RESEARCH ARTICLE OPEN ACCESS

Simulation of Characteristics of Soil Improvement on Clayey Silt

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ABSTRACT

When construction works were performed on soft soil foundations, the problems of subsoil were found. The soil improvement technique is needed to modify the poor subsoil. Stone column method is one of a ground improvement techniques. The stone column is caused to use on three factors which are the stiffness of material, the densification of surrounding soil during the installation of stone column and the acting as a vertical drain.In this study, Plaxis 2D software is used to determine the characteristics of soil improvement under embankment with three conditions of ground water level. The main purpose of this study is to compare the deformations (settlement), excess pore water pressure in subsoil and the factor of safety for long term stability of with and without soil improvement.

***Keywords* :—** stone column, embankment, settlement, pore water pressure, factor of safety

I. INTRODUCTION

Ground improvement techniques used in geotechnical engineering to improve and stabilize the soft clay or silts and loose sands , under the construction of highway , storage tank , embankments , bridge abutments and so on. Stone column method is one of a Ground improvement techniques [1]. This method was used first in France in 1830s. Since 1950s it is in wide range of use especially in Europe. Two types of stone column installation are vibro-replacement and vibro-displacement.

The vibro replacement technique is most effective in very soft to soft compressible clays/silts and in loose silty sands. However, vibro stone columns are highly dependent on the lateral support provided by the surrounding soil and consequently are not suitable for use in very weak soils. If the strength of the surrounding soil is insufficient, excessive column deformation will occur [3].

Soft soil improvement by using stone column is due to three factors. The first one is including the stiffer column materials (such as crushed stone, gravels, etc.) in soft soil. The second is the densification of surrounding soil during the installation of stone column. The last one is acting as the vertical drain.In recent history, the stone column was limited in 0.2 mdiameter and 2 m length and then this technique was developed in increasing diminution of the stone column from 0.5 m to 1.5 m diameter and 15 m length [8].

The bearing capacity of stone column is related to the shear strength parameters such as cohesion and friction angles of soil. The unit weight of soil is increased within the installation of stone column. The main purpose of this study is to determine the behavior of with and without soil improvement by using Plaxis 2D software.

II. THEORY BACKGROUND

Stone columns are column of gravels constructed in the ground. A suitable technique of ground imorovement for foundations on soft clay is to install vertical stone column in the ground. Stone column is an essentially method of soil improvement in which cohesive soil is replaced by gravels or crushed stone in vertical holes to form the columns or piles within the soil. The gravel used for the stone column has a size range of 6 to 40 mm [10].

The stone column serves two basic functions, namely

(a) Providing strength to the soil

(b) Acting a vertcal drains to allow subsoil consolidation to occur quickly under any given loading.

Stone column improves the shear strength of the subsoil to increase the bearing capacity. It improves the stiffness of subsoil to decrease settlements. It has the ability to carry very high loads since ccolumn are ductile. Rapid consolidation of subsoil is facilitated in stone column.

As the disadvantages of using stone column, sensitive clay is not adequately regain the shear strength. Soil improvement by stone column cannot be achieved in clays with sensitively greater than 4 [11].

III. RESEARCH METHODOLOGY

Soft soil is selected from Hinthada Municipal Embankment (on the western bank of Ayeyarwady river and near of the downtown of Hinthada) . The study area is located on the West Bank of Ayeyarwady River. It is located in grid coordinate (742443) of one inch topographic map No.85 O/6. Topography of the project area is low lying farms. This area is instruded by river flood during raining season. The embankment is 6m high and 46m long, 4m wide and the slope gradient is 1:2. Embankment fill soil is selected from Pathein-Monywa Road , 76 Mile.The physical properties of selected soils are obtained from some experimental tests. The physical properties and input data for Plaxis software of selected soils are presented in Table 1 and 2. As a parametric study, the input parameters of stone column are also decribed in Table 2. In this paper, the water table was considered three conditions as shown in Table 3.

TABLE 1
PHYSICAL PROPERTIES OF SOIL MATERIALS

Soil Samples	Clayey Silt	Embankment Fill Soil
% Gravel	0	6
% Sand	5.8	50
% Silt	52.2	20
% Clay	42	24
G_s	2.66	2.65
L.L	36.8	36
P.L	22.93	24
PI	13.87	12
USCS	CL	SC
	Clayey Silt	Clayey Sand
Load	20 kN/m^2	

TABLE 2
INPUT PARAMETER FOR PLAXIS SOFTWARE

Parameters	Unit	Embankment Fill	Soft Clay	Stone column
Material model	-	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Type of material	-	Undrained	Undrained	Drained
Dry unit weight	kN/m^3	16.5	16	17
Saturated unit weight	kN/m^3	20	19	22
Horizontal permeability	m/day	0.000441	0.0005063	10
Vertical permeability	m/day	0.000441	0.0005063	10
Young modulus	kPa	8000	2000	58000
Poisson ratio	-	0.3	0.35	0.3
Cohesion	kPa	12	20	0.0001
Friction angle	degree	37	0	42
Dilitancy angle	degree	0	0	0

TABLE 3
TYPES OF WATER TABLE

Condition I	Water Table @ 2m below G.L
Condition II	Water Table @ G.L
Condition III	Water Table @ 5m above G.L

IV. ANALYSIS RESULTS AND DISCUSSIONS

In this study, the construction of the embankment without any improvement was simulated with Mohr-Coloumb Model, using PLAXIS 2D VERSION 8.2. In my study, the embankment was taken symmetric and only one half of the embankment is consisdered in the finite element analysis.The plain strain condition and 15-noded traingular elements were used in this analysis.The model range in vertical direction was 15m deep and the horizontal direction was 24m away from the centre line of embankment. In this study, three types of water were considered. In a finite element mesh, 1st condition was 172 elements and 1457 nodes, 2nd condition was 177 elements and 1499 nodes, 3rd condition was 167 elements and 2004 nodes were generated in the finite elemenyt mesh respectively.

A. Boundary Condition and Calculations

The displacement boundary conditions were defined taking (ie, On y=0 plane, ux=0 and uy =0 where ux and uy are horizontal and vertical displacements respectively) [2].

The nodes on the two vertical boundaries are fixed against horizontal movement but allowed to move freely in the vertical direction. Assuming that the horizontal displacement can be defined as zero at nodes that are enough distant from the embankment, the plane of x= 24m was considered as the lateral boundary with zero displacement in x direction (ie, on planes x= 24, y = 15). The upper boundary formed by the embankment and the existing ground surface are left free to displace. Drainage boundaries are assumed to be at the ground surface and at the bottom of the mesh (ie, the excess pore pressure at the nodes along the boundaries are set to zero), whereas the lateral boundaries are closed.The Mohr-Coulomb's model was used to simulate the soil and stone column behaviors.

In this study, initial K_o-procedure is used determine the initial stress in-situ stress state. The coefficient of lateral earth pressure Ko is based on Jaky's formula, Ko=1-sin ϕ [8]. While calculating the initial stress, the embankment was deactivated.

All stages are modelled as consolidation-Stage construction phases. After completing the construction of embankment, the deformations (settlement) and excess pore pressure are determined for long term stability. And then the calculation of saety factor is considered by phi-c reduction.

The input parameters for embankment models of settlement and excess pore pressure are shown in Fig 1, 2, 3, 4, 5 and 6.

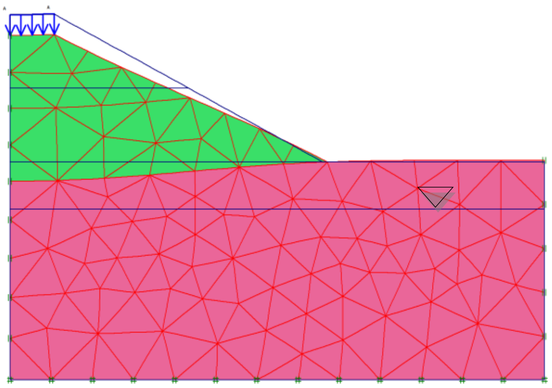

Fig. 1 Result of settlement without improvement (Condition I)

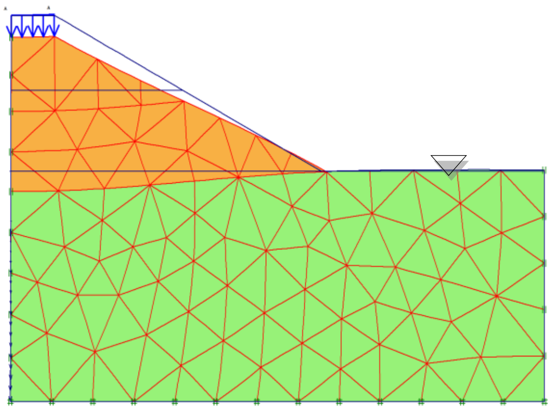

Fig. 2 Result of settlement without improvement (Condition II)

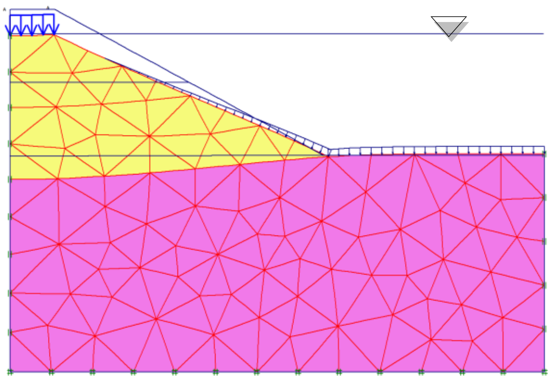

Fig. 3 Result of settlement without improvement (Condition III)

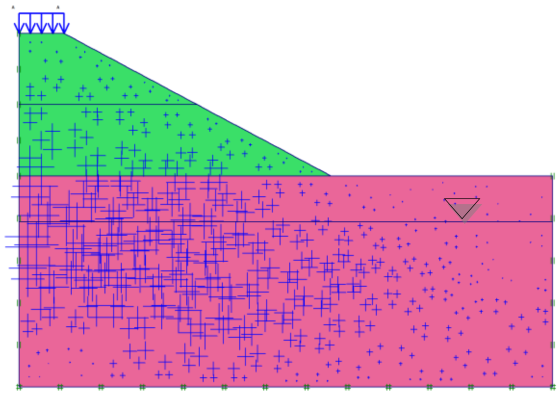

Fig. 4 Result of excess pore pressure without improvement (Condition I)

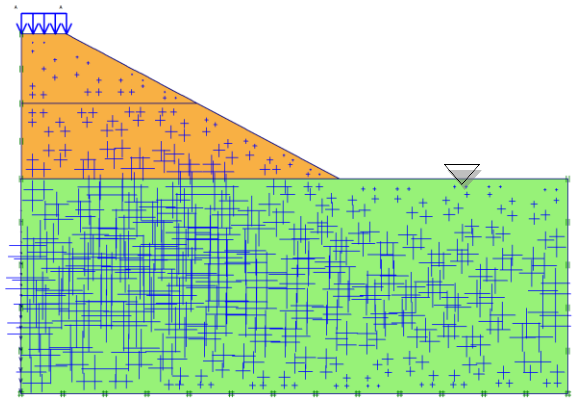

Fig. 5 Result of excess pore pressure without improvement (Condition II)

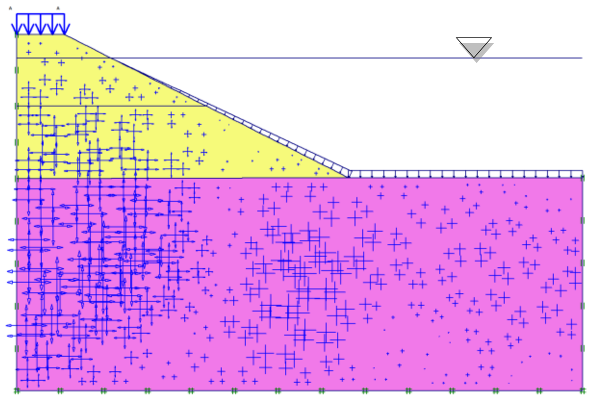

Fig. 6 Result of excess pore pressure without improvement(Condition III)

B. Analysis Results of Soft Soil For With and Without Soil Improvement

In this section, the characteristics of soil improvement of embankment underlying on soft soil foundation such as deformation (settlement) and the excess pore water pressures of subsoil were presented by two dimensional numerical models.

1) ***Results of Settlement:*** The design tolerance of the settlement is 200mm (0.2m) at the centre of the embankment after the completion of the embankment [4].

2) The comparison results of without soil improvement (natural) state and using stone column with spacing to diameter ratios 2D and 3D are presented in Fig 4, 5 and 6.

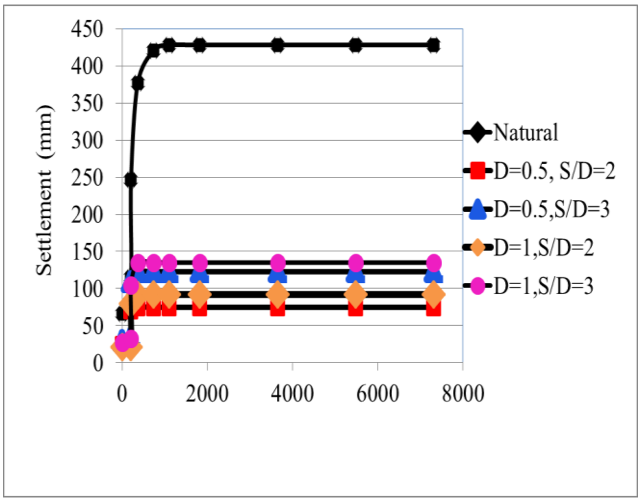

Fig. 7 Comparison result of settlement for Condition I

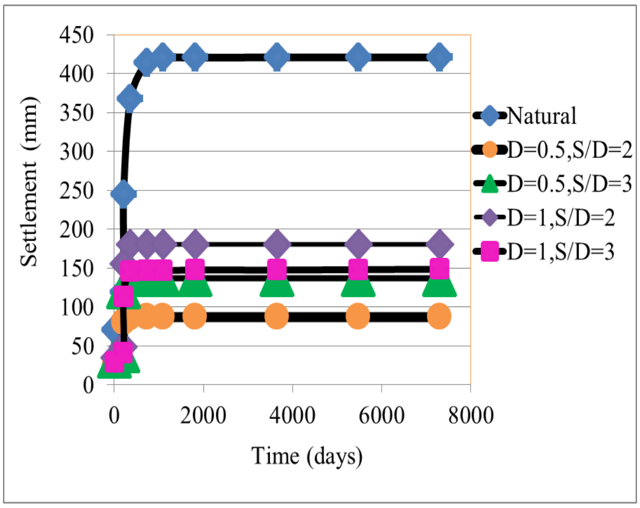

Fig. 8 Comparison result of settlement for Condition II

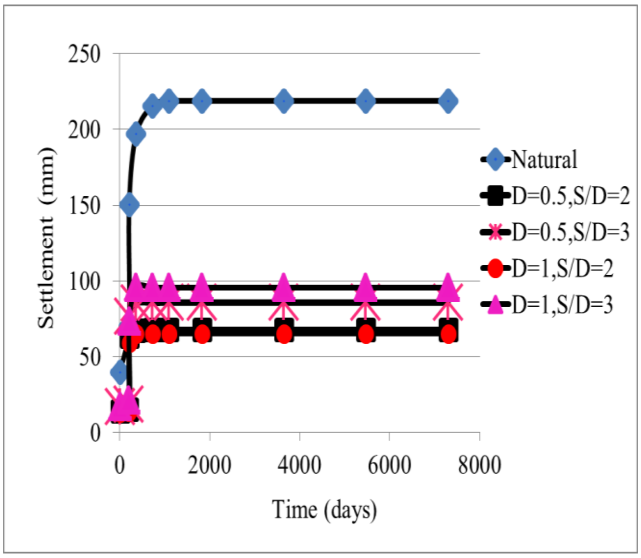

Fig. 9 Comparison result of settlement for Condition III

According to the analysis results, the deformation settlement of embankment is over the allowable settlement before using the soil improvement. After using the improving method, the values of settlement is reached to allowable limits.

Before using the improvement method, the settlement is found 428 mm at condition I. After using improvement method, the deformation (settlement) is decreased to 75 mm, 123 mm, 92 mm and 135 mm respectively. All of these results were reached into allowable limit.

And also the settlement is decreased from 421 mm to 87 mm, 137 mm, 180 mm and 149 mm at condition II and from 219 mm to 68 mm, 85 mm, 65 mm and 95 mm at condition III. Therefore, it can be concluded that the soil improvement method is very useful to control the deformation of embankment.

3) ***Results of Excess Pore Pressure:*** The stability of embankment is depent on the permeability of the soil, compressibility of pore water and the velocity of the pressure change .

Excess pore pressure is pore water prressure generated by loading the soil. However sand and gravel are good permeability, clayey silt is not very permeable.So, the excess pore pressure is an important factor for long term stability of embankment.

The comparison results of without soil improvement (natural) state and using stone column with spacing to diameter ratios 2D and 3D are presented in Fig 10, 11 and 12.

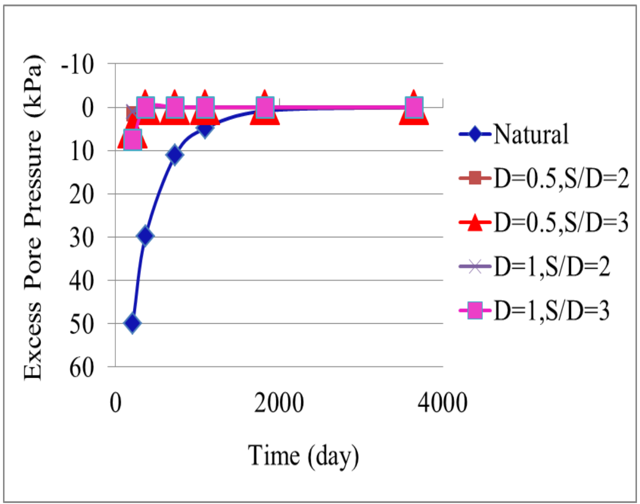

Fig. 10 Comparison result of excess pore pressure for Condition I

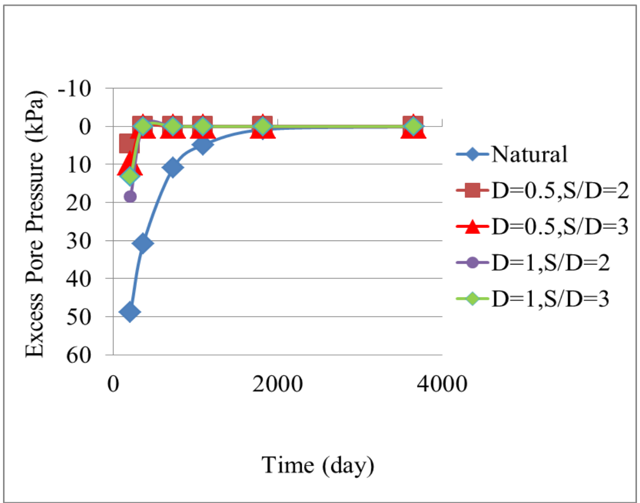

Fig. 11 Comparison result of excess pore pressure for Condition II

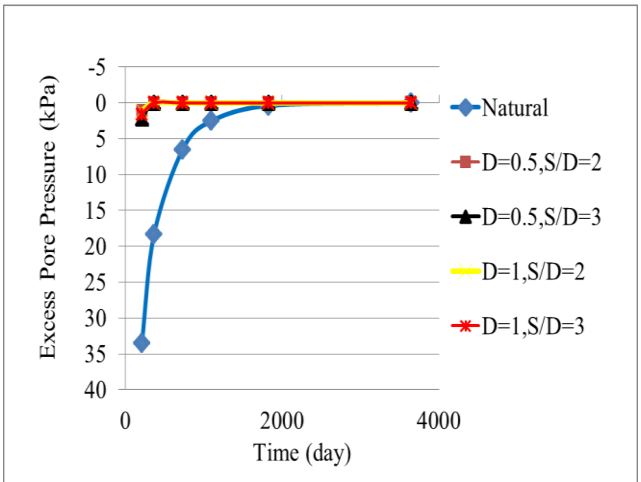

Fig. 12 Comparison result of excess pore pressure for Condition III

According to the analysis results, the differential conditions of excess pore pressure is occurred. The maximum excess pore pressure is reached to 49.93 kPa at condition I, 48.8 kPa at condition II and 33.5 kPa at condition III respectively until using the stone column.

After using the stone column, the rate of excess pore pressure is very rapidly down in foundation. Because of the stone column acts as vertical drains to remove the excess water in the foundation soft soil. Alternatively, the stone column is effected to good permeability.

C. *Factor of Safety*

In the construction of embankment, it is one of the fact that not only the final stability but also the stability during the construction. Factor of safety for soft soil under embankment is the range of 1.4 to 1.5 for long term stability. Stone columns with diameter 0.5m and 1m with spacing to diameter ratio 2 and 3 are used for improvement. Comparison results of factor of safety for with and without improvement are presented in Fig (10).

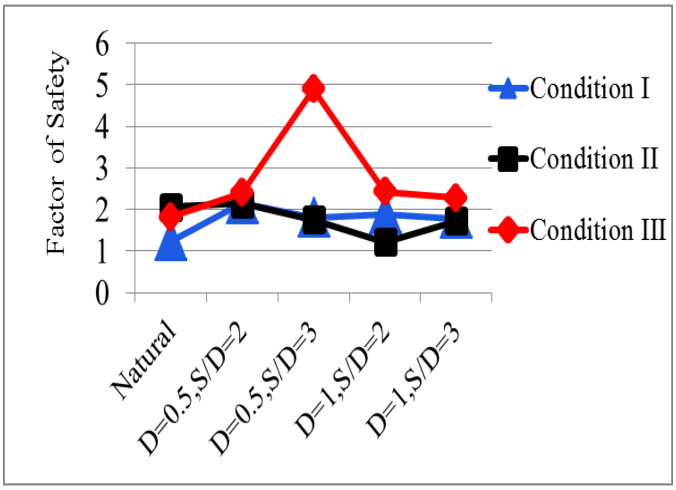

Fig. 10 Comparison results of factor of safety

When the embankment was constructed on the existing soft soil, the factor of safety does not reach to the allowable limit for all condition of water table. After considering the soil improvement technique, the factor of safety is increased over 1.5 for all conditions. From the above results, using stone column is affected to improve the factor of safety for embankment stability.

V. CONCLUSIONS

In this paper, a numerical study on embankment under soft soil foundation with two dimensional plane strain condition has been presented . And then the settlement behavior, excess pore pressure and factor of safety are analyzed.

In this paper, three types of water level was considered. For condition I (water tabel is located 2m from G.L), the deformation (settlement) was found 0.428m (428 mm). This result is over allowable limit (200 mm).

According to the analysis results, the deformation (settlement) is 0.421m and 0.219 m respectively for condition II (water table at G.L) and condition III (water table at 5m from G.L) respectively.Therefore, using stone is suitable to control the deformation of embankment.In this without improvement processs, the consolidation time is long time.

After analysing the improvement process, the deformation settlement is reduced 80% and the consolidation time rate is increased about 5 to 10 times . And then the factor of safety is over than the allowable limit 14 to 1.5 for all conditions.

Finally, according to the results of study, it can be concluded the following

(1) The performance of soil improvement is effected the reducing settlement of soil due to the high stiffness of the stone column.
(2) Increased the time-rate of consolidation process
(3) Controlled the excess pore pressure
(4) When the embankment was fully constructed with stone column, the factor of safety is reached to allowable limit.

ACKNOWLEDGMENT

First of all, the author would like to express her thankfuls to Dr. Khin Latt, Professor and .Head of Department of Civil Engineering at WYTU for her suggestion and guidance, and Daw Hsu Nandar Htun, Lecturer, Department of Civil Engineering at WYTU for her suggestions. Special thanks to Dr. Khin Swe Tint, PhD (Civil Engineering), Visiting Professor, Department of Mining Engineering at YTU and Founder (Geotech Family) for her supervisions, suggesstions and guidance.

And also thankful to all persons who helped directly and indirectly towards the completion of this paper.

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