The Effect of Granular Material on Behaviour of Stone Columns in Soft Clay under Embankment

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Received on:2/4/2015 & Accepted on:11/6/2015

ABSTRACT

The stone column material is one of the main controlling parameters in the design of stone columns. It is shown to be affecting the stiffness of the stone columns and hence settlement of the treated soil. Several materials with friction angles of stone column material used to reinforce weak soil as stone columns. Finite element analyses were carried out to evaluate the settlement of soft clay reinforced with stone columns using 15-noded triangular elements in Plaxis 2D v8 software. An analysis carried out using Mohr-Coulomb's criterion model for stones columns and soft soil clay. The numerical results from the FEM provide calculated settlement, excess pore water pressure and lateral bulging of the stone column. It was found that friction angle 40^{o} reduces the total settlement and lateral bulging to approximately 0.038m, 0.00086m respectively of that of reinforced clay with friction angle of crushed stone 27.5^{o}.

Keywords: Soil improvement, Stone column, Friction materials.

تأثير المواد الحبيبةعلى تصرف الاعمدة الحجرية في التربة الناعمة تحت الاملائيات

الخلاصة

ان المواد المستخدمة في الاعمدة الحجرية واحده من اهم العوامل المؤثرة في تصميمها. حيث تكون مؤثرة على قوة العمود ومقدار الهبوط الحاصل في التربة المعالجة بها. في هذه الدراسة تم استخدام مواد مختلفة في زاوية الاحتكاك الداخلي لمعالجة التربة الضعيفة وتم عمل موديل رياضي باستخدام طريقة العناصر المحدده لتحليلها باستخدام برنامج البلاكسيس ثنائي الابعاد حيث استخدم موديل المور كولمب فيها. ان نتائج التحليل باستخدام العناصر المحددة بينت كل من قيمة الهبوط للتربة تحت المنشأ ومقدار قيمة ضغط الماء والانتفاخ الجانبي للعمود الحجري وان استخدام زاوية احتكاك داخلي 40 يؤدي الى تقليل من قيمة قيمة الهبوط الكلي للعمود038m ومصاحبا لتقليل قيمة الانتفاخ الجانبي 0.00086m مقارنة باستخدام مواد لها زاوية احتكاك 27.5^{o}.

INTRODUCTION

The special nature of soft soil deposits is arguably the most interesting soil to work with from the viewpoint of geotechnical engineering. Soft soils are fairly widespread all over the world and some of which are located in important cities. There are two main problems encountered when undertaking civil engineering constructions in soft soil deposits, they are excessive settlement and low shear strength. Ground improvement by stone columns is considered as it has shown to be a

https://doi.org/10.30684/etj.2015.116242
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very effective method to increase the shear strength and the bearing capacity of ground soils as well as reducing total and differential settlements (Ambily and Gandhi 2007).

Related studies on theoretical, experimental and field observations on the behaviour of stone columns have been done by many researchers (Ambily and Gandhi 2007; Malarvizhi and Ilamparuthi 2007; Andreou et al. 2008; Lo et al. 2010; Awf A.Al-Kaisi, Hiba H. Ali 2013; Namir K.S. Al-Saoudi , et. al 2014). They presented a detailed experimental study on the behaviour of single column and group of seven columns by varying parameters like spacing between the columns, shear strength of soft clay and loading condition. Finite element analysis with the software package PLAXIS has also been performed with 15 nodes triangular elements used to analyse and show the behaviour of stone column with different parameters (Lo et al. 2010). Malarvizhi and Ilamparuthi (2007) studied load versus settlement response of the stone column and effect of reinforced stone column, i.e. geogrid-encased stone column in the laboratory. Load tests were performed on soft clay bed stabilized with single stone column and reinforced stone column having various slenderness ratios and using the different type of encasing material. They found that the settlement of the stabilized bed with smaller diameter columns is higher than the larger diameter columns, and the hoop stress generated in the geogrid was responsible for the increasing in load capacity of the encased stone columns. Andreou et al. (2008) investigate that the response of a soft foundation soil reinforced by granular columns to vertical loading is highly dependent upon the drainage conditions, the material of the stone column and the loading rate of the soil. The research also proved that as the confining pressure increases, the strength of the reinforced soil decreases.

In the present study, the effect of various friction angles on the behaviour stone columns is investigated through parametric study carried out by commercially available finite element package PLAXIS. The material and diameter of stone columns, as well as spacing between the stone columns, were analysed. The simulation of the column installation in weak clay by means of vibro-compaction technique is as per the method described by Guetif et al. (Guetif et al. 2007). The analyses were carried out assuming a unit cell concept for columns that were arranged in a square pattern and the deformations in soft soil were restrained within the unit cell represented by the equivalent area of each column.

Site for Case Study

The project selected for this study is Ipoh-Rawang Double Tracking Project. This project connects Rawang and Ipoh towns with electrified trains for the betterment of the public transport. This project also forms part of the Trans-Asia Railway line which connects Kunming in China and Singapore. This project covers a distance of approximately 150 km. The alignment of the new double track line follows closely the existing single track line and in many locations one of the lines is shared. The location map can be referred in Figure1.

Figure1 Location plan of Ipoh-Rawang Double Tracking in Malaysia

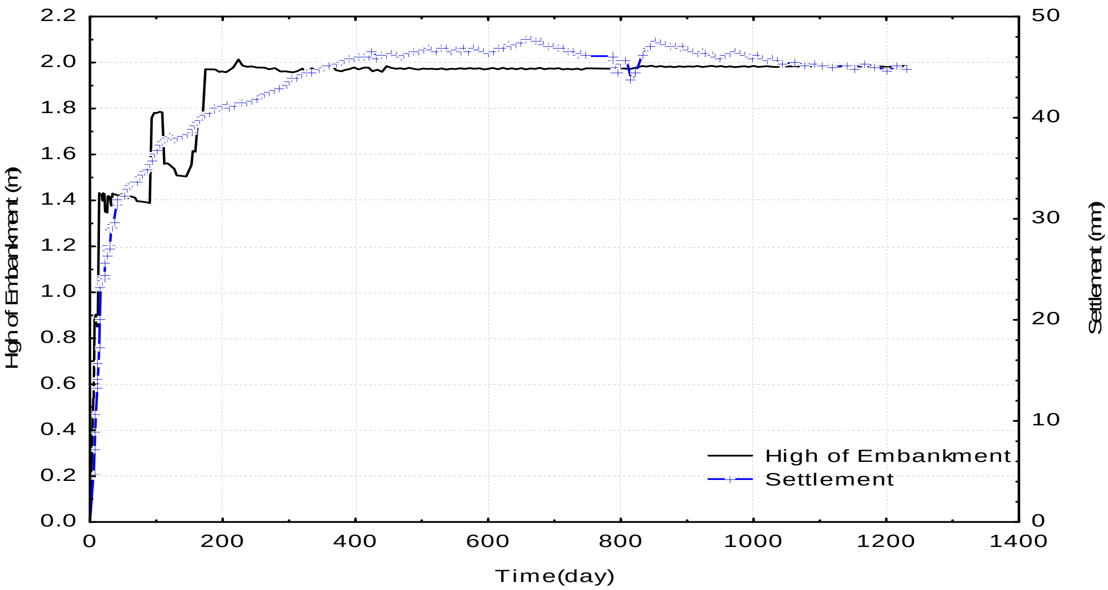


Figure (2). Typical settlement data at 2 m height embankment.

In this project vibro replacement with stone columns adopted as ground treatment. Its economy reason method and leads to gain time of consolidation (Mounir and Lassaad 2008). The settlement carried out from filed shows that the stone column treated soil drained relatively quickly after constructed an embankment layer. After one month of applied a fresh embankment layer, soft soil consolidation will be effective. Figure 2 shows constructed embankment with time as well as settlement during 1231 days.

MATERIALS AND METHODS

The materials used

Three basic materials are used in the present study which is soft clay as soil, reclamation fill as embankment and stone column used to improve soft clay soil, as shown in table 1.

Table(1) : Materials soil parameters adopted for FEM analysis

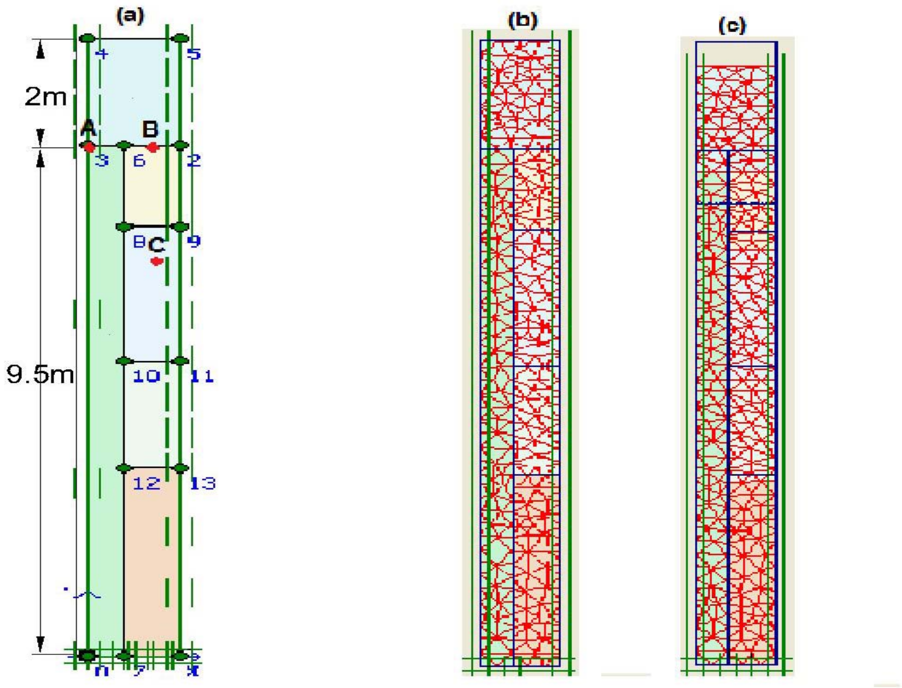
Parameter	Reclamation Fill	Soft clay	Stone columns
Material model	MC	MC	MC
Loading	Drained	Undrained	Drained
Soil unit weight			
γ_{unsat},(kN/m^3)	17	15	15
γ_{sat},(kN/m^3)	18	16	16
Horizontal permeability:			
k_h, (m/day)	1	7.36x10^{-5}	1
Vertical permeability:			
k_v, (m/day)	1	3.68x10^{-5}	0.5
Young's modulus:			
E, (kN/m^2)	20,000	2000	100000
Poisson's ratio(v)	0.3	0.4	0.3
Cohesion c`, (kN/m^2)	*DV	28	*DV
Friction angle(φ°)	30	1	27.5,28.5,29.5,38,40
Dilatancy angle(ψ°)	0	0	0

DV-default value.

Model geometry and input parameters

The FEM package of Plaxis 8 program analysis has been performed on all the valuable information (Plaxis 2002) of the given soils. The soft clay layer is considered 9.5 m deep with reclamation fill limited as blanket layer (see Figure 3). As the clay layer has an impermeable layer in the bottom, the soft clay layer has one way drainage path in the vertical direction while the crushed stone column has two drainage paths in both the vertical and the horizontal directions. The current analyses consider that the entire area of the non-reinforced and the reinforced soft clay has been loaded with the fill soil as embankment loads.

Under such embankments, it is convenient to consider a representative cylindrical unit cell. Hence, all the analyses have been performed using axisymmetric idealization of a cylindrical unit cell consisting of the stone column and the soft soil under the embankment fill. The stone columns are installed in a square orientation pattern. The schematic of the models employed for these analyses were also shown in Figure3 (b and c). Square influence zone around the column is approximated and converted to a circle zone with the same area, d_e = 1.13(S). where, d_e is the diameter of the influence area of the unit cell and S: spacing distance between stone columns (Balaam and Booker 1981). The radius of the unit cell is (d_e/2) in this model is extended from the column center to the outer border of the unit cell. Only half of the model has been used (Weber 2008). The boundaries for unit cell in Plaxis model used where the vertical and the horizontal displacements in the bottom boundaries were restricted while only the horizontal displacement in the lateral boundaries was restricted. The fine finite element mesh with 15 nodes triangular elements has been used. The soft clay has been modeled by the Mohr Coulomb Model under undrained conditions while the stone material and the embankment fill have been modeled using Mohr Coulomb Model under drained conditions. The parameters of the soil are as illustrated in table 1. The consolidation analyses are performed during and after each of the construction stage. A closed consolidation boundary is applied to both sides and down side of the model to preventing lateral drainage.



Figure(3). Model parts of the unit cell (a) Stone column reinforced soft soil. (b) Mesh before deformation for soft soil. (c) Deformation for soft soil with stone column.

Result and discussions of numerical modeling:

The settlement

A typical relationship between time and settlement for reinforced soft clay with different friction angles of crushed stone column can be seen in Figure 4. Similar behavior of development of the settlement with consolidation time has been observed each of friction angles. The consolidation time of the reinforced clay is increases with increasing friction angle of crushed stone column as demonstrated. The settlement decreases with increasing friction angle this is clear at the end of applied embankment layer. The plot shows that crushed stones of friction angle 40^{o} gives smaller settlement to the others.

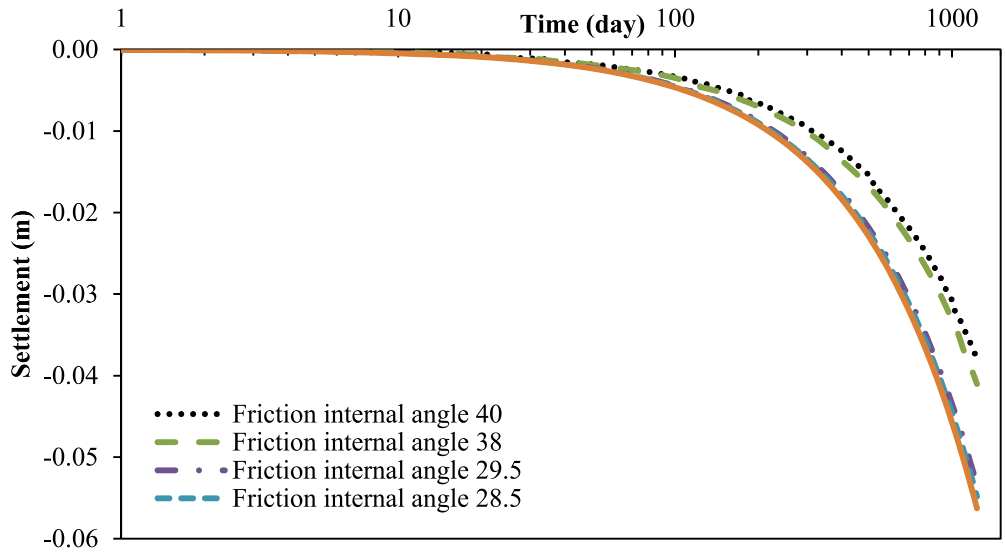


Figure (4) Settlement of the reinforced soft soil with stone columns during the time of the construction at point A

The unit cell technique with various geometric dimensions is used to study the effect of spacing between columns on the column behavior. In figure 5 it is show that the settlement of stone column increased as the spacing between columns increased. The highest value of the settlement was observed when the spacing between columns is 4 m and when the angle is 27.5°.

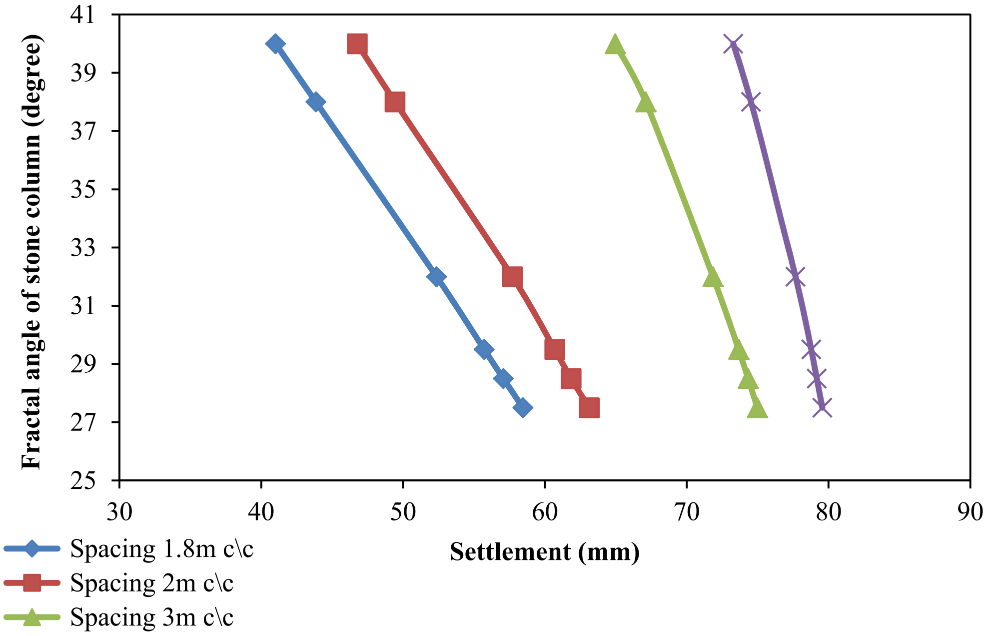


Figure (5). Effect of stone columns spacing on the friction angle-settlement relationship.

Lateral bulging of the stone column

The stone column with a diameter (d) of 1.0 m and a spacing ratio S/d of 2.0 has been loaded with layer of embankment until the end of embankment layer and period of consolidation in undrain condition. The lateral displacement, along the stone column-soft soil interface at sections I-I was calculated. As the increase in weight class, the displacement side gradually increases and because of that, stone column is turned from flex to the plastic case this happens when the column cannot return to its original form at lateral bulging as shown in Figure 6. Expansion of the side of the column increased gradually until it reaches its highest value, as every various material of stone column have different value of maximum bulging value. In comparison, the maximum values of lateral bulging for friction angle 27.5^{o} recorded the largest value 0.0023m, while friction angle 40^{o} recorded lower value of 0.00086 m. After that the lateral widening begins to decrease gradually as the length of the column closer to zero value at the end of the stone column for all the group of crushed stone.

By observing the form of curves in Figure 6, it is found that the lateral expansion of the angle (27.5^{o}) with the largest values of deformation in the clay. Soil heading toward the bottom is also higher compared to other groups and takes a wider area.

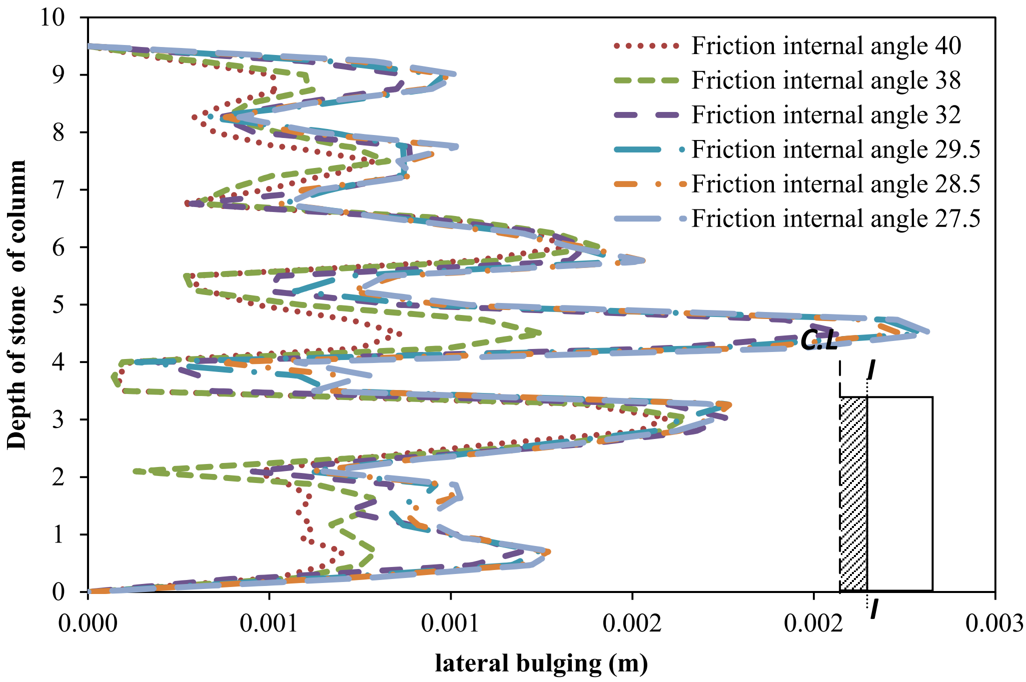


Figure (6). Lateral bulging and yielding distribution of the stone column at the consolidation end of the construction stage.

CONCLUSIONS

The installation of the stone column in peat was simulated by adopting the composite cell model. Meanwhile, the numerical analyses were carried out by using the finite element software PLAXIS. The simulation shows a significant improvement in the characteristics of the soft soil subjected to vibro-compacted column. Based on the results obtained in this study, the following conclusions were made:

1- Among of different friction angle of crushed stone column used, crushed stone of the angle (40^o) are more effective in reducing settlement of soft clay under embankment.

2- The maximum values of bulging of stone column have reduced with depth and it is various with friction angle crushed.

3- It's noted that bulging is approximately 0.0023m for 27.5, 0.0022 for 28.5^o, 0.002 for 32^o, 0.00125 for 38^o and 0.00086 for 40^o.

4- Finally the area of lateral bulging of stone columns increases with decrease of value of angle crushed stone which causes large dilatancy of crushed and the value transferred stress is bigger.

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