Comparison between predicted and actual ground settlement improved using stone columns

Khong-Siong Chee
Cheekhongsiong@yahoo.com

ABSTRACT: Ground improvement is an important technique require for today's construction industry. Stone column is one of the ground improvement techniques that reinforced the ground with compacted stone. It is a very efficient method to improve the strength parameters of soils such as shear strength, bearing capacity and reduce the consolidation settlement. It offers a much economical and sustainable alternative to piling and deep foundation solutions. Many methods have been developed by past researchers to predict the ground settlement improved with stone columns. However, the predicted ground settlement is complicated and remains a problem for practical applications. The main purpose of the study is to outline and recommend the appropriate method to predict the ground settlement improved using stone columns. Ground settlement improved using stone columns will be analyzed in both analytical (Equilibrium Method and Priebe Method) and numerical (PLAXIS 2D V8) methods. Comparison between field monitored settlement and predicted settlement proved that Priebe Method was reliable even though it does not capture all the fundamental soil parameters and stress changes that take place during stone columns installation and during embankment construction.

1 INTRODUCTION

The existing soil for a given site might not be suitable to support the desired facilities. Therefore, as a geotechnical engineer, it is necessary to ensure the soil properties within the influence zone to be improved in order to meet the design criteria. Various ground improvement techniques available including driven piles, installation of prefabricated vertical drains and removal and replacement of soft soils. Among the ground improvement techniques mentioned above, stone columns are one of the ground improvement method frequently used for soft soil.

Stone column is used to strengthen and reduce the compressibility of the soft soils. However, the application of this technique consists of several limitations due to construction restriction and specific details at site. Stone columns are not suitable in liquid soils with low undrained shear strength because the lateral support may be too small (Raju and Sridhar, 2008).In addition, site contains sensitive clays and silt with sensitivity greater than 4 are also not suitable for stone column which the soil will lose the strength when the soil had been disturbed (Karun and Nigee, 2013). Besides, the technique is only suitable to apply for structures that can accept high order of settlement tolerance. However, surcharging or preloading can be considered if stringent settlement criteria are required.

Stone column are commonly installed as partial replacement of soil to improve soft clay foundation for rapid embankment construction. The main purpose is to accelerate the primary consolidation of the foundation by the following two mechanisms. First, the high column permeability causes radial drainage resulting in faster dissipation of excess pore water pressure and second, the high column stiffness reduces foundation load or vertical stress on the soil body and so reduces the generation of excess pore pressure (Tan *et al.*, 2008).

2 SOIL CONDITIONS

An instrumented test embankment was constructed at Kodiang, Kedah to evaluate the performance of the soft ground treated with stone columns.

Prior to stone columns installation and embankment construction, dynamic penetration test and cone penetration test (CPT) were carried out. Besides, Pressuremeter Tests (PMT) was also carried out to obtain the Constrained Modulus of the subsoil which is useful for settlement calculation using Priebe Method. Table 1 shows the subsoil conditions for the proposed site. The ground water table is considered at the ground surface.

Table 1: Idealized Subsoil Profile (Yee et al., 2014)

Layer	Depth (m)	Description	Undrained Shear Strength (kPa)	Constrained Modulus (kPa)
1	0 - 6	Very soft silty clay	10	1,000
2	6 - 9	Stiff silty clay	60	18,000
3	9 - 13	Stiff silty clay	Settlements assumed negligible. Borehole data indicates SPT'N' values from 11 to 14, CPT indicates q_c values greater than 1.5 MPa	
4	>13	Limestone	Settlements assumed negligible. SPT hammer rebound. RQD values in between 50% to 100%.	

3 METHOD OF ANALYSIS

The settlement of ground treated with stone column might be affected by design parameter selection, installation effects and stress distribution. A comparison between predicted and actual ground settlement improved using stone columns had been carried out to identify the most accurate and reliable method in predicting the settlement. In this study, the settlement prediction will purely focus on 3 methods, which are Equilibrium method, Priebe Method and Numerical modelling using finite element software, PLAXIS 2D V8 with plane strain model suggested by Tan et al. (2008). Two dimensional finite element models were developed using Plaxis 2D V8, plane strain model. 15 triangular node elements were used to develop the mesh. The mesh was generated using fine generation utilizing the global coarseness of the model. The simulations had been carried out under consolidation process according to the field construction record. The material parameters for stone columns using in Plaxis Model are: unit weight = 22kN/m3; Poisson's ratio = 0.3; effective stress cohesion = 0 kPa and effective stress angle of friction = 42°.

4 RESULTS AND DISCUSSIONS

A plot of fill height, settlement versus time is shown in Figure 1 below. Same settlement trend observed between field monitored settlement and predicted settlement with the increasing in applied load. But the magnitude of field monitored settlement is always lower than the predicted settlement. The observation is mainly because the predicted settlements make use of the parameters obtained from laboratory testing (Nazir et al., 2013) whereas the settlement at field was happened in a 3-dimensional condition. Hence the predicted settlement will be always higher than the actual field settlement under normal circumstances.

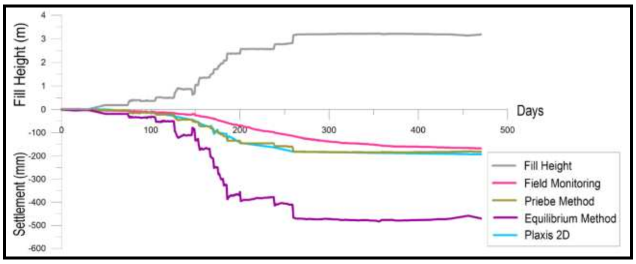

Figure 1: Average Settlement Plot for All Settlement Gauges

Referring to the graph plotted above, the estimated settlement using Equilibrium Method shows significantly higher settlement compared to the field monitored settlement. This finding is in line with the paper prepared by Goughnour and Bayuk (1979), the estimated settlement using Equilibrium Method heavily depends on the selected value of the stress concentration factor. In this study, two numbers of total cells had been installed on top of stone column to measure the load on the stone column during construction. However, additional assumption on the remaining load transfer to the soil and the total area of soil which support the remaining load have to be estimated. As no instruments were installed to obtain the accurate total applied load acting to the ground improved with stone columns in this study; a general assumption of fill with 20kN/m3 is adopted in the calculation. Even though the results of settlement obtained in this study are tally with Goughnour and Bayuk (1979) and Barksdale and Bachus (1983), additional instrumentations to investigate the stress distribution and the extents of its influence zone between soils and stone columns need to be studied.

Priebe Method only takes into account of the stiffness of stone columns and the stiffness of confined soils in settlement estimation. Once the applied load added during construction, the computation of settlement will be the ultimate settlement, whereas the field monitored settlement requires longer time in achieving ultimate settlement due to the dissipation of excess pore water pressure for the confined soil does not happen immediately after the additional load applied on the ground. Therefore the graph plotted above shows the predicted settlement using Priebe Method is always higher at any particular time compare to actual field settlement. The gap between the settlements reduces from rest period to the end of construction. Besides, Priebe Method is developed based on unit cell idealization concept. In fact, the actual settlement measured is based on group stone columns concept. The subsoil will be confined by group of stone columns and the test embankment will be supported by a group of columns rather than a unit cell analysis as what Priebe Method practicing. Therefore the actual monitored settlement will definitely be lower than the predicted settlement.

Plaxis 2D analysis using Plane Strain model with consolidation process simulated according to field construction record also having similar settlement trend as field monitored settlement. The same conditions as Priebe Method was observed from the graphs showing that the settlement simulated using Plaxis 2D is always higher than the monitored settlement at field and the gap between the settlements only reduces from rest period to the end of construction. The observation above is mainly because the analysis simulated by Plaxis 2D is in ideal condition; the dissipation of the pore water pressure for the surrounding soft soil is fast in order for the settlement to take place. However, the stone column installed at field might cause a smear zone in the soil adjacent to the soil-column interface (Han and Ye, 2002) and reduce the horizontal permeability of soil. Besides, the performance of stone columns in dissipating the excess pore water pressure can be affected by clogged effect. Due to the high hydraulic gradient at soil column interface, migration of clay or silt particles into pores of stone column inevitably occur and resulting in a significant reduction in column permeability (Adalier and Elgamalal, 2004). This had reduced the effective radius of the stone columns designed.

5 CONCLUSIONS

In this paper, a comparison between actual settlement and predicted settlement using both analytical (Equilibrium Method and Priebe Method) and numerical (finite element software, PLAXIS 2D V8) methods for the instrumented test embankment constructed at Kodiang, Kedah show that the settlement simulated using finite element software (Plaxis 2D V8) and the settlement estimated using Priebe Method achieved a good agreement with the actual ground settlement monitored. Therefore, Priebe Method is proved to be reliable to estimate the ground settlement improved using stone column in this study.

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