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Performance of Pile Supported Embankments over Soft Clay

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ABSTRACT

Piled-embankment system is a ground improvement technique that can provide a solution for supporting the embankment over soft clay deposit. The main aim of this paper is to study the behavior of piled-embankment system over soft clay layer. A series of full-scale numerical modeling for the problem under investigation are studied using elasto-plastic Finite Element Modelling (FEM) program (2D PLAXIS V. 8.6). The studied parameters include the height of the soft clay (H), shear strength of the soft clay soil below the embankment (cu), relative length of piles (L/H), relative pile's spacing (S/D), pile's diameter (D) and the relative thickness of embankment (h/H). Each series was performed to study the effect of one parameter while other parameters were kept constant. The results showed that, using piled-embankment system on a soft clay deposit has a significant effect in reducing the settlement with time. It has been found that, the settlement of the embankment on a soft clay layer is reduced by as much as 77% of its initial value in the case of embankment without piles.

Keywords: Piled-embankments, improvement, soft clay

INTRODUCTION

It is becoming increasingly necessary to construct on land that was previously considered inappropriate for construction, such as soft clay. The properties of soft clay make it highly compressible and low in shear strength, meaning that excessive settlement is of concern. Piled-embankment is a ground improvement technique that can provide a solution for this problem. Piled-embankments have the ability to transfer the greater part of the embankment load and any surcharge to more competent material to a greater depth due to the arching concept. Consequently, the soft foundation soil has little direct impact on the performance of the embankment. The concept of granular soil arching over an area where there is partial loss of support from underlying strata has long been recognized in the study of soil mechanics. Differential settlement can be a problem for piled-embankments. Significant differential settlement can cause undesirable effects on any structures constructed on the embankment. Arching limits the amount of differential settlement of the embankments. The aim of this research is to examine the effects of different parameters on the load transfer and settlements of the embankment as hown in Figure (1).

Han and Gabr (2002), conducted early laboratory experiments, from which they came up with the 'trapdoor' theory. Sand was placed above a platform that contained a narrow strip on trap door. As stated by Han and Gabr (2002), Terzaghi showed that when the trapdoor was lowered slightly, the pressure on it reduced significantly whereas the pressure on the adjacent parts of the platform increased by the same amount. They also conducted a numerical study on reinforced piled-embankments using a finite difference program package (FLAC). In their study, they employed a 'unit cell' for a square pile cap arrangement that is assumed to be similar to a circle, and analytically modeled using axisymmetric. Springs were used to model the pile cap

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and the subsoil vertical response. From this study, they showed that the embankment's ability to arch increases as height increases. Hong and Naeim (2011) studied the reinforced piled-embankments and investigated numerically the efficiency of the embankment. In their study, they showed that the shear strength of the embankment fills slightly increased the efficiency of the embankment. In their study, they found that the ratio of the pile-subsoil stiffness increased the embankment efficiency. A punching model to define the mechanism of load transfer from punching shear based on a series of model tests for piled- embankments was presented and discussed.

Fig. 1: Construction of Piled-Embankment on Soft Clay, (Cao et Al. 2006)

Goals and objectives:

Piled-embankments on soft soils have been studied by many investigators (Cao et al, 2006; Han and Gabr, 2002; Poulos et al, 1998). However, various aspects of the behavior of the piled-embankments are not yet completely understood, and there is little consensus on identifying the Settlement-time relationship with using such piled-embankment technique. This research aims to investigate principles behind the load transfer process in piled-embankments and how they can be used effectively to reduce the embankment settlement.
In this paper, the variation of Settlement-time relationship of embankments over soft clay layer with and without piles was studied and explained. Keeping in view of this aspect, there is need to study diversity parametric effect on the Settlement-time relationship of embankment with and without piles using finite element software package (PLAXIS 2D).

NUMERICAL MODEL

Numerical modelling of piles supported embankments over soft clay was carried out to study the geotechnical behavior of piled-embankment system. The plane strain model as shown in Figure (2) was used with 15 node elements. A fine mesh was generated by the program.
The Mohr-Coulomb soil model was used for simulation of soft clay soil behavior. In this study, the Mohr-Coulomb model was considered to model elasto-plastic behavior of sand soil. It involves five input parameters which are Young's modulus (Es); Poisson's ratio (υ) for soil elasticity; Shear parameters, the undrained shear strength (c_u) for soft clay and angle of friction (Φ) for sand and the angle of dilatancy (Ψ). Since we considered sand soil in this study in the drained case, soil cohesion was set to ($1*10^{-3}$ kPa) to avoid errors in the numerical analysis. The soft clay soils studied in different series are named (E, F and G) in this research based on different values of the undrained shear strength (c_u). Table (1) shows the different properties of soils (E, F and G). The calculation steps for this study are the consolidation with interval time.

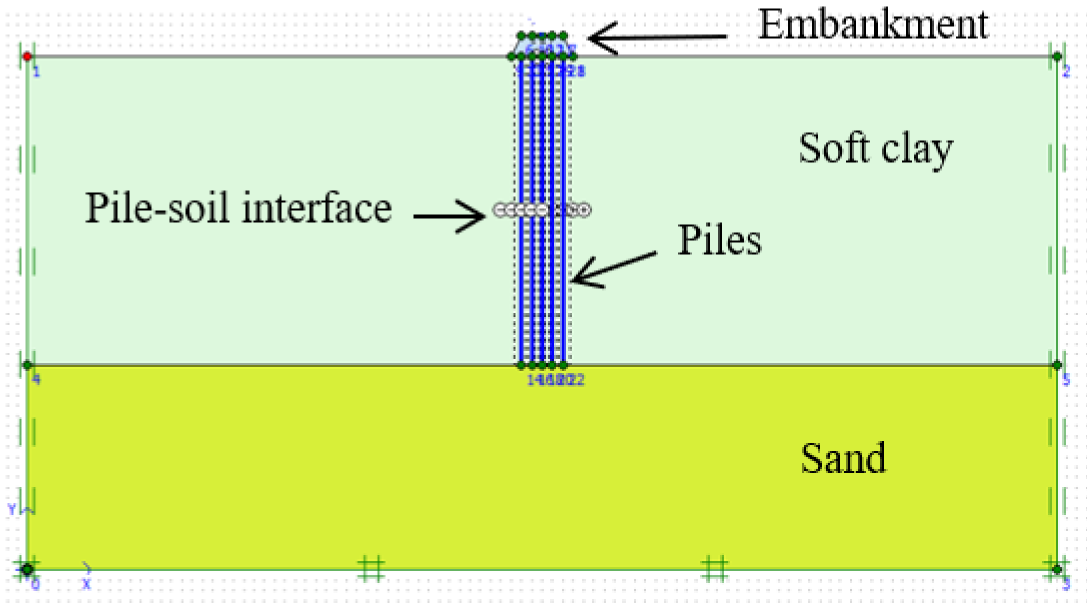

Fig. 2: The Geometry of 2D PLAXIS Model

The secant modulus of 50% strength (E50) using the empirical formula of Poulus (1998) to calculate stiffness parameters of the clay soil. The soil stiffness parameter presented is a function of the undrained shear strength (c_u) of the clay soil as shown in Table (1).

A nonlinear analysis was assumed, so that (E50) represents a secant modulus for low load levels.

$$E_S = 200 * c_u \dots\dots\dots\dots (1)$$

Table 1: Estimated (Mohr-Coulomb) model parameters of soft clay soil

Soil Code in different series	Undrained shear strength, c_u (kPa)	Angle of Friction, Φ (°)	Young's modulus, E_s (kN/m^2)	Poisson ratio, ʋ	Unit weight, γ (kN/m^3)
Soil E	10	0.0	2000	0.35	16
Soil F	15		3000	0.34	17
Soil G	20		4000	0.33	17

The Mohr-Coulomb model parameters used for the simulation of sand soil are shown in Table 2

Table 2: Estimated (Mohr-Coulomb) model parameters of sand soil

Soil Code	Unit weight, γ (kN/m^3)	Angle of Friction, Φ (°)	Young's modulus, Es (kN/m^2)	Poisson ratio, ʋ
Sand	18	35	50000	0.3

The pile is simulated as a beam element and modeled by axial and bending stiffness. Piles were considered as reinforced concrete (R.C.) piles. For R.C. piles, the modulus of elasticity was set to be 22*10^6 kN/m^2 and the Poisson's ratio (ʋ) was taken as 0.25. Table (3) shows the properties of model piles. For the spaced piles in the long direction. These piles were considered as an equivalent wall in the 2D analysis as stated by Le Hello and Villard, (2009). The thickness of the equivalent wall, $t_{equivalent}$ (t_{equ}) can be found from equation (2). It is also used to consider the effect of out-plane spacing (S) and the pile's diameter (D) in the analysis.

$$\pi * \frac{D^2}{4} = \text{Spacing}(S) * t_{equivalent} \dots\dots\dots\dots (2)$$

The interface between piles and the soil is also considered to fulfill the soil structure interaction. The interface strength was mentioned by (R_{int}) coefficient. The value of this coefficient (R_{int}) was set to be 0.7. To achieve horizontal and vertical fixities equal to zero, the standard fixities in the model were considered.

NUMERICAL ANALYSIS

The model geometry of the soil domain and the embankment adopted for this analysis was taken as 100 m in width and the sand layer was taken 20 m thickness to satisfy the boundary conditions of side and base effects. A total of 63 numerical modeling tests of different cases were performed using PLAXIS 2D program. The friction angle of sand layer blew the soft clay was taken as 35°.

The studied parameters are shown in Figure (3). The studied parameters include the depth of the soft clay height (H), shear strength of the soft clay soil below the embankment (c_u), length of piles (L/H), pile's spacing (S/D), pile's diameter (D) and thickness of embankment (h/H). Each series was run to study the effect of one parameter while other parameters were kept constant. Numerous series of numerical analysis were performed to study the Settlement-time behavior of embankment with and/or without piles over soft clay layer as shown in Table (4).

Table 3: Pile's parameters adopted in 2D PLAXIS program

Piles Diameter, D (m)	Axial Stiffness, EA (kN/m)	Flexural Rigidity, EI (kN.m^2/m)	Equivalent Thickness, d_{equ} (m)
0.50	11*10^7	9*10^6	0.50
1.00	22*10^7	18*10^6	1.0
1.50	44*10^7	36*10^6	2.0

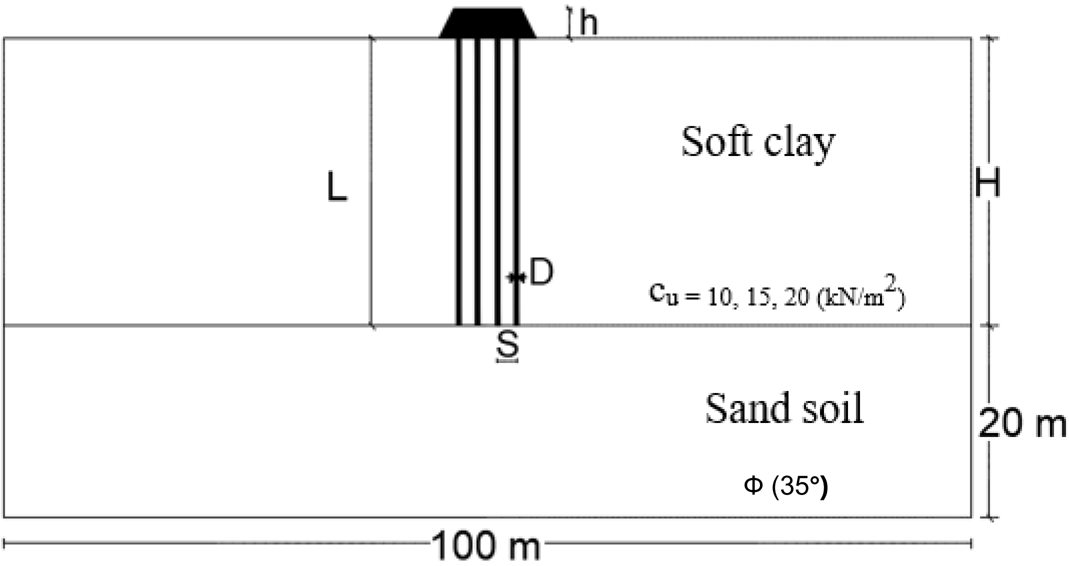

Fig. 3: The Geometry Model for Different Studied Parameters in the 2D PLAXIS model

Table 4: Series and studied parameters

Series	Constant parameters	Variable parameters
Without piles		
1	c_u=10, h/H=0.2	H=15,20,30
2	H=30, h/H=0.2	c_u =10,15,20
3	c_u =10, H=30	h/H=0.05,0.1,0.2
With piles		
4	H=30, S=4D, D=0.5, L/H=0.25, h/H=0.2	c_u =10,15,20
5	H=30, S=4D, c_u=10, L/H=0.25, h/H=0.2	D=0.5,1,1.5
6	H=30, S=4D, c_u =10, L/H=0.25, D=0.5	h/H=0.05,0.1,0.2
7	H=30, S=4D, c_u =10, h/H=0.2, D=0.5	L/H=0.25,0.5,0.75,1,1.5
8	H=30, D=0.5, c_u=10, L/H=0.25, h/H=0.2	S/D=2,3,4

Where: c_u : is the undrained shear strength of the soft clay (kN/m^2); h: is the thickness of the embankment (m); H: is the thickness of soft clay layer (m); D: is the pile's diameter (m); L: is the pile length (m); and, S:is the spacing between piles

NUMERICAL MODEL VALIDATION

The results obtained by Satibi (2009) are adopted to verify the numerical model considered in this study. The variation of stresses with settlement for soft clay layer supporting an embankment and reinforced with floating piles is shown in Figure (4). The results obtained by Satibi (2009) are also plotted in the same Figure. From this Figure, it can be clearly seen that the obtained results using our models are in a good agreement with the results obtained by Satibi (2009).

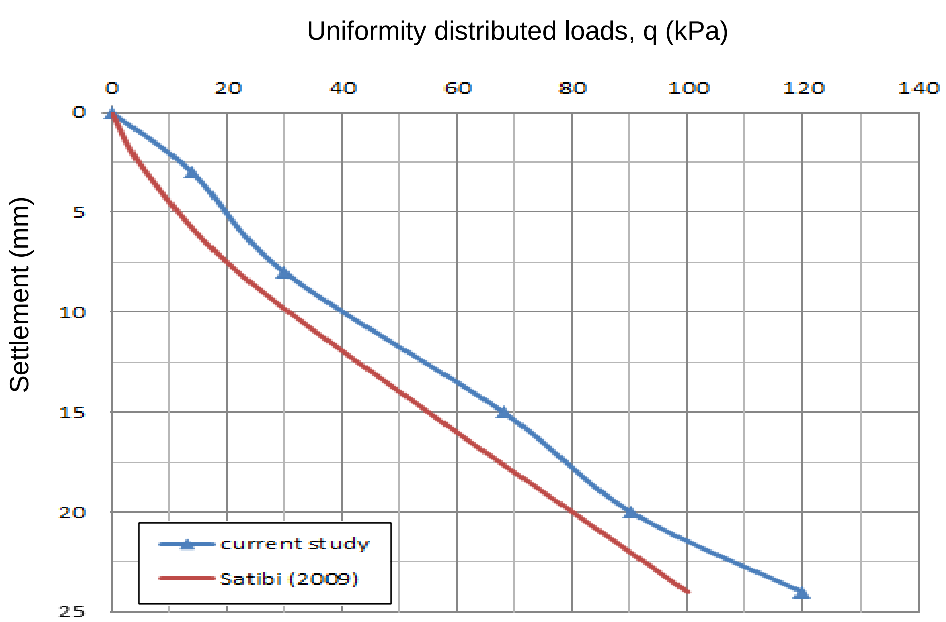

Fig. 4: Validation of our Model with the Results Obtained by Satibi, (2009)

RESULTS AND ANALYSIS

The effect of placing embankment on soft clay layer with and without piles is studied in the form of time-consolidation settlement relationship for different investigated parameters.

Effect of soft clay layer depth (H)

Using abovementioned modelling parameters and soil properties, the analysis was carried out using PLAXIS 2D for embankment over soft clay layer with and without piles. The settlement–time relationships were obtained at different investigated parameters. For comparison, the settlement of soft clay layer was plotted versus time without and with piles for different soft clay layer height (H of 15, 20 and 30 m) and constant parameters of c_u = 10 kPa, h/H = 0.1, as shown in Figures (5 and 6) respectively.

In Figure 5, it can be seen that the settlement is gradually decreased with the decrease of soft clay layer thickness. The variation of soft clay layer thickness from (30 m to 20 m) and (30 m to 15 m) reduced the final settlement by 59% and 76% respectively for soft clay cohesion of c_u = 10 kPa. From the same figure, it can be also noticed that the variation of soft clay layer thickness from (30 m to 20 m) and (30 m to 15 m) reduced the final consolidation time by 12.5% and 25% respectively.

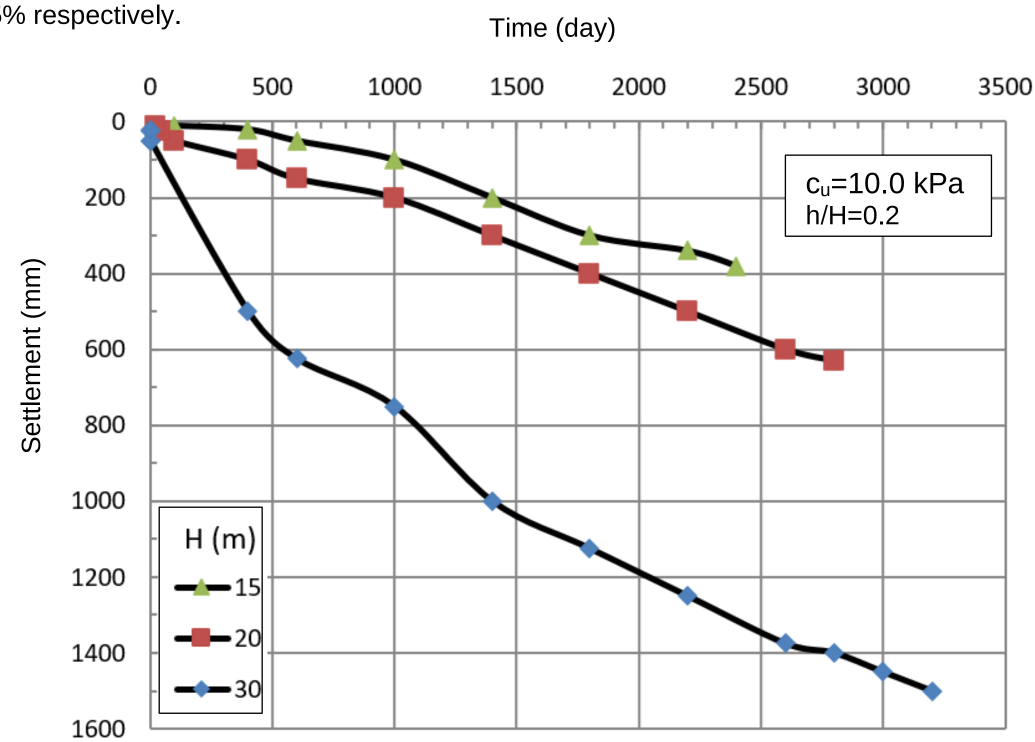

Fig. 5: The Settlement–Time Relationship of Embankment over Soft Clay Without Piles for Different Soft Clay Layer Thickness (H)

Time (day)

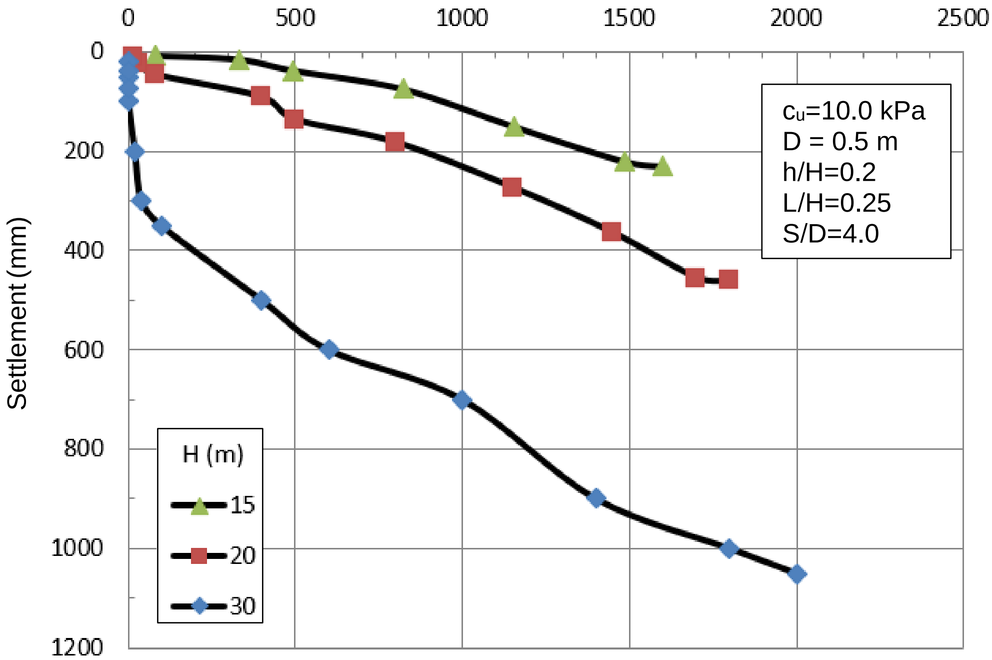

Fig. 6: The Settlement–Time Relationship of Embankment Over Soft Clay with Piles for Different Soft Clay Layer Thickness (H)

From Figure (6) it is found that, the decrease of soft clay layer height (H) leads to significant decrease in embankment settlement and the time. The settlement of embankment is reduced by as much as 65% for clay layer thickness of 30m. The increase of soft clay layer thickness from (20 to 30) m could increase the settlement by 56%, while this value is found to be 80% for clay layer thickness varied from 15 to 30m. The settlement of the piled-embankment over soft clay in the two cases of with and without piles increased significantly with increasing the soft clay layer height (H).

Effect of shear strength of the soft clay (c_u)

Figures (7 and 8) show the relationship between the settlement of the embankment without and with piles versus time for shear strength of the soft clay with cohesion of (10, 15 and 20) kN/m^2 at H = 30m and h/H = 0.1. It is noticed that the increase of (c_u) of soft clay has a great effect in reducing the embankment settlement. The increase of shear strength of the soft clay from 10 to 15 kPa decreased the settlement by 83% while at c_u = 20 kPa this decrease is found to be 60% of its initial value at c_u = 10 kPa. From these two figures, it can be also noticed that the increase of cohesion can significantly reduce both settlement of the embankment and time. At early stage of time (T < 100 days), the linear relationship is achieved for the values of investigated cohesion. Meanwhile, at (T >100 days) the settlement of the embankment is increased with the increase in time as a nonlinear relationship. The final settlement of embankment is found to be 1050, 580 and 400 mm for clay cohesion of (10, 15 and 20) kN/m^2 respectively. It can be concluded that, the increase of cohesion from 10 kN/m^2 to 20 kN/m^2 reduced the final settlement by 62% of its initial value and this explains that the settlement in the case of using piles compared without piles is reduced to a large extent with raising the shear strength of the soft clay (c_u).

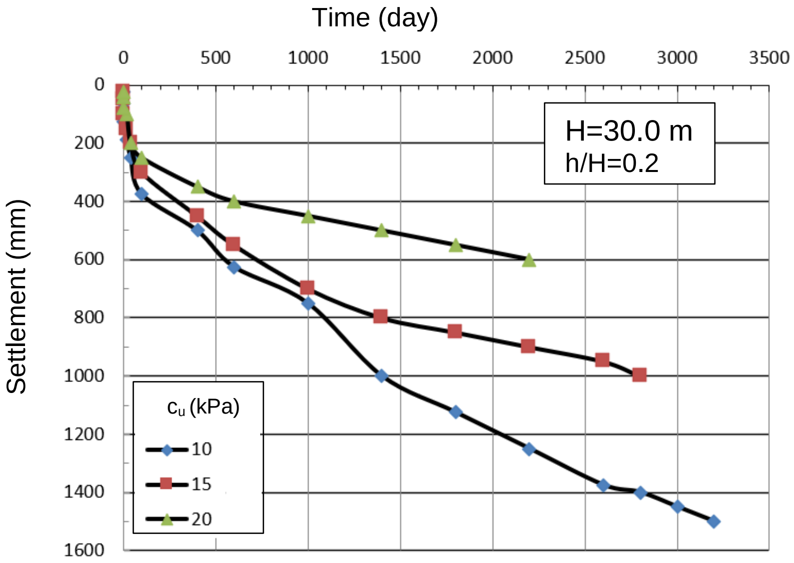

Fig. 7: The Settlement-Time Relationship of Embankment over Soft Clay without Piles for Different Shear Strength Values of Soft Clay (c_u)

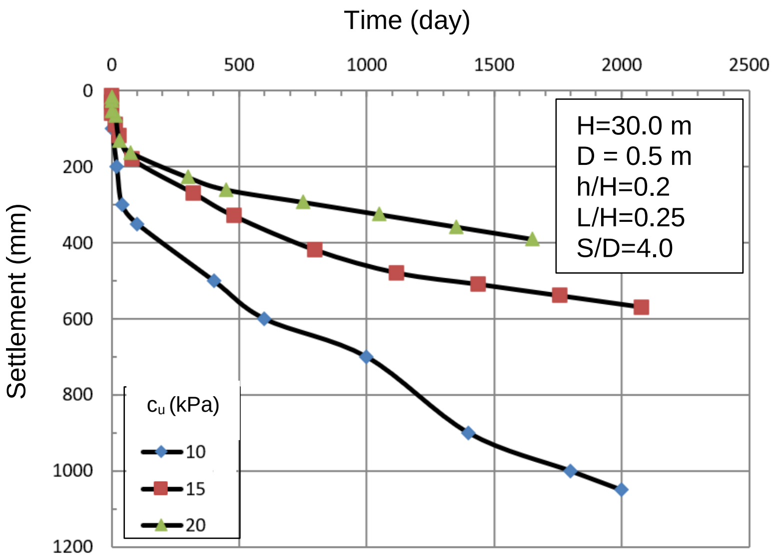

Fig. 8: The Settlement-Time Relationship of Embankment over Soft Clay with Piles for Different Shear Strength Values of Soft Clay (c_u)

Thickness of embankment (h/H)

The settlement of the soft clay layer was plotted versus time of the consolidation without and with piles for different thickness of embankment (h/H) equals 0.05, 0.1 and 0.2 for constant parameters of c_u = 10 kPa, H = 30 m, as shown in Figures (10 and 11). From these two figures, it can be noticed that, the settlement for the case of using piles compared to the case of without piles increases significantly with the increase of the embankment thickness (h/H).

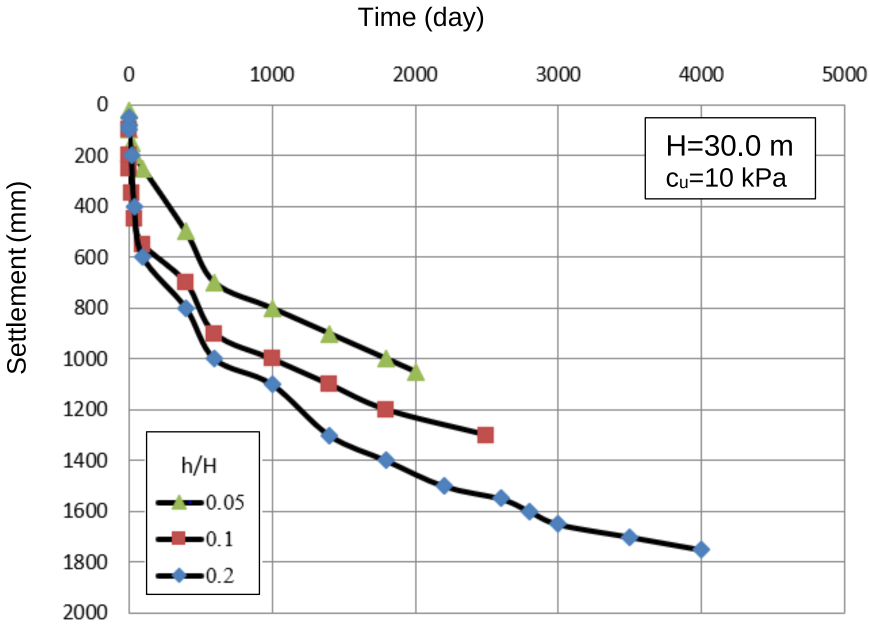

Fig. 9: The Settlement-Time Relationship of Embankment over Soft Clay without Piles for Different Thickness of Embankment (h/H)

\From Figure (9) it can be seen that, the settlement is gradually decreased with the decrease of the embankment thickness (h/H). The variation of the embankment thickness (h/H) from (0.2 to 0.1) and (0.2 to 0.05) reduced the final settlement by (18% and 31%) respectively.

From Figure (10) it can be also seen that, the settlement is gradually decreased with the decrease of the embankment thickness (h/H). The variation of the embankment thickness (h/H) from (0.2 to 0.1) and (0.2 to 0.05) reduced the final settlement by (27% and 54%) respectively.

Meanwhile it can be concluded that, using piled-embankment decreased the settlement by (31%, 47% and 57%) with different embankment thickness (h/H) equals (0.3, 0.2 and 0.1) respectively.

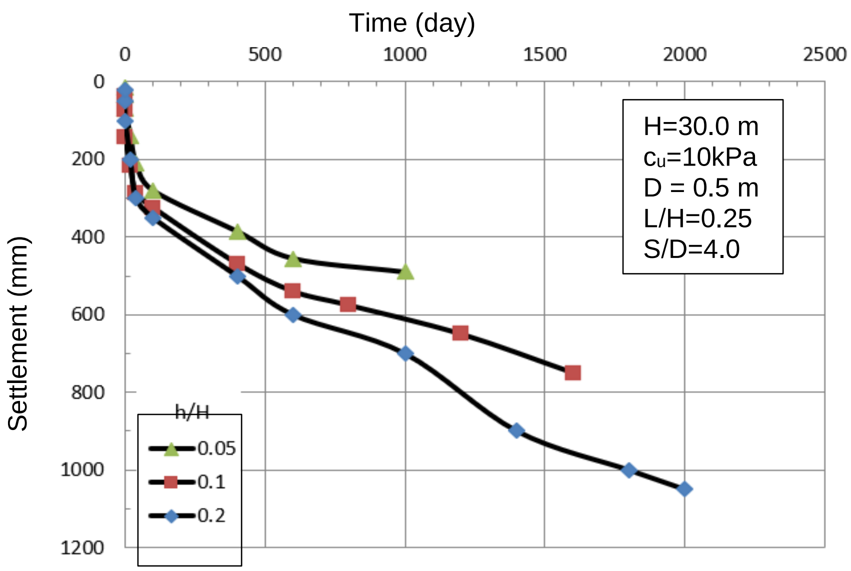

Fig. 10: The Settlement-Time Relationship of Embankment Over Soft Clay with Piles for Different Thickness of Embankment (h/H)

Effect of pile's length

The effect of piles length (L/H) on the behaviour of embankments over soft clay with piles is investigated by varying the piles length (L/H). The time was plotted versus the total displacement for different piles length ratios (L/H) of (0.25, 0.5, 0.75, 1 and 1.5) for constant parameters of H = 30m and h/H = 0.1 as shown in Figure (11).

The obtained results from this figure show that, the increase of pile's length can also decrease the embankments consolidation time and decrease the settlement. It is noticed that the consolidation rate can significantly reduce with lesser time by the increase of pile length. It can be noticed that the increase of pile length (L/H) by (0.25, 0.5, 0.75, 1 and 1.5) decreased the settlement by (23%, 31%, 58%, 73%) respectively. Meanwhile, the increase of pile length (L/H) by (0.25, 0.5, 0.75, 1 and 1.5) decreased the final consolidation time by (5%, 20%, 50%, and 70%).

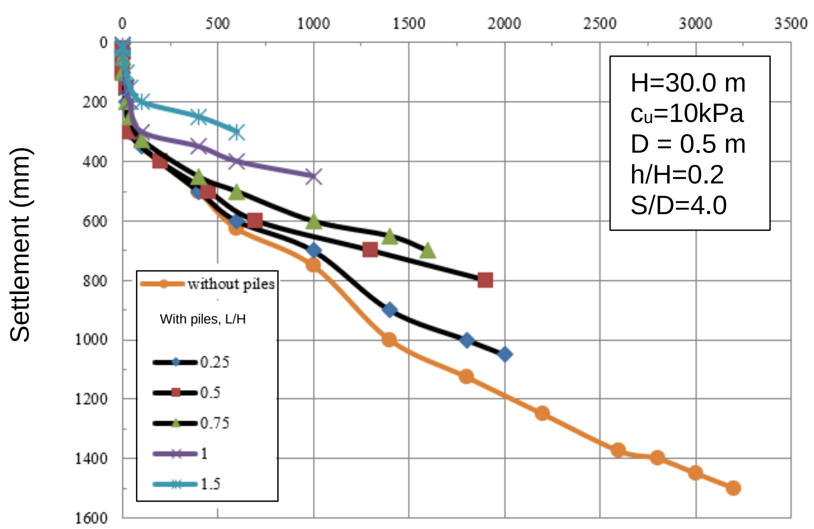

Fig. 11: The Settlement-Time Relationship of Embankments Over Soft Clay with Piles for Different Pile's Length (L/H)

Effect of pile diameter

Figure (12) shows the relation between the consolidation time of the embankment versus the total displacement for different values of pile diameter (D = 0.5, 1 and 1.5 m) at constant parameters of H = 30m, h/H = 0.1, L/H = 0.25, S/D = 4 and soft clay cohesion of c_u = 10 kPa. It is noticed that the increase of diameter of piles in the soft clay layer has a great effect in reducing the embankment settlement. It can be concluded that the increase of piles diameter from (0.5m, 1m and 1.5m) reduced the final embankment settlement by 35% and 54% of its initial value as can be seen from this figure. From the same figure, it can be noticed that the increase of diameter of piles (from 0.5m to 1.0m and 1.5m) could reduce the final consolidation time by 20% and 40% respectively.

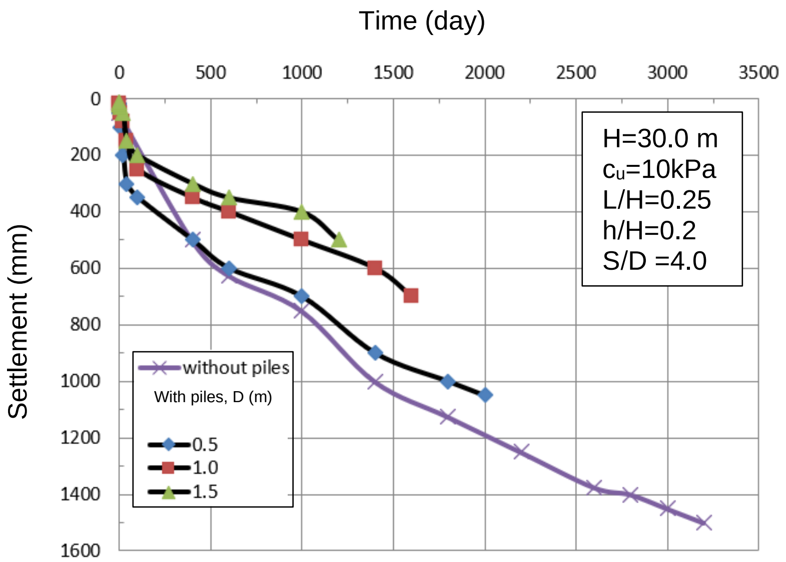

Figure 12: The Settlement-Time Relationship of Embankments Over Soft Clay with Piles for Different Diameter of Piles (D).

Effect of spacing between piles (S/D)

The effect of spacing between piles (S/D) on the Settlement of embankments over soft clay with piles is also investigated. The consolidation time was plotted versus the embankment settlement for different spacing between piles ratios (S/D = 2, 3 and 4) as presented in Figure (13) for constant parameters H = 30m and h/H = 0.1.

It can be seen that, the increase of spacing between piles (S/D) decreased the arching mechanism between piles. As a result of this, the consolidation time is decreased. It has been found that the variation of the spacing (S/D) (from 4 to 3 and 2) could reduce the embankment settlement by 46% and 58% respectively. Also, the final consolidation time has been decreased by 50% and 70%. Meanwhile, the settlement of the embankment has been decreased by 31% by using piles with (S/D = 4).

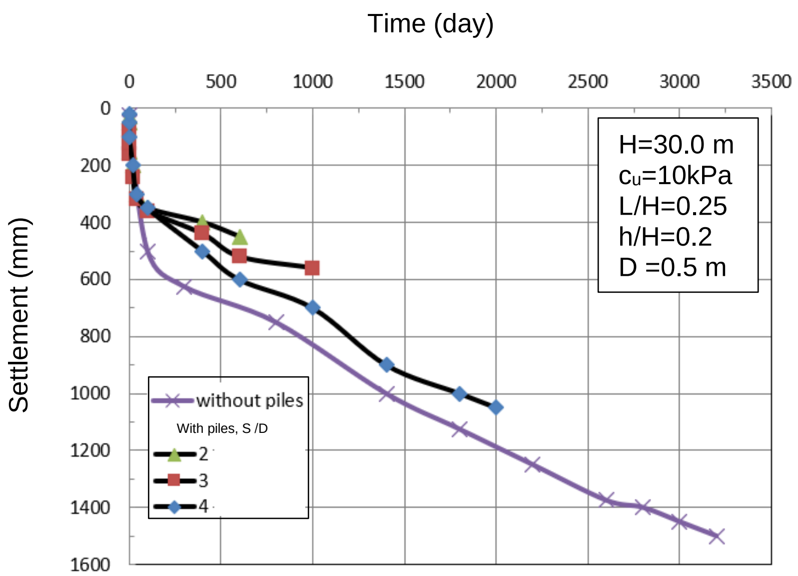

Fig. 13: The Settlement-Time Relationship of Embankments Over Soft Clay with Piles for Different Pile's Spacing Ratios (S/D)

CONCLUSIONS

From this study the following conclusions can be summarized:

1. The increase of soft clay height (H) leads to a significant increase in the settlement by 65% of its initial value without piles.
2. The increase in the shear strength of the soft clay layer below the embankment (c_u) led to a significant decrease in the settlement by as much as 62% of its initial value without piles.
3. The embankment settlement values were found to be decreased by 47% and 57% for thickness of embankment (h/H) 0.1 and 0.2 respectively.
4. The increase of piles length (L/H) led to a significant decrease in the settlement by up to 73 % of its initial value without piles (at L/H equals 1.5).
5. The increase of diameter of piles (D) led to a remarkable decrease in the settlement by up to 54 % of its initial value (at D = 1.5m).
6. The increase in the spacing between piles (S/D) ratio led to a significant decrease in the settlement by up to 70 % of its initial value without piles (at S/D equals 2).

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