STUDY ON THE SETTLEMENT BEHAVIOR OF EMBANKMENT ON THE SOFT GROUND REINFORCED BY SOIL-CEMENT COLUMNS

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ABSTRACT

The reinforcement of soft ground under road-embankment by using the soil-cement columns have been widely applied around the world. However, there were some problems in the settlement calculation of the reinforced ground. These problems may be the reasons why there are large differences between the calculated settlement and the measured settlement of soft ground reinforced by soil-cement columns. In order to generally study the settlement behavior of embankment on the reinforced ground, the analyses of settlement have been carried out for an embankment on soft ground of the Thu-Thiem region, HoChiMinh City, Vietnam. When calculating the final settlement of reinforced ground, if the engineers use the elastic modulus of soil-cement columns obtained from the unconfined compression test, these values may be unsuitable because the in situ soil-cement columns have a remarkable lateral earth pressure. Therefore, this is one of the causes of the difference between the elastic modulus of soil cement columns obtained from the in situ and from the unconfined compression test. Based on the analyses with PLAXIS software and the static load tests for the single soil-cement column and the group of soil-cement columns, there was a significant difference of (2.1 to 4.6)times between elastic modulus of soil cement columns obtained from the in situ and from the unconfined compression test. When calculating the settlement over time of reinforced ground, the rate of settlement mainly depends on the permeability coefficient of soil cement columns and the redistribution of stresses in the reinforced ground. Under the embankment loading, the stress concentration to the soil-cement columns will reduce the stress on the surrounding soils. The analysis results with PLAXIS software showed the rapid reducing of excess pore water pressure in the surrounding soils although the permeability coefficient of soil cement columns is smaller than the permeability coefficient of surrounding soils. Therefore, the redistribution of stress is the main cause for reducing the time of settlement.

1. INTRODUCTION

When calculating the final settlement of embankment on the soft ground reinforced by the soil-cement columns, there was a suggestion that the elastic modulus value of soil-cement columns can be taken from the unconfined compression test for the soil-cement mixture samples (Bergado, et al., 1996), (Bergado, et al., 1999). However, this value is normally different with the reality one. In actual, the soil-cement columns are effected by the considerable lateral pressure but in the laboratory, the sample is compressed without lateral pressure by the unconfined compression test. Based on an actual construction, the results of the elastic modulus of soil-cement columns are analysed for the single column and group of columns by the static compression test. The stastic compression tests are simulated by the Plaxis 3D Foundation software for the single column and group of columns, then these results are used for adjusting the elastic modulus of soil-cement column so that the simulated results are reasonable fit with the observation results. Futhermore, this paper analyze the consolidation process of the soft ground reinforced by the soil-cement columns.

2. AN ANALYSIS OF DETERMINATION ON THE FINAL SETTLEMENT OF EMBANKMENT ON THE SOFT GROUND REINFORCED BY SOIL-CEMENT COLUMNS

2.1 The determination of the elastic modulus value of soil-cement column in the field

In order to get the actual value of elastic modulus of soil-cement column, we use the trial and error method by using many different values of soil-cement column for the finite element simulation to match the reality of static compression test.

2.1.1 Characteristics of soil layers, and soil-cement columns

***** The soil parameters of layers are given in table 1.

Table 1. Soil paramters of the ground

Property	Unit	Sand layer (Back filling)	Layer 1 (Peat)	Layer 3[a] (Clay-Stiff)	Layer 4a (Sandy Clay - Stiff)	Layer 4b (Clayed Sand medium dense)	CDM Column
Material model		M-C	M-C	M-C	M-C	M-C	M-C
Behavior		Drained	Undrained	Undrained	Undrained	Drained	Undrained
Thickness	m	0.5	11.5 ~ 18.1	3 ~11.8	2,3 ~ 8,2	1,9 ~ 6,8	20,5
γ_{unsat}	kN/m^2	18	14,8	19,4	19,3	19,9	18
γ_{sat}	kN/m^2	18,5	15,8	19,8	19,6	20	18,6
$k_x = k_z$	m/day	1	4,64E-5	7,86E-6	8,64E-4	0,864	8,64E-6
k_y	m/day	1	4,64E-5	5,24E-6	5,76E-4	0,864	8,64E-6
E_{ref}	kN/m^2	12000	2100	10000	9300	12000	52000
ν		0,2	0,3	0,3	0,3	0,3	0,2
c	kN/m^2	1	11,9	41,8	26,3	2	250
φ	^{0}	30	4	11	9	18	30

* The soil-cement columns are designed with the parameters as shown in table 2.

Table 2. Soil-cement column's parameters

Property	Unit	Value
Diameter	m	0,6
Spacing	m	1,3
Length	m	20,5
Pattern		Square grid
Designed compression resistance strength	kN/m^2	800
Designed shear strength	kN/m^2	400
Cement content	kg/m^3	250

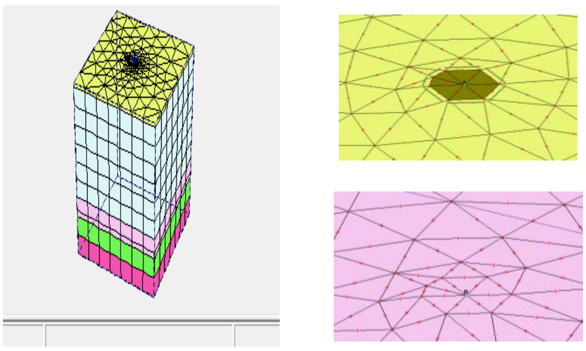

Fig. 1 Simulation mesh of the column load test

2.1.2 Simulation of the column load test by the FEM

From the designed load bearing capacity value of soil-cement column, Q_d = 133.5 kN, we simulate the progress of static compression test of soi-cement column by Plaxis 3D Foundation. The soil-cement column parameters are determined from the laboratory testing on the cored samples of real column in the field. The first analysis is undertaken with the elastic modulus of soil-cement column which is determined from the unconfined compression test, E_{50} = 52000 kN /m^2. We chose 2 points for the calculation such as: column head (point A), and column tip (point B).

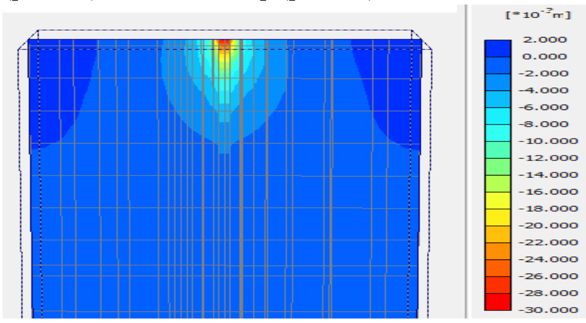

Fig. 2 Vertical displacement of the column under designed load

It can be seen that the settlement of column by the simulation is three times larger than the settlement obtained from the static compression load test. The deformation mainly occurs in the column with the settlement of the column head is S_A = 28,85mm, but the settlement of the column tip is only S_B = 0.1209mm, it proved that the settlement of soil layers below the pile tip is small; the settlement of the column is mainly due to the deformation of the column of 28,73mm. Therefore, the using of elastic modulus of soil-cement column which is determined from the unconfined compression test may result in a considerable error for the numerical simulation.

2.1.3 Comparison of simulation results and the static load test' s results for the single column

In order to have a good match between the results of numerical simulation and the results of static load test, it is possible to adjust the elastic modulus value obtained from the unconfined compression test. With the elastic modulus value of 240000 kN/m^2, the simulation result has a small difference with the real one as Fig. 3.

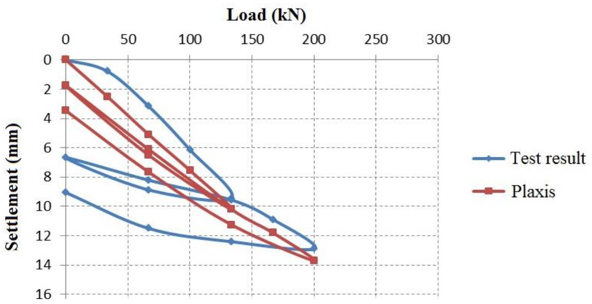

Fig. 3 Relationship between load and settlement of single column

2.1.4 Comparison of simulation results and the static load test' s results for the group of columns

To monitor the actual behavior of soil cement columns group, the static load test was also conducted with a group of 4 columns (Vietnamese Standard, 2012a). The parameters for the Plaxis 3-D Foundation simulation are same as above. There is a steel plate in the column head with the parameters as shown in table 3.

Also, with the elastic modulus value of 240000 kN/m^2, the simulation result has a small difference with the real one as Fig. 5.

Table 3. Parameters of steel plate

Parameter	Unit	
Dimensions	m	2 x 2
Thickness	mm	40
Unit weight	kN/m^3	78,5
Elastic modulus	kN/m^2	2,1 .10^8
Possion ratio		0.1

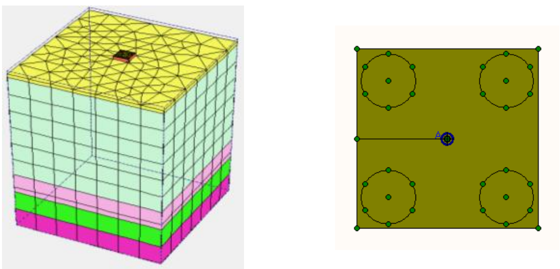

Fig. 4 Simulation mesh of the 4-columns group load test

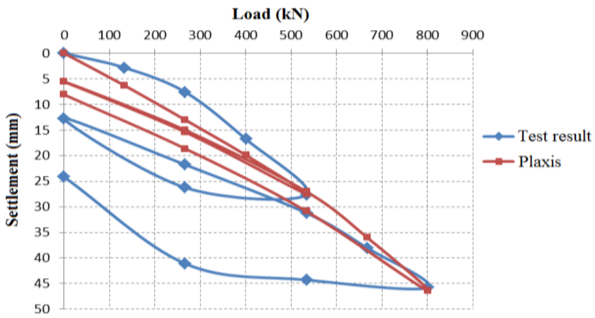

Fig. 5 Relationship between load and settlement of 4-columns group

2.2 Final settlement of embankment on the soft ground reinforced by soil-cement columns

2.2.1 Determination by the analytical solution

According to TCVN 9403 2012 (Vietnamese Standard, 2012b), the settlement of reinforced ground can be determined as follow:

$$S_1 = \frac{qH}{E_{tb}} = \frac{qH}{aE_C + (1-a)E_S} \quad (1)$$

where: E_c, E_s are the elastic modulus of soil cement column, and modulus of deformation of soil, respectively, H is the thickness of reinforced ground, q is static load.

The above formula was applied to calculate the final settlement of an embankment as shown in Fig. 6. The parameters for simulation are same as above, and the value of elastic modulus of soil cement column 240000 kN/m^2 is drawn from the above analysis. The embankment has parameters as follows:

- Width of embankment: B = 29,2 m
- Height of embankment:1,7 m
- Total static load on the ground surface: 58,5 kN/m^2

2.2.2 Determination by the numerical solution

Applying the plane strain simulation with the equivalent cross section of the soil cement columns. The equivalent width of the column is as follow:

$$W_n = \frac{A_p}{s} = \frac{\left(\frac{\pi \times 0,6^2}{4}\right)}{1,3} = 0,217(m)$$

where: A_p: cross section of the soil cement column, s: spacing between the soil cement columns.

With the value of elastic modulus of soil cement column of 240000 kN/m^2, the final settlement of embankment is 4.9cm, and 5.37cm by the analytical calculation, and by the numerical simulation, respectively. With a difference of 8.7% between the two calculated results, the value of elastic modulus above resulted in the reasonably settlement.

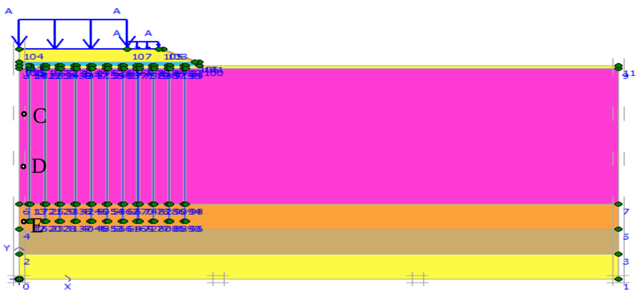

Fig. 6 Simulation of the embankment on soft ground reinforced by soil cement columns

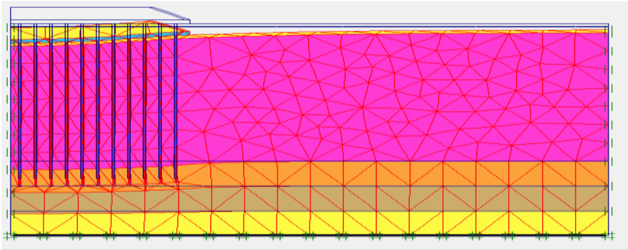

Fig. 7 Deformation mesh of the embankment on soft ground reinforced by soil cement columns

3. AN ANALYSIS OF THE CONSOLIDATION PROCESS OF SOFT GROUND REINFORCED BY THE SOIL-CEMENT COLUMNS

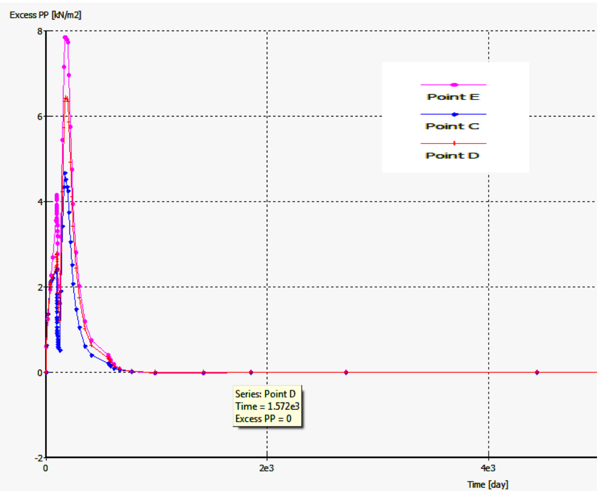

Fig. 8 Excess pore water pressure at point C, D, E

As Fig. 8, the excess pore pressure at E point has a value of 7.843 kN/m^2, at D point has a value of 6.339 kN/m^2, and at C point has a value of 4.673 kN/m^2. These values is smaller than the value of load of 58.5 kN/m^2 at the surface. Futhermore, these excess pore prsessures are dissipated in 900 days. This can be explained by the stress concentration occurs in the reinforced ground: most of the load acting on the ground is transferred to the soil cement columns.

Therefore, the redistribution of stress is the main cause for reducing the time of settlement.

4. CONCLUSION

The analyses and calculations mentioned above lead to the conclusions as follows:

- There is a difference between the elastic modulus which determined from the unconfined compression test on in-situ sample and the one determined from field. From the load test results of single soil cement column and group columns at field, and the simulation by Plaxis 3D Foundation shows that the elastic modulus E_{50} of soil cement column at site is (2.1~4.6) times the E_{50} at laboratory. The reason of difference is that the soil cement column in actual is effected by a considerable lateral pressure but in the unconfined compression test the sample is free with lateral pressure. Thus, when calculating the final settlement of embankment on the soft ground reinforced by soil-cement columns, if we take the E_{50} value from the unconfined compression test on soil-cement mixture sample, we should use an appropriate adjustment factor.
- The analysis results with PLAXIS software showed the small values of excess pore water pressure, and the rapid reducing of excess pore water pressure in the surrounding soils although the permeability coefficient of soil cement columns is smaller than the permeability coefficient of surrounding soils. Therefore, the redistribution of stress is the main cause for reducing the time of settlement.

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