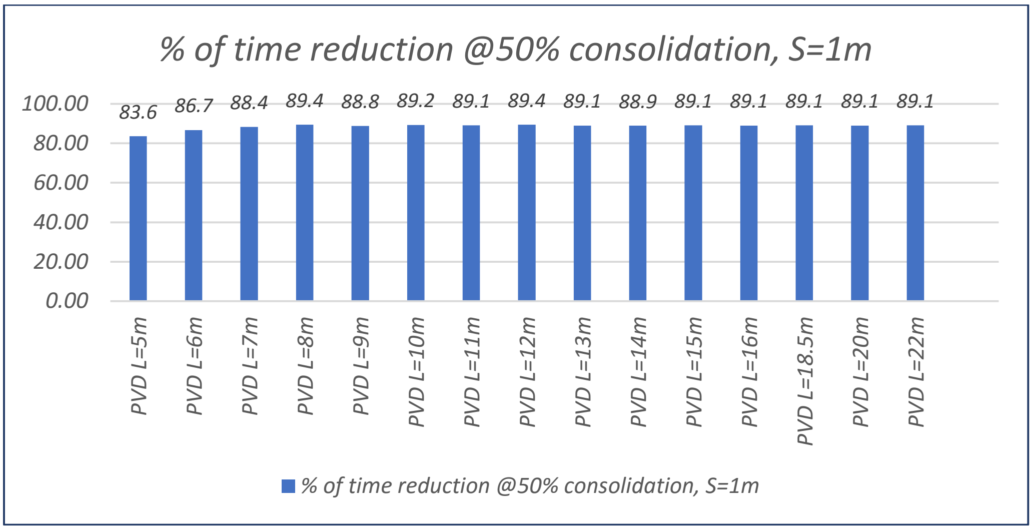

Figure 10: Percent of time reduction at 50% consolidation with respect to PVD’s length with spacing 1m

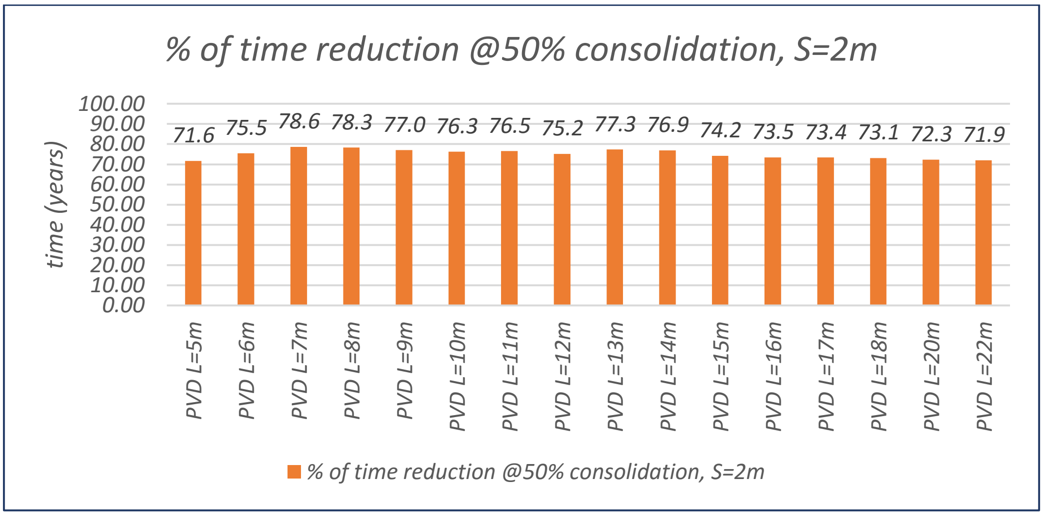

Figure 11: Percent of time reduction at 50% consolidation with respect to PVD’s length with spacing 2m

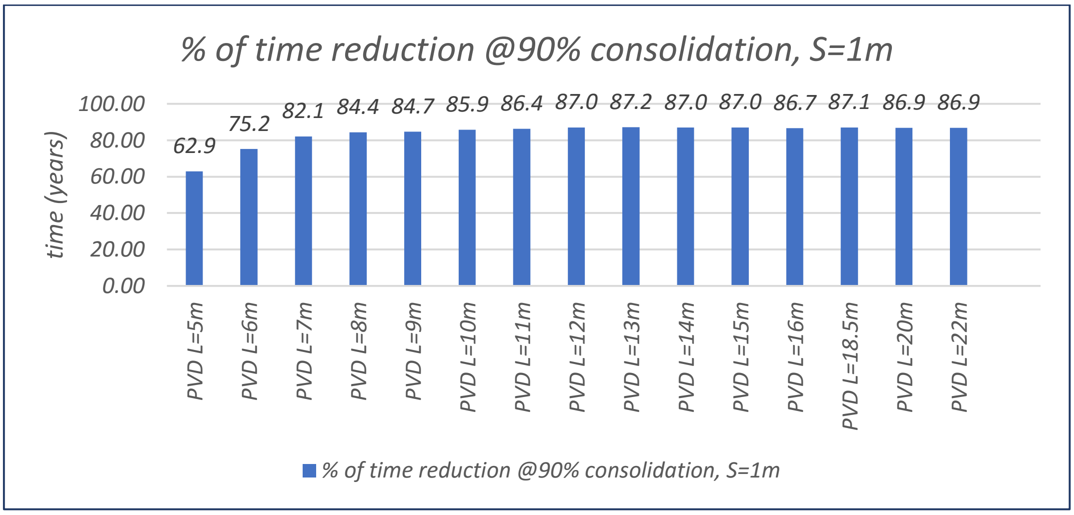

Figure 12: Percent of time reduction at 90% consolidation with respect to PVD’s length with spacing 1m

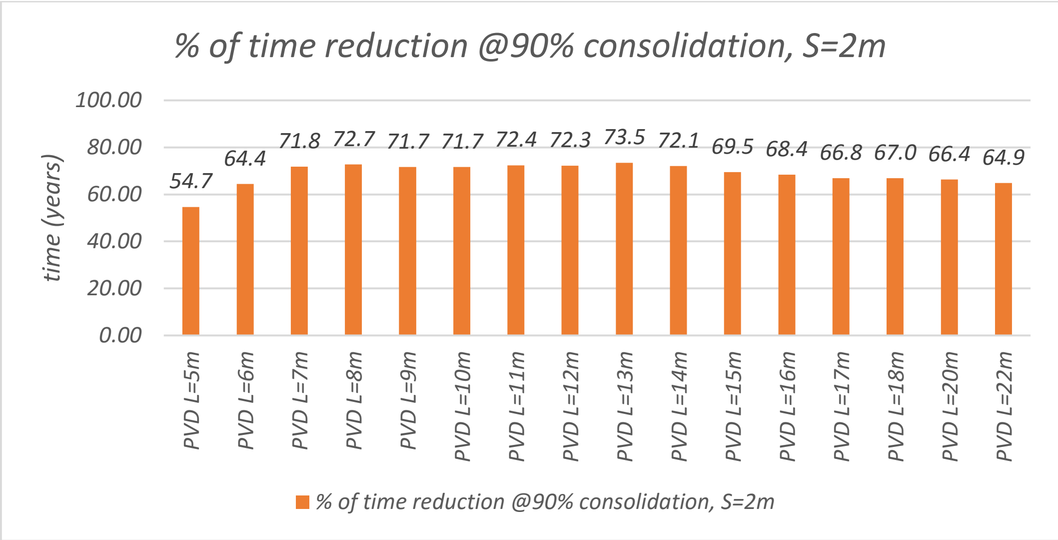

Figure 13: Percent of time reduction at 90% consolidation with respect to PVD's length with spacing 2m

The analysis shows that the time taken to reach 50% consolidation using spacing 1m is less than the un-improved clay by about 85% and no significant difference in time reduction for different PVD's length as shown in Figure 10. Also, Figure 12 shows that the PVD's with spacing 1m has no significant effect by increasing its length more than 11 meters. However, Figure 11 shows that the time taken to reach 50% consolidation using spacing 2m is less than the un-improved clay by about 75% and no significant difference in time reduction for different PVD's length. Also, the PVD's with spacing 2m has no significant effect by increasing its length more than 8 meters as shown in Figure 13.

CONCLUSIONS

The results of (Hird, et al., 1992), (Indraratna & Redana, 1997) and (Chai & Miura, 2001) approaches to model the PVD's are not identical to the field monitored data but still good approaches to model the PVDs.

The study shows that PVDs with proper spacing and length have a huge effect on reducing consolidation time. On the other hand, Using PVDs may be more efficient at clay thicknesses less than that in the case study. The time reduction to reach 90% consolidation using PVD length 11m and spacing 1m is 86.4%, which is a huge value, but still, the time taken to reach 90% consolidation is about 37 year which is not a great achievement.

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