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EFFECT OF PREFABRICATED VERTICAL DRAINS ON THE CONSOLIDATION TIME OF SOFT CLAY

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الملخص العربى:

يتناول هذا البحث دراسة زمن تصلب التربة الطينية اللينة أسفل جسور الطرق باستخدام المصارف الرأسية، كما هو معروف فإن التربة الطينية اللينة تتميز بانضغاطها العالي ومقاومتها المنخفضة للقص. ومن ثم أوضح هذا البحث أولا تحسين التربة الطينية اللينة باستخدام المصارف الرأسية كنوع من الحلول لتحسين التربة الطينه اللينه وذلك باستخدام تحليل ثلاثي الأبعاد باستخدام برنامج PLAXIS 3D، ثانيا، أظهرت هذه الدراسة أن المصارف الرأسية سابقة التجهيز هى الحل الأفضل لتقليل زمن تصلب التربة الطينية اللينة مقارنة بالمصارف الرملية والزلطية. وأخيرا، في هذا البحث، توجد دراسة لأفضل مسافات بينية وأفضل طول للمصارف الرأسية سابقة التجهيز لتقليل زمن تصلب التربة الطينية اللينة.

Abstract.

This paper represents a case study for time of consolidation of soft clay soil under highway embankments using vertical drains. As it known that the soft clay soil is characterized by its high compressibility, low shear strength. Hence, in this research firstly we explained the usage of vertical drains as a kind of solution to improve the soft clay by using three-dimensional finite element analysis (PLAXIS 3D). Secondly, this study showed that prefabricated vertical drain is the best solution to decrease the time of consolidation compared to sand drains and stone column. And finally in this paper, there is a study of the best spacing and length of prefabricated vertical drain to decrease the time of consolidation of soft clay soil.

Keywords.

Soft clay, soil improvement, sand drains, prefabricated vertical drain, Stone column, PLAXIS 3D finite element, consolidation time and settlement.

Introduction.

As long as Soft soils nowadays are usually beside a coastal areas and most river estuaries all over the world and most structures built on these deposits are incompatible with such weak foundation soil conditions. In Egypt's coastal areas; specially Port Said governorate, soft clay is widespread. These soils are characterized by low shear strength and bearing capacity as well as excessive settlements, high compressibility and over long time. When selecting these areas for development work, it is important to stabilize the existing soft clay foundations prior to construction in order to avoid unacceptable differential settlement due to compressibility.

To enhance soft soil, there are three main types of vertical drains, first of all, the cylindrical columns of sand constructed using conventional piling equipment (Gaafer et al., 2015). Sometimes, the sand was contained within a geotextile sock. The second type of drains is prefabricated vertical drain consisting of a plastic core with holes surrounded by a geotextile jacket (Indraratna et al., 2007). The jacket behaves as a filter to stop clogging and allow pore water to enter to the drain. It is made of polypropylene geotextile or non-woven polyester (Sathananthan, 2005). Figure (1) Shows the usage of PVD in the construction of embankments for roads.

The Third type of drains is stone column as a ground enhancement technique is of recent origin, the method is generally used in a clayey soil (Hirkane et al., 2014).

To begin with vertical drains, it appeared in 1920 by Daniel.J.Moran who used the first application of sand drains in order to improve the soft soil below the road way to San Francisco Oakland Bay Bridge (Sathananthan, 2005).

In addition, In Japan, during 1940, vertical sand drains behavior was inapprehensible because the foundation bearing capacity was considered appropriate for full load after installation which resulted in multiple foundation failure (Aboshi, 1992). Furthermore, after second world war the enhancement of soft soil has been developed because of greater control of drains performance in various types of soft soil and better installation methods (Jamiolkowski et al., 1983). On the other hand, Prefabricated drain system first installed in the field in 1937 by Walter Kjellman who used pipes made from wood and fiber but this system unfortunately was ineffective and costly. Later on in 1939, Kejllman fabricated a cardboard drain with a cross-section 100 mm wide and 3 mm thickness, after that, Prefabricated drains were developed and a lot of different types were appeared (Bergado et al., 1996). The stone column maneuver was adopted particularly in European countries early in the sixties and became by time more and more successfully practiced. the stone columns is mainly a “hole“, vertical cylindrical drilled in a soft soil layer and filled with consolidated stone pieces and gravel having high potential drainage. This maneuver can be used to develop soft layers under dams and embankments as a trial to increase the bearing capacity, minimize settlements, and to accelerate the consolidation process such as vertical drains (Bouassida and Hazzer, 2008). Stone columns may have specific use in soft soils such as N.C clay, mud and peat, they are usually inserted on volume displacement basis excavating a hole with specified diameter and chosen depth. (Mokhtari et al., 2012).

As a dealing with slow installation and high cost of sand drains, engineers shifted to another solution, which is prefabricated vertical drain (PVD). Since the first PVD type used by Kjellman in 1939 (Bergado et al., 1996), many types of PVD has increase in a rapid manner.

Nowadays the filter jacket is made from geotextile which provides high tensile strength. PVD has a width to thickness ratio of 30-35.

The commonest PVD dimensions are 4 mm × 100 mm (Indraratna et al., 2007).

Finally, some pros of PVD versus sand drains are (Hirkane et al., 2014) and (Gaafer et al., 2015):

Rapid, easy installation possible.
Made of uniform material, easily handheld, stored and transported.
instruments needed is lighter than the rigs used for equivalent sand drains.
Financially low compared to traditional sand drains.
Higher resistance to lateral displacement.
There is greater guarantee of a continuous water path.
The main aim of these present study is to compare between sand drains, stone columns and prefabricated vertical drain (PVD) for decreasing time of consolidation and to study effect of spacing and length of prefabricated vertical drains (PVD).

Fig. (1) Using of PVD in the construction of embankments for roads.

Finite Element Modelling

The analysis was performed using the three-dimensional finite element code, PLAXIS 3D 2021. The results were verified by Hammad Mahmoud, (2020). Plaxis 3D was used to verify this model, Figure (2) Shows Soil profile and surcharge loads adopted in the analyses. Results of settlement with time calculated from the numerical modeling are compared to the corresponding measured data from the Field respectively as illustrated in Figure (3). The figure shows that the results are in good agreement.

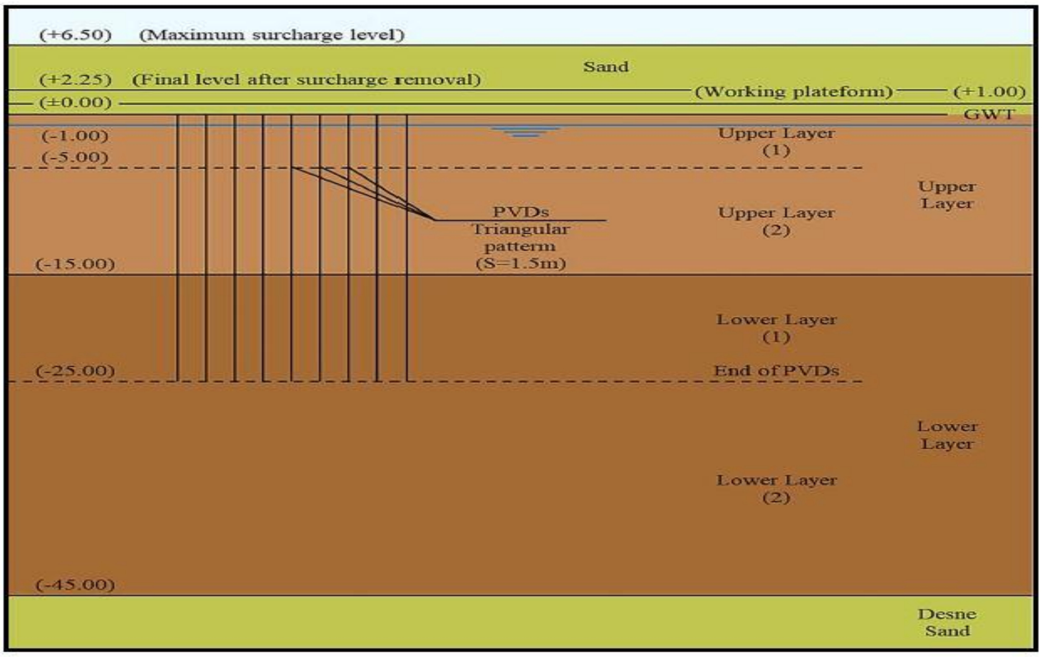

Fig. (2) Soil profile and surcharge loads adopted in the analyses.

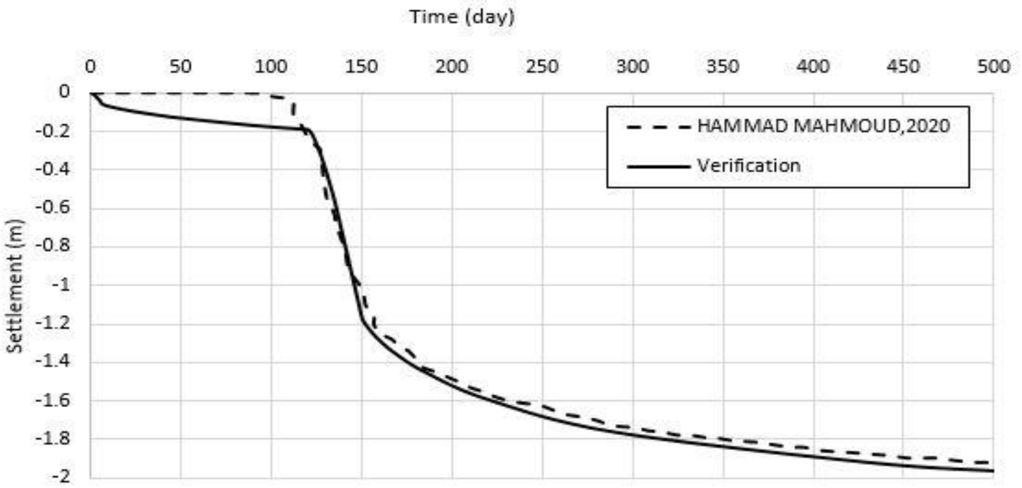

Fig. (3) The relationship between settlement and time for Hammad Mahmoud, 2020 and verification

Results and Discussion :

The Soft soil creep (SSC) model was chosen because it is considered as one of the most commonly models for formulating vertical drains in soft clay. SSCM takes the effect of the consolidation and the creep together, which gives more accurate results.

The analysis had been carried out to study the following:

The comparison of prefabricated vertical drains, sand drains and stone columns to decrease the time of consolidation.

The effect of spacing between prefabricated vertical drains.

The effect of length for prefabricated vertical drains.

3-1 Soil Model.

Parameters of the soft clay layer below the embankment used in this research were indicated in site investigation report project No. 21/03 by A&A Consultant (2014) which present the nature of the soft clay layer founded in Port Said governorate, Egypt. The soil properties and the finite element parameters are given in Table 1. An embankment with 4m height and 40 m base width was used in this study where only half of the embankment was modeled in the finite element mesh as shown in figure (4). A soft clay soil depth of 40 m was used in this study because the stresses in this case is almost ineffective below this depth. The lateral boundary is 100 m away from the centerline of the embankment.

Table 1: Soil Material Parameters in PLAXIS 3D Modeling Analysis

Parameter	Name and Unit	Sand	Clay	Sand Drains	Stone Column
Material Model	Model	MC	SSCM	MC	MC
Thickness	H (m)	1	40	-	-
Unit weight	γ (kN/m^3)	17	15	18	19
Initial void ratio	e_o	0.5	1.2	0.5	0.5
Stiffness	E_{ref} (MPa)	20	-	20	55
Modified compression index	λ^*	-	0.138	-	-
Modified swelling index	k^*	-	0.012	-	-
Modified creep index	μ^*	-	0.0004	-	-
Cohesion	c' (KN/m^2)	0.0	1.0	0.0	0.0
Friction angle	φ' (◦)	29.0	26.0	30.0	43.0
Horizontal permeability	$k_{x,y}$ (m/day)	1	1.72E-4	1	12
Vertical permeability	k_z (m/day)	0.5	0.86E-4	0.5	6

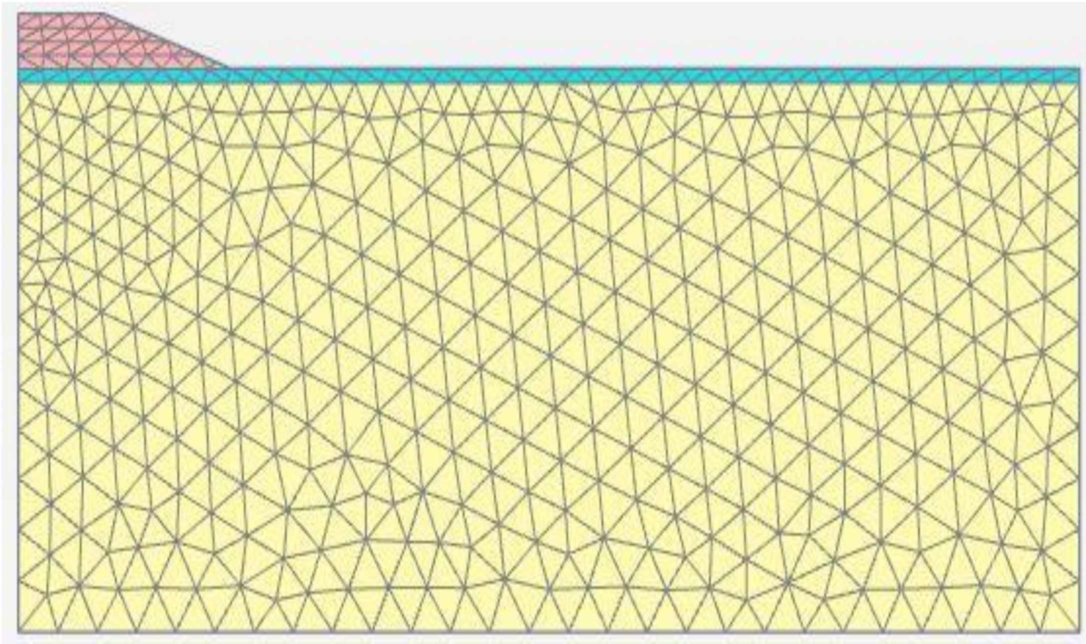

Fig. (4) Finite element mesh for the analysis of embankment

3-2 Comparison between Sand Drains, Stone Columns and Prefabricated Vertical Drain.

Sand drains, stone columns and prefabricated vertical drains (PVD) are used to decrease time of consolidation and improvement of soft clay. In this study, comparison between three techniques is carried out to investigate the best method for decreasing time of consolidation for soft clay.

The group of both of stone columns and sand drains is arranged at spacing 4D = 2.00 m and L= 21.0 m, where D is the diameter of column stone and sand drains = 0.50 m for where L is the length of stone columns and sand drains = 21 m. The spacing between PVD and length are 2.00 m and 21.0 m respectively. Figure (5-a) shows the Comparison between settlement and time of settlement for soft clay with and without reinforcement by using PVD, stone columns and sand drains, to more clarify, figure (5-b) shows the Comparison between settlement and time of settlement for soft clay PVD, stone columns and sand drains at time of 90% consolidation.

From these figures, it can be observed that, the time of consolidation at 90 % consolidation is 26 years, 466 days, 730 days and 1050 days for soft clay without drains compared to PVD, sand drains and stone columns respectively. Decreasing of consolidation time for soft clay using PVD is the best when it is compared with the soft clay reinforced by stone columns and sand drains. Also, the PVD is the best with respect to time of construction compared to stone columns and sand Drains.

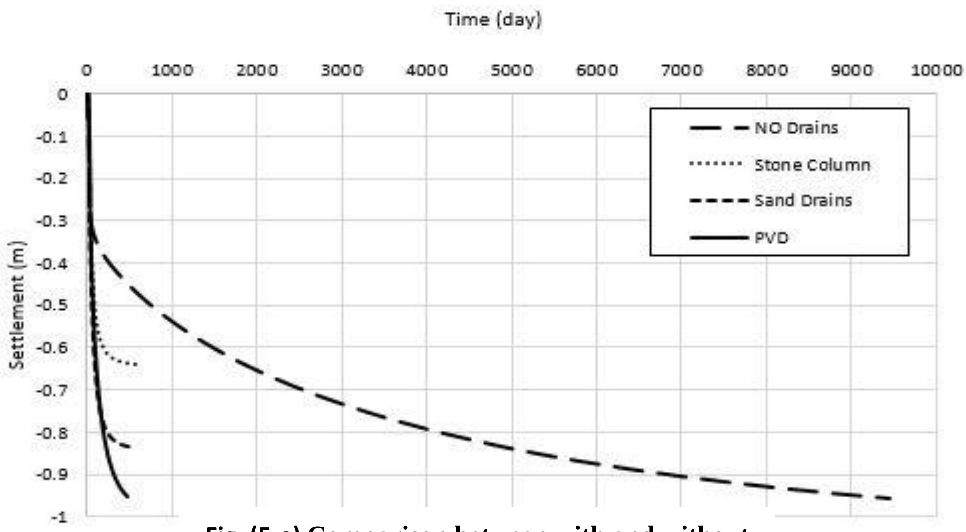

Fig. (5-a) Comparison between with and without drains at time of 90% consolidation

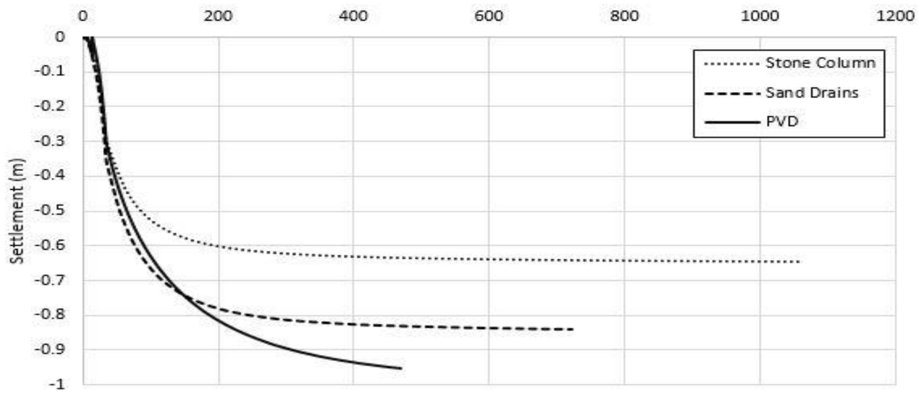

Fig. (5-b) Comparison between PVD, sand drains and stone columns at time of 90% consolidation

3-3 Effect of length and spacing of prefabricated vertical drain.

In order to investigate the effect of length of PVD on decreasing time of settlement of soft clay, length of 11.0 m, 16.0 m, 21.0 m, and 26.0 m is applied with spacing of 1.0m, 1.50 m, 2.0 m. The analysis has been carried out and time of settlement of soft clay under embankment is obtained. Figures (6,8,9,10) show the relationship between the length of PVD and time of settlement for soft clay. The time of settlement at 90% consolidation is decreasing with increasing length of PVD up to 21 m after that, there is no much variation in time of settlement with increasing the length of PVD for all spacing that length more than 21.0 m. It is also observed that the length of 21.0 m, which is almost half of clay layer, is the best length of PVD for decreasing time of settlement for soft clay under embankment.

In order to investigate the effect of spacing between PVD on decreasing time of settlement of soft clay, spacing 1.0 m, 1.50 m, 2.0 m, 2.50 m, 3.0 m and 4.0 m is applied at length 21.0 m. The analysis has been carried out and the time of settlement of soft clay under embankment is obtained. Figures (7 &11) show the relationship between the spacing between PVD and time of settlement for soft clay. The time of settlement at 90% consolidation is increasing with the decreasing the spacing between PVD. It is observed that there is no much variation in decreasing time of settlement with decreasing the spacing between PVD for all spacing that less than 1.50m. the spacing between PVD 1.50 is the best spacing between PVD to decrease time of settlement for soft clay under embankment.

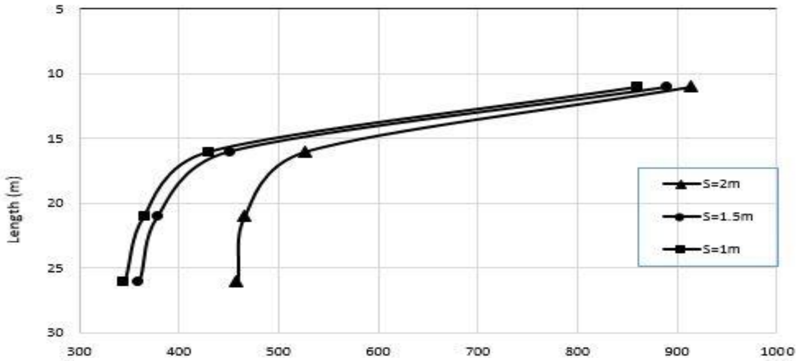

Fig. (6) Relationship between length of PVD and time of settlement for spacing 1.0 m, 1.50 m and 2.0 m

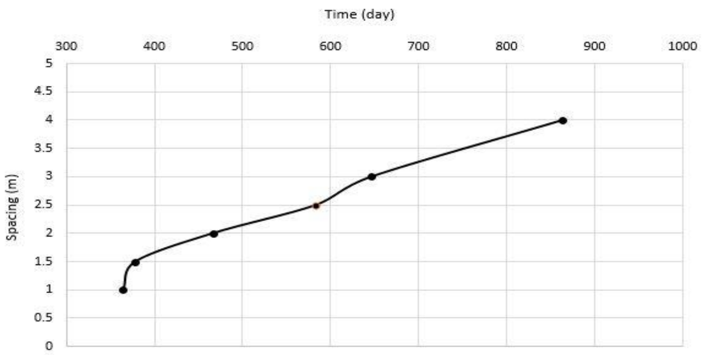

Fig. (7) Relationship between spacing of PVD and time of settlement for length 21.0 m

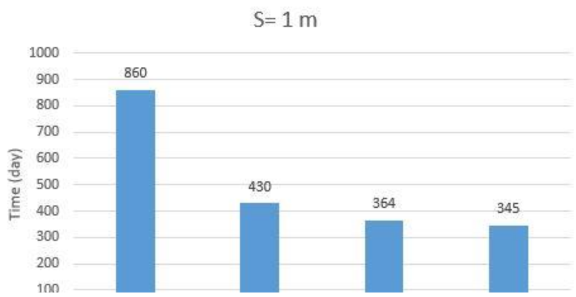

Fig. (8) Relationship between length of PVD and time of settlement for spacing 1.0 m at 90 % consolidation

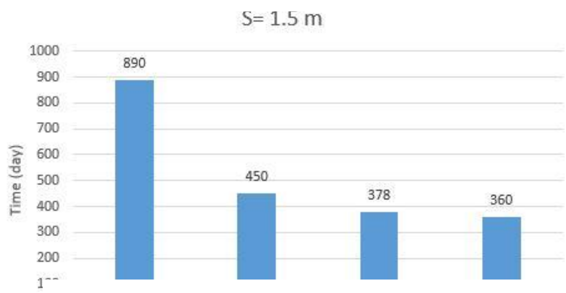

Fig. (9) Relationship between length of PVD and time of settlement for spacing 1.5 m at 90 % consolidation

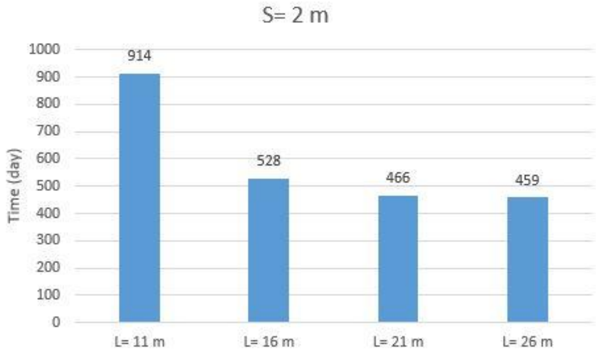

Fig. (10) Relationship between length of PVD and time of settlement for spacing 2.0 m at 90 % consolidation

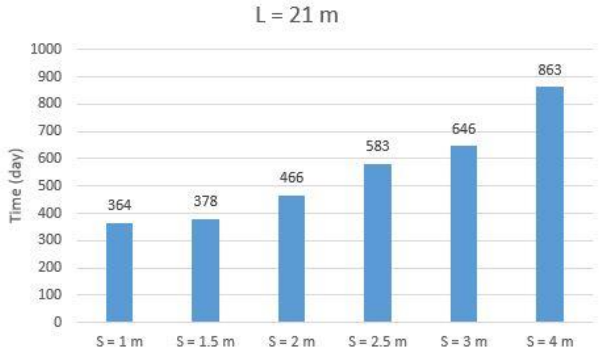

Fig. (11) Relationship between spacing of PVD and time of settlement for length 21.0 m at 90 % consolidation

Conclusions.

In this paper, three-dimensional finite element analysis using PLAXIS 3D was carried out, to compare between the effect of sand drains, stone columns and prefabricated vertical drains (PVD) on the time of consolidation for soft clay under embankment. Effect of Spacing and length of prefabricated vertical drain (PVD) is presented. From this study, the following conclusions are obtained:

The prefabricated vertical drains show the best results to decrease time required for consolidation, compared with that for stone columns and sand drains.

The time of construction for prefabricated vertical drains is much less than that required for stone columns and sand drains.

There is no much variation in time of settlement with increasing the length of prefabricated vertical drains more than 21.0 m, and the length of 21.0 m, which is almost half of clay layer, is the best length of prefabricated vertical drains for decreasing time of settlement for soft clay under embankment.

There is no much variation in decreasing time of settlement with decreasing the spacing between PVD less than 1.50m, and the spacing between prefabricated vertical drains 1.50 m is the best spacing for decreasing time of settlement for soft clay under embankment.

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